



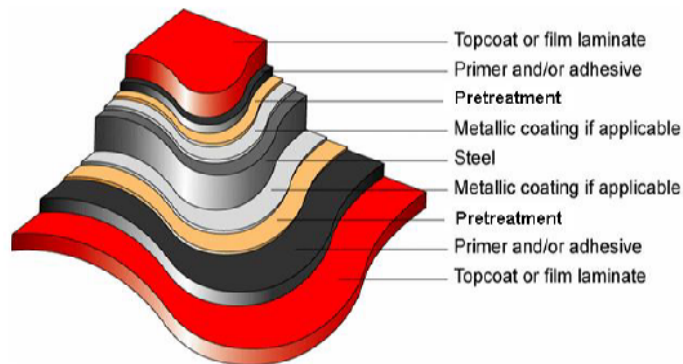
EUROPEAN COMMISSION
DIRECTORATE-GENERAL JRC
JOINT RESEARCH CENTRE
Institute for Prospective Technological Studies

Integrated Pollution Prevention and Control

Reference Document on
Best Available Techniques on

Surface Treatment using Organic Solvents

Dated May 2007



This document is one of a series of foreseen documents as below (at the time of writing, not all documents have been finalised):

Reference Document on Best Available Techniques . . .	Code
Large Combustion Plants	LCP
Mineral Oil and Gas Refineries	REF
Production of Iron and Steel	I&S
Ferrous Metals Processing Industry	FMP
Non-ferrous Metals Industries	NFM
Smitheries and Foundries Industry	SF
Surface Treatment of Metals and Plastics	STM
Cement and Lime Manufacturing Industries	CL
Glass Manufacturing Industry	GLS
Ceramic Manufacturing Industry	CER
Large Volume Organic Chemical Industry	LVOC
Manufacture of Organic Fine Chemicals	OFC
Production of Polymers	POL
Chlor – Alkali Manufacturing Industry	CAK
Large Volume Inorganic Chemicals - Ammonia, Acids and Fertilisers Industries	LVIC-AAF
Large Volume Inorganic Chemicals - Solid and Others industry	LVIC-S
Production of Speciality Inorganic Chemicals	SIC
Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	CWW
Waste Treatments Industries	WT
Waste Incineration	WI
Management of Tailings and Waste-Rock in Mining Activities	MTWR
Pulp and Paper Industry	PP
Textiles Industry	TXT
Tanning of Hides and Skins	TAN
Slaughterhouses and Animals By-products Industries	SA
Food, Drink and Milk Industries	FDM
Intensive Rearing of Poultry and Pigs	ILF
<i>Surface Treatment Using Organic Solvents</i>	<i>STS</i>
Industrial Cooling Systems	CV
Emissions from Storage	ESB
Reference Document . . .	
General Principles of Monitoring	MON
Economics and Cross-Media Effects	ECM
Energy Efficiency Techniques	ENE

EXECUTIVE SUMMARY

The BAT (Best Available Techniques) Reference Document (BREF) entitled 'Surface Treatment Using Organic Solvents (STS)' reflects an information exchange carried out under Article 16(2) of Council Directive 96/61/EC (IPPC Directive). This Executive Summary describes the main findings, a summary of the principal BAT conclusions and the associated consumption and emission levels. It should be read in conjunction with the preface, which explains this document's objectives; how it is intended to be used and legal terms. It can be read and understood as a standalone document but, as a summary, it does not present all the complexities of this full document. It is therefore not intended as a substitute for this full document as a tool in BAT decision making.

Scope of this document

The scope of this document is based on Annex 1, 6.7, to the IPPC Directive 96/61/EC: *'Installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating, with a consumption capacity of more than 150 kg per hour or more than 200 tonnes per year.'*

Industry asked for clarification of the definitions of 'organic solvents' and 'consumption capacity'. At the conclusion of the information exchange, it could be seen that the exchange had dealt with information on organic solvents being defined as VOCs (as defined in the Solvent Emissions Directive, Council Directive 1999/13/EC). It could equally be seen that, in determining conclusions on BAT, the exchange had focused on installations whose actual use of solvents exceeded the consumption capacity thresholds stated in the IPPC Directive (where the use in the activity included solvents recovered from waste gas emission abatement equipment). Interpretation of these capacity thresholds is discussed in the context of work carried out by DG Environment to develop some guidance on the interpretation of certain provisions of the Directive.

This document discusses:

- three printing processes using solvents on a large scale (heatset web offset, flexible packaging and publication gravure)
- coating and/or painting of winding wires, cars and commercial vehicles, buses, trains, agricultural equipment, ships and yachts, aircraft, steel and aluminium coil, metal packaging, furniture and wood, as well as other metal and plastic surfaces
- adhesive application in the manufacture of abrasives and adhesive tapes
- impregnation of wood with preservatives
- cleaning and degreasing associated with these activities. No separate degreasing industry was identified.

The use of water-soluble alternatives to solvent-based coatings (such as e-coat) are discussed in this document: other water-based surface treatments are discussed in the STM BREF.

Other activities have not been considered in this document. These include:

- other dressing, waterproofing, sizing or impregnation processes that may be in the scope of the BREF(s) on Textiles and Tanneries
- the production of laminate boards, chipboard, etc. as these use water-based resins
- industries (or those parts of) or activities using solvents widely known to operate below the thresholds
- the manufacture of paints, inks, adhesives, etc., which are not within the scope.

All the industries in this document are also regulated by the Solvent Emissions Directive (the SED, Council Directive 1999/13/EC). Where emission limit values (ELVs) are prescribed in the SED, these are assumed to be minimum ELVs pursuant to the IPPC Directive (Article 18(2)). They are not used as emission values associated with BAT.

General information

This is not a homogenous sector and covers several industries, with installation sizes ranging from SME to multinational. About 4.5 million tonnes of solvents a year are sold for use in Europe, 27 % (2003) of this is used in the paint and coatings industries, a decrease from 47 % (1998) due to increased use of water-based, powder technologies and other low-solvent technologies. Printing ink formulations use about 7 % and adhesives about 4 % (These figures include significant non-IPPC uses).

Key environmental issues

The main environmental issues relate to the emission of solvents to air, water and groundwaters, and soil. Energy usage is also important, as are particulate emissions to air, waste minimisation and management (including reducing raw material consumption by increased application efficiency) and site condition on cessation of activities.

Structure of this document

Chapters 2 through to 19 each address an industry in the sector and consist of the four following sections:

- Section 1: general information on the industry or activity concerned
- Section 2: a description of the industrial processes used within this industry or activity
- Section 3: data and information concerning current consumption and emission levels
- Section 4: techniques to be considered for determining BAT as explained below for Chapter 20; however, the emphasis is on techniques or information specific to the individual industry or activity.

Chapter 20 describes generic techniques for the reduction of consumptions and emissions and other techniques that are considered to be most relevant for determining BAT and BAT-based permit conditions in more detail, and are relevant for more than one of the industries or activities concerned.

Consumptions and emissions

The best data relates to production throughput based on production parameters, e.g. surface (m²) treated or solids input to the process. Most data are for specific plants or ranges for industries. In most cases, emission values associated with a selection of BAT in each industry are given based on suitable production parameters.

Best available techniques

The BAT chapter (Chapter 21) identifies those techniques that are considered to be BAT at a European level, based mainly on the information in Chapter 20 and the specific industry chapters. This takes into account the Article 2(11) definition of best available techniques and the considerations listed in Annex IV to the IPPC Directive. The BAT chapter does not set or propose emission limit values but suggests consumption and emission values that are usually associated with the use of a combination of BAT.

Where water-based surface treatments (as defined in IPPCD, Annex 2.6) are operated with solvent-based processes, the relevant BAT for the water-based treatments can be found in the STM BREF. Additional techniques and supporting information may be found in particular in the CWW BREF, the Storage BREF and the Monitoring REF, as well as other BREFs. These techniques have not, however, been validated for the industries covered in this document.

The following paragraphs summarise the key BAT conclusions relating to the most relevant environmental issues. Although the industry is complex in size and range of activities, the same generic BAT may be considered for all. Other BAT are given that apply to specific processes. The BAT elements for a specific installation will be a selection of the BAT described related to the activity, taking into account the considerations in Annex IV to the IPPC Directive.

Generic BAT

Installation design, construction and operation. BAT is to minimise consumptions and emissions (particularly to soil, water and groundwater, as well as to air) by:

- implementing and adhering to environmental and other management systems, whether or not these are externally validated. These include planning the ongoing reduction of the environmental footprint of the installation (including actions and investments), benchmarking consumptions and emissions (over time against internal and external data), considering eventual decommissioning in designing new plants or upgrades, etc.
- using simple risk management to design, construct and operate an installation, together with techniques described in this document and in the Storage BREF when storing and using process chemicals and raw materials. These BAT aid site decommissioning by reducing unplanned emissions, recording the history of usage of priority and hazardous chemicals and dealing promptly with potential contamination
- using operational techniques including automation, training, and written procedures for operation and maintenance.

Monitoring. BAT is to monitor solvent emissions in order to be able to minimise them by:

- using a solvent management plan, which is essential to calculate fugitive or total emissions: these should be made regularly, although key parameters can be established for benchmarking and regular control. Direct measurements should be made according to the techniques referred to
- ensuring equipment critical to emissions calculations is maintained regularly, and recalibrated when necessary.

Reducing water consumption and/or conserving raw materials in water-based treatment processes. BAT is to use:

- techniques such as cascade (multiple) rinsing, ion exchange or membrane separation
- control measures to minimise the use of cooling waters
- closed cooling systems and/or heat exchangers.

Minimising energy usage. BAT is to apply the techniques described, in particular: by minimising the air volumes to be moved, minimising reactive energy losses, controlling high energy demands on equipment start up, using energy efficient equipment, etc.

Raw material management. BAT is to:

- minimise the environmental impact of emissions when selecting suitable raw materials
- minimise raw material usage by using one or a combination of techniques described.

Systems for surface treatment, application and drying/curing. BAT is to minimise VOC emissions and energy consumption, and maximise raw material efficiency (i.e. minimise waste) by selecting a system that combines these objectives. This applies to a new plant or when upgrading.

Cleaning. BAT is to use the techniques described to:

- conserve raw materials and reduce solvent emissions by minimising colour changes and cleaning
- reduce solvent emissions by collecting and re-using purge solvent when cleaning spray guns
- minimise VOC emissions by selecting one or more techniques according to the process and equipment, persistence of the contamination and whether cleaning the equipment or the substrate.

Using less hazardous substances (substitution). BAT is to:

- use non-solvent or low solvent techniques for cleaning as described generally, and for production as described for the specific industries
- minimise adverse physiological effects by replacing those with the risk phrases R45, R46, R49, R60 and R61 in accordance with Article 5(6) of Council Directive 1999/13/EC
- minimise adverse ecotoxic effects by replacing those with the risk phrases R58 and R50/53 where there is a risk of emission to the environment and alternatives exist
- reduce stratospheric (high level) ozone depletion by replacing those with the risk phrases R59. In particular, all halogenated or partially halogenated solvents with the risk phrase R59 used in cleaning should be replaced or controlled as described
- minimise the formation of tropospheric (low level) ozone by using VOCs or mixtures with a lower ozone formation potential (OFP) where other measures cannot achieve the associated emission values or are not technically applicable (such as having unfavourable cross-media effects), and when substituting as described above. However, this cannot be applied to complex formulations such as automotive paints and specific single solvent systems where no replacement exists yet, such as publication gravure. Where the OFP is not increased, substitution can be made using solvents with a flashpoint of >55 °C.

Emissions to air and waste gas treatment. BAT is to (in the design, operation and maintenance of the installation):

- minimise emissions at source, recover solvent from emissions or destroy solvents in waste gases. Emission values are given for individual industries. (Using low solvent materials can lead to excessive energy demands to operate thermal oxidisers. Oxidisers may be decommissioned where the negative cross-media effects outweigh the benefits of destroying the VOC)
- seek opportunities to recover and use excess heat generated in VOC destruction and minimise the energy used in extraction and destruction of VOCs
- reduce solvent emissions and energy consumption by using the techniques described, including reducing the volume extracted and optimising and/or concentrating the solvent content.

Particulates discharged to air from paint spraying. BAT is to use a combination of the techniques described. Associated emission values are:

- 5 mg/m³ or less for existing installations
- 3 mg/m³ or less for new installations.
-

The industry for the coating of wood and furniture recorded a split view: the associated emission value is 10 mg/m³ or less for both new and existing installations. The rationale is: this value is economically and technically feasible in the industry.

Waste water. BAT is:

- to minimise emissions to water by using water minimisation techniques, carry out waste water pretreatment and treatment as described
- to monitor raw materials and effluent to minimise the discharge of materials with aquatic toxicity, and reducing their effects where there is a risk of contact with water by one or more of the following: use of less harmful materials, reduced material use and losses in process treatment and by spillages, and treatment of waste waters
- where solvents may be in contact with water, to prevent hazardous levels in the atmosphere of receiving sewers by maintaining a safe discharge level
- for paint shops using water, to use the techniques described. Associated emission values for discharge to surface waters are COD 100 - 500 mg/l and suspended solids 5 - 30 mg/l
- for wet scrubber systems, reduce water consumption and effluent discharges and treatment by optimising paint transfer minimising paint sludge build up.

Techniques for biological waste water treatment can be found in the CWW BREF. Other techniques and associated emission values are discussed in the STM BREF.

Materials recovery and waste management. BAT is to reduce material usage, material losses, and recover, re-use and recycle materials as described.

Odour nuisance. BAT is, where a sensitive receptor is affected, to use a VOC emission control technique, such as using less odorous materials and/or processes, and/or waste gas treatment including high stacks.

Noise. BAT is to identify significant noise sources and any potential sensitive receptors in the vicinity. Where noise may have an impact, BAT is to use good practice techniques such as closure of bay doors, minimising deliveries and/or using engineered controls, such as silencers on large fans.

Groundwater protection and site decommissioning. BAT to address these issues are given in the BAT for installation design, construction and operation, above.

Specific industry BAT

Printing with heatset web offset. BAT is to use a combination of techniques for printing, cleaning, waste gas management, as well as generic BAT to reduce the sum of fugitive emissions and the VOCs remaining after waste gas treatment. Associated emission values for the combined isopropyl alcohol (IPA) and cleaning solvent are:

- for new or upgraded presses, 2.5 to 10 % VOC expressed as wt-% of the ink consumption
- for existing presses, 5 to 15 % VOC expressed as wt-% of the ink consumption.

Note that the top half of the ranges are associated with IPA emissions for 'difficult' jobs (as defined). Concentration techniques cannot be used because of odour problems.

Printing flexible packaging by flexography and packaging gravure. BAT is to:

- use a combination of techniques described to reduce the sum of fugitive and non-fugitive VOC emissions. Associated emission values for the three scenarios occurring in the industry are (using the reference emission defined in Annex IIb to the SED):

(Scenario 1) Installations where all production machines are solvent-based and connected to abatement equipment:

- with incineration: total emissions 7.5 - 12.5 % of the reference emission
- with solvent recovery: total emissions 10.0 - 15.0 % of the reference emission

(Scenario 2) Existing installations, where there is waste gas abatement equipment but not all solvent-based production machines are connected:

(2.1) for the machines that are connected to the abatement equipment:

- with incineration: total emissions 7.5 - 12.5 % of reference emission relating to those machines
- with solvent recovery: total emissions 10.0 - 15.0 % of the reference emission relating to those machines

(2.2) for the machines not connected to waste gas treatment, BAT is one of:

- use low solvent or solvent free products on these machines
- connect to the waste gas abatement equipment when there is capacity
- preferentially run high solvent content work on machines connected to waste gas abatement

(Scenario 3) Where installations have no waste gas abatement equipment and are using substitution, it is BAT to follow the developments of low solvent and solvent free inks, varnishes and adhesives, and continuously decrease the amount of solvents consumed.

In Scenarios 1 and 2.1, where an installation has a solid:solvent ratio of higher than 1:5.5 for the total of the solvent-based inks, varnishes and adhesives, the emission values may not be obtainable. In this case, it is BAT to cover the ink fountains or apply chamber doctor blades and to apply a suitable combination of other techniques, as described.

BAT is also to:

- minimise energy consumption when optimising waste gas treatment in all sites
- seek opportunities to recover and use any surplus energy in all sites.

Printing with publication gravure. BAT is to:

- reduce the sum of fugitive emissions and the VOCs remaining after gas treatment, expressed as total solvent input:
 - for new plants to 4 to 5 %, using techniques applicable to new plants
 - for existing plants to 5 to 7 %, using techniques applicable to existing plants
- prevent the excessive use of energy by using the optimum number of regenerations required to maintain emissions within the emission values expressed
- reduce the emissions of toluene to a municipal sewer to below 10 mg/l by air stripping.

Manufacturing of winding wire. BAT is to:

- minimise energy consumption after drying the wire by cooling using room and/or exterior air
- reduce the total VOC emissions by a combination of the described techniques as well as the generic BAT. Total emission values associated with these techniques are:
 - 5 g/kg or less for non-fine wires (>0.1 mm diameter)
 - 10 g/kg or less for fine wires (0.01 – 0.1 mm diameter)
- reduce VOC emissions further by seeking and implementing low or no solvent techniques in place of solvent-based lubricants.

Manufacturing of abrasives. BAT is to:

- reduce total VOC emissions by one or more of the following in conjunction with the generic BAT:
 - using no or low solvent-based bonding materials. This can be done when water cooling is not required during the process, e.g. for the manufacture of dry grinding abrasives
 - increasing the internal solvent concentration in the driers
 - using a suitable combination of the waste gas treatment techniques.

Total emission values for VOCs associated with these techniques are 9 – 14 wt-% of the solvent input.

Manufacturing of adhesive tapes. BAT is to:

- for the production of tapes using solvent-based adhesives, reduce VOC emissions by using a combination of techniques in conjunction with the generic BAT, including:
 - using non-solvent based adhesives when applicable. Water-based and hot melt adhesives only use small amounts of solvents (e.g. in cleaning). However, they can only be used in certain applications
 - using one of the following waste gas treatments or combinations: a+b, a+c, b, or c, where:
 - a) condensation after a pre-drying step using an inert gas drier
 - b) adsorption with a recovery efficiency of more than 90 % of the solvent input and direct emissions after this abatement technique of less than 1 %
 - c) oxidisers with energy recovery.

Emission values associated with these techniques are 5 wt- % or less of the total solvent input.

Coating of cars. BAT is to:

- minimise the energy consumption in the selection and operation of painting, drying/curing and associated waste gas abatement systems
- minimise solvent emissions, as well as energy and raw material consumptions, by selecting a paint and drier system as described. A whole coating system needs to be considered, as individual steps may be incompatible. The associated emission values are 10 - 35 g/m² (e-coat area) (or 0.3 kg/body + 8 g/m² to 1.0 kg/body + 26 g/m² equivalent). Lower values have been achieved in two exceptional circumstances that are reported
- establish and implement plans for existing plants to reduce consumptions and emissions to achieve the emission values above bearing in mind the cross-media effects, cost benefits,

high capital costs and long payback periods to achieve these values. It is important to note that major step improvements will require techniques with significant capital costs. It may be more cost effective and environmentally beneficial to wait for step changes than to make smaller short-term improvements that will not achieve the same improvement, depending on the time scale

- where spray booth waste gas treatment is applied, concentrate the VOC by using one of the described pretreatment techniques
- optimise transfer efficiencies using one or more of the techniques described
- minimise raw material consumption and waste by maximising material transfer efficiencies
- minimise waste production by either dewatering paint sludge, recycling paint sludge or using the water emulsion technique.

Coating of trucks and commercial vehicles. BAT is to:

- minimise solvent emissions, as well as energy and raw material consumptions, using a combination of paint and drier systems in conjunction with waste gas treatment systems. In particular, use solvent-free polyurethane materials applied with airless spraying for noise dampening and floor covering, as well as pre-coated materials. Overall associated emission values are 10 - 55 g/m² for new truck cabins and 15 - 50 g/m² for new vans and trucks (e-coat area). Use a combination of techniques to reduce solvent emissions from cleaning. The associated emission values are less than 20 g/m² (e-coat area)
- minimise raw material consumption and waste by maximising material transfer efficiencies
- minimise waste production by either dewatering paint sludge, recycling paint sludge or using the water emulsion technique.

Coating of buses. BAT is to:

- minimise solvent emissions, as well as energy and raw material consumptions, using a combination of paint and drier systems in conjunction with waste gas treatment systems. In particular, use solvent-free polyurethane materials applied with airless spraying for noise dampening and floor covering, as well as pre-coated materials. Overall associated emission values are 92 – 150 g/m² (e-coat area)
- use a combination of techniques to reduce solvent emissions from cleaning. The associated emission values are less than 20 g/m² (e-coat area)
- minimise raw material consumption and waste by maximising material transfer efficiencies
- minimise waste production by either dewatering paint sludge, recycling paint sludge or using the water emulsion technique.

Coating of trains. BAT is to:

- reduce VOC emissions by using a combination of techniques including the generic BAT. Associated emission values are 70 - 110 g VOC/m² of the painted area (not e-coat area)
- use a combination of techniques to reduce particulate emissions to air. The associated emission values are 3 mg/m³ or less.

Coating of agricultural and construction equipment. BAT is to:

- reduce solvent consumptions and emissions, maximise efficiency of the coating application and minimise energy usage by a combination of paint, drier and waste gas treatment techniques. The associated emission values are either:
 - emissions of 20 – 50 mg C/m³ in waste gas and 10 – 20 % for fugitive emissions, or
 - overall emissions of 0.2 to 0.33 kg VOC/kg solids input
- reduce material consumptions, solvent emissions and the amount of airflow to be treated by using dipping techniques for the coating of components prior to assembly
- use other paint systems to replace paints based on halogenated solvents.

Coating of ships and yachts. BAT is to:

- minimise emissions to the environment by including the BAT in this section in the dry docks discipline for the installation
- reduce solvent emissions by a combination of generic BAT and some or all of:

Executive Summary

- using water-based, high-solids or 2-component paints where not limited by customer and/or technical requirements
- reducing overspray and increasing application efficiency by a combination of techniques
- for new construction, spray sections prior to assembly in enclosed areas with waste gas extraction and treatment
- reduce particulate emissions by one or a combination of techniques
- reduce waste water contamination by removing paint residues, leftovers and containers, used abrasives, mud, oil residues and any other scrap materials from the dock before flooding, storing them in containers for proper management, e.g. re-use and/or disposal.

Coating of aircraft. BAT is to:

- minimise emissions of Cr(VI) to water by using alternative passivation systems
- reduce solvent emissions to air by:
 - using high-solids paints
 - capturing and treating waste gases during paint application on components
- reduce emissions from cleaning by one or more of:
 - automation of cleaning equipment
 - measuring solvent used for cleaning
 - using pre-impregnated wipes
- reduce particulate emissions to air using techniques described. The associated emission values are 1 mg/m³ or less.

Coating of other metal surfaces. BAT is to:

- reduce solvent consumptions and emissions, maximise efficiency of the coating application and minimise energy usage by one or a combination of paint, drier and waste gas treatment techniques. The associated emission values are 0.1 to 0.33 kg VOC/kg solids input. However, this does not apply to installations where the emissions are included in the mass emission calculations for the serial coatings of vehicles
- reduce material consumptions by using high efficiency application techniques
- use other paint systems to replace paints based on halogenated solvents.

Coil coating. BAT is to:

- reduce energy consumption using a selection of techniques. Associated consumption values are:

Energy consumption per 1000 m ² of substrate	Minimum	Maximum
Electricity used as kWh/1000 m ² for aluminium	270	375
Electricity used as kWh/1000 m ² for steel	250	440
Fossil fuels used as MJ/1000 m ² for aluminium	4000	9800
Fossil fuels used as MJ/1000 m ² for steel	3000	10200

Coil coating: energy consumption for aluminium and steel substrates

- reduce solvent emissions using a combination of techniques described. Associated emission values are:
 - for new plants: 0.73 – 0.84 g/m² for waste gases, and 3 – 5 % for fugitive emissions
 - for existing plants: 0.73 – 0.84 g/m² for waste gases, and 3 – 10 % fugitive emissions. Existing plants will only achieve the lower values of the range when they are significantly upgraded
- recycle the aluminium and steel from residual substrates.

Coating and printing of metal packaging. BAT is to:

- reduce energy consumption by using various techniques and/or energy recovery from thermal waste gas treatment. Associated consumption values, e.g. for DWI cans are:
 - natural gas 5 - 6.7 kWh/m²
 - electricity 3.6 - 5.5 kWh/m²

- recovered energy (where energy can be recovered, but not possible where emissions levels are met by substitution) 0.3 - 0.4 kWh/m²
- reduce solvent emissions using a selection of techniques. Associated emission values are:

	VOC emission level at application (g/m ²) ⁽²⁾	
	Solvent-based	Water-based
Food contact		
• DWI drink cans	6.7 – 10.5	3.2 – 4.5
• sheet for ends, cans and components	4 – 93	1 – 30
• drums	90 – 100	
Non-food contact		
• sheet for ends, cans and components	4 – 93	1 – 30
• drums	60 – 70	11 – 20
Print paint		
• sheet for ends, cans and components ⁽¹⁾	2.5 – 13	1 – 6
Notes:		
¹ UV ink and paint applications are limited to non-food and special applications but can achieve lower values than reported in this table		
² Values also include fugitive emissions		

Metal packaging: emission values for solvents associated with BAT

- minimise emissions to water using a selection of techniques. The associated emission values are:

Compound	Concentration (mg/l)
COD	<350
AOX	0.5 – 1
HC	20 or less
Sn	4 or less

Metal packaging: emission values for waste water

Coating of plastic workpieces. BAT is to:

- reduce solvent consumptions and emissions, maximise efficiency of coating application and minimise energy usage by one or a combination of paint, drier and waste gas treatment techniques. The associated emission values are 0.25 to 0.35 kg VOC/kg solids input. However, this does not apply to installations where the emissions are included in the mass emission calculations for the serial coatings of vehicles
- reduce material consumption by using high efficiency application techniques
- give priority to water-based techniques for new and upgraded systems
- degrease simple polypropylene areas by hand with solvent impregnated wipes.

Coating of furniture and wood. BAT is to:

- reduce solvent consumptions and emissions, maximise efficiency of coating application and minimise energy usage by a combination of paint, drier and waste gas treatment techniques. The associated emission values are either 0.25 kg VOC or less per kg solids input, or as in the table below:

Paint system organic solvent content	Solvent content (wt-%)	Emission reduction measures	VOC emission (g/m ²)
High	65	High efficiency application techniques and good housekeeping	40 - 60
Medium	20		10 - 20
Low	5		2 - 5

Wood coating: VOC emissions for various paint systems and with primary emission reduction measures

Executive Summary

- reduce particulate emissions to air (see generic BAT₃ above). This industry recorded a split view: the associated emission value is 10 mg/m³ or less for both new and existing installations. The rationale is: this value is economically and technically feasible in the industry.

Wood preservation. BAT is to:

- reduce solvent emissions by using vacuum impregnation with water-based or high concentration pesticide systems, with waste gas treatment for solvent systems
- use the final vacuum stage of the process cycle to remove excess solvent or carrier
- use a solvent with lower ozone-forming potential for solvent systems
- drain surplus pesticide in contained areas with both water- and solvent-based systems.

It is not BAT to spray as this has a low overall application efficiency.

Coating of mirrors. BAT is to:

- reduce solvent consumptions and emissions (mainly xylene) by a combination of the techniques described and generic BAT. The associated emission values are 1 to 3 g/m² for waste gas emissions (2 to 3% of the solvent input) and 5 to 10 g/m² for fugitive emissions (8 to 15 % of the solvent input)
- reduce the use of hazardous materials by using low lead paints.

This industry also uses water-based surface treatments described (with BAT) in the STM BREF.

Emerging techniques

Several techniques are discussed that are being developed further for, or transferred to, various industries. In particular, for inks, coatings or adhesives: using less or no solvents, improved water-based systems, 1- and 2-component systems, very high solids paints and powder coating. These often involve developing non-thermal drying or curing by UV or other radiation. For applying a final coat of lubricant on winding wires, the key development is in using low or non-solvent techniques, which is currently limited in its application. In the automotive coating industries, developments are taking place in water-dilutable, 1- and 2-component clear coats, very high solids, powder coatings, polyurethane (PU) paint which can be applied to both metals and plastics, increased use of pre-coated materials, and as a consequence of many of these developments, a reduction in the number of paint layers.

Concluding remarks

The information exchange on best available techniques for surface treatment using organic solvents was carried out from 2003 to 2006. The information exchange was successful and a high degree of consensus was achieved during the work and following the final meeting of the Technical Working Group. Only one split view was recorded on the particulate emissions from the coating of furniture and wood.

At the conclusion of the information exchange, it could be seen that the exchange had dealt with information as recorded in the Scope of this document.

Gaps in knowledge and recommendations for future research are given in the Concluding Remarks chapter. Key issues for further work are POCP and the cost-benefit of burning natural gas to abate VOCs.

The EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface of this document).

PREFACE

1. Status of this document

Unless otherwise stated, references to ‘the Directive’ in this document means the Council Directive 96/61/EC on integrated pollution prevention and control. As the Directive applies without prejudice to Community provisions on health and safety at the workplace, so does this document.

This document forms part of a series presenting the results of an exchange of information between EU Member States and industries concerned on best available technique (BAT), associated monitoring, and developments in them. *[It is published by the European Commission pursuant to Article 16(2) of the Directive, and must therefore be taken into account in accordance with Annex IV of the Directive when determining ‘best available techniques’.]

** Note: bracket will be removed when the procedure of publication by the Commission is completed.*

2. Relevant legal obligations of the IPPC Directive and the definition of BAT

In order to help the reader understand the legal context in which this document has been drafted, some of the most relevant provisions of the IPPC Directive, including the definition of the term ‘best available techniques’, are described in this preface. This description is inevitably incomplete and is given for information only. It has no legal value and does not in any way alter or prejudice the actual provisions of the Directive.

The purpose of the Directive is to achieve integrated prevention and control of pollution arising from the activities listed in its Annex I, leading to a high level of protection of the environment as a whole. The legal basis of the Directive relates to environmental protection. Its implementation should also take account of other Community objectives such as the competitiveness of the Community’s industry thereby contributing to sustainable development.

More specifically, it provides for a permitting system for certain categories of industrial installations requiring both operators and regulators to take an integrated, overall look at the polluting and consuming potential of the installation. The overall aim of such an integrated approach must be to improve the management and control of industrial processes so as to ensure a high level of protection for the environment as a whole. Central to this approach is the general principle given in Article 3 that operators should take all appropriate preventative measures against pollution, in particular through the application of best available techniques enabling them to improve their environmental performance.

The term ‘best available techniques’ is defined in Article 2(11) of the Directive as ‘the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole.’ Article 2(11) goes on to clarify further this definition as follows:

‘techniques’ includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

‘available’ techniques are those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;

‘best’ means most effective in achieving a high general level of protection of the environment as a whole.

Furthermore, Annex IV of the Directive contains a list of ‘considerations to be taken into account generally or in specific cases when determining best available techniques... bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention’. These considerations include the information published by the Commission pursuant to Article 16(2).

Competent authorities responsible for issuing permits are required to take account of the general principles set out in Article 3 when determining the conditions of the permit. These conditions must include emission limit values, supplemented or replaced where appropriate by equivalent parameters or technical measures. According to Article 9(4) of the Directive, these emission limit values, equivalent parameters and technical measures must, without prejudice to compliance with environmental quality standards, be based on the best available techniques, without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In all circumstances, the conditions of the permit must include provisions on the minimisation of long-distance or transboundary pollution and must ensure a high level of protection for the environment as a whole.

Member States have the obligation, according to Article 11 of the Directive, to ensure that competent authorities follow or are informed of developments in best available techniques.

3. Objective of this document

Article 16(2) of the Directive requires the Commission to organise ‘an exchange of information between Member States and the industries concerned on best available techniques, associated monitoring and developments in them’, and to publish the results of the exchange.

The purpose of the information exchange is given in recital 25 of the Directive, which states that ‘the development and exchange of information at Community level about best available techniques will help to redress the technological imbalances in the Community, will promote the worldwide dissemination of limit values and techniques used in the Community and will help the Member States in the efficient implementation of this Directive.’

The Commission (Environment DG) established an information exchange forum (IEF) to assist the work under Article 16(2) and a number of technical working groups have been established under the umbrella of the IEF. Both IEF and the technical working groups include representation from Member States and industry as required in Article 16(2).

The aim of this series of documents is to reflect accurately the exchange of information which has taken place as required by Article 16(2) and to provide reference information for the permitting authority to take into account when determining permit conditions. By providing relevant information concerning best available techniques, these documents should act as valuable tools to drive environmental performance.

4. Information sources

This document represents a summary of information collected from a number of sources, including in particular the expertise of the groups established to assist the Commission in its work, and verified by the Commission services. All contributions are gratefully acknowledged.

5. How to understand and use this document

The information provided in this document is intended to be used as an input to the determination of BAT in specific cases. When determining BAT and setting BAT-based permit conditions, account should always be taken of the overall goal to achieve a high level of protection for the environment as a whole.

The rest of this section describes the type of information that is provided in each section of the document.

Chapter 1 provides general information on the industries or activities concerned. Chapters 2 through to 19 each consist of the four following sections:

1. general information on the industry or activity concerned
2. a description of the industrial processes used within this industry or activity
3. data and information concerning current consumption and emission levels reflecting the situation in existing installations at the time of writing
4. techniques to be considered for determining BAT as explained below for Chapter 20; however, the emphasis is on techniques or information specific to each individual industry or activity falling under the scope of this document.

Chapter 20 describes techniques for the reduction of consumption and emission reductions and other techniques that are considered to be most relevant for determining BAT and BAT-based permit conditions in more detail, and are relevant for all or most industries or activities concerned. This information includes information on the consumption and emission levels considered achievable by using the technique, the costs and the cross-media issues associated with the technique, and the extent to which the technique is applicable to the wide range of installations falling under the scope of this document. This includes, for example, in which industry or activity the technique is currently applied and whether it is, or is not, applicable to other industries or activities, including new, existing, large or small installations. Techniques that are generally seen as obsolete are not included.

Chapter 21 presents the techniques and the consumption and emission levels that are considered to be compatible with BAT in a general sense. Section 21.1 sets out generic BAT applicable in all industries in this sector, and Section 21.2 through to 21.19 set out specific BAT for each industry to be used in conjunction with those in Section 21.1.

The purpose is thus to provide general indications regarding the consumption and emission levels that can be considered as an appropriate reference point to assist in the determination of BAT-based permit conditions or for the establishment of general binding rules under Article 9(8). It should be stressed, however, that this document does not propose emission limit values. The determination of appropriate permit conditions will involve taking account of local, site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In the case of existing installations, the economic and technical viability of upgrading them also needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations.

Although an attempt is made to address some of these issues, it is not possible for them to be considered fully in this document. The techniques and levels presented in Chapter 21 will therefore not necessarily be appropriate for all installations. On the other hand, the obligation to ensure a high level of environmental protection including the minimisation of long-distance or transboundary pollution implies that permit conditions cannot be set on the basis of purely local considerations. It is therefore of the utmost importance that the information contained in this document is fully taken into account by permitting authorities. The rest of this section describes the type of information that is provided in each section of the document.

Since the best available techniques change over time, this document will be reviewed and updated as appropriate. All comments and suggestions should be made to the European IPPC Bureau at the Institute for Prospective Technological Studies at the following address:

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Interface between the IPPC and the Solvents Emissions Directives

The following presentation of the issues is related to the interface between Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations (Solvents Emissions Directive) and Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (IPPC Directive).

It should be noted that the ultimate interpretation of Community law is a matter for the European Court of Justice and therefore it cannot be excluded that interpretation by the Court may raise new issues in the future.

The Solvents Emissions Directive contains the following main explicit references to the IPPC Directive:

- Article 4 of the Solvents Emissions Directive requires that *'without prejudice to Directive 96/61/EC, Member States shall adopt the necessary measures to ensure that existing installations comply with Article 5, 8 and 9 no later than 31 October 2007'*. This makes clear that compliance with the conditions laid down in the Solvents Emissions Directive does not remove the obligation to operate in compliance with all the provisions of the IPPC Directive, including a permit containing emission limit values or equivalent parameters and technical measures determined according to the provisions of Article 9(4) or Article 9(8) of the latter. As presented in the standard BREF preface, a certain flexibility is anchored in the provisions of Article 9(4) of the IPPC Directive as well as in the definition of BAT. However, if stricter conditions, compared to the conditions of the Solvents Emissions Directive, are determined by a competent authority or through general binding rules to be necessary to fulfil the requirements of the IPPC Directive for a particular permit, these stricter conditions shall apply.
- Article 6 of the Solvents Emissions Directive provides for the possibility for Member States to define and implement national plans for reducing emissions from the activities and existing installations covered by that Directive excluding surface cleaning and dry cleaning. However, according to Article 6(1) of that Directive, *'a national plan may under no circumstances exempt an existing installation from the provisions laid down in Directive 96/61/EC'*. Therefore, even if an installation is covered by a national plan, it still needs to operate in compliance with all the provisions of the IPPC Directive, including a permit containing emission limit values or equivalent parameters and technical measures determined according to the provisions of Article 9(4) or Article 9(8) of the IPPC Directive.

The IPPC Directive has the following reference to other legislation and emission limit values:

- Article 18(2) states that: *In the absence of Community emission limit values defined pursuant to this Directive, the relevant emission limit values contained in the Directives referred to in Annex II and in other Community legislation shall be applied as minimum emission limit values pursuant to this Directive for the installations listed in Annex I.*

The Solvents Emissions Directive is not listed in the Annex II as it came into force after the IPPC Directive. However, it is clearly '*other Community legislation*' for the purposes of Article 18(2), and the emission limit values it contains are therefore the minimum emission limit values for this industry sector.

Best Available Techniques Reference Document on Surface Treatment using Organic Solvents

EXECUTIVE SUMMARY	I
PREFACE	XI
SCOPE	XLI
1 GENERAL INFORMATION ON SURFACE TREATMENT USING ORGANIC SOLVENTS	1
1.1 Organic solvents and treating surfaces	1
1.2 Key environmental issues	2
1.2.1 Overall	2
1.2.2 Solvents	3
1.2.3 Metals	4
1.2.4 Other pollutants	4
1.2.5 Energy	5
1.2.6 Raw material usage	5
1.2.7 Water usage	5
1.2.8 Solid and liquid wastes	5
1.2.9 Airborne particles	5
1.2.10 Noise	5
2 PRINTING	7
2.1 General information on printing	7
2.1.1 Printing industry in the European Community	7
2.1.2 The products	11
2.1.2.1 Newspapers	11
2.1.2.2 Magazines and catalogues	11
2.1.2.3 Books	12
2.1.2.4 General printing	12
2.1.2.5 Security printing	12
2.1.2.6 Labels	12
2.1.2.7 Business forms	12
2.1.2.8 Paper and cardboard packaging	13
2.1.2.9 Flexible packaging	13
2.1.2.10 Products requiring thick ink films	13
2.1.2.11 Wallpaper, decorative paper and paper-based foils for the furniture and lamination industry	13
2.1.2.12 Envelopes	14
2.2 Applied processes and techniques in printing	14
2.2.1 Pre-press and proofing systems	14
2.2.2 Creating the image carrier: printing plate, cylinder, stencil making and computer-to- plate (CTP)	15
2.2.3 Printing	16
2.2.3.1 Letterpress and letterset	16
2.2.3.2 Flexography	16
2.2.3.3 Offset: general	18
2.2.3.4 Sheetfed offset	20
2.2.3.5 Web presses (heatset and coldset offset)	21
2.2.3.6 Gravure	22
2.2.3.7 Screen printing	23
2.2.3.8 Digital printing	25
2.2.3.9 Laminating and varnishing in flexible packaging	25
2.2.4 Finishing	26
2.2.5 Associated activities	26
2.3 Current consumption and emission levels in printing	28
2.3.1 The printing industry as a whole	28
2.3.2 Heatset web offset	28
2.3.2.1 Mass balances – heatset	28
2.3.2.2 Consumptions – heatset	35
2.3.2.2.1 Constituents and additives	35

2.3.2.2.2	Printing inks	35
2.3.2.2.3	Dampening solutions	35
2.3.2.2.4	Varnishes	36
2.3.2.2.5	Cleaning agents	36
2.3.2.2.6	Energy and resources	38
2.3.2.2.7	Printing substrates and other consumptions	39
2.3.2.3	Emissions – heatset	39
2.3.2.3.1	Emissions to air – sources and fugitive emissions	39
2.3.2.3.2	Waste	41
2.3.2.3.3	Waste water	42
2.3.3	Flexible package printing – flexography and gravure	43
2.3.3.1	Mass balances – flexible packaging	43
2.3.3.2	Consumptions – flexible packaging	47
2.3.3.2.1	Organic solvents	47
2.3.3.2.2	Printing inks and varnishes	48
2.3.3.2.3	Cleaning agents	52
2.3.3.2.4	Adhesives in lamination	53
2.3.3.2.5	Energy and resources	53
2.3.3.3	Emissions – flexible packaging	54
2.3.3.3.1	Emissions to air	54
2.3.3.3.2	Waste	58
2.3.3.3.3	Waste water	59
2.3.4	Publication gravure	59
2.3.4.1	Mass balances – publication gravure	59
2.3.4.2	Consumptions – publication gravure	63
2.3.4.2.1	Printing inks	63
2.3.4.2.2	Cleaning agents	63
2.3.4.2.3	Energy and resources	64
2.3.4.2.4	Printing substrates and others	64
2.3.4.3	Emissions – publication gravure	64
2.3.4.3.1	Emissions to air	64
2.3.4.3.2	Waste	65
2.3.4.3.3	Waste water	66
2.4	Techniques to consider in the determination of BAT for printing	66
2.4.1	Heatset offset printing	67
2.4.1.1	Conventional heatset inks	67
2.4.1.2	Replacement of conventional heatset inks (substitution)	68
2.4.1.2.1	Inks based on vegetable oils	68
2.4.1.3	Reducing emissions from the dampening solution	69
2.4.1.3.1	Replacement of IPA in the dampening solution (substitution)	69
2.4.1.3.2	Optimising the concentration of IPA in the dampening solution	70
2.4.1.3.3	Ceramic, metal and hydrophilic distributing and plate rollers	71
2.4.1.3.4	Exact adjustment of the inking rollers	72
2.4.1.3.5	Apply a spray system in the dampening unit	72
2.4.1.3.6	Cooling the dampening solution	73
2.4.1.3.7	Cooling the dampening rollers and plate cylinders	73
2.4.1.3.8	Removal of IPA solutions from the dampening unit	74
2.4.1.4	Filtering the dampening solution	74
2.4.1.5	Controlling the hardness of the water for the dampening solution	75
2.4.1.6	Waterless offset	75
2.4.1.7	Waste gas collection and treatment	76
2.4.1.7.1	Encapsulation of presses or extraction and treatment of air from the press room	76
2.4.1.7.2	Extraction and treatment of air from the driers	77
2.4.1.8	Cleaning	78
2.4.1.8.1	Replacement (substitution) and control of VOCs used in cleaning	78
2.4.1.8.2	Automatic high pressure cleaners for dampening rollers	79
2.4.1.8.3	Automatic cleaning systems for printing and blanket cylinders	79
2.4.2	Flexography and packaging gravure	80
2.4.2.1	Conventional solvent-based inks	81
2.4.2.2	Replacement of conventional solvent-based inks (substitution)	81
2.4.2.2.1	UV curing alternatives	81
2.4.2.2.2	Electron beam (EB) curable alternatives	83

2.4.2.2.3	Water-based inks	83
2.4.2.3	Conventional solvent-based varnishes and adhesives	85
2.4.2.4	Substitutes for conventional varnishes and adhesives	85
2.4.2.4.1	Water-based varnishes and adhesives.....	85
2.4.2.4.2	High solid alternatives.....	86
2.4.2.4.3	UV curing alternatives.....	87
2.4.2.4.4	Solvent-free alternatives.....	87
2.4.2.4.5	Co-extrusion.....	88
2.4.2.5	Waste gas treatment	88
2.4.2.5.1	Encapsulation/enclosure	88
2.4.2.5.2	Extraction and treatment of air from the presses and other production areas.....	89
2.4.2.5.3	Peak volume bypass and peak/trough smoothing: extraction and treatment of air from the presses and production areas	90
2.4.2.5.4	Maintenance of waste gas treatment equipment, bypasses, collection systems, etc.	90
2.4.2.5.5	Automatic and timely closure of a bypass system.....	91
2.4.2.6	Cleaning	91
2.4.2.6.1	Replacement of VOCs with less volatile solvents for cleaning floors (substitution).....	91
2.4.2.6.2	Cleaning machine parts and equipment in automatic cleaning/washing machines.....	92
2.4.2.6.3	Cleaning of machine parts with high pressure water spray	92
2.4.3	Publication gravure printing.....	92
2.4.3.1	Conventional solvent-based inks.....	93
2.4.3.2	Substitutes for conventional solvent-based inks.....	93
2.4.3.2.1	Water-based alternatives	93
2.4.3.2.2	Using retention inks	94
2.4.3.3	Waste gas treatment	95
2.4.3.3.1	Increased temperature in the press room	95
2.4.3.3.2	Increasing drying time.....	95
2.4.3.3.3	Discontinuous air extraction from the driers	96
2.4.3.3.4	Continuous air extraction from the driers.....	96
2.4.3.3.5	Enclosed press and ventilation air is routed to the waste gas treatment system discontinuously.....	97
2.4.3.3.6	Enclosed press and ventilation air is routed to the waste gas treatment system continuously	97
2.4.3.3.7	Discontinuous air extraction from the press, the driers and the press room ..	98
2.4.3.3.8	Continuous air extraction from the press, the driers and the press room.....	98
2.4.3.3.9	Closed air loop ventilation	99
2.4.3.3.10	Air-knives on the printed web	100
2.4.3.4	Cleaning	100
2.4.3.4.1	In-press cleaning of printing cylinders	100
3	MANUFACTURE OF WINDING WIRE	103
3.1	General information on the winding wire industry	103
3.1.1	Product characteristics and end use applications	104
3.2	Applied processes and techniques in winding wire manufacturing.....	104
3.2.1	Typical manufacturing process for enamelled wires.....	105
3.3	Current consumption and emission levels in winding wire manufacturing.....	107
3.3.1	Mass balances	107
3.3.2	Consumptions	109
3.3.2.1	Coatings	109
3.3.2.2	Lubricants.....	110
3.3.3	Emissions	110
3.3.3.1	Emissions to air	110
3.3.3.2	Emissions to water	113
3.3.3.3	Waste.....	113
3.4	Techniques to consider in the determination of BAT in winding wire manufacturing	114
3.4.1	General techniques in winding wire manufacturing.....	114
3.4.2	Energy management.....	115
3.4.2.1	Wire cooling with room air or exterior air	115
3.4.3	Conventional solvent-based processes	116

3.4.3.1	Applying conventional solvent-based coating baths with die application and coating circuit.....	116
3.4.3.2	Applying conventional solvent-based coatings with dosed coating supply and felt application.....	116
3.4.3.3	Applying conventional solvent-based lubricants using felts.....	117
3.4.4	Conventional water-based emulsions.....	118
3.4.5	Replacement of conventional solvent-based materials (substitution).....	118
3.4.5.1	High solids enamel coatings.....	118
3.4.5.2	Water-based enamel coatings.....	119
3.4.5.3	UV curing enamel coatings.....	119
3.4.5.4	Cresol-free enamel coatings.....	120
3.4.5.5	Powder polyester enamel coatings.....	120
3.4.5.6	Solvent-free lubricants.....	121
3.4.6	Replacement of conventional solvent-based coating processes (substitution).....	122
3.4.6.1	Extrusion enamel coatings.....	122
3.4.6.2	Hot melt enamel coatings.....	122
3.4.6.3	2-component epoxy enamel coatings.....	123
3.4.6.4	Electrocoat enamel coatings.....	124
3.4.6.5	Self-lubricating coatings.....	124
3.4.7	Waste gas treatment.....	125
3.4.7.1	Waste gas from enamelling.....	125
3.4.7.2	Lubrication.....	126
4	MANUFACTURING OF ABRASIVES.....	127
4.1	General information on the abrasives industry.....	127
4.1.1	Areas of application.....	127
4.1.2	Production and sales.....	127
4.1.3	Characterisation of the product ‘abrasive’ and its quality demands.....	128
4.1.3.1	Backing.....	129
4.1.3.2	Bonding material.....	130
4.1.3.3	Abrasive grain.....	131
4.1.4	Quality requirements.....	133
4.2	Applied processes and techniques in abrasives manufacturing.....	133
4.2.1	Process overview.....	133
4.2.2	Detailed process steps.....	134
4.2.2.1	Pretreatment of backings.....	134
4.2.2.2	Coating of the backing with bonding materials.....	135
4.2.2.3	Coating of the backing with grain.....	135
4.2.2.4	Flexing.....	136
4.2.3	Components of installations and required differentiation.....	136
4.3	Current consumption and emission levels in abrasives manufacturing.....	137
4.3.1	Mass balances.....	137
4.3.2	Consumptions.....	140
4.3.3	Emissions.....	140
4.3.3.1	Emissions to air.....	140
4.3.3.2	Emissions to water.....	141
4.3.3.3	Waste.....	141
4.4	Techniques to consider in the determination of BAT for the manufacturing of abrasives.....	141
4.4.1	Conventional solvent-based bonding materials.....	142
4.4.2	Substitution of conventional solvent-based bonding materials.....	143
4.4.2.1	Solvent-free bonding materials.....	143
4.4.3	Drying.....	143
4.4.3.1	Convection drying.....	143
4.4.3.2	Electromagnetic drying.....	143
4.4.4	Waste gas treatment.....	144
4.4.4.1	Increase of the internal solvent concentration.....	144
4.4.4.2	Containment and collection of waste gases.....	144
4.4.4.3	Dry filter systems.....	144
4.4.4.4	Thermal oxidation.....	144
4.4.4.5	Regenerative thermal oxidation.....	144
4.4.4.6	Biological treatment.....	144
4.4.5	Waste water treatment.....	145
5	MANUFACTURING OF ADHESIVE TAPE.....	147

5.1	General information on the manufacturing of adhesive tape.....	147
5.1.1	Applications of pressure-sensitive adhesives.....	147
5.2	Applied processes and techniques in adhesive tape manufacturing.....	148
5.2.1	Construction of adhesive tapes.....	148
5.2.2	Materials for the production of adhesive tapes.....	148
5.2.3	Production process of adhesive tapes.....	150
5.3	Current consumption and emission levels adhesive tape manufacturing.....	153
5.3.1	VOC emission balance.....	156
5.4	Techniques to consider in the determination of BAT for the manufacturing of adhesive tape.....	157
5.4.1	Conventional solvent-based adhesives.....	157
5.4.2	Replacement of conventional solvent-based adhesives (substitution).....	158
5.4.2.1	Hot melts adhesives.....	158
5.4.2.2	Water-based adhesives.....	158
5.4.2.3	UV curing adhesives.....	159
5.4.3	Replacement of conventional solvent-based adhesives manufacturing (substitution).....	159
5.4.3.1	Solvent-free manufacturing of adhesive tape.....	159
5.4.4	Drying.....	160
5.4.4.1	Inert gas convection drying.....	160
5.4.4.2	Infrared radiation curing.....	160
5.4.4.3	Ultraviolet (UV) curing.....	161
5.4.4.4	Electron beam curing (EB).....	161
5.4.5	Waste gas treatment.....	161
5.4.5.1	Condensation (refrigeration).....	161
5.4.5.2	Adsorption to activated carbon and recovery on-site.....	161
6	COATING OF CARS.....	163
6.1	General information on the car industry.....	163
6.1.1	Production and sale figures.....	163
6.2	Applied processes and techniques in the car industry.....	164
6.2.1	Quality requirements.....	164
6.2.2	Serial coating.....	165
6.2.3	Applied coating materials.....	166
6.2.4	Coating processes.....	166
6.2.4.1	Coating application techniques.....	166
6.2.4.2	Description of the process steps.....	166
6.2.4.2.1	Pretreatment.....	166
6.2.4.2.2	Electrocoating.....	167
6.2.4.2.3	Seam sealing and underbody protection.....	167
6.2.4.2.4	Application of the primer.....	168
6.2.4.2.5	Cleaning.....	168
6.2.4.2.6	Types of topcoatings and their application.....	168
6.2.4.2.7	Drying and curing.....	170
6.2.4.2.8	Cavity conservation.....	170
6.2.4.2.9	Rework.....	170
6.2.4.2.10	Transport conservation.....	170
6.3	Current consumption and emission levels in the car industry.....	171
6.3.1	Mass balances.....	171
6.3.2	Consumptions.....	171
6.3.2.1	Materials.....	171
6.3.2.2	Water.....	172
6.3.2.3	Energy.....	173
6.3.3	Emissions.....	174
6.3.3.1	Emissions to air.....	174
6.3.3.2	Emissions to water.....	177
6.3.3.3	Waste.....	178
6.4	Techniques to consider in the determination of BAT for the coating of cars.....	178
6.4.1	Coating systems.....	179
6.4.2	Conventional solvent-based materials.....	180
6.4.3	Substitution of solvent-based materials.....	181
6.4.3.1	Water-based paint systems.....	181
6.4.3.2	Powder coating.....	182
6.4.3.3	Powder slurry coating.....	183

6.4.4	Paint application techniques and equipment	184
6.4.4.1	Paint application by immersion	184
6.4.5	Spray booths	185
6.4.6	Minimisation of raw material consumption	185
6.4.6.1	Recovery of used solvents	185
6.4.7	Drying techniques	185
6.4.8	Waste gas treatment	186
6.4.9	Waste water treatment	186
7	COATING OF VANS, TRUCKS, AND TRUCK CABS	187
7.1	General information on the coating of vans, trucks and truck cabs	187
7.2	Applied processes and techniques in the coating of vans, trucks and truck cabs	187
7.2.1	Drivers cabs and light commercial vehicles	187
7.2.2	Coating of truck chassis	188
7.2.3	Painting of axles	189
7.3	Current consumption and emission levels in the coating of vans, trucks and truck cabs	189
7.3.1	Mass balances	189
7.3.2	Consumptions	190
7.3.2.1	Materials	190
7.3.2.2	Water	190
7.3.2.3	Energy	190
7.3.3	Emissions	191
7.3.3.1	Emissions to air	191
7.3.3.2	Emissions to water	192
7.3.3.3	Waste	192
7.4	Techniques to consider in the determination of BAT for the coating of vans, trucks and truck cabs	193
7.4.1	Conventional solvent-based materials	194
7.4.2	Replacement of solvent-based materials (substitution)	194
7.4.2.1	Water-based paint systems	194
7.4.3	Paint application techniques and equipment	195
7.4.3.1	Electrocoating	195
7.4.3.2	High volume low pressure spraying (HVLP)	195
7.4.3.3	Electrostatically atomising spray processes	196
7.4.3.4	Electrostatically assisted high rotation bells	196
7.4.3.5	Wet separation spray booths	196
7.4.4	Waste gas treatment	196
7.4.4.1	Oxidation	196
7.4.4.2	Adsorption to activated carbon	197
7.4.5	Waste water treatment	197
8	COATING OF BUSES	199
8.1	General information on the coating of buses	199
8.2	Applied processes and techniques in the coating of buses	199
8.2.1	Pretreatment	199
8.2.2	Ground coating/dip coating	199
8.2.3	Underbody protection and seam sealing	199
8.2.4	Application of the primer	200
8.2.5	Application of the topcoat	200
8.2.6	Cavity sealing	200
8.2.7	Alternative systems and abatement techniques	200
8.2.8	Examples of coating installations for buses	201
8.3	Current consumption and emission levels in the coating of buses	202
8.3.1	Mass balances	202
8.3.2	Consumptions	202
8.3.2.1	Materials	202
8.3.2.2	Water	203
8.3.2.3	Energy	203
8.3.3	Emissions	203
8.3.3.1	Emissions to air	203
8.3.3.2	Emissions to water	204
8.3.3.3	Waste	204
8.4	Techniques to consider in the determination of BAT for the coating of buses	204
8.4.1	Conventional solvent-based materials	205

8.4.2	Replacement of solvent-based materials (substitution).....	206
8.4.2.1	Water-based paint systems.....	206
8.4.2.2	High solid paints.....	206
8.4.3	Paint application techniques and equipment.....	207
8.4.3.1	Electrocoating (e-coat).....	207
9	COATING OF TRAINS.....	209
9.1	General information on the coating of trains.....	209
9.2	Applied processes and techniques in the coating of trains.....	209
9.3	Current consumption and emission levels in the coating of trains.....	211
9.3.1	Mass balances.....	211
9.3.2	Consumptions.....	211
9.3.2.1	Materials.....	211
9.3.2.2	Water.....	212
9.3.2.3	Energy.....	212
9.3.3	Emissions.....	212
9.3.3.1	Emissions to air.....	212
9.3.3.2	Emissions to water.....	213
9.3.3.3	Waste.....	213
9.4	Techniques to consider in the determination of BAT for the coating of trains.....	213
9.4.1	Conventional solvent-based materials.....	214
9.4.2	Substitution of solvent-based materials.....	215
9.4.2.1	Water-based paints.....	215
9.4.2.2	High solid paints.....	215
9.4.2.3	Coil coated materials.....	216
9.4.3	Paint application techniques and equipment.....	216
9.4.3.1	Conventional high and low pressure spraying.....	216
9.4.3.2	High volume low pressure spraying (HVLP).....	216
9.4.3.3	Airless spraying.....	216
9.4.3.4	Electrostatically assisted compressed air, airless and air assisted spraying.....	216
9.4.3.5	Wet separation spray booths.....	217
9.4.4	Minimisation of raw material consumption.....	217
9.4.5	Waste water treatment.....	217
9.4.5.1	Ultra and nanofiltration.....	217
9.4.6	Waste gas treatment.....	217
9.4.6.1	Venturi particle separation.....	217
9.4.6.2	Scrubber.....	217
9.4.6.3	Dry filter systems.....	217
9.4.6.4	Electrostatic filter.....	217
9.4.6.5	Thermal oxidation.....	217
10	COATING OF AGRICULTURAL AND CONSTRUCTION EQUIPMENT.....	219
10.1	General information on the coating of agricultural and construction equipment.....	219
10.2	Applied processes and techniques in the coating of agricultural and construction equipment.....	219
10.3	Current consumption and emission levels in the coating of agricultural and construction equipment.....	220
10.3.1	Mass balances.....	220
10.3.2	Consumptions.....	220
10.3.2.1	Materials.....	220
10.3.2.2	Water.....	220
10.3.2.3	Energy.....	221
10.3.3	Emissions.....	221
10.3.3.1	Emissions to air.....	221
10.3.3.2	Emissions to water.....	221
10.3.3.3	Waste.....	221
10.4	Techniques to consider in the determination of BAT on the coating of agricultural and construction equipment.....	221
10.4.1	Conventional solvent-based materials.....	222
10.4.2	Replacement (substitution) and reduction of solvent-based materials.....	223
10.4.2.1	Water-based paint systems.....	223
10.4.2.2	Powder coating.....	223
10.4.2.3	Coil coated material.....	224
10.4.3	Paint application techniques and equipment.....	224

10.4.3.1	Conventional dipping	224
10.4.3.2	Electrocoating (e-coat)	225
10.4.3.3	High volume low pressure spraying (HVLP)	225
10.4.4	Training	226
10.4.5	Batch painting/colour grouping	226
10.4.6	Waste gas treatment	226
10.4.7	Waste water treatment	226
11	COATING OF SHIPS AND YACHTS	227
11.1	General information on the coating of ships and yachts	227
11.2	Applied processes and techniques in the coating of ships and yachts	227
11.2.1	New construction	228
11.2.2	Ship repair and ship maintenance	228
11.2.3	Coating of ships	228
11.2.4	Coating repair and maintenance of yachts	230
11.3	Current consumption and emission levels in the coating of ships and yachts	231
11.3.1	Mass balances	231
11.3.2	Consumptions	231
11.3.2.1	Materials	231
11.3.2.2	Water	231
11.3.2.3	Energy	231
11.3.3	Emissions	232
11.3.3.1	Emissions to air	232
11.3.3.2	Emissions to water	232
11.3.3.3	Waste	233
11.4	Techniques to consider in the determination of BAT for the coating of ships and yachts	233
11.4.1	Management systems – dock discipline	234
11.4.2	Enclosure techniques	235
11.4.2.1	Open areas	235
11.4.2.2	Partially enclosed areas, windbreaks, spray curtains, etc	235
11.4.2.3	Fully enclosed areas	236
11.4.3	Surface preparation	237
11.4.3.1	Dry blasting – open system	237
11.4.3.2	Dry blasting – closed system, vacuum or shroud blasting	238
11.4.3.3	High pressure fresh water jetting or blasting	238
11.4.3.4	Wet or slurry blasting	239
11.4.3.5	Other surface treatments	239
11.4.4	Coating materials	240
11.4.4.1	Conventional solvent-based coating materials	240
11.4.4.2	Replacement of solvent-based materials (substitution)	241
11.4.4.2.1	Water-based paints	241
11.4.4.2.2	High solid paints	242
11.4.5	Additional corrosion protection – cathodic protection	242
11.4.6	Paint application techniques and equipment	243
11.4.6.1	Airless spraying	243
11.4.6.2	Hot spraying	243
11.4.6.3	Integrated air extraction at the point of application	244
11.4.7	Alternatives to antifouling paints based on biocides	244
11.4.7.1	Fouling release coatings based on silicones	244
11.4.7.2	Mechanical methods	245
11.4.7.3	Electrochemical processes	245
11.4.8	Waste gas treatment	246
11.4.9	Waste water treatment	247
11.4.10	Waste management	247
12	COATING OF AIRCRAFT	249
12.1	General information on the coating of aircraft	249
12.2	Applied processes and techniques in the coating of aircraft	249
12.2.1	Construction	249
12.2.1.1	Painting of components	249
12.2.1.2	Painting of exterior surfaces	250
12.2.1.3	Temporary corrosion protection	250
12.2.2	Maintenance	251
12.2.2.1	Paint removal	251

12.2.2.2	Cleaning	251
12.2.2.3	Pretreatment	251
12.2.2.4	Primer	251
12.2.2.5	Topcoat.....	252
12.2.2.6	Clear coat	252
12.3	Current consumption and emission levels in the coating of aircraft	252
12.3.1	Construction.....	252
12.3.1.1	Material consumption.....	252
12.3.1.2	Water consumption	253
12.3.1.3	Energy consumption.....	253
12.3.1.4	Emissions to air	253
12.3.1.5	Emissions to water	253
12.3.1.6	Waste.....	253
12.3.2	Maintenance.....	253
12.4	Techniques to consider in the determination of BAT for the coating of aircraft.....	254
12.4.1	Conventional solvent-based materials.....	255
12.4.2	Replacement of solvent-based materials (substitution)	256
12.4.2.1	High solid paints	256
12.4.3	Replacement of hexavalent chromating (substitution).....	256
12.4.4	Paint application techniques and equipment	257
12.4.4.1	Electrostatically assisted spraying.....	257
12.4.4.2	Wet separation spray booths	257
12.4.4.3	Components painting – enclosure and automated application	257
12.4.5	Waste gas treatment	257
12.4.5.1	Venturi particle separation	257
12.4.5.2	Scrubber	258
12.4.5.3	Treatment of waste gases from body painting.....	258
13	COATING OF OTHER METAL SURFACES.....	259
13.1	General information on the coating of other metal surfaces.....	259
13.2	Applied processes and techniques.....	259
13.3	Current consumption and emissions levels	259
13.4	Techniques to consider in the determination of BAT for serial painting of other metal surfaces	260
13.4.1	New multiple coating systems for the painting of aluminium rims/wheels	261
14	COIL COATING INDUSTRIES.....	265
14.1	General information on coil coating.....	265
14.1.1	The size of the coil coating industry	265
14.2	Applied processes and techniques in coil coating	266
14.2.1	Typical coil coating line process description	267
14.2.1.1	Entry.....	267
14.2.1.2	Leveller	267
14.2.1.3	Accumulator.....	268
14.2.1.4	Cleaning section.....	268
14.2.1.5	Conversion coating (pretreatment).....	268
14.2.1.6	Prime coat application.....	268
14.2.1.7	Finish coat application	268
14.2.1.8	Embosser/laminator.....	269
14.2.1.9	Cooling systems	269
14.2.1.10	Exit.....	269
14.2.2	Coating types	269
14.3	Current consumption and emission levels in coil coating	271
14.3.1	Mass balances	271
14.3.2	Consumptions	271
14.3.2.1	Materials.....	271
14.3.2.2	Water.....	274
14.3.2.3	Energy	275
14.3.3	Emissions	275
14.3.3.1	Emissions to air	275
14.3.3.2	Emissions to water	277
14.3.3.3	Waste.....	277
14.4	Techniques to consider in the determination of BAT for coil coating	278
14.4.1	Water management	279

14.4.1.1.1	Re-use of water within the plant.....	279
14.4.1.1.2	Monitoring rinsing water before discharge by conductivity measurements.....	279
14.4.1.2	Reverse cascade rinsing.....	279
14.4.2	Conventional solvent-based coatings.....	279
14.4.3	Replacement of solvent-based coatings (substitution).....	280
14.4.3.1	High solid coatings.....	280
14.4.3.2	Water-based coatings.....	281
14.4.3.3	Powder coatings.....	281
14.4.3.4	Laminate film coatings.....	282
14.4.4	Coating application techniques and equipment.....	283
14.4.4.1	Roller coating.....	283
14.4.4.2	Cleaning of application equipment.....	284
14.4.5	Conversion coatings.....	284
14.4.5.1	Conversion coating containing chrome.....	284
14.4.5.2	Chrome-free conversion coatings.....	284
14.4.6	Application of conversion coatings.....	285
14.4.6.1	'Spray, squeegee and rinse' application.....	285
14.4.6.2	'No rinse' or 'dry in place' application.....	285
14.4.7	Drying.....	286
14.4.7.1	Convection drying or curing.....	286
14.4.7.2	Radiation curing processes.....	286
14.4.8	Waste gas treatment.....	286
14.4.8.1	Air extraction from conversion coatings station.....	286
14.4.8.2	Air seals on the entrance and the exit of the ovens/driers.....	287
14.4.8.3	Negative pressure in drying.....	287
14.4.8.4	Air extraction from coating preparation.....	287
14.4.8.5	Air extraction from the paint application station.....	287
14.4.8.6	Air extraction from the oven/drier.....	288
14.4.8.7	Air extraction from the cooling zone.....	288
14.4.8.8	Recuperative thermal oxidation.....	289
14.4.8.9	Regenerative thermal oxidation – dual bed.....	289
14.4.9	Waste water treatment.....	289
14.4.9.1	Treatment of rinse-water before discharge.....	289
14.4.9.2	Treatment of waste water containing chromate.....	290
14.4.9.3	Hydroxide precipitation.....	291
15	COATING AND PRINTING OF METAL PACKAGING.....	293
15.1	General information.....	293
15.2	Applied processes and techniques in the coating and printing of metal packaging.....	295
15.2.1	Two piece can manufacture (DWI).....	295
15.2.2	Flat sheet coating and priming.....	297
15.2.3	Three piece can manufacture.....	298
15.2.4	End, cap and closure manufacture.....	299
15.2.5	Extruded aluminium tubes manufacture.....	300
15.2.6	Drum manufacture.....	302
15.3	Current consumption and emission levels in the coating and printing of metal packaging.....	303
15.3.1	Mass balances.....	303
15.3.2	Consumption and emissions data.....	303
15.3.3	Consumptions.....	305
15.3.3.1	Materials.....	305
15.3.3.2	Water.....	307
15.3.3.3	Energy.....	307
15.3.4	Emissions.....	308
15.3.4.1	Emissions to air.....	308
15.3.4.2	Emissions to water.....	310
15.3.4.3	Waste.....	310
15.4	Techniques to consider in the determination of BAT for the coating and printing of metal packaging.....	311
15.4.1	Conventional solvent-based coating and ink systems.....	312
15.4.1.1	Solvent-based inks in two piece DWI can manufacture.....	312
15.4.2	Replacement of coatings and inks containing solvents (substitution).....	313
15.4.2.1	Water/solvent-based coating and ink systems.....	313

15.4.2.2	Water-based coating systems and compounds in metal packaging manufacture based on sheetfed technology.....	314
15.4.2.3	Sheetfed coating.....	314
15.4.2.4	Liquid side stripe.....	315
15.4.2.5	Repair spray.....	316
15.4.2.6	Powder spray side strip coating.....	316
15.4.2.7	Coil coated materials.....	316
15.4.2.8	Pre-coated coil.....	317
15.4.2.9	UV compounds (varnish and inks).....	317
15.4.3	Application of coatings and ink.....	318
15.4.3.1	Rollers for two piece DWI can manufacture.....	318
15.4.3.2	Rollers for sheetfed technology.....	318
15.4.3.3	Rollers for aluminium extruded tube manufacture.....	319
15.4.3.4	Compressed air spraying.....	319
15.4.3.5	Airless spraying.....	320
15.4.3.6	Electrostatic spraying.....	320
15.4.3.7	Powder spraying.....	321
15.4.3.8	Curtain coater.....	321
15.4.3.9	Radiation curing.....	322
15.4.4	Printing.....	322
15.4.4.1	Lithographic (wet offset) for sheetfed technology.....	322
15.4.4.2	Waterless lithographic.....	322
15.4.4.3	Waterless offset lithography for aluminium extruded tube manufacture.....	323
15.4.5	Waste gas treatment.....	323
15.4.5.1	Dry filter systems.....	323
15.4.5.2	Electrostatic filter.....	324
15.4.5.3	Thermal oxidation.....	324
15.4.5.4	Catalytic oxidation.....	324
15.4.5.5	Adsorption to activated carbon.....	324
15.4.5.6	Biological treatment.....	324
15.4.6	Waste water treatment.....	324
15.4.6.1	Flocculation/sedimentation.....	324
15.4.6.2	Ultra and nanofiltration.....	325
16	COATING OF PLASTIC WORKPIECES.....	327
16.1	General information on the coating of plastic workpieces.....	327
16.2	Applied processes and techniques in the coating of plastic workpieces.....	327
16.2.1	Coating of bumpers.....	328
16.2.2	Coating of wheel covers.....	330
16.2.3	Coating of steering wheels.....	331
16.2.4	Coating of reflectors.....	331
16.2.5	Coating in the production of TVs, hi-fis and computer housings.....	331
16.3	Current consumption and emission levels in the coating of plastic workpieces.....	331
16.3.1	Mass balances.....	332
16.3.2	Consumptions.....	332
16.3.2.1	Materials.....	332
16.3.2.2	Water.....	334
16.3.2.3	Energy.....	334
16.3.3	Emissions.....	334
16.3.3.1	Emissions to air.....	335
16.3.3.2	Emissions to water.....	335
16.3.3.3	Waste.....	335
16.4	Techniques to consider in the determination of BAT for the serial painting of plastic workpieces.....	336
16.4.1	Minimisation of raw material consumption.....	336
16.4.1.1	Batch painting/colour grouping.....	337
16.4.1.2	Pig-clearing systems.....	337
16.4.1.3	Increase of the number of high rotation bells.....	337
16.4.2	Water management.....	338
16.4.3	Conventional solvent-based materials.....	338
16.4.4	Replacement of solvent-based materials (substitution).....	339
16.4.4.1	Water-based paints.....	339
16.4.4.2	Powder coating – conventionally dried.....	339

16.4.4.3	Radiation curing paints	340
16.4.4.4	One layer coating after fluoridation	340
16.4.5	Paint application techniques and equipment	341
16.4.5.1	In-mould painting.....	341
16.4.5.2	Conventional high and low pressure spraying.....	341
16.4.5.3	High volume low pressure spraying (HVLP).....	342
16.4.5.4	Electrostatically assisted high rotation bells.....	342
16.4.5.5	Electrostatically assisted compressed air, airless and air assisted spraying	342
16.4.5.6	Processing of powder coatings – electrostatically assisted spraying.....	343
16.4.6	Drying	343
16.4.6.1	Convection drying.....	343
16.4.6.2	Ultraviolet (UV) curing.....	344
16.4.6.3	Electron beam curing	344
16.4.6.4	Use of condensation driers	345
16.4.7	Waste gas treatment	345
16.4.7.1	Electrostatic filter.....	345
16.4.7.2	Venturi particle separation	345
16.4.7.3	Scrubber	345
16.4.7.4	Treatment of waste gases from the painting booths	346
16.4.7.5	Concentration and recirculation of waste gases from the painting booths	346
16.4.7.6	Thermal oxidation	347
16.4.7.7	Biological treatment.....	347
16.4.8	Waste water treatment.....	347
16.4.8.1	Ultra and nanofiltration	347
17	COATING OF FURNITURE AND WOOD MATERIALS	349
17.1	General information on the coating of furniture and wood materials.....	349
17.2	Applied processes and techniques in the coating of furniture and wood materials	350
17.2.1	Pretreatment of the wood surface.....	350
17.2.2	Application of a base coat.....	351
17.2.3	Application of a topcoat.....	352
17.2.4	Application of the paint.....	355
17.2.5	Flashing off and drying/curing.....	356
17.2.6	Examples of some coating processes	356
17.2.7	Finishing with solid coating substances.....	358
17.3	Current consumption and emission levels in the coating of furniture and wood materials....	358
17.3.1	Mass balances	358
17.3.2	Consumptions	358
17.3.2.1	Materials.....	358
17.3.2.2	Water.....	360
17.3.2.3	Energy	360
17.3.3	Emissions	360
17.3.3.1	Emissions to air	360
17.3.3.2	Emissions to water	360
17.3.3.3	Waste.....	361
17.4	Techniques to consider in the determination of BAT for the painting of furniture and wood materials.....	361
17.4.1	Minimisation of raw material consumption	362
17.4.1.1	Batch painting/colour grouping.....	362
17.4.1.2	Pig clearing systems	362
17.4.1.3	Online mixing system for 2-component products	362
17.4.2	Conventional solvent-based materials.....	363
17.4.3	Replacement of solvent-based materials (substitution).....	363
17.4.3.1	Water-based coatings	363
17.4.3.2	Powder coating – conventionally dried	364
17.4.3.3	UV radiation curing paints	365
17.4.4	Paint application techniques and equipment	365
17.4.4.1	Rolling and filling by using reverse coaters	365
17.4.4.2	Curtain coating (casting).....	366
17.4.4.3	Conventional dipping	367
17.4.4.4	Flooding.....	367
17.4.4.5	Vacuum coating	368
17.4.4.6	Conventional high and low pressure spraying.....	369

17.4.4.7	High volume low pressure spraying (HVLP).....	369
17.4.4.8	Electrostatically assisted compressed air, airless and air assisted spraying	369
17.4.4.9	Powder coatings – electrostatically assisted spraying	370
17.4.5	Spray booths.....	370
17.4.5.1	Wet separation booth.....	370
17.4.5.2	Paint-in-paint spray booth.....	370
17.4.6	Drying.....	371
17.4.6.1	Convection drying.....	371
17.4.6.2	Microwave drier.....	371
17.4.6.3	High frequency driers.....	372
17.4.6.4	Infrared radiation curing.....	372
17.4.6.5	Near-infrared radiation curing.....	372
17.4.6.6	Ultraviolet (UV) radiation.....	372
17.4.6.7	Electron beam curing	372
17.4.6.8	Combined convection/radiation drying (thermal reactor)	373
17.4.7	Waste gas treatment	373
17.4.7.1	Dry filter systems	373
17.4.7.2	Electrostatic filter	373
17.4.7.3	Venturi particle separation	373
17.4.7.4	Scrubber	373
17.4.7.5	Biological treatment.....	373
17.4.7.6	Thermal oxidation	373
17.4.7.7	UV oxidation.....	374
17.4.8	Waste water treatment.....	374
17.4.8.1	Waste water treatment for wet separation paint spray booths	374
17.4.8.2	Ultra and nanofiltration	374
17.4.9	Waste treatment	374
17.4.9.1	Recovery of used solvents by applying distillation.....	374
18	WOOD PRESERVATION.....	375
18.1	General information on wood preservation.....	375
18.2	Applied processes and techniques on wood preservation	375
18.3	Current consumption and emission levels on wood preservation	376
18.3.1	Mass balances	376
18.3.2	Consumptions	376
18.3.2.1	Materials.....	376
18.3.2.2	Water.....	376
18.3.2.3	Energy	376
18.3.3	Emissions.....	376
18.3.3.1	Emissions to air.....	376
18.3.3.2	Emissions to water, soil and groundwater.....	378
18.3.3.3	Waste.....	378
18.4	Techniques to consider in the determination of BAT on wood preservation.....	378
18.4.1	Conventional solvent-based preservatives	379
18.4.2	Replacement of conventional solvent-based preservatives (substitution).....	379
18.4.2.1	Creosote	379
18.4.2.2	Concentrated pesticide systems.....	380
18.4.2.3	Water-based preservatives.....	380
18.4.3	Application systems	381
18.4.3.1	Vacuum application	381
18.4.4	Waste gas treatment	382
19	MANUFACTURE OF MIRRORS.....	383
19.1	General information on the manufacture of mirrors.....	383
19.2	Applied processes and techniques in the manufacture of mirrors	383
19.2.1	Incoming glass pane.....	384
19.2.2	Preparation of the glass surface.....	384
19.2.3	Silvering.....	384
19.2.4	Paint coating.....	385
19.2.5	Drying	385
19.2.6	Exit of the finished product.....	385
19.3	Current consumption and emission levels in the manufacture of mirrors	385
19.3.1	Mass balances	385
19.3.2	Consumptions	385

19.3.2.1	Materials.....	385
19.3.2.2	Water.....	385
19.3.2.3	Energy.....	385
19.3.3	Emissions.....	386
19.3.3.1	Emissions to air.....	386
19.3.3.2	Emissions to water.....	386
19.3.3.3	Wastes.....	386
19.4	Techniques to consider in the determination of BAT for the manufacture of mirrors.....	387
19.4.1	General techniques in the manufacture of mirrors.....	387
19.4.2	Replacement of conventional solvent-based paints (substitution).....	387
19.4.2.1	High solids paints.....	387
19.4.3	Paint application techniques and equipment.....	388
19.4.3.1	Curtain coating.....	388
19.4.4	Drying.....	388
19.4.5	Waste gas treatment.....	388
20	TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT APPLICABLE IN ALL INDUSTRIES.....	391
20.1	Environmental management techniques.....	392
20.1.1	Environmental management tools.....	392
20.1.2	Ongoing environmental improvement and cross-media issues.....	399
20.1.3	Benchmarking consumptions and emissions and subsequent action.....	400
20.1.4	Costing environmental benefits and estimating cross-media effects.....	401
20.2	Installation design, construction and operation (including good housekeeping).....	403
20.2.1	Pollution prevention for unplanned releases.....	403
20.2.2	Storage and handling of chemicals, hazardous materials and waste.....	404
20.2.2.1	Handling and use of solvents in production areas.....	406
20.2.3	Automation of equipment.....	407
20.2.4	Training.....	408
20.2.5	Optimisation of processes/equipment.....	409
20.2.6	Maintenance.....	409
20.3	Monitoring.....	410
20.3.1	Mass balances for solvents.....	410
20.3.2	Direct measurement of solvents and emissions to air.....	414
20.3.3	Water.....	415
20.3.3.1	Preventing hazardous atmospheres in sewers.....	415
20.3.3.2	Monitoring of BOD and COD and biodegradability.....	416
20.3.3.3	Monitoring and controlling aquatic toxicity.....	416
20.4	Water management.....	418
20.4.1	Re-use/recycling of rinsing water.....	418
20.4.1.1	Regeneration by ion exchange.....	418
20.4.1.2	Re-use of water within the plant.....	418
20.4.1.3	Cascade rinsing.....	418
20.4.1.4	Control of water usage.....	420
20.5	Energy management.....	421
20.5.1	Optimisation of electrical power supply.....	423
20.5.2	Optimising electricity demand.....	423
20.5.3	Energy efficient equipment.....	424
20.6	Raw material management.....	424
20.6.1	Just-in-time management.....	424
20.6.2	Quality assurance of paints and solvents.....	425
20.6.3	Minimisation of raw material consumption.....	425
20.6.3.1	Advanced mixing systems.....	425
20.6.3.2	Re-use of returned paints or inks.....	426
20.6.3.3	Re-use of recovered coatings or inks.....	427
20.6.3.4	Direct piping of paint or ink from storage.....	428
20.6.3.5	Direct piping of solvents from storage.....	429
20.6.3.6	Batch painting/colour grouping.....	430
20.6.3.7	Pig-clearing systems.....	430
20.7	Coating processes and equipment.....	431
20.7.1	Pretreatments prior to painting.....	431
20.7.1.1	Solvent-based degreasing.....	431
20.7.1.2	Water-based pretreatments.....	431

20.7.1.2.1	Water-based degreasing	432
20.7.1.2.2	Phosphating	432
20.7.1.2.3	Conversion coating containing chrome	433
20.7.1.2.4	Chrome-free conversion coatings	434
20.7.1.2.5	Bath maintenance, water and waste reduction and waste water reduction ..	434
20.7.2	Paint systems	435
20.7.2.1	Conventional solvent-based paints	435
20.7.2.2	Solvent-based high solid paints	436
20.7.2.3	Water-based paints	436
20.7.2.4	Water-based coatings with reduced flash-off requirement	439
20.7.2.5	Radiation curing paints	439
20.7.2.6	Powder coatings – conventionally cured	440
20.7.2.7	Powder slurry	443
20.7.2.8	Pre-coated materials	443
20.7.2.9	Paints containing toxic metals	444
20.7.3	Paint application processes and equipment	444
20.7.3.1	Roller coating	445
20.7.3.2	Curtain coating (casting)	446
20.7.3.3	Conventional dipping	446
20.7.3.4	Electrocoating	448
20.7.3.5	Flooding	450
20.7.3.6	Vacuum coating	450
20.7.3.7	In-mould painting	451
20.7.3.8	Conventional high and low pressure spraying	451
20.7.3.9	High volume low pressure spraying (HVLP) (high efficiency spray guns)	452
20.7.3.10	Hot spraying	453
20.7.3.11	Airless spraying	454
20.7.3.12	Air assisted airless spraying	455
20.7.3.13	CO ₂ atomisation – the unicarb system	455
20.7.3.14	Electrostatic atomising processes	456
20.7.3.15	Electrostatically assisted high rotation bells	457
20.7.3.16	Electrostatically assisted high rotating discs	458
20.7.3.17	Electrostatically assisted compressed air, airless and air assisted spraying	458
20.7.3.18	Application of powder coatings – electrostatically assisted spraying	459
20.7.3.19	Application of powder coatings – powder sintering	460
20.7.4	Techniques to manage overspray	460
20.7.4.1	Wet separation spray booth	460
20.7.4.2	Paint-in-paint spray booth	462
20.7.4.3	Water emulsion techniques	462
20.7.4.4	Cold plate spray booths	463
20.7.5	Water treatment techniques to reduce waste water and wastes and for treatment of waste water	463
20.7.5.1	Multiple (cascade) rinsing	463
20.7.5.2	Use of ion exchangers	464
20.7.5.3	Membrane filtration	465
20.7.5.4	Bath desludging	465
20.7.5.5	Process solution filtration	466
20.7.5.6	Continuous discharge of paint sludge	466
20.7.5.7	Decantation system	466
20.7.5.8	Coagulation of paint solids in wet cleaners	467
20.8	Drying and/or curing	467
20.8.1	Evaporation processes	468
20.8.1.1	Conventional drying by convection	468
20.8.1.2	Inert gas convection drying	469
20.8.1.3	Induction drying	469
20.8.1.4	Radiation drying (microwave and HF)	470
20.8.2	Radiation curing processes	471
20.8.2.1	Infrared radiation curing	472
20.8.2.2	Near-infrared radiation (NIR) curing	473
20.8.2.3	Ultraviolet (UV) curing	473
20.8.2.4	Electron beam curing (EB)	474
20.8.3	Thermal reactor (combined convection/radiation drying)	475
20.9	Cleaning techniques	476

20.9.1	General principles for cleaning	476
20.9.2	Minimising cleaning	478
20.9.3	Preparation prior to solvent or other types of cleaning	479
20.9.4	Conventional solvent cleaning	479
20.9.5	Cleaning with solvents with lower evaporation speed	480
20.9.6	Cleaning with powerful solvents	480
20.9.7	Cleaning with solvents with lower ozone-forming potential	480
20.9.8	Water-based cleaning	480
20.9.9	Cleaning by hand	480
20.9.10	Washing machines using solvents	481
20.9.11	Cleaning with solvent recovery	482
20.9.12	Cleaning with high pressure water spray	482
20.9.13	Ultrasonic cleaning	483
20.9.14	Dry ice (CO ₂) cleaning	483
20.10	Substitution: using less harmful substances – general principles	484
20.10.1	Replacement of cleaning agents (substitution)	487
20.10.1.1	Cleaning agents with a flashpoint of >40 °C	487
20.10.1.2	Cleaning agents with a flashpoint of >55 °C	488
20.10.1.3	Cleaning agents with a flashpoint of >100 °C	489
20.10.1.4	Vegetable cleaning agents (VCAs)	490
20.10.1.5	Powerful non-volatile solvents	491
20.10.1.6	Water-based cleaning	491
20.10.2	Using solvents with lower ozone-forming potential (OFP)	492
20.10.3	Replacement of halogenated solvents	495
20.10.4	Replacement of solvents and other materials with CMR properties (substitution)	495
20.10.5	Water-based cleaning agents	496
20.11	Waste gas treatment	496
20.11.1	Design, optimisation and management of extraction and abatement techniques	497
20.11.1.1	System selection, design and optimisation	497
20.11.1.2	System maintenance	501
20.11.1.3	Bypassing peak emission flows (peak shaving)	502
20.11.1.4	Utilising over-capacity – smoothing variations	503
20.11.1.5	Maintaining solvent concentration to treatment by variable frequency drives	504
20.11.1.6	Dedicated/decentralised waste gas treatment systems for each point source	504
20.11.1.7	Central waste gas treatment	505
20.11.2	Containment and collection of waste gases	506
20.11.2.1	Encapsulation/enclosure	506
20.11.2.2	Air seals on the entrance and the exit of the ovens/driers	506
20.11.2.3	Negative pressure in drying	507
20.11.2.4	Air extraction from coating processes	507
20.11.2.5	Air extraction from drying processes	508
20.11.2.6	Air extraction from the cooling zone	508
20.11.2.7	Air extraction from cleaning processes	509
20.11.2.8	Air extraction from storage of raw materials and wastes	509
20.11.3	Pretreatment, filtration and scrubbing	510
20.11.3.1	Increase of the internal solvent concentration	510
20.11.3.2	Increase of the external solvent concentration	512
20.11.3.3	Increasing the external air concentration using a plenum	513
20.11.3.4	Membrane filtration	514
20.11.3.5	Venturi particle separation	514
20.11.3.6	Dry filter systems	515
20.11.3.7	Electrostatic filter (precipitator)	516
20.11.3.8	Scrubber	517
20.11.4	Oxidation	517
20.11.4.1	Fuel supplement in process heating	518
20.11.4.2	Thermal oxidation	518
20.11.4.3	Recuperative thermal oxidation	520
20.11.4.4	Regenerative thermal oxidation – dual bed	521
20.11.4.5	Regenerative thermal oxidation – three bed or rotating air distributor	523
20.11.4.6	Catalytic oxidation	524
20.11.4.7	UV oxidation	526
20.11.5	Condensation	527
20.11.5.1	Direct cooling	527

20.11.5.2	Indirect cooling	528
20.11.5.3	Refrigeration	528
20.11.5.4	Cryogenic treatment	529
20.11.5.5	Condensation above freezing point	530
20.11.6	Adsorption.....	530
20.11.6.1	Adsorption using activated carbon or zeolites.....	530
20.11.6.2	Continuous monitoring of the adsorber performance.....	534
20.11.7	Absorption to liquid	534
20.11.7.1	Absorption to water.....	534
20.11.7.2	Absorption to oil and recovery.....	535
20.11.8	Biological treatment.....	535
20.11.9	NO _x abatement techniques.....	537
20.11.9.1	Selective non-catalytic reduction (SNCR)	537
20.11.9.2	Selective catalytic reduction (SCR)	538
20.11.9.3	Water scrubber	538
20.12	Waste water treatment.....	539
20.12.1	Flocculation.....	539
20.12.2	Separation	540
20.12.3	Electroflocculation.....	540
20.12.4	Vacuum distillation	541
20.12.5	Biological treatment.....	541
20.12.6	Ultra and nanofiltration and reverse osmosis.....	542
20.13	Waste minimisation and treatment of wastes containing solvent.....	543
20.13.1	Recovery of used solvents from the process	543
20.13.2	Treatment of used solvents for re-use	544
20.13.2.1	Filtration.....	544
20.13.2.2	Distillation.....	545
20.13.3	Disposable cleaning wipes	546
20.13.4	Re-usable cleaning wipes.....	547
20.13.5	Recovery of used solvents from wipes.....	547
20.13.6	Re-usable containers	548
20.13.7	Treatment of used activated carbon	549
20.13.7.1	On-site recovery of the used activated carbon and other adsorbents.....	549
20.13.7.2	Off-site regeneration/solvent removal of the used activated carbon and other adsorbents.....	549
20.13.7.3	Incineration of the used activated carbon or other adsorbents	550
20.13.8	Waste water sludges.....	550
20.13.8.1	Centrifuges.....	550
20.13.8.2	Filter press.....	551
20.14	Dust abatement.....	551
20.15	Odour abatement	551
20.15.1	Venting tanks during deliveries of solvent-based materials.....	552
20.16	Noise abatement.....	552
21	BEST AVAILABLE TECHNIQUES FOR SURFACE TREATMENT USING ORGANIC SOLVENTS.....	555
21.1	Best available techniques applicable in all industries in the sector	559
21.2	Best available techniques for printing.....	570
21.2.1	BAT for heatset web offset	570
21.2.2	BAT for flexography and packaging gravure (flexible packaging printing).....	572
21.2.3	BAT for publication gravure.....	575
21.3	Best available techniques for winding wire manufacturing	576
21.4	Best available techniques for the manufacturing of abrasives.....	576
21.5	Best available techniques for the manufacturing of adhesive tape.....	577
21.6	Best available techniques for the coating of cars	577
21.7	Best available techniques for the coating of vans, trucks and truck cabs.....	579
21.8	Best available techniques for the coating of buses	580
21.9	Best available techniques for the coating of trains	582
21.10	Best available techniques for the coating of agricultural and construction equipment (ACE).....	583
21.11	Best available techniques for the coating of ships and yachts.....	584
21.12	Best available techniques for the coating of aircraft	585
21.13	Best available techniques for the coating of other metal surfaces.....	586
21.14	Best available techniques for coil coating.....	586

21.15	Best available techniques for the coating and printing of metal packaging	588
21.16	Best available techniques for the coating of plastic workpieces	589
21.17	Best available techniques for the coating of furniture and wood materials	590
21.18	Best available techniques for wood preservation	591
21.19	Best available techniques for mirror manufacturing	592
22	EMERGING TECHNIQUES FOR SURFACE TREATMENT USING SOLVENTS.....	593
22.1	Printing/coating	593
22.1.1	UV curing flexography	593
22.2	Winding wire manufacture	593
22.2.1	Waxing of fine wires	593
22.3	Manufacture of abrasives	594
22.3.1	High speed drying and hardening processes	594
22.4	Manufacture of adhesive tape	594
22.5	Coating of cars and light vans	594
22.5.1	Improved water-dilutable 1- and 2-component clear coating	594
22.5.2	Developments in powder coating	595
22.5.3	Low cost conversion concept	595
22.5.4	Increased use of pre-coated materials	595
22.5.5	Polyurethane (PU) paint systems	596
22.5.6	Reduction in paint layers	596
22.6	Coating of trucks and commercial vehicles	597
22.7	Coating of buses	597
22.8	Coating of trains	597
22.9	Coating of agricultural and construction equipment	597
22.10	Coating of ships and yachts	597
22.10.1	Hot electrostatic air mix	597
22.10.2	Replacement of antifouling paints based on biocides (substitution)	597
22.10.2.1	Paints with natural biocides	597
22.10.2.2	Coatings with special surface properties for a reduction of fouling	598
22.11	Coating of aircraft	598
22.12	Coating of other metal surfaces	598
22.13	Coil coating industries	598
22.14	Coating and printing of metal packaging	599
22.14.1	Low solvent content coating (waterborne paint)	599
22.14.2	Radiation curing processes	599
22.15	Serial coating of plastic workpieces	600
22.16	Coating of furniture and wood materials	600
22.16.1	Power coating	600
22.16.2	Peroxide and IR bleaching	601
22.16.2.1	Non-thermal plasma treatment	601
22.17	Wood preservation	602
22.18	Manufacture of mirrors	602
22.19	Waste gas treatment	602
22.19.1	Electrically heated carbon adsorption tubes	602
22.20	Waste water treatment	602
22.20.1	Wet separation spray booth – with SiO ₂ particles	602
23	CONCLUDING REMARKS	605
23.1	Timing of the work	605
23.2	Sources of information and progress of the work	605
23.3	Degree of consensus	607
23.4	Gaps in knowledge and recommendations for future research and information gathering	607
23.4.1	General issues:	607
23.4.2	Industry specific issues	609
23.5	Review of this document	611
	REFERENCES	613
	GLOSSARY	621
24	ANNEXES	629
24.1	Models for estimating cost benefit	629
24.1.1	EGTEI model and synopsis sheets	629
24.1.2	Regional environmental costing model (MKM, MilieuKostenModel)	631

24.2	Calculation of VOC emissions and the units used	637
24.2.1	Compliance with the Solvent Emissions Directive	637
24.2.1.1	Emission limit values (ELVs) and fugitive emissions (SED Annex IIA)	637
24.2.1.2	Emission reduction scheme (SED Annex IIB)	638
24.2.2	Precision	639
24.2.3	Application efficiency of the coating	640
24.3	Measuring fugitive emissions – direct method	641
24.3.1	Application to the printing sector	646
24.4	The common cases for mass balances	649
24.5	Determination of VOC emissions from vehicle paint shops	653
24.5.1	Basic principles/overview	653
24.5.2	Explanation	655
24.5.2.1	Monitoring of VOC emission mass flows	655
24.5.2.1.1	End-of-pipe measurements	655
24.5.2.1.2	Calculation of solvent mass balances	657
24.5.2.1.3	Methods for the determination of specific mass flows	658
24.5.2.2	Determination of the surface area throughput	659
24.5.2.2.1	Vehicle surface area	659
24.5.2.2.2	Number of vehicles per time period	660
24.5.2.3	Time scale for mass balance representativeness	660
24.5.2.3.1	Limit values based on small averaging periods	660
24.5.2.3.2	Limit value based on annual mean value	661
24.6	Some Solvent Emission Directive limit values	662
24.7	Calculation of effective POCP	663
24.8	Marginal social costs of climate change	666
24.9	Removal efficiency of waste gas treatment techniques	667

List of figures

Figure 1.1: Non-methane volatile organic solvent emissions from IPPC processes for 2001	4
Figure 2.1: Overview of main printing processes	10
Figure 2.2: Eight-colour flexo press with a central impression cylinder (satellite press).....	18
Figure 2.3: Schematic of an A4 colour sheetfed offset press with four, three-cylinder printing units	21
Figure 2.4: 4 + 4 colour publication gravure press.....	23
Figure 2.5: The stencil printing principle.....	24
Figure 2.6: VOC balance of the virtual plant	31
Figure 2.7: Specific VOC consumption and emission levels in a virtual heatset process	32
Figure 2.8: Specific input of substances and output of waste in a virtual heatset process	33
Figure 2.9: Specific energy consumption in a virtual heatset process.....	38
Figure 2.10: VOC balance of a virtual publication gravure plant	61
Figure 3.1: Typical manufacturing process for enamelled wires	105
Figure 4.1: Overview on different types of abrasives	128
Figure 4.2: Schematic process flow for coated abrasives.....	134
Figure 5.1: Schematic layout of an adhesive tape production line	150
Figure 5.2: Different types of adhesive application units.....	151
Figure 5.3: Lamination unit.....	151
Figure 5.4: Waste generation (2004).....	154
Figure 5.5: Energy consumption (2004).....	154
Figure 5.6: Solvent flow (2004).....	155
Figure 5.7: VOC balance of the reference plant.....	156
Figure 6.1: Scheme of a typical vehicle body paint process.....	165
Figure 6.2: Range of VOC emissions from 65 car paintshops in Europe.....	176
Figure 7.1: VOC emissions for several van, truck and cab assembly plants in Europe	192
Figure 8.1: VOC emissions for several bus assembly plants in Europe.....	203
Figure 13.1: Comparison of the use of solvent-based clear coat and the use of powder clear coat.....	262
Figure 14.1: Typical layout of a coil coating line	267
Figure 14.2: Typical layers of a steel coated product.....	270
Figure 15.1: Production process for beverage cans	295
Figure 15.2: Production process for flat metallic sheet.....	297
Figure 15.3: Production process for three piece cans	298
Figure 15.4: Production process for ends, caps and closures	300
Figure 15.5: Production process of extruded aluminium tubes	301
Figure 15.6: Production process of drums.....	302
Figure 16.1: Water-based bumper coating process	329
Figure 16.2: Process flow for the coating of wheel covers with a conventional coating system.....	330
Figure 16.3: Fate of the VOC input in the car bumper plant.....	335
Figure 18.1: Flow diagram of typical wood preservation installation showing consumptions and emissions	375
Figure 19.1: Flow chart of the manufacture of mirrors	384
Figure 20.1: All solvent inputs and outputs (using definitions from the SED)	411
Figure 20.2: Scheme of waste water treatment applied in a wet separation spray booth	461
Figure 20.3: Schematic of a phosphating unit with an ion exchanger.....	464
Figure 20.4: Assessment of potential substitutions by POCP	493
Figure 20.5: Overview of application ranges of the available VOC abatement technologies	497
Figure 20.6: Example of gas consumption below autothermal point for flex pack	499
Figure 20.7: Plenum chamber	514
Figure 24.1: No end-of-pipe abatement, and no internal recycling	649
Figure 24.2: No end-of-pipe abatement, but with internal solvent recovery and re-use.....	650
Figure 24.3: With solvent capture and re-use (internally and externally)	651
Figure 24.4: Destructive end-of-pipe abatement	652
Figure 24.5: Basic input/output mass flows of solvents in a paint shop.....	654

List of tables

Table 2.1: Number of printing enterprises in European countries.....	7
Table 2.2: Number of employers in the European printing industry	8
Table 2.3: Turnover of the European printing industry, all activities	9
Table 2.4: Differences between publication gravure and packaging gravure presses	22
Table 2.5: Operational data of a virtual heatset offset plant.....	29
Table 2.6: Production conditions of the virtual heatset offset plant	29
Table 2.7: Input and output of the virtual heatset plant.....	30
Table 2.8: Combinations of heatset press and job type analysed	34
Table 2.9: Solvent consumption data for heatset press and job type	34
Table 2.10: Heatset virtual plant VOC emissions	34
Table 2.11: Typical basic recipe for heatset web offset printing inks	35
Table 2.12: Cleaning agents in heatset and offset processes in general	37
Table 2.13: Energy consumption in virtual heatset plant (from Table 2.7).....	38
Table 2.14: Achievements of applied incineration techniques in heatset plants	41
Table 2.15: Mass balance of a good practice flexo printing plant.....	44
Table 2.16: Machinery and conditions of production of the virtual flexo printing plants.....	45
Table 2.17: VOC and waste balance of solvent-based virtual flexo printing plant	46
Table 2.18: VOC and waste balance of mixed-process virtual flexo plant	46
Table 2.19: Typical solvents used in solvent-based packaging printing processes	47
Table 2.20: Typical solvents used in water-based packaging printing processes.....	47
Table 2.21: Specific VOC use in package printing processes	48
Table 2.22: Average basic recipe for solvent-based flexo printing inks	49
Table 2.23: Typical flexo ink for paper as bought	49
Table 2.24: Typical hydrocarbon solvent-free flexo ink for paper as bought	49
Table 2.25: Typical recipe of a gravure ink as bought	50
Table 2.26: Average basic recipe for water-based gravure inks.....	50
Table 2.27: Typical recipe of a water-based gravure ink for coated paper as bought	51
Table 2.28: Typical recipe of a water-based flexo ink for paper and cardboard as bought.....	51
Table 2.29: Typical water-based varnish for cartons in gravure printing processes	51
Table 2.30: Average ink application values	52
Table 2.31: Energy balance of the virtual solvent-based flexo printing plant.....	53
Table 2.32: Energy balance of the mixed-based virtual flexo printing plant	54
Table 2.33: Reduction of fugitive emissions from flexible packing printing.....	56
Table 2.34: Characteristics of waste water from water-based ink processes.....	59
Table 2.35: Mass balance of a good practice publication gravure plant.....	60
Table 2.36: VOCs in publication gravure	62
Table 2.37: Specific toluene input of two plants in Flanders, Belgium	62
Table 2.38: Toluene balances of two gravure printing plants	62
Table 2.39: Average basic recipe of purchased publication gravure ink.....	63
Table 2.40: Reference to techniques generally applicable to the sector.....	67
Table 2.41: Reference to techniques generally applicable to the sector.....	80
Table 2.42: Reference to techniques generally applicable to the sector.....	92
Table 3.1: European production figures for enamelled wires and the correlated consumption of organic solvents from 1970 to 2000	103
Table 3.2: Groupings of winding wire types.....	103
Table 3.3: Mass balance from a plant producing medium sized winding wires.....	107
Table 3.4: Mass balance from a plant producing fine winding wires.....	108
Table 3.5: Main winding wire products and applied coating systems.....	109
Table 3.6: Examples of measurements of emissions to air.....	110
Table 3.7: Winding wires: Further examples of NO _x emissions	112
Table 3.8: Reference to techniques generally applicable to the sector.....	114
Table 4.1: Abrasive production in 1999 in Germany	127
Table 4.2: Selected backing materials for coated abrasives	129
Table 4.3: Alumina applied as inert abrasive grain (typical values)	131
Table 4.4: Silicon carbide applied as abrasive grain (typical values).....	131
Table 4.5: Use of solvents in manufacturing attributed to products.....	132
Table 4.6: Components of installation and differentiation	136
Table 4.7: Mass balance of abrasive manufacturing in plant 1	138
Table 4.8: Mass balance of impregnation plant for the manufacturing of abrasives in plant 2	139
Table 4.9: Mass balance of abrasive manufacturing in plant 3	140

Table 4.10: Reference to techniques generally applicable to the sector.....	142
Table 5.1: Applications of solvent-based pressure-sensitive adhesives for adhesive tapes.....	148
Table 5.2: Pressure-sensitive adhesives for the production of adhesive tapes.....	149
Table 5.3: Conditions of production for a solvent-based adhesive tape production plant.....	153
Table 5.4: Benchmark comparison for solvent and energy used and waste generated.....	155
Table 5.5: Reference to techniques generally applicable to the sector.....	157
Table 5.6: Comparison between a natural rubber process using solvents and a solvent-free natural rubber process.....	160
Table 6.1: Europe's top vehicle producers.....	163
Table 6.2: Specific paint consumption of several paint systems.....	172
Table 6.3: Typical energy consumption of car paintshops.....	173
Table 6.4: Reference to techniques generally applicable to the sector.....	179
Table 6.5: Examples of combinations of coatings for cars.....	179
Table 7.1: Specific consumption values for paints for the coating of new drivers cabs.....	190
Table 7.2: Overview of the gas consumption of chassis, and drivers cabs and vans.....	190
Table 7.3: Reference to techniques generally applicable to the sector.....	193
Table 8.1: Specific material consumptions for different layers.....	202
Table 8.2: Reference to techniques generally applicable to the sector.....	205
Table 9.1: Layer construction for rail vehicles according to the regulations of the Deutsche Bahn AG.....	210
Table 9.2: Material consumption per coated wagon.....	212
Table 9.3: Reference to techniques generally applicable to the sector.....	214
Table 10.1: Reference to techniques generally applicable to the sector.....	222
Table 10.2: Solvent and energy consumption data from two installations, i.e. old and new.....	223
Table 11.1: Reference to techniques generally applicable to the sector.....	234
Table 12.1: Coated surfaces for an A 320.....	252
Table 12.2: Consumption of materials for the painting of exterior surfaces of planes.....	252
Table 12.3: Material consumption exemplified for a B 747 – 400 by Lufthansa Technik.....	254
Table 12.4: Reference to techniques generally applicable to the sector.....	255
Table 13.1: Reference to techniques generally applicable to the sector.....	260
Table 13.2: Input/consumption of resources per coated aluminium wheel.....	261
Table 13.3: Emissions related to 1 million wheels/year.....	262
Table 14.1: Number of production lines and yearly production of pre-coated steel and aluminium in some European countries.....	266
Table 14.2: Coil coating statistics for 2002.....	266
Table 14.3: Typical operating parameters of an organic coil coating line.....	267
Table 14.4: Organic coating types used in the coil coating industry.....	271
Table 14.5: Usage of organic coatings 1993 and 2002.....	271
Table 14.6: Inputs to the coil coating process, their uses and typical end-of-life destination.....	272
Table 14.7: Solvents used most frequently in organic coating.....	273
Table 14.8: Typical paint consumptions in coil coating.....	273
Table 14.9: Chemicals containing non-solvents.....	274
Table 14.10: Electricity use for aluminium and steel substrates.....	275
Table 14.11: Fossil fuels consumption for aluminium and steel substrates.....	275
Table 14.12: Typical air emissions from coil coating processes (all are point sources).....	276
Table 14.13: Specific VOC emissions for several coating systems.....	276
Table 14.14: Typical wastes from a coil coating line process.....	278
Table 14.15: Reference to techniques generally applicable to the sector.....	279
Table 15.1: Overview of the metal packaging manufacturing techniques.....	293
Table 15.2: Techniques used for coating and printing of metal packaging.....	294
Table 15.3: Data for the coating and printing of beverage cans.....	303
Table 15.4: Data for the coating and printing of flat sheet.....	304
Table 15.5: Data for three piece can coating and printing.....	304
Table 15.6: Data for cap coating and printing.....	304
Table 15.7: Mass balances for drum coating and printing.....	304
Table 15.8: Consumption of materials in one plant.....	305
Table 15.9: Consumption of raw materials in the coating and printing of flat sheet.....	306
Table 15.10: Consumption of raw materials in the coating and printing of three piece cans.....	307
Table 15.11: Consumption of raw materials in the coating and printing of ends, caps and closures.....	307
Table 15.12: Energy use and recovery in two installations.....	308
Table 15.13: VOC emissions levels reported in different coating and printing of metal packaging.....	308
Table 15.14: Emission values of clean gas after waste gas treatment from plant A.....	309
Table 15.15: Emission values of clean gas after waste gas treatment from plant B.....	309
Table 15.16: Emission values of clean gas after waste gas treatment from plant C.....	309

Table 15.17: Emissions to air from the coating and printing of drums	310
Table 15.18: Wastes arising from coating and printing of metal packaging	310
Table 15.19: Emissions from the coating and printing of drums	311
Table 15.20: Reference to techniques generally applicable to the sector	311
Table 16.1: Proportions of solvents in different coating systems used for the coating of bumpers	330
Table 16.2: Comparison of the proportions of solvent in coating systems applied for the coating of wheel covers	331
Table 16.3: VOC use in 2000	332
Table 16.4: Breakdown of conventional VOC materials	333
Table 16.5: Breakdown of low VOC materials to achieve low VOC emissions	334
Table 16.6: Reference to techniques generally applicable to the sector	336
Table 16.7: Waste water emission levels from the coating of plastic workpieces	338
Table 17.1: Composition of different types of wood stains	351
Table 17.2: Overview of the properties of wood stains and paints	354
Table 17.3: Achievable application efficiency factors	355
Table 17.4: Quantities of paint materials applied in different application techniques	359
Table 17.5: Applied paints and amounts of organic solvents: examples of different applications in the wood and furniture industry	359
Table 17.6: Specific VOC emissions for various paint systems and, some, with primary emission reduction measures	360
Table 17.7: Reference to techniques generally applicable to the sector	362
Table 18.1: Wood preservation default emission factors (EF), abatement efficiencies and costs for each combination	377
Table 18.2: Wood preservation: Primary abatement measures	377
Table 18.3: Wood preservation: Secondary abatement measures	377
Table 18.4: Reference to techniques generally applicable to the sector	378
Table 19.1: Air emission values from three different mirror lines	386
Table 19.2: Water emission values after treatment	386
Table 19.3: Reference to techniques generally applicable to the sector	387
Table 20.1: Information breakdown for each technique described in Chapter 20 and in all the Sections 4 in each of the Chapters 2 to 19	391
Table 20.2: Example for the introduction of interior robot spraying on a car assembly line	407
Table 20.3: Example for the introduction of exterior robot spraying using metallic paints on a car assembly line	408
Table 20.4: Specific rinsing quantity of water (litres of rinsing water per litre drag out) as a function of given rinsing criterion and the number of stages in reverse cascade rinsing	419
Table 20.5: Energy saving measures and techniques	422
Table 20.6: Examples of applicability of cleaning techniques and options	477
Table 20.7: Examples of solvent substitutes used in the STS sector	484
Table 20.8: Influence of the emission value on choice of 2 or 3 bed oxidiser	498
Table 20.9: Comparison of marginal social costs of climate change with marginal damage costs from VOC emissions (see Annex 24.8)	500
Table 20.10: Emissions and costs in relation to incineration capacity	502
Table 20.11: Maximum allowable levels of LEL in the driers in flexible packaging printing	510
Table 21.1: Cleaning: techniques to use to reduce VOC emissions	565
Table 21.2: Heatset printing techniques to reduce IPA usage in the dampening solution	571
Table 21.3: Heatset techniques to reduce fugitive emissions from cleaning	572
Table 21.4: Flexography and packing gravure techniques to reduce VOC emissions	574
Table 21.5: Publication gravure techniques to reduce VOC emissions	575
Table 21.6: Vehicle coatings: techniques to reduce VOCs that can be implemented in the shorter term	578
Table 21.7: Trains: techniques to reduce solvent emissions to air	582
Table 21.8: ACE: techniques related to coating materials	583
Table 21.9: ACE: application techniques	583
Table 21.10: ACE: waste gas treatment techniques	583
Table 21.11: Coil coating: energy consumption for coating of aluminium and steel substrates	586
Table 21.12: Coil coating: a selection of techniques to control solvent consumptions and emissions	587
Table 21.13: Metal packaging emission values for solvents associated with BAT	588
Table 21.14: Metal packaging techniques to reduce solvent emissions	588
Table 21.15: Metal packaging: emission levels for waste water	589
Table 21.16: Wood coating: VOC emissions for various paint systems using some primary emission reduction measures	590
Table 21.17: Wood coating techniques to reduce solvent consumption and emission, and increase efficiency of coating	591

Table 24.1: Table of EGTEI synopsis sheets relevant to this document	631
Table 24.2: Average costs and VOC reduction potential of all the measures analysed by the model.....	634
Table 24.3: Possible cost-effective measures for the reduction of VOC emissions per industry	636
Table 24.4: Factors in SED for determining annual reference emission values	638
Table 24.5: Emissions related to sources from a plant processing 1000 tonnes of solvents	643
Table 24.6: Example of a possible outcome of the calculation of inaccuracies	644
Table 24.7: An example showing results of the improvement of accuracy.....	645
Table 24.8: An example showing results of the increased accuracy	645
Table 24.9: Input/output flows in vehicle paintshops (according to SED 1999/13/EC).....	657
Table 24.10: Example 1 of an effective POCP calculation	663
Table 24.11: Example 2 of an effective POCP calculation	664
Table 24.12: Examples of relative rates of evaporation (RA) for a selection of VOCs	664
Table 24.13: Examples of APOCP _e for a selection of VOCs and a reference VOC in the five different environments A, B, C, D and E	665
Table 24.14: Waste gas abatement techniques	673
Table 24.15: Chemical groups of common solvents and their carbon content.....	675
Table 24.16: Removal efficiency of oxidation techniques	676
Table 24.17: Removal efficiency solvent recovery for activated carbon	677

SCOPE

The scope of this document is based on Annex 1, 6.7 to Council Directive 96/61/EC of 24 September 1996 on Integrated Pollution Prevention and Control (the IPPC Directive):

Annex 1, 6.7:

'Installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating, with a consumption capacity of more than 150 kg per hour or more than 200 tonnes per year.'

Information on the interpretation of certain issues raised by the implementation of the IPPC Directive will be found in the guidance documents being prepared by the Commission's services. Information on how some issues are addressed in relation to the Scope of this document are given below.

Installation

'Installation' is defined in the IPPC Directive, Article 2.3, as: 'A stationary technical unit where one or more activities listed in Annex I (to the IPPC Directive) are carried out, and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution'.

Organic solvents and VOC

Commercially used organic compounds are chemicals containing carbon [76, TWG, 2004]. The Solvent Emissions Directive [123, EC, 1999] defines organic solvent as: *'any VOC which is used alone or in combination with other agents, and without undergoing a chemical change, to dissolve raw materials, products or waste materials, or it is used as a cleaning agent, or as a dissolver, or as a dispersion medium, or as a viscosity adjuster, or as a plasticiser, or as a preservative.'*

Organic solvents can be classified by chemical structure. There are three main groups:

- oxygenated solvents such as:
 - alcohols
 - aldehydes
 - esters
 - ethers
 - glycol ethers and their esters
 - ketones
- hydrocarbon solvents:
 - aliphatics
 - aromatics
- halogenated solvents.

The definition of VOC in the Solvent Emissions Directive is: *'any organic compound having at 293.15 K a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the particular conditions of use.'* However, Art.3(k) of the NEC Directive [139, EC, 2001] reads: *'Volatile organic compounds' and 'VOC' mean all organic compounds arising from human activities, other than methane, which are capable of producing photochemical oxidants by reactions with nitrogen oxides in the presence of sunlight'*. Apart from these, more examples of different VOC definitions, in European and national legislation and guidelines, can be found. Commonly, two phrases are in use: NMVOC which stands for non-methane VOC, and VOC. When the latter phrase is used, it is not always clear if methane is included or excluded. However, in this document, when considering consumptions and emissions, VOC is usually used to mean NMVOC.

Industry asked for clarification of the definitions of 'organic solvents' and 'consumption capacity'. At the conclusion of the information exchange, it could be seen that the exchange had dealt with information on organic solvents being defined as VOCs (as defined in the Solvent Emissions Directive, Council Directive 1999/13/EC). It could equally be seen that, in determining conclusions on BAT, the exchange had focused on installations whose actual use of solvents exceeded the consumption capacity thresholds stated in the IPPC Directive (where the use in the activity included solvents recovered from waste gas emission abatement equipment). Interpretation of these capacity thresholds is discussed in the context of work carried out by DG Environment to develop some guidance on the interpretation of certain provisions of the Directive.

Surface treatment

Section 6.7 in Annex I to the IPPC Directive refers to the following surface treatments: painting, adhesive application, further coating processes, impregnating, waterproofing, printing and surface cleaning. However, the information exchange does not consider BAT for industries or those parts of industries that are widely held to operate below the consumption capacities of the IPPC Directive, Annex 1 (6.7). The following are considered in detail:

- printing (by heatset web offset, flexography and packaging gravure, publication gravure)
- painting and other coating activities (winding wires, cars, trucks, buses, trains, agricultural and construction equipment, ships and yachts, aircraft, other metal surfaces, metal coil, metal packaging, plastics, furniture, wood and mirrors)
- waterproofing (by painting and wood preservation)
- adhesive application (in the manufacture of abrasives and adhesive tapes)
- cleaning and degreasing in conjunction with other surface treatment activities (see The boundary of this document with other BREFs, below)
- preservation of wood.

The following were not included where they form part of the activities addressed in the BREFs for Textiles and Tanneries:

- dressing
- waterproofing
- sizing.

The manufacture of coating preparations, paints, inks and adhesives, and solvent extraction and rubber conversion processes are not in the scope of Annex 1, Section 6.7 to the IPPC Directive. Wood treatment processes such as the manufacturing of chipboard, the lamination of particle and fibre-board (e.g. with impregnated phenolic paper) were not included because they use water-based adhesives.

Surface cleaning

Surface cleaning can have three different interpretations:

1. Cleaning as the 'core' activity, i.e. the activity is predominantly cleaning.
2. Cleaning where another surface treatment is the 'core' activity (i.e. a surface treatment activity described in Annex I, Section 6.7 to the IPPC Directive), i.e:
 - cleaning of surfaces of substrates prior to surface treatment
 - cleaning of equipment.

In both these cases, the techniques have been included in the scope of this document as surface treatment or associated activities.

3. Cleaning using solvents where surface treatment is not the main activity. For example, the cleaning of a vessel between batches during manufacture of a solvent-based product such as paint. This is not considered as an associated activity to surface treatment and is therefore not considered to be in the scope of this document.

The boundary of this document with other BREFs

Surface treatment using solvents is also sometimes addressed in other BREFs. Examples of these BREFs are:

- the tanning of hides and skins
- the textile finishing industry
- the pulp and paper manufacturing industry
- ferrous metal processing
- glass and mineral fibres
- the surface treatment of metals and plastics (cleaning and surface pretreatment).

These BREFs can be used to validate, compare and challenge the submitted information. Conclusions reflected in the other BREFs do not affect or restrict the conclusions in this document.

Additional techniques and supporting information can be found in other IPPC reference documents, in particular the CWW BREF¹, the Storage BREF² and the Monitoring REF³. BAT conclusions in these documents have not been validated for solvent coating processes but where similar physical and/or chemical conditions exist and considering the economic viability, the conclusions may be applied in this sector.

There are examples of activities that fall into the scope of the BREF on the Surface Treatment of Metals and Plastics (STM) addressing category 2.6: *'Installations for the surface treatment of metals and plastic materials using an electrolytic or chemical process where the volume of the treatment vats exceeds 30 m³'*, and also fall into the scope of this document. The choice on where to put information on the activities that fall into the scope of both BREFs or in one of the two is made for practical reasons and the data are referenced. Electrocoating (e-coat) is addressed in this document.

¹ The BAT reference document on the Waste Water and Waste Gas Management/Treatment in the Chemicals Sector 67 EIPPCB (2003). "Reference document on Best Available Techniques in Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector", European Commission.

² The BAT reference document Emissions from Storage 91 EIPPCB (2005). "Reference document on Best Available Techniques on Emissions from Storage".

³ The reference document on the General Principles of Monitoring 113 EIPPCB (2003). "Reference Document on the General Principles of Monitoring".

1 GENERAL INFORMATION ON SURFACE TREATMENT USING ORGANIC SOLVENTS

[128, TWG, 2005]

Where this documents refers to solvents, it means organic solvents (unless further clarification is given such as 'water-based', etc.).

1.1 Organic solvents and treating surfaces

Organic solvents are largely derived from the petroleum industry and made by established producers (although there are alternatives, such as vegetable oil esters). 4.5 million tonnes of solvents are sold and used in Europe and by far the largest demand for solvents comes from the paint and coatings industry. However, this has decreased from about 46 % in 1998 to 27 % in 2003. This is probably already due to a large shift to water-based and powder technologies, where these are technically feasible. Of the remainder, 7 % are used in printing ink formulations and 4 % in adhesives formulations. It is not possible to provide a further breakdown of these figures, as solvents producers do not know, for example, which type of formulations the solvents are used in, or if they are used for cleaning, etc.

The historic solvents sales data show a marginal average growth of 0.1 % per year over the last 10 years, below GDP growth. Projections of future consumption estimate no growth. The declining trend over the last years is linked to:

- increasing environmental legislation
- increased penetration of water-based or alternative technologies, where feasible
- solvent recycling and more effective use of solvents.

Organic solvents are usually categorised into classes of products. The most important classes are:

- oxygenated solvents: this includes esters, ketones, alcohols and glycol ethers (and their acetate derivatives)
- hydrocarbon solvents: aromatic (e.g. toluene, xylene), aliphatic and paraffinic hydrocarbon solvents
- chlorinated solvents (not included in these statistics).

Within the solvents family, there has been a tendency to move away from aromatic and white spirit types of solvents, and to use less volatile products (less combustible, less potential exposure, less VOC release) where possible.

The production of solvents directly involves about 10000 jobs and a turnover of EUR 2500 million to 3000 million. Solvent usage involves about 10 million jobs in more than 500000 companies in the EU-25, most of which are SMEs representing a global turnover of about EUR 200000 million.

In this IPPC sector, the industries described use solvents for a wide range of activities. They are used in cleaning the surfaces to be treated, as well as a carrier for the treatment (such as ink, paint, preservative, insulation, adhesive). The industries themselves use the treatments for one or a combination of:

- communication (printing)
- decoration
- prevention of corrosion and/or decay of surface or product
- product preservation and delivery (such as food and drink cans, food packaging, aerosol cans, toiletries, drums, etc.)
- the application of a layer with a special function (e.g. electrical insulation, abrasion, adhesion).

This chapter (Chapter 1) provides general information on all the industries or activities concerned. Chapters 2 through to 19 each address an industry in the sector and consist of the four following sections:

- Section 1: general information on the industry or activity concerned
Section 2: a description of the industrial processes used within this industry or activity
Section 3: data and information concerning current consumption and emission levels reflecting the situation in existing installations at the time of writing
Section 4: techniques to be considered for determining BAT as explained below for Chapter 20; however, the emphasis is on techniques or information specific to the individual industry or activity.

Chapter 20 describes general techniques for the reduction of consumption and emission reductions and other techniques that are considered to be most relevant for determining BAT and BAT-based permit conditions in more detail, and are relevant for all or most industries or activities concerned.

Chapter 21 is in two parts: Section 21.1 sets out generic BAT applicable in all industries in this sector. Section 21.2 through to 21.19 set out specific BAT for each industry to be used in conjunction with those in Section 21.1.

Paragraph 5 of the Preface sets out more fully how to understand and use this document.

1.2 Key environmental issues

1.2.1 Overall

The STS coating industries have a major role to play in extending the life of metals, such as for automotive bodies, ships, aircraft and construction materials, as well as providing means of preserving and delivering food and other products in packaging. The main environmental issues relate to solvent emissions to air, water and soil, particulate emissions to air, energy usage, waste minimisation and management, and site condition on cessation of activities.

Because of the flammable nature of solvents, their potential impact on the health and safety of workers and often their offensive odours, they have been controlled and extracted from the processes for many years. The industry can also discharge particles from the processes, especially from spraying and sanding. The extraction, and where applied, treatment of solvents and particles uses large fans and other equipment that can be major sources of noise. Many installations also use production equipment that is inherently noisy. Solvents may be used not only in cleaning the substrates but also equipment, giving rise to wastes containing solvents which may need special management for recovery and disposal. The sector uses significant energy both in the production processes, but also in end-of-pipe waste gas collection and treatment. The following issues are crucial:

- minimisation of the consumption of raw materials and energy
- minimisation of emissions by process design, management and maintenance and by waste gas treatment
- assuring chemical safety and prevention of environmental accidents.

The measures to achieve better environmental performance are frequently complex and have to be assessed in respect to their potential impacts on workplace health and safety, on the quality of the product and other processes, the age and type of installation, as well as on the benefits to the environment as a whole. Best available techniques will be balanced against these criteria and therefore include changes within process units as well as end-of-pipe abatement techniques.

Sophisticated process control and treatment techniques play an important part in achieving improved environmental performance. However, competent operation and regular maintenance are as essential as is the choice of technology. Important considerations therefore include good management and working practices, good process and site design, education of the workforce on environmental and process performance, workplace safety and accident prevention, and finally, monitoring of the process and environmental performance.

1.2.2 Solvents

Because of their properties and the quantities involved, solvents are the key materials of concern:

- VOCs react with NO_x in the presence of sunlight to form ozone in the troposphere. This usually refers to NMVOC (non-methane volatile organic solvents)
- halogenated solvents, their toxicity and their impact on reducing ozone in the stratosphere
- some solvents are toxic to aquatic organisms
- some solvents are not readily biodegradable, so they have the potential to contaminate soils. Traditional solvents are not PBT (persistent, bioaccumulative, toxic) and none are vPvB (very persistent, very bioaccumulative). However, solvents can readily spread through soil to groundwater, where there are limited or no mechanisms for their removal or breakdown. There are numerous reports of aquifers used for drinking water being contaminated by solvents (although not necessarily from these industries).

Surface treatment using solvents was the third largest source of VOC emissions from European IPPC industries in 2001, according to EPER, see Figure 1.1. However, the register has a threshold for reporting only emissions greater than 100 tonnes released to air a year, so many installations with lower releases will not have reported.

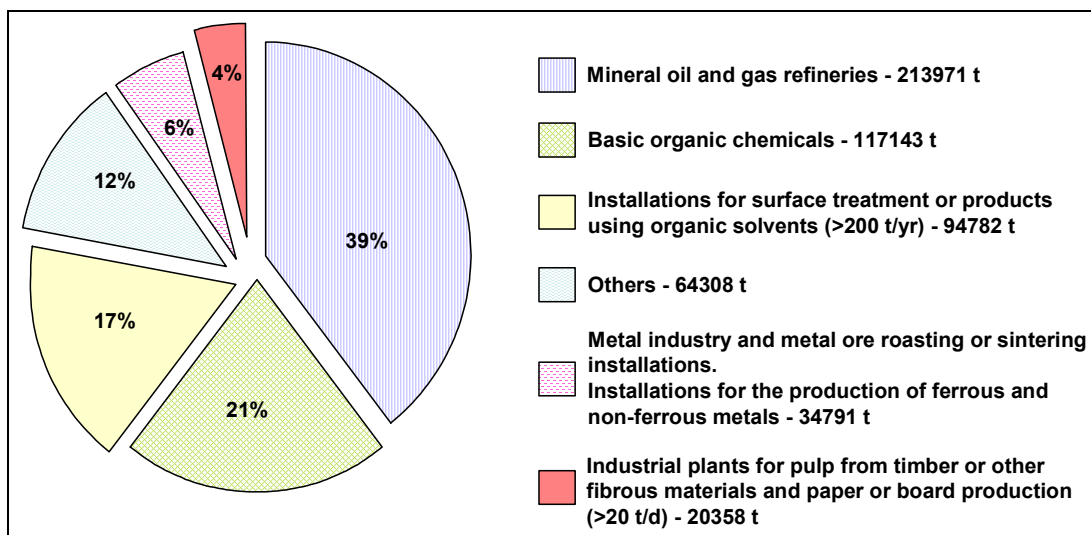


Figure 1.1: Non-methane volatile organic solvent emissions from IPPC processes for 2001 [194, EPER, 2001]

1.2.3 Metals

Toxic metals such as cadmium lead, chromium and nickel are often referred to as occurring in water-based pretreatment and pigments for inks and paint. These are controlled by other legislation such as Directive 76/769/EEC restricting the marketing and use of these and other pigments across the EU, the End of Life Vehicles Directive and the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment, etc. They are not widely used in large scale surface treatments using organic solvents and are not used by the printing processes discussed in detail in this document[98, EC, 1976] [102, EC, 2000] [103, EC, 2003].

Organotin compounds and other toxic compounds may be used as catalysts in electrocoat paint systems.

Water-based passivation of zinc or zinc-alloy surfaces or aircraft bodies prior to painting is one use of hexavalent chromium that continues (in 2005) because of the difficulty in finding suitable replacements. This is discussed in the STM BREF [59, EIPPCB, 2006].

Copper, chromium and arsenic salts are used in water-based wood preservation (see Chapter 18).

Small amounts of copper are used in copper phthalocyanine blue pigments for inks, but are not water-based. They are only periodically discharged and only found at background levels in effluents. The complex is strongly bound and not readily available.

1.2.4 Other pollutants

A key substitute for solvent-based coatings is the use of water-based coatings. These sometimes require biocides to stop them degrading in storage or use, or may have high COD and/or BOD from solubilisers, etc. which may have low biodegradability in some cases.

In the coating of ships, the removal of old, and the application of fresh, antifouling can give rise to contaminants such as TBTO (tributyl tin oxide) and other biocides. New types of antifouling are controlled by the IMO (see Chapter 11).

The preservation of wood uses toxic components in the treatment systems. Wood preservation accounted for about 30 % of EU-15 POP emissions in 1991, and although the use of POPs has decreased significantly, they are a factor in site decommissioning, in particular.

Ammonia is used as a stabiliser in some water-based solutions.

1.2.5 Energy

All the industries are significant users of energy throughout the activities: in the surface treatment processes, in associated activities, and in the pollution abatement equipment. Significant amounts of energy are used to extract solvent contaminated air, and gas may be used as a support fuel for thermal destruction of VOCs at low concentrations. The balance of energy usage and VOC abatement must be carefully considered. In many cases, integrated solutions, such as better control of fugitive emissions and planned maintenance may abate significantly more VOC, in a more energy efficient way, than solutions based on waste gas treatment alone.

1.2.6 Raw material usage

High efficiency techniques can be used to reduce material consumption generally. The emission of solvents can be significantly reduced by high efficiency application techniques and high solids coatings materials.

1.2.7 Water usage

Water is used in cooling and in other processes, in particular water-based pretreatments and coatings. Minimising water consumption is important, and therefore dealt with in this document and in the STM BREF.

Important water-based pollutants for this sector are highlighted in Section 1.2.4.

1.2.8 Solid and liquid wastes

Where solvents are used, the wastes generated may often be classified as hazardous. The proper storage and disposal of wastes is discussed.

1.2.9 Airborne particles

These arise from some of the processes (such as sanding wood and other substrates) and from spray coating processes.

1.2.10 Noise

Many installations also use production equipment that is inherently noisy, such as folders and cutters in printing, metal presses and also because of the high production volumes and rates. These may be enclosed because of workplace health and safety. Waste gas extraction equipment relies on large fans which are a major source of noise, and some types of waste gas treatment are also noisy.

2 PRINTING

[4, Intergraf and EGF, 1999] [128, TWG, 2005] unless stated differently.

2.1 General information on printing

2.1.1 Printing industry in the European Community

The printing industry is one of the largest of the European Union's manufacturing industries, being in the top ten of such industries in most countries. It is an industry which serves all sectors of the economy including public authorities, financial services, publishers, distributive services and manufacturing industries. Its customers range from major institutions to the smallest business. There are many thousands of competing firms, with capacity exceeding market take-up in most areas, so competition is intense. The entire industry in EU-25 and EFTA countries employs about 970000 people in about 125000 companies with a combined turnover of about EUR 170000 million, see Table 2.1, Table 2.2 and Table 2.3. The notes to Table 2.3 describe the printing activities included in these figures, which include many activities and installations outside the scope of this document.

		2000	2001	2002	2003	2004
EU-25^(a)						
BE	Belgium		1794	1693	1683	1633
CZ	Czech Republic	4112	3708 ^(b)	5286	6100	-
DK	Denmark	1736	1569	1473	1352	-
DE	Germany	13584	14680	12934	12574	-
EE	Estonia	140	153	168	168	-
EL	Greece	-	-	-	-	-
ES	Spain	15445	14452	14445	13958	-
FR	France	17114	16962	16766	-	-
IE	Ireland	353	357	380	-	-
IT	Italy	20400	20320	20269	19603	-
CY	Cyprus	277	302	316	318	-
LV	Latvia	273	258	-	-	-
LT	Lithuania	262	274	291	295	-
LU	Luxembourg	86	78	77	-	-
HU	Hungary	661	4265	4322	-	-
MT	Malta	194	189	-	-	-
NL	Netherlands	2976	2848	2668	3665	3183
AT	Austria	1045	1010	1088	1095	-
PL	Poland	11001	10333	11416	-	-
PT	Portugal	3055	3116	2988	3237	-
SI	Slovenia	1282	1413	1133	-	-
SK	Slovakia	186	240	245	201	-
FI	Finland	1368	1311	1276	-	-
SE	Sweden	3951	3835	3683	-	-
UK	United Kingdom	18937	18814	18777	18283	-
Totals:		118438	118573	121694	-	-
EFTA^(a)						
NO	Norway	1100	-	-	-	-
CH	Switzerland	2634	-	-	-	-
(a) Economical indicator for structural business statistics. Classification of economic activities – NACE Rev.1.1 – DE 22.2						
(b) Provisional value						
Extract from Eurostat New Chronos database. Company size coverage may vary from country to country						

Table 2.1: Number of printing enterprises in European countries
[177, Eurostat, 2005/6]

		2000	2001	2002	2003	2004
EU-25^(a)						
BE	Belgium		22006	21309	19586	19169
CZ	Czech Republic	-	17531 ^(b)	18118	20274	-
DK	Denmark	16643	15023	14025	12590	-
DE	Germany	196489	191822	186432	165511	-
EE	Estonia	^(c)	^(c)	2489	2336	-
EL	Greece	-	-	-	-	-
ES	Spain	87209	82852	84949	82864	-
FR	France	120978	119698	115796	-	-
IE	Ireland	8672	8523	7936	-	-
IT	Italy	99106	98980	93680	94903	-
CY	Cyprus	1382	-	-	1573	-
LV	Latvia	3609	3917	-	-	-
LT	Lithuania	3145	3363	3515	3628	-
LU	Luxembourg	1141	1143	1140	-	-
HU	Hungary	16076	21213	23683	-	-
MT	Malta	1284	1249	-	-	-
NL	Netherlands	48447	48006	46550	36532	47900
AT	Austria	16803	16560	16066	15196	-
PL	Poland	38653	38233	34684	-	-
PT	Portugal	24588	25259	22857	24762	-
SI	Slovenia	5731	5778	6058	-	-
SK	Slovakia	5592	6118	5046	3863	-
FI	Finland	13317	13129	12390	-	-
SE	Sweden	24314	23839	22606	-	-
UK	United Kingdom	-	201000	191000	185000	-
Totals:		733179	947711	930329	-	-
EFTA^(a)						
NO	Norway	10476	-	-	-	-
CH	Switzerland	32302	-	-	-	-
(a) Economical indicator for structural business statistics. Classification of economic activities – NACE Rev.1.1 – DE 22.2						
(b) Provisional value						
Extract from Eurostat New Chronos database. Company size coverage may vary from country to country						

Table 2.2: Number of employers in the European printing industry
[177, Eurostat, 2005/6]

As well as printing on paper, additional markets for printing on other substrates such as plastics, cardboard and metal are also considerable (for printing on metal, see Metal packaging, Chapter 15).

While many of the listed products can be produced on the same kind of machine, economics dictate that some of them have to be printed on specialised equipment. The main processes described (see Figure 2.1) all have specific properties and associated costs, and are used as requirements demand. Sometimes, more than one process may be used on the same job, and occasionally a specific printing press may incorporate more than one process.

Printing processes convert original text and pictures into an image on a carrier (but see digital, below), and the main process types are named according to how this image is carried. The carrier can be a plate, cylinder or stencil. All image carriers have two separate surfaces – an image (printing) area and a non-image (non-printing) area. The image area accepts the ink, but the non-image area does not accept or retain any ink.

Turnover (Total EUR million)					
		2001	2002	2003	2004
EU-25					
BE	Belgium	7698	7548	7244	7319
CZ	Czech Republic				
DK	Denmark	3418.3	3248.7	2904.4	
DE	Germany	34404	32692	32828	33050
EE	Estonia	45.2	141.5	182.9	
EL	Greece				
ES	Spain	5855	6070	6090	6325
FR	France	22454.5	12003.2	21046.9	
IE	Ireland	829	800.7		
IT	Italy	21593.5	22531.7	22447.3	
CY	Cyprus	177.7	165.1	158	
LV	Latvia		184.3	193	
LT	Lithuania	150	183.2	182.8	
LU	Luxembourg	279.425	281.643	309.557	
HU	Hungary	1441.4	1679.1		
MT	Malta	139.7	169.1		
NL	Netherlands	11516.1	10954.8	10134.9	
AT	Austria	3317.5	3264.6	3274.7	3287.47
PL	Poland				
PT	Portugal	253.3	153.8	89.2	
SI	Slovenia				
SK	Slovakia	374.4	370.9	368.2	
FI	Finland	3326	3198	3055	3147
SE	Sweden	9048	8914	8684	8850
UK	United Kingdom	44225.4	42146.2	35043.9	
Total EU-25:		186327.1	172291.8	166318.2	
EFTA					
NO	Norway	2784.4	2837.3		
CH	Switzerland	13000	12800	12400	12500
Notes: The totals are the sum of all economic activities in NACE Rev.1.1 - DE 22.2, Printing and service activities related to printing: <ul style="list-style-type: none"> ◦ 22.21: Printing of newspapers ◦ 22.22: Printing ◦ 22.23: Book binding ◦ 22.24: Pre-press activities (composition and plate-making) ◦ 22.25: Ancillary activities related to printing 					

Table 2.3: Turnover of the European printing industry, all activities
[177, Eurostat, 2005/6]

The main printing processes are listed below (and see Figure 2.1) and described in Section 2.2:

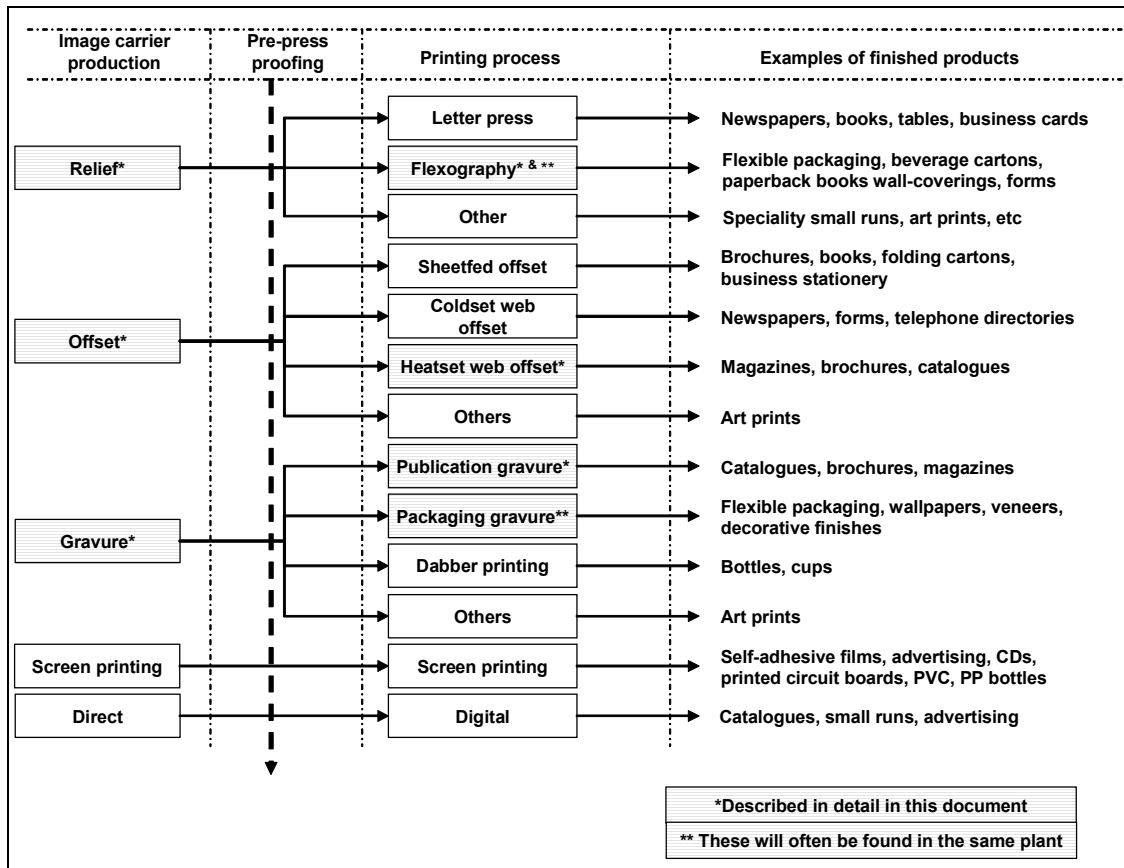


Figure 2.1: Overview of main printing processes

Relief printing

This uses a printing surface that is in relief, i.e. raised above the non-printing surface. *Letterpress* and *flexography* are examples of this process. Flexographic printing can run in installations large enough to exceed the criteria in IPPCD Annex 1 (6.7), but often at this size it is found running with packaging gravure, together with laminating and varnishing.

Offset printing

The image and non-image areas are in the same plane on a plate, which can be of metal, plastic or paper (a technique known as *lithography*, usually abbreviated to '*litho*').

Because offset plates do not last when being constantly abraded by contact with the printing substrate on long print runs, the image is put or 'offset' onto a softer intermediate blanket which transfers the image to the substrate. This type of printing is known as '*offset*' and is the most commonly used process.

The substrate can be fed as a roll or web, known as '*webfed*', or as sheets ('*sheetfed*'). '*Heatset*' and '*coldset*' refers to the technique used to dry the ink. Heatset web offset can run in installations large enough to exceed the criteria in IPPCD Annex 1 (6.7).

Gravure

This is the best known of the intaglio printing processes, but copperplate and die stamping are others. Here, the printing areas are tiny recesses inscribed on a cylinder below the non-printing areas. These recesses are filled with ink, the surplus ink is removed and the substrate is pressed against the printing cylinder. Publication gravure and packaging gravure can run in installations large enough to exceed the criteria in IPPCD Annex 1 (6.7).

Stencil

Screen printing is an example of stencil printing, in which the printing and non-printing areas are carried on a screen. The non-printing areas are formed by blocking out parts of the screen, while the ink is forced through the non-blocked parts onto the substrate.

Digital

Produces an image directly onto a substrate from digital information without the creation of an intermediate permanent image.

The business use of the processes

While many businesses also handle the creation of the image and all the processes involved before the actual printing takes place, along with the binding and finishing, a large number of companies exist solely to do these specific operations. Equally, many thousands of commercial firms such as banks do their own printing in-house.

Additionally, there are many high street printing shops (copy shops). Traditionally, they used the same equipment as the smaller 'conventional' printer, but now these businesses are based on photocopying and inkjet and/or digital printing.

2.1.2 The products**2.1.2.1 Newspapers**

Virtually all newspapers are printed by coldset web offset. A typical local newspaper plant could have one or two presses with four units on each press, but larger, specialist printers doing national newspapers may have as many as ten presses. Coldset machines with a narrower web are also used for the production of advertising flyers, paperback books and telephone directories.

Older letterpress machines may still be found in some countries, but their use has declined rapidly over the last 20 years. One or two firms have changed to the flexography process recently. Where the newspaper printers switch to flexography, this is always water-based.

2.1.2.2 Magazines and catalogues

Magazines with a circulation of over 10000 are generally printed by heatset web offset, although shorter runs will be done by sheetfed offset. Heatset web offset is also used to print travel brochures, mail order catalogues, and advertising material for inserting into newspapers and magazines. It is also used for printing some colour books.

Very long run magazines and similar publications tend to be printed by gravure, where the extra costs of making a gravure cylinder over those of offset plate making, can be sustained. As a result of the high level of investment and the high output, these processes are generally used in large companies.

Gravure has a reputation for being able to print on relatively poor paper surfaces, yet still achieve a good, rich print. Heatset web offset, on the other hand, requires a good coated or uncoated paper to achieve the same quality. Some firms have both gravure and heatset web offset presses to print magazines of different run lengths.

2.1.2.3 Books

Most colour and short-run black and white books tend to be printed by sheetfed offset, whereas long-run single colour books such as paperbacks are printed on the web, usually by coldset web offset but sometimes by letterpress. Mainly, sections of 8, 16 or 32 pages are printed at one time, and then bound to produce the book.

Several hundred firms in each country are capable of printing short-run books by sheetfed offset, for in-house or off-site binding. Long-run work would only be done by a few specialists.

A very small number of specialised continuous belt presses are in existence, which print the entire book in one operation, rather than in several separate sections. These normally print by letterpress using flexible plates. The production of short-run books and booklets is mainly a local operation, but long-run work is open to national and international competition.

2.1.2.4 General printing

There is an enormous variety of printed work known as general or commercial work, which includes advertising literature, company reports and accounts, greetings cards, calendars, brochures, leaflets, posters and the like, which are printed by sheetfed offset.

2.1.2.5 Security printing

The general category of security printing includes a large number of products, from banknotes, passports, stamps, cheques, tickets and coupons to those that rely on the security of the information, such as company reports and accounts, city financial documents and examination papers. This requires a wide range of processes, some of which are specific only to security printing.

2.1.2.6 Labels

There are basically two types of label, i.e. wet labels and self-adhesive roll labels. The former are usually printed by conventional sheetfed offset, then guillotined for subsequent glueing and wrapping around cans and bottles. Self-adhesive labels are printed on a web made up of several layers, including the backing paper, adhesive and front layer, which is printed and cut to the desired shape.

Self-adhesive roll label printing is a highly specialised operation and the equipment is only used for that purpose. The presses may be rotary letterpress, flexo, or offset (water-based or waterless), and may also incorporate screen printing and foil blocking. A specific press may incorporate several processes.

2.1.2.7 Business forms

The printing of business forms is also highly specialised, although the market is rapidly declining due to ever increasing IT capabilities. It can be broken down into two areas: continuous forms and cut sets which are usually A4 size. Business form sets may be printed in sheet form, then collated to form the set, and glued by pasting one edge of a thick block of many sets, for later separation by the user.

2.1.2.8 Paper and cardboard packaging

Paper and cardboard packaging comes in three main forms: paper packaging such as paper bags, and cartons made from either solid or corrugated cardboard. It is a very large market, of around the same order of magnitude as the markets for newspapers, books and security printing.

Cheap paper bags will often be printed by flexography, using water-based inks.

There are a number of markets: food and drink packaging, and pharmaceuticals are the largest. With food packaging, printing is often done using UV inks, to ensure complete drying (curing) and no leaching of ink into the food.

Cartons made of solid board are printed by sheetfed offset on large, multicolour machines, to a high quality and accuracy. Corrugated board is generally printed in water-based sheetfed flexography [76, TWG, 2004].

For longer runs, printing may be by web offset, flexography or gravure. Gravure is used when high quality is required, for instance, for cigarette packets.

2.1.2.9 Flexible packaging

Printing of flexible packaging can include PVC, polycarbonates or PET films and foils. The production of flexible packaging often includes laminating different plastic films and aluminium foil together (before or after printing) [76, TWG, 2004].

2.1.2.10 Products requiring thick ink films

Screen printing produces a characteristically thicker film and is therefore used for many different products such as:

- high visual impact such as in the point of sale advertising, posters, car decals
- PVC, polycarbonate or PET bottles
- CDs, DVDs
- printing designs onto paper for transfer to T-shirts using heat
- some specialist wall coverings
- the thick coatings needed for 'scratch card' gaming tickets
- the magnetic strips on railway tickets and credit cards
- applying etch resist in making printed circuit boards (more information can be found in the STM BREF [59, EIPPCB, 2006])
- textiles.

The substrates printed in screen printing consist of about 40 % of the printing on self-adhesive films, 20 % of printing on plastics (including rigid plastics), and 20 % of printing on cardboard. Much use of the process is also made in printing on textiles and metals. Run lengths are usually very small, with two thirds of all orders being under 1000 copies.

2.1.2.11 Wallpaper, decorative paper and paper-based foils for the furniture and lamination industry

A variety of processes are used to print wall coverings, with gravure (similar to packaging gravure, see Section 2.2.3.6) and flexography having largely replaced offset. Many products are also embossed, and it is quite common to see combinations of all three processes used on the same reel of wall covering.

Many printers use the same range of inks to print both vinyl-coated and plain papers by both gravure and flexography. One or two firms have recently started to introduce water-based gravure inks, but these are still very much in the minority as the process needs more development for most products.

Some specialist firms use the screen process for short-run, expensive wall coverings.

2.1.2.12 Envelopes

Envelopes can be printed by flexography for the inside, and using water- or solvent-based inks for the outside. Printing, glueing and die cutting can be carried out at the same time from a reel. Alternatively, envelopes can be 'pre-printed' by offset, and printed sheets or printed reels are die cut after printing. Supplementary to this, the finished envelope can be printed on the outside by sheetfed offset using conventional or UV drying inks [76, TWG, 2004].

2.2 Applied processes and techniques in printing

Production processes in graphic production are schematically shown in Figure 2.1. The printing process can be divided into four main unit processes: pre-press and proofing systems, making the image carrier printing, and finishing, and they are discussed in the following sections. Of these four processes, the printing process has the most significant environmental impacts: the others are associated activities and are explained in general terms to give a clear idea of printing installations [76, TWG, 2004, 128, TWG, 2005].

2.2.1 Pre-press and proofing systems

The pre-press processes include text and image processing. It is fairly similar for all printing technologies. Today it is mainly produced electronically. Once the desired format and images are assembled, the data can be transferred in one of two ways:

- exposed on photographic film. The photographic emulsion on the film is composed of silver halide and gelatine. The exposed film is developed, fixed and rinsed in automatic machines. This method is used decreasingly, and largely when the film is the end-product of the pre-press stage
- digitally. This is becoming the predominant method [76, TWG, 2004].

A proof print is often made for checking the reproduction process. Today, proofs can be made directly from the data in the computer being shown on the screen, or being printed out with an inkjet or laser print [21, Nordic Council of Ministers, 1998].

Organic solvents are not used in the pre-press process and there are normally no other emissions to air. Emissions to water from the pre-press process can be silver compounds in the rinsing water, used developer, or fixer and chromium compounds from cleaning chemicals [21, Nordic Council of Ministers, 1998].

2.2.2 Creating the image carrier: printing plate, cylinder, stencil making and computer-to-plate (CTP)

The image carriers are used in the printing processes to transfer the printing ink directly or indirectly (offset processes transfer the ink indirectly) to the substrate (paper, cardboard, plastic, etc.). They are normally made by copying the films onto light-sensitive coatings on the printing plates, cylinders or screens, respectively. Before this, the films have to be mounted so that they correspond to the size of the printing form and the printing sheet or web. The printing form has to be developed or washed-out, and sometimes engraved or etched, before it is ready for printing.

New technology makes it possible to produce printing forms directly from the computer without the photomechanical process and the photographic films are no longer needed. The process is known as computer-to-plate (CTP) [21, Nordic Council of Ministers, 1998].

Degreasing, etching and electroplating are techniques used in cylinders in the gravure process and are discussed in the STM BREF [59, EIPPCB, 2006]. The STM BREF also discusses the application and forming of photopolymers, which are used in printing designs during the production of printed circuit boards.

Letterpress and flexography

The printing plates used in letterpress printing are made of photopolymers which cross-link and harden under exposure to UV light [76, TWG, 2004]. While some plates still have to be processed using solvents, most systems rely on water-based methods and jets of air [4, Intergraf and EGF, 1999].

Origination and image-forming for the flexographic process are the same as for a letterpress, except that the photopolymers used are softer. They can also be made of rubber.

Litho, offset

The printing plates are usually aluminium coated with a photosensitive coating, although the base can be plastic or special papers. The image is formed photochemically, leaving a surface area of the plate treated to receive ink in the relevant (image) areas. The non-printing areas are 'wetted' by a water or water-solvent mixture called the dampening solution, which rejects ink. The waterless offset process uses special plates which have an ink-repelling surface which is photochemically removed in the printing areas.

Gravure

The cylinder used in the gravure printing process consists of a steel base which is plated with copper (more information can be found in the STM BREF [59, EIPPCB, 2006]). The image is then engraved in the copper, usually by using electromechanical or laser-engraving machines. A minority of cylinders are still made by traditional photographic and etching methods. The cylinder is degreased, deoxidised and polished. Following this, a thin layer of hard chromium is electroplated on to protect the image in the softer copper. Chromium is deposited by electrolysis in a bath containing chromic oxide and sulphuric acid (see the STM BREF [59, EIPPCB, 2006]). Again, after the chrome plating, the cylinder is polished [76, TWG, 2004].

The production of the cylinder is slow and expensive, compared to other printing methods, and the cylinder is heavy and difficult to handle. It is therefore used in gravure printing only for long runs, as heatset can achieve similar quality. In packaging gravure, the alternative (flexography) does not achieve such a high quality, and the runs can often repeat using the same cylinders. [128, TWG, 2005]

Screen printing

The image carrier is a stencil supported by a fabric stretched tightly on a frame. This image carrier is called a screen.

The production of screen stencils falls into four main categories: hand cut stencils, electronically cut stencils, photomechanical stencils and the direct method.

In the first of these, the stencil is cut by hand with a sharp scalpel from adhesive-backed masking material. The second method is a development of this, when the stencil is cut using computer controlled techniques. The manually or computer generated artwork is scanned with the controlling drafting head directing a cutting blade or stylus to create complex, accurate stencils from masking material. While use of this latter method will undoubtedly increase with computer automation, the major method in use today is the photomechanical stencil.

With photomechanical stencil making, light-sensitive material is exposed to an opaque positive image, thus hardening the non-image areas hit by light and rendering them insoluble. The unexposed image areas are dissolved away to leave open, clear reverse stencil areas.

With the direct method, the screen is coated with a photosensitive emulsion, and the image is projected directly onto the photostencil from a UV light source. After exposure the image is washed out in the same manner as other methods. This avoids the generation of an opaque positive image [76, TWG, 2004].

2.2.3 Printing

After the image carrier has been mounted in the press, the printing can be started.

2.2.3.1 Letterpress and letterset

[4, Intergraf and EGF, 1999] [21, Nordic Council of Ministers, 1998]

Letterpress and letterset are (as flexography) relief printing methods, where the image is raised compared with the then non-printing areas. Letterpress was the most widely used printing process up until the early 1970s when offset lithography and other processes superseded it for a variety of reasons including higher speeds, better quality and lower unit costs. Nowadays, wooden blocks and metal type have been replaced by a plastic relief plate, which is obtained by exposure of a negative film to light, the light hardening the plate in the image areas and the unhardened areas being processed away. Flatbed letterpress has limited uses for a range of short-run general jobbing work.

Letterset is an indirect flexographic printing process. The image is transferred to a rubber blanket (as in offset) and then onto the object to be printed. This is used for printing beverage cans, often with solvent-based inks (see Chapter 15) [76, TWG, 2004].

Cleaning operations are mainly done by hand with the same cleaning materials as used in the offset processes.

2.2.3.2 Flexography

[4, Intergraf and EGF, 1999] [128, TWG, 2005]

Flexographic printing employs direct rotary printing using resilient relief plates such as rubber or, as is more likely these days, photopolymers and fast-drying solvent or water-based inks.

Flexography is almost exclusively a reel or webfed process. It is a simple method of printing normally with a very easy inking system using one main dispensing roller with a rough surface.

Specially designed flexo presses now produce a wide range of printed products. It is particularly suitable for long-run web printing, and is very adaptable to a wide range of substrates – from thin paper to heavy corrugated cardboard, thin cellophane to thick flexible sheeting, vinyls and foils. The main applications of the process are flexible packaging, cartons for liquids, some newspapers, paperback books, labels, paper/plastic bags, cartons/packaging and wall coverings.

Plants producing and printing corrugated cardboard use sheetfed presses. The corrugated cardboard is cut into rigid sheets which go through the whole press horizontally. The presses are either ‘bottom printers’ or ‘top printers’, i.e. print on the underside or topside of the substrate.

Inking unit

Many different products and substrates may be printed on the same press and, therefore, inks may have to be changed regularly. Food packaging inks have changed over the years from those based on aromatic solvents to aliphatics, that is, from toluene and xylene to ethanol and ethyl acetate. These inks dry by evaporation; however, UV curing inks are also used [76, TWG, 2004].

The ink has low viscosity, is fluid and traditionally held in an inkpan from where it is picked up by a rotating rubber fountain roll. The fountain roll subsequently delivers the ink to the metering roll. Excess ink is removed from the metering roll with a doctor blade before it is transferred to the printing plate.

A more modern system is the chamber doctor blade where the ink reservoir is connected with a fountain head from which the ink is supplied directly onto the ink-metering (anilox) roll. As the ink is circulated by pumps in the box-like construction, the transfer of ink onto the anilox roll is independent of the press speed. Two doctor blades, connected to the fountain head, fit closely against the anilox roll.

Ink-metering (anilox) roll

In a flexo press, the ink is transferred from the ink-fountain to an ink-metering (anilox) roll. The ink-metering roll is ceramic and covered with cells by which the ink is metered out onto the printing plate; how much depends on the depth and structure of the cells, the pattern formation and the screen count. The cells can be mechanically or laser engraved, and if necessary can be re-engraved.

Plate cylinder

The plate cylinder is usually a steel cylinder onto which the printing plates are mounted with a double-sided adhesive. Flexo printing plates are usually made of UV sensitive polymers or rubber, and are resilient and flexible, which has given the technique its name.

Impression cylinder

Flexographic printing machines may be designed as a series of units, or in compact form. In series construction, each printing unit has its own impression cylinder and are lined up in stands one behind the other. In compact form, several printing units (up to a maximum of eight) may be supported on both sides or, in the case of small presses, hung from one side (cantilever type) of a central impression cylinder. This is also known as a satellite press [76, TWG, 2004]. Figure 2.2 shows an eight-colour flexo press with a central impression cylinder (satellite press).

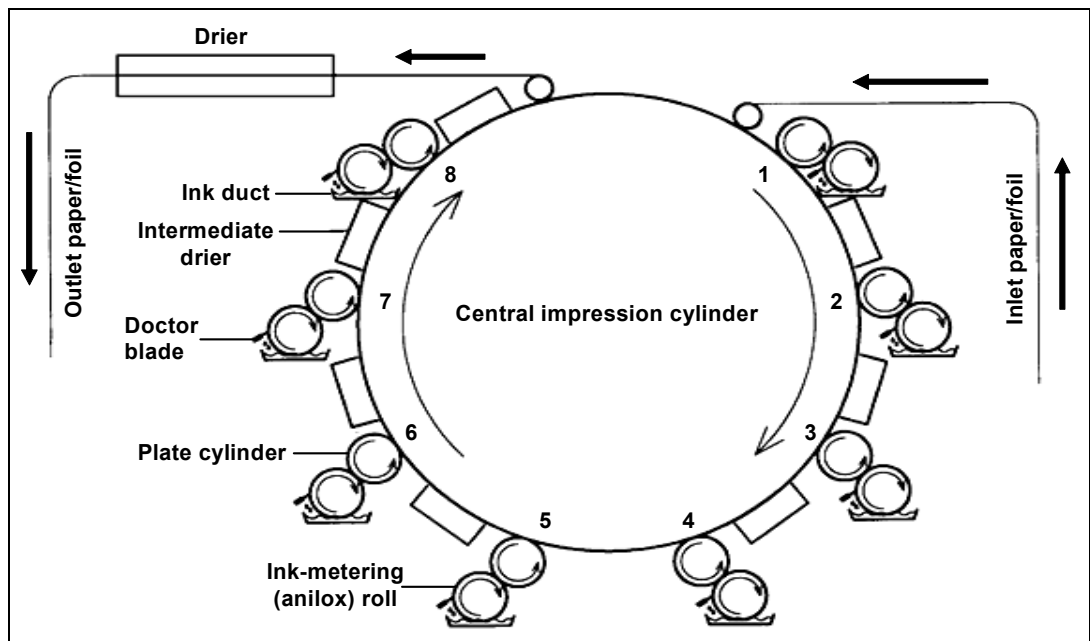


Figure 2.2: Eight-colour flexo press with a central impression cylinder (satellite press)
[35, Aminal, et al., 2002]

Cleaning

Cleaning of printing plates and machine parts is done with solvents similar to those in the inks or vanishes. Ultrasound cleaning and cleaning with high pressure powder can be used for persistent contamination.

2.2.3.3 Offset: general

[4, Intergraf and EGF, 1999] [128, TWG, 2005]

Offset printing is a planographic printing technique, i.e. where the image and non-image areas are on the same plane as the image carrier. The non-printing areas are kept free of ink by being ink-repellent while, on the other hand, the printing areas are ink-receptive. This is achieved by the offset ink being oil-based and the non-printing areas are kept clean with water or water-based solutions, as the water and oil repel each other. The additives to the water are usually isopropyl alcohol (IPA) or isopropyl alcohol substitutes/extenders, etc. However, waterless printing is also possible, where the non-printing areas are kept free of ink by an ink-repellant coating [21, Nordic Council of Ministers, 1998] [11, IMPEL, 2000, 76, TWG, 2004].

Offset is currently the most widely used printing process, due to its versatility, speed, quality, and cost-effectiveness achieved by a series of developments in plates and extending their life by the offset process, improved materials allowing higher quality and ease of use with photosetting.

Offset machines come in a variety of sizes, from the small offset sheetfed press which prints A3 through the large sheetfed press of 1200 x 1600 mm or more dealing with many colours at a time, to the large web presses printing paper two metres wide at very high speeds. The versatility of the process allows the production of a very wide variety of printed products [76, TWG, 2004].

Modern web presses are built with eight units which makes it not only possible to print eight colours on one side of the substrate, but also to print four colours on each side in one run. Modern presses are also built to meet an increasing demand for automation and new presses come equipped with automatic cleaning systems for plates, blankets and impression cylinders, automatic systems for changing plates, etc. [21, Nordic Council of Ministers, 1998] [76, TWG, 2004].

Depending on the type of printing process, substrate or products printed, the offset process is further divided into sub-processes [11, IMPEL, 2000] [76, TWG, 2004]:

- sheetfed offset
- heatset web offset
- coldset offset.

Offset inks used in sheetfed and coldset offset dry through adsorption into the paper and by oxidation. With glossy paper especially, adsorption happens too slowly for modern fast printing presses. Modern high speed webfed offset presses, onto which non-adsorbent paper is printed, are, therefore, equipped with forced hot air drying systems; these offset printing processes are called 'heatset'.

The dampening unit

[4, Intergraf and EGF, 1999] [128, TWG, 2005]

The task of the dampening unit in an offset machine is to wet the surface of the printing plate with a uniform film of moisture during printing, so that when inking follows, it only adheres to the plate in the image areas.

Film dampening units are the most widely used. These put down a thin film of dampening solution onto the plate using a series of rollers which distribute the liquid in a controlled and consistent way.

This dampening unit construction operates either with water or, in many cases, with a water-isopropanol solution, (or in some cases, ethanol. Note that ethanol has a higher OFP; see Section 20.10.2) and uses the technologically favourable (in respect of printing) properties of IPA. The acidic IPA-based dampening solutions (with a pH of normally between 4 – 5.5) enhance the desensitising action in the non-image areas and maintains their hydrophilic properties. Other commonly used additives are: gum Arabic, corrosion inhibitors, wetting agents, drying stimulators, fungicides, antifoaming agents, etc. [21, Nordic Council of Ministers, 1998].

IPA has a lower surface tension than water and, therefore, has the capacity to wet the plate more effectively. The process is complex, but empirically, it is generally accepted that a thinner film of dampening solution can therefore be deposited on the plate, which allows greater control, especially on high quality print jobs. Set up times can be reduced, so less paper is wasted. The printing can be sharper, and less water on the plate means fewer problems with paper stretch.

The extent of IPA use varies from country to country, with the make and model of the press, the paper type and the difficulty of the job. Since IPA evaporates faster than water, circulation units for the dampening solution and the dosing of IPA or ethanol are, in many cases, fitted with a cooling unit in order to reduce evaporation. The dampening solution is continuously pumped towards the press, and the excess returns to the container via an overflow. The concentration of IPA in the container is measured continuously. IPA is added automatically when the concentration diminishes.

The inking unit

[4, Intergraf and EGF, 1999]

The inking unit found on offset presses varies with the size of the press and the job it is designed to do. Large presses and those designed to print quality work are likely to have many rollers in the ink train to ensure uniform ink distribution (more than 20 rollers is not unusual). Three or more of these actually apply the ink to the plate, with the quantity of ink being applied at any point across the width of the plate being adjustable by turning ink screws by hand or, increasingly these days, this can be computer controlled.

Rollers are made of, or covered with, different materials, such as steel, synthetic rubber or polyurethane. From time to time, the ink needs to be removed by cleaning.

Drying may be accelerated by infrared heating or, alternatively, special inks may be used which are cured by ultraviolet radiation [4, Intergraf and EGF, 1999].

Cleaning

Depending on the printed image, the substrate and the ink being used, paper debris such as dust and lint, and printing ink constituents can build up on the rubber blanket. The quality of printing then declines so the blanket surface has to be cleaned. With smaller and medium format machines, cleaning is carried out by hand and predominantly with wipes and cleaning agents. In the case of larger sheetfed machines, the use of automatic blanket cleaning units (with cleaning programmes) is increasing.

Obviously, the image has to be removed from the blanket between jobs. Both in manual and automated blanket cleaning, mainly hydrocarbons and water (to remove paper solids on the rubber blanket) are used. The cleaning agents are predominantly naphthenic and aliphatic hydrocarbons. Increasingly high-boiling hydrocarbons with a flashpoint of $>100\text{ }^{\circ}\text{C}$ and vegetable oil esters and/or mixtures of hydrocarbons and vegetable oil esters are used.

When a print run (or shift) is finished and the next printing work requires the use of other inks, cleaning of the inking units (ink rollers, ink ducts) and printing units (impression cylinders, etc.) is necessary. In the case of oxidative drying printing inks, such cleaning work may also be necessary at the end of each shift. To clean the inking rollers, cleaning agents are sprayed on and the cleaning residues are wiped off. Sheetfed machines of modern design are increasingly fitted with automatic cleaning units. The cleaning of the ink ducts is done either by hand or in special cleaning units, usually with the same materials as used for blanket cleaning [76, TWG, 2004].

2.2.3.4 Sheetfed offset

[128, TWG, 2005]

The sheetfed offset process is normally used for printing volumes of up to 20000 impressions, the mean value being approximately 7000. The printing capacity of a modern sheetfed press can run 15000 impressions or more per hour. Sheetfed offset is mostly used for printing on paper, and any kind of paper can be used. Single or multilayer cardboard is printed in sheetfed offset for folding boxes. Even plastic coated cardboard and thick plastic sheets can be printed, and tin plates are printed for metal boxes in special offset presses [21, Nordic Council of Ministers, 1998].

A printing unit in a sheetfed offset press consists of the following five main parts:

- dampening unit
- inking unit
- plate unit
- blanket unit
- impression unit.

The most common system with sheetfed machines is the three-cylinder printing unit, as shown in Figure 2.3.

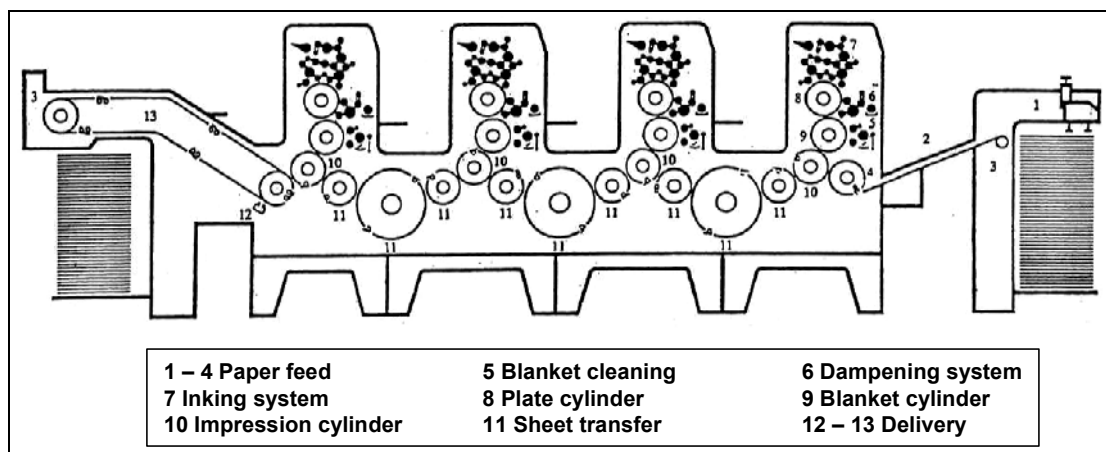


Figure 2.3: Schematic of an A4 colour sheetfed offset press with four, three-cylinder printing units [21, Nordic Council of Ministers, 1998] [4, Intergraf and EGF, 1999]

The inks used for sheetfed work are invariably thick, oily pastes which dry by adsorption into the paper and sometimes by oxidation and therefore have no emissions. The basic constituents of offset inks are pigments, binders, solvents and additives. In addition, certain substances are added to the inks to adjust their properties [21, Nordic Council of Ministers, 1998]. The binder is the main constituent of the offset ink and has the function of transferring the ink pigment as a fine layer of particles over the roller system of the inking unit and onto the substrate [76, TWG, 2004].

The dampening solutions used in the sheetfed offset processes are similar to those in heatset offset.

Waterless sheetfed offset, operates exactly as the name implies – there is no dampening of the plate, and rejection of the ink in the non-image areas is achieved by a silicone coating which is removed in the image areas. In such cases, the dampening unit is not used, or is removed from the press. New presses are available without any dampening units fitted [76, TWG, 2004].

2.2.3.5 Web presses (heatset and coldset offset)

The web presses, which print on a reel of paper, can be split into two groups – heatset and coldset, indicating the method of ink drying. Heatset prints on coated and uncoated, glossy and non-glossy papers to produce mass circulation magazines, holiday brochures and catalogues, and there are solvent emissions from the driers. Coldset is used mainly for newspapers and business forms, printed on absorbent uncoated papers, with no solvent emissions from the inks. Heatset offset is discussed in more detail in this document, but coldset is not [4, Intergraf and EGF, 1999] [76, TWG, 2004].

Dampening unit

As described above, in Section 2.2.3.3

Inking and drying unit

Inks used for heatset web work are dried, as their name implies, by using ovens to drive off the solvent from the ink, resulting in emissions to air. In these ovens, a hot air current of 180 – 300 °C drives out 80 – 90 % of the solvents which have a boiling range from 240 – 310 °C and fixes the film on printing ink. Water cooled chilling rollers are applied to cool the warm web after leaving the oven.

Cleaning

In heatset web offset machines, automatic blanket cleaning units are now almost standard equipment. Modern web presses are increasingly fitted with automatic ink cleaning units.

2.2.3.6 Gravure

[4, Intergraf and EGF, 1999] [21, Nordic Council of Ministers, 1998] [11, IMPEL, 2000] [128, TWG, 2005]

In gravure printing, the image consists of small indentations in a smooth surface of a cylinder. This consists of a steel base which is plated with copper and covered with a thin layer of hard chromium. It tends to be a more specialised process than either relief or litho printing, being mainly used for long runs as the cylinder making costs are relatively high. In this process, the cylinder is flooded with ink, and the surface scraped clean to leave ink only in the recessed, image areas.

Gravure is used for printing two major graphic products: publications and flexible packaging (see Table 2.4). Minor graphic applications are labels, gift wrapping paper, cardboard packaging, banknotes and postage stamps. Outside the graphic industry, this method is used for the printing of wallpaper, imitation wood (laminates) and imitation tiles for floors and walls.

	Publication gravure	Packaging gravure
Web width	900 – 4320 mm	800 – 1400 mm
Printing units	Mostly 8 units, sometimes 9 or 10 units	Generally between 6 and 10, often 8 colour units + one lacquering unit
Production speed	15 m/sec = 900 m/min	Generally some 250 – 300 m/min; also dependent on diameter of cylinders in use
Construction	Mostly 4 units per side of paper	Units in line, each printing a separate colour on the same side of the substrate
Colours	Four inks in 8 units, five inks in the case of 9 or 10 units possible	All colours, often also white basis
Substrates	Paper	Paper, many different kinds of plastic films, metallised paper and plastic, aluminium foil; often multi-material, multilayer substrate
Solvents in use	Toluene >99.9 % pure	Ethyl acetate, ethanol, MEK and others. Mostly in mixtures in Northern Europe and pure in Italy
Abatement techniques	Solvent recovery plant	Incineration mostly, solvent recovery mainly in Italy and sporadically elsewhere

Table 2.4: Differences between publication gravure and packaging gravure presses

Publication gravure is best known for being capable of producing very high quality colour printing on lower quality, cheaper grades of paper. The press web width can be anything between 900 up to 4320 mm usually with eight units printing four colours on each side [37, CITEPA, 2003]. The paper that runs through the press can reach a speed of up to 15 metres per second.

Most packaging gravure presses have a web width of about one metre, or sometimes a bit wider. They print eight or even ten colours on one side, with each press unit printing one colour [37, CITEPA, 2003].

Today, gravure is almost totally a webfed process, although sheetfed presses are available running at up to 10000 sheets per hour. These have hot air driers and are aimed at the specialised markets of high quality decorative effects using metallic inks on metallised papers and foils. They are, however, seldom used at present, presumably because of the high costs of cylinder making, which make high (web) run lengths more economic [4, Intergraf and EGF, 1999].

Other similar processes are copperplate printing and die-stamping. Both employ the filling of recessed image areas with ink, but in these cases, the ink is thick and dries by oxidation and adsorption rather than relying on solvent evaporation. Copperplate is used for the printing of banknotes and other security documents, while die-stamping is employed for letter headings.

Inking unit

[21, Nordic Council of Ministers, 1998] [37, CITEPA, 2003]

The high speed of gravure presses requires the use of fast drying inks, which are dried between colours in driers. Therefore, in gravure, inks are low in viscosity and nearly all of them are solvent-based. Publication printing inks contain 50 % toluene when leaving the ink factory. A dilution is made in the printing plant to obtain the proper toluene concentration: ink that is ready for use contains 70 – 80 % toluene. In packaging printing inks, ethanol and ethyl acetate are used almost exclusively. The solvents are evaporated by heat and air in drying sections, see Figure 2.4 which shows that each printing unit is equipped with a drier on top [76, TWG, 2004].

All installations in the publication gravure in Europe are equipped with activated carbon adsorbers to recover the toluene that is evaporated [37, CITEPA, 2003]. The presses are normally encapsulated. The recovered toluene is re-used either on site to dilute the ink, or sold to the ink supplier. Solvent vapours from the inks in the packaging gravure are normally incinerated, although in Italy they are often recovered.

Water-based gravure inks have not yet proved very successful and, until now, only used sporadically in packaging printing. The use of water-based gravure inks in the United States has now ceased [21, Nordic Council of Ministers, 1998] [76, TWG, 2004].

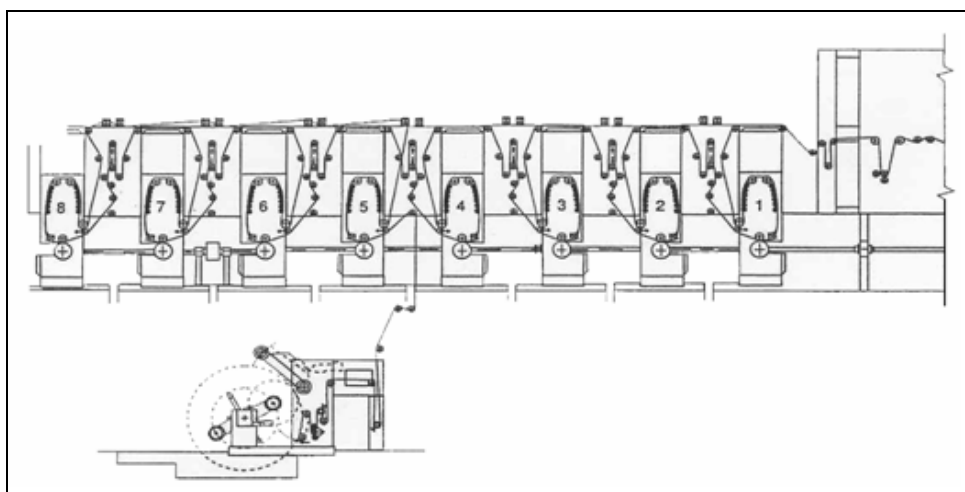


Figure 2.4: 4 + 4 colour publication gravure press

Cleaning

Cylinders are automatically or manually cleaned with the same solvent as the ink. If the job is expected to be repeated, the cylinders might be saved, or else they are made ready for the next printing job by replacing the engraved copper/chromium layer with a new one [76, TWG, 2004].

2.2.3.7 Screen printing

[4, Intergraf and EGF, 1999] [21, Nordic Council of Ministers, 1998] [128, TWG, 2005]

Screen printing is a form of stencilling where the ink is forced through the clear elements of the stencil onto the substrate to be printed, see Figure 2.5

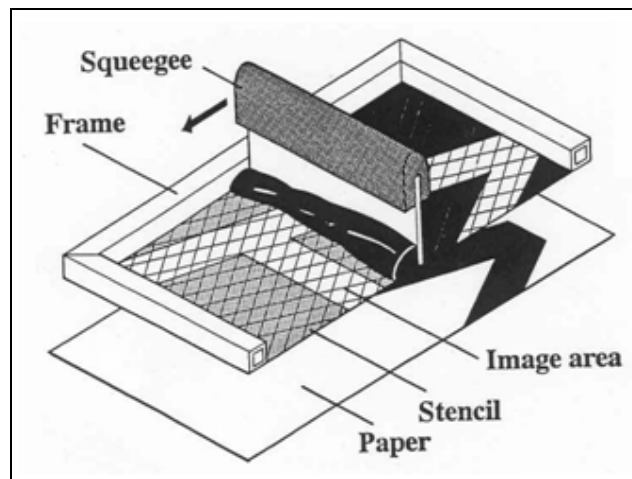


Figure 2.5: The stencil printing principle

The process is very versatile as it can be used to print on almost any surface or material of any size, shape or thickness, including not only all the usual printing materials, but others such as metal, wood, plastic, glass, cork and fabric.

The material to be printed on is positioned under the stencil screen in close contact, the frame is loaded with ink and the ink is forced through the clear parts of the stencil by a squeegee. The printed material is racked separately to aid air drying or passed through a hot air drier when higher productivity is required. Alternatively, the substrate is dried by exposure to ultraviolet light.

This process can produce brilliant solid colours, or lighter colours on a dark substrate. Inks can be formulated to be opaque and hide any matter underneath, or transparent to make use of the colour combinations available by halftone screen printing. Screen printing is capable of laying down a heavier ink film than any of the other printing processes.

Low set-up costs have always made the process attractive for short runs, but due to increased automation and process improvements, it is now a major printing process capable of very high quality printing across a wide range of products from one colour and multiple special colours through to four-colour processes.

Most screen printing is on sheetfed presses. Webfed screen printing is used for products such as wallpaper.

Printing and inking unit

A whole range of inks are used to match the great variety of end-products. Inks containing solvents dry by solvent evaporation. The selection of solvents is determined by the binder, substrate and method of drying. Typical solvents are aromatic and aliphatic hydrocarbons, glycol ethers and esters, alcohols and ketones. The typical organic solvent content is 50 % for line colours and 70 % for four colour process inks [76, TWG, 2004].

UV inks and water-based inks are also applied. Water-based inks contain organic solvents varying from 5 % when used on paper substrate to 20 % when used on plastic substrate.

Apart from normal organic pigments, some 'heavy' inorganic pigments are still used. Some yellow inks that are used, e.g. for printing on PVC, can contain up to 25 % lead chromate. Some red and green colours are based on lead. Directive 76/769/EEC bans the marketing and use of these and other pigments across the EU (see Section 1.2.3) except for limited specific applications, such as road signs.

Cleaning

Two distinct cleaning processes are used: de-inking for screen re-use with the same image, and cleaning the stencil (de-coating) for screen reclamation and re-use with a new image.

2.2.3.8 Digital printing

[4, Intergraf and EGF, 1999, 21, Nordic Council of Ministers, 1998] [128, TWG, 2005]

Digital printing is printing straight to the substrate from digital information without the use of film or the creation of a separate image carrier. A unique feature of this process is that it is possible and economic to change the image or part of the image on each copy, so personalising the message and the print. These characteristics allow considerable flexibility for short-runs (10 - 200 copies) and rapid changes, originally for black and white printing, and now for colour work. However, they are also used for the printing of very large circulation products such as spare part catalogues, where a very quick updating of data is needed [76, TWG, 2004].

The 'inks' used in these machines are either liquid or dry toners. Liquid toners are all two-part systems, including the toner itself as pigmented particles, and the carrier which is a volatile solvent such as ethyl acetate, methyl ethyl ketone or ethyl and butyl lactates, in which the particles are suspended for handling. The toner is applied to the plate and the carrier liquid remains in the system. Any carrier remaining with the toner is boiled off in the machine's fusing section. Most modern presses have a solvent recovery system, and the liquid is retained within the system for recycling.

All dry toners consist of a base resin, pigment, charge modifier, dye and other essentials. Popular resins are styrene-acrylates and polyesters, sometimes blended. The resin is the fusible part of the toner, and it is the binder which provides bulk to the particle. The pigment may be carbon black in black toners, but is often a dye in colour toners. Dry toner waste is basically plastic powder. Both liquid and dry toner waste can contain paper dust, clay fillers, or photoconductor dust and water.

Commercially, inkjet digital printing machines range from 1 to 10 metres wide. They provide four colour quality prints in runs from 1 - 300. The length of print can vary from 1 - 30 metres. Inkjet printers are also used to produce 'mock-ups' prior to long runs in other forms of printing. They are capable of printing onto paper, board, plastics, textiles and metal (including complete vehicles such as buses, for advertising). Normally the inks are solvent-based containing volatile solvents such as methyl ethyl ketone, ethyl and butyl lactate. More recently UV curing digital inks have become available [76, TWG, 2004].

An intermediate type of printing is in operation, in which the digital image is exposed onto a printing plate already positioned on the press (or, in the case of multicolour printing, several plates positioned in line). This process combines flexibility of image (ability to change the image at will) with the creation of a plate, making it attractive for medium length runs (above the true economic run length of a digital press but below that of the conventional press). These presses use the same conventional printing inks as in litho sheetfed presses.

2.2.3.9 Laminating and varnishing in flexible packaging

Flexible packing materials are often multilayer materials built up by lamination and with a protective coating called varnishing. The processes are technically similar to packaging gravure printing. While no image is printed, the substrate is totally covered (i.e. 100 % covered). Solvent-based, water-based and chemically-reactive (2-component) adhesives and resins are used.

2.2.4 Finishing

[4, Intergraf and EGF, 1999] [21, Nordic Council of Ministers, 1998]

(For flexible packing, see Section 2.2.3.9, laminating and varnishing). Print finishing services are provided by printing companies themselves and also by a number of specialised, independent plants (purely print finishing plants).

The most important print finishing services include the processing of:

- books by folding, collecting, stitching, binding and trimming
- magazines, leaflets, catalogues and printed advertising products (e.g. brochures, sample cards, etc.) by folding, gathering, glueing and perfect binding
- other printed matter, printed papers or cardboard (e.g. forms, labels, packaging, calendars) by folding, punching, embossing, glueing and laminating.

Each of these steps will involve guillotining and collating. These mechanical processes, as well as folding, binding and punching, do not use solvents and, therefore, are not described any further in this document. In processes such as glueing and laminating, however, solvent-based products are sometimes used, and so these are further described.

Laminating

Traditionally, most laminating was done with solvent-based systems, where the adhesive-coated film was passed through an oven to drive off the solvent before being pressed onto the printed surface. Nowadays, 2-component adhesives are used, often of the epoxy type containing solvents such as ethanol and ethyl acetate, or of the urethane type. The emissions from this process are significant. In some places, the vapours are incinerated or recovered for re-use. Water-based and solvent-free adhesives or UV curing laminating adhesives are also applied [76, TWG, 2004].

Binding by using adhesives (glueing)

Glueing is part of many working processes in bookbinding and print finishing. For the processing of the book block and the production of, e.g. the case for hard case books, adhesive binding is the most frequently used binding technique, both for books and multiple page leaflets. Adhesive binding is often referred to as 'perfect binding'.

The adhesive used can be based on natural products or can be synthetic. The latter one may be dispersion, hot-melt or polyurethane. Natural products mainly comprise starch adhesives, dextrans and animal glues.

Traditionally, most used glues are water-based or hot-melt and some are solvent-based.

Varnishing

'Coating', 'varnishing' and 'overprinting' are synonyms for the coating that is spread over the printed surface for protection or decoration. The overprint varnish is a colourless, transparent ink without pigments. Varnishes dry by evaporation, oxidation or by UV curing, and varnishes can be applied in line on the press or on a separate machine [21, Nordic Council of Ministers, 1998] [76, TWG, 2004].

2.2.5 Associated activities

Other activities can be found associated with these processes, but not all installations will carry out all of these activities. The following are key examples of associated activities, but the list is not comprehensive. Some of the activities are described elsewhere in this document, others are not.

Photographic processes

These are always black and white only. There are waste fixatives and developers, which may require storage and/or treatment prior to disposal to waste water or for disposal as waste. Silver is likely to be present in the discarded solutions, but may be recovered on-site, and/or sent off-site for reprocessing).

Image carrier production

The printing processes are defined in part by the way the image is carried to the substrate (see Section 2.1.1. The following types of image carriers are used:

- offset plates (in heatset web offset)
- flexographic plates (in flexography)
- gravure cylinders (in packing and publication gravure)
- screens (in screen printing).

The techniques for electroplating and associated activities used in the preparation of gravure cylinders are described in the STM BREF.

Waste gas treatment

Waste gases are contained, collected and frequently treated for occupational health and safety (to prevent fires and explosions), and environmental reasons (to reduce the emission of VOCs). The following different types of waste gas treatment systems are currently applied, and more details can be found in Section 20.11 and Annex 24.9:

- thermal incineration
- thermal recuperative incineration
- catalytic incineration
- regenerative incineration
- adsorption with recovery
- biological.

Storage of hazardous materials and wastes

These are materials that may cause harm to the environment and occupational health and safety problems if not stored and handled carefully:

- flammable raw materials such as liquid inks (as used in flexography, gravure and screen printing), developers, fixers (both before and after dilution) solvents for dampening solutions, extenders, process make up, cleaning, solvents for recovery, or surplus recovered solvent for sale, fuel oils, etc.
- hazardous wastes such as used wipes containing solvents and other cleaning agents, waste fixative and waste developer, waste cleaning solvents. In gravure, chemical waste from preparing gravure printing rollers.

In some plants, underground tanks are used to store fuel oil, and in some cases, other liquids such as waste fixative and developer. In large plants, underground tanks may be used to store ink (publication gravure) and solvents (publication gravure and flexible packaging printing). The tanks may have underground pipes to connect them to the building where the printing process takes place [4, Intergraf and EGF, 1999].

More information on storage types and techniques can be found in Section 20.2 and also in the ESB BREF.

Waste water treatment

The printing processes can generate waste water at the image creation stage (development/fixing) and cleaning particularly with water-based or water washable inks. The waste waters may be treated before discharge. Commonly applied techniques are flocculation, precipitation and ultrafiltration, see Section 20.12 [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003].

2.3 Current consumption and emission levels in printing

2.3.1 The printing industry as a whole

An overview of the printing industry is given in the preceding sections of Chapter 2. The consumptions and emissions given in this section are from the information exchange to the three largest processes most likely to exceed the thresholds in Annex 1 (6.7) to the IPPCD. Other printing processes may be found in the same installation as associated activities, or occasionally operating above the threshold.

2.3.2 Heatset web offset

2.3.2.1 Mass balances – heatset

In 1999, the results of an inventory amongst heatset printing plants in Germany were reported. One of the results of this inventory was that the performance data from different units of different plants were compared and used to simulate a virtual plant that could meet the legal requirements, especially those of the Solvent Emissions Directive. This virtual plant is not an existing plant, but made up of information from well-performing units from different existing plants representing good practice and good environmental performance. This plant could feasibly exist.

In this section, the mass balances of the theoretical virtual plant from this inventory are reported. Actual plants can vary widely with production parameters, such as ink coverage, run length, type of paper, etc. [76, TWG, 2004]. However, it should be noted from Table 2.5 [76, TWG, 2004] that:

- waste gas treatment usually operates at 700 - 800 °C, not 900 °C
- the percentage of IPA is not defined: w/w or v/v.

The operational data and production conditions of the virtual plant are shown in Table 2.5 and Table 2.6. The mass balances of this virtual heatset offset plant are shown in Table 2.7 and Figure 2.6 shows the VOC balance.

Machines	<p>2 x 32-pages heatset offset machine; 4 blanket-to-blanket units; web width: 1260 mm; cylinder circumference: 890 mm; max. press speed 17 m/s; average velocity approx. 13 m/s at production run.</p> <p>Total power supply: 1134 kW for press speed up to 14.8 m/s; Electricity consumption at an average press speed of 13 m/s: 996 kW of which approx.:</p> <ul style="list-style-type: none"> • 2 x 470 kW power supply printing press (2 x 295 kW motor power supply; 2 x 120 kW auxiliary drives (printing unit, auxiliary aggregates, control); 2 x 19 kW air blast; 2 x 30 kW roller bearing, 2 x 6 kW remoistening unit) • 2 x 6 kW power supply paper reel transport system • 2 x 91 kW power supply cooling centre
Products	Commercial printing, e.g. advertising supplements; weekly papers
Printing substrate	Web printing papers with an average weight of approx. 60 g/m ²
Printing ink	Heatset ink (vapour pressure <0.01 kPa at 20 °C; mineral oil content = 35 % of which about 90 % evaporates in the drier)
Dampening solution	Water (max. 10 °dH), 8 % IPA, 3 % other dampening solution additives
Drier	2 x direct combustion (natural gas), temperature (paper web exit): 120 – 140 °C, waste gas volume flow approx. 7200 Nm ³ /h (at 13 m/s production run), ventilator: 72 kW
Waste gas treatment	<p>1 x regenerative thermal oxidation (thermoreactor), combustion chamber approx. 900 °C, VOC destruction efficiency: 99 %. Purified gas exit temperature at 140 °C; heat recovery: 93 % thermal efficiency.</p> <p>Heating up with 2100 kW gas, normal operation 2 x 700 kW gas. 2 x 200 kW electricity demand (ventilators); electricity consumption 1900 kW/yr, auxiliary combustion approx. 15 kW gas (at 13 m/s; 1.2 g/m² ink per page)</p>
Cleaning agents	20 % roller/blanket for cleaning by hand (100 %VOC; vapour pressure 0.05 kPa at 20 °C) and 80 % blanket for clean-up device (0 % VOC; vapour pressure <0.01 kPa at 20 °C), re-usable solvent wipes (40 gram dry weight/item)

Table 2.5: Operational data of a virtual heatset offset plant
[18, UBA Germany, 2003]

Production	3 shifts on 5.5 weekdays, 280 working days x 24h = 6700 yearly working hours; approx. 30 % preparation and servicing time, approx. 70 % production =>4700 production hours of the printing presses
Products	approx. 18000 t/yr commercial printings from approx. 20000 t/yr paper input and 500 t/yr ink input
Dampening solution	Approx. 1025 t/yr; consisting of 950 tonnes water, 50 tonnes IPA and 25 tonnes other additives
Cleaning	Approx. 15 t/yr (80 % for interim cleaning, 20 % for basic cleaning) and 100000 wipes.

Table 2.6: Production conditions of the virtual heatset offset plant
[18, UBA Germany, 2003]

The following mass balance in Table 2.7 is calculated for the virtual plant described in Table 2.5 and Table 2.6.

INPUT	Amount	Unit	Notes	OUTPUT	Amount	Unit	Notes
				Products			
				Commercial printings	18000	t/yr	Paper and ink
Material				Waste			
Printing substrate	20000	t/yr		Paper/misprints	2800	t/yr	
Printing inks	500	t/yr	Mineral oil concentration in ink 35 %, of which 85 – 90 % evaporates in the drier [76, TWG, 2004]	Ink residues	6	t/yr	Ink waste and in cleaning wipes, no VOCs
Dampening solution	950	t/yr	Without VOC				
IPA	50	t/yr	100 % VOC	Dampening solution residues	2	t/yr	4 % VOC
Dampening solution additives	25	t/yr	5 % VOC				
Cleaning agents	15	t/yr	80 % VOC-free for interim cleaning, 20 % for basic cleaning	Mixture of cleaning agents and water	23	t/yr	50 % high boiling solvents
Cleaning wipes	100000	Items/yr	Usually reusable wipes, weight approx. 40 g/item	Cleaning wipes	100000	Items/yr	Containing 1 t ink and 3 t cleaning agents with 100 % VOC, of which 50 % evaporates fugitively
VOC total	203	t/yr		VOC in waste	2	t/yr	In wipes, cleaning agents and waste dampening solution
Energy				Exhaust gas			
Energy in total	27100	MW h/yr		Volume flow	67.7 x 10 ⁶	m ³ /yr	19 mg VOC/m ³
Gas energy	13700	MW h/yr		VOC in purified gas	1.3	t/yr	
Electric energy	13400	MW h/yr		NO _x in purified gas	2.7	t/yr	40 mg NO _x /m ³
<i>Of which: Printing press</i>	8900	MW h/yr		CO in purified gas	3.4	t/yr	50 mg CO/m ³
<i>Cooling</i>	1700	MW h/yr		Fugitive			
<i>Waste gas treatment</i>	700	MW h/yr		VOC fugitive	47	t/yr	23 %

Table 2.7: Input and output of the virtual heatset plant [18, UBA Germany, 2003]

The VOC balance of the virtual plant is shown in Figure 2.6.

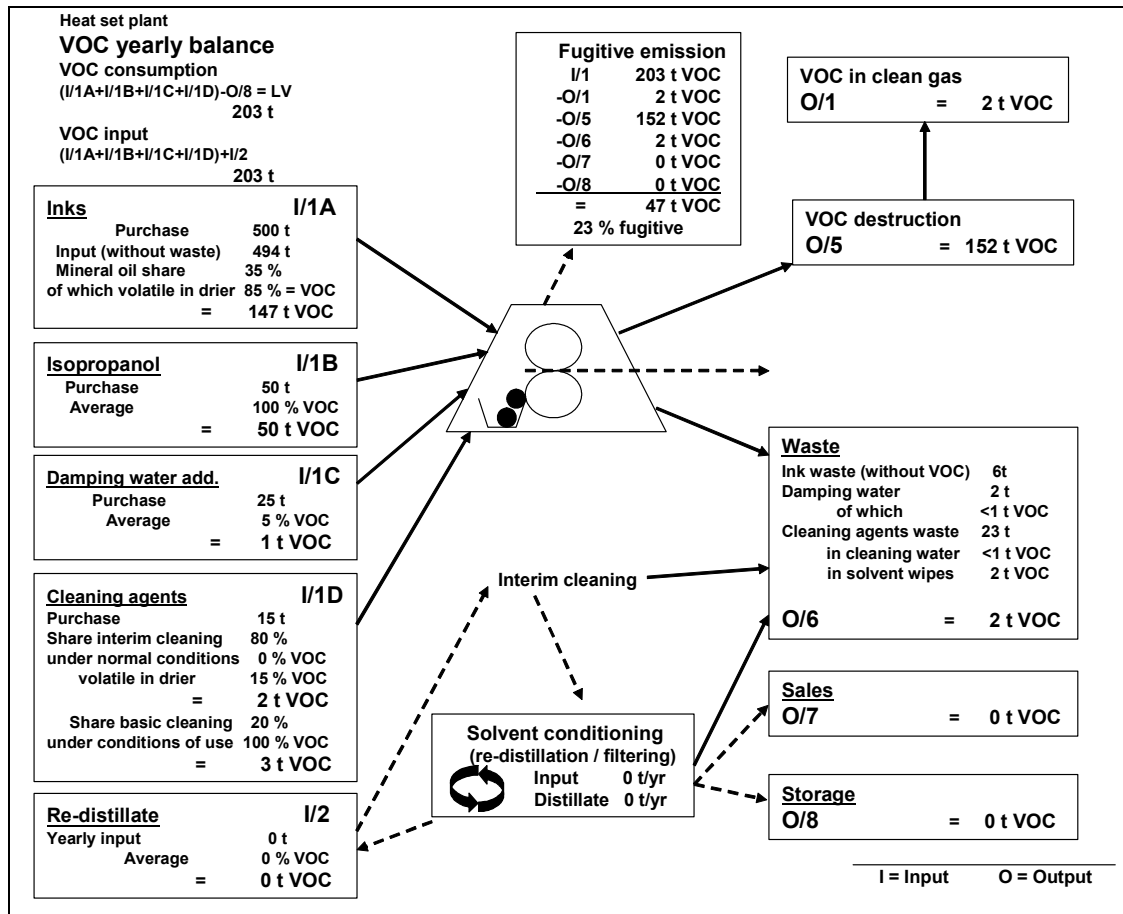


Figure 2.6: VOC balance of the virtual plant [18, UBA Germany, 2003]

However, it should be noted that Figure 2.7 [76, TWG, 2004]:

- shows that IPA VOC content is assumed to be 100 %, although it may contain up to 15 % water
- shows that in heatset printing, two large (32-page) fast presses, working three shifts during 280 days per year are needed to exceed a consumption of 200 t/yr. Most heatset plants have either two 8-page presses or one 8-page and two 16-page presses. Two 32-page presses in one plant is rare.

Heatset plants bigger than this virtual plant can be composed of several printing units which are similar to the virtual plant, although more and more plants are equipped with presses of differing web widths. The specific consumption and emission data can then be taken from this virtual plant. However, the specific consumption and emission values are significantly dependent on the manufactured products and will increase with [76, TWG, 2004]:

- decreasing print volume
- rising employment of special colours or change of colour sequence
- extremely high demands on the printing quality, or difficult printing images
- decreasing paper quality.

Several theoretical mass balances have been calculated from the virtual plant. Average VOC consumptions and emissions in relation to one tonne of ink used are shown in Figure 2.7. Average input of material and output of waste of the virtual plant are shown in Figure 2.8. However, these values are average values, which can – dependent on the above-mentioned parameters – vary in practice by more than +/- 10 % [76, TWG, 2004].

Figure 2.7 shows that of 400 kg VOC input, 308 kg is captured and treated by thermal oxidation, so 92 kg are fugitive, which equals 23 % of the VOC input. After treatment, 3 kg of VOC are still in the waste gas and emitted and the efficiency of the waste gas treatment is 99 %.

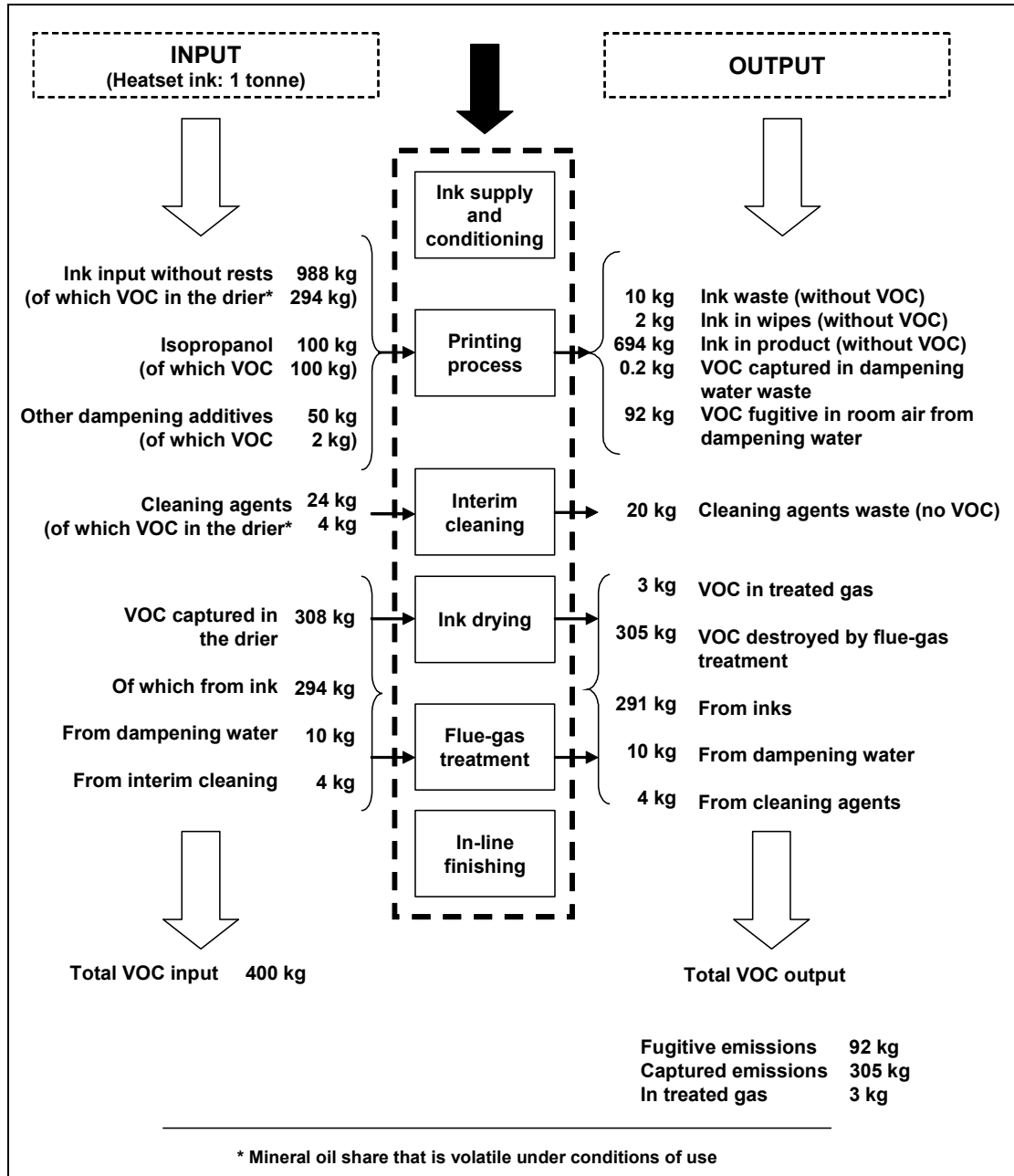


Figure 2.7: Specific VOC consumption and emission levels in a virtual heatset process [18, UBA Germany, 2003]

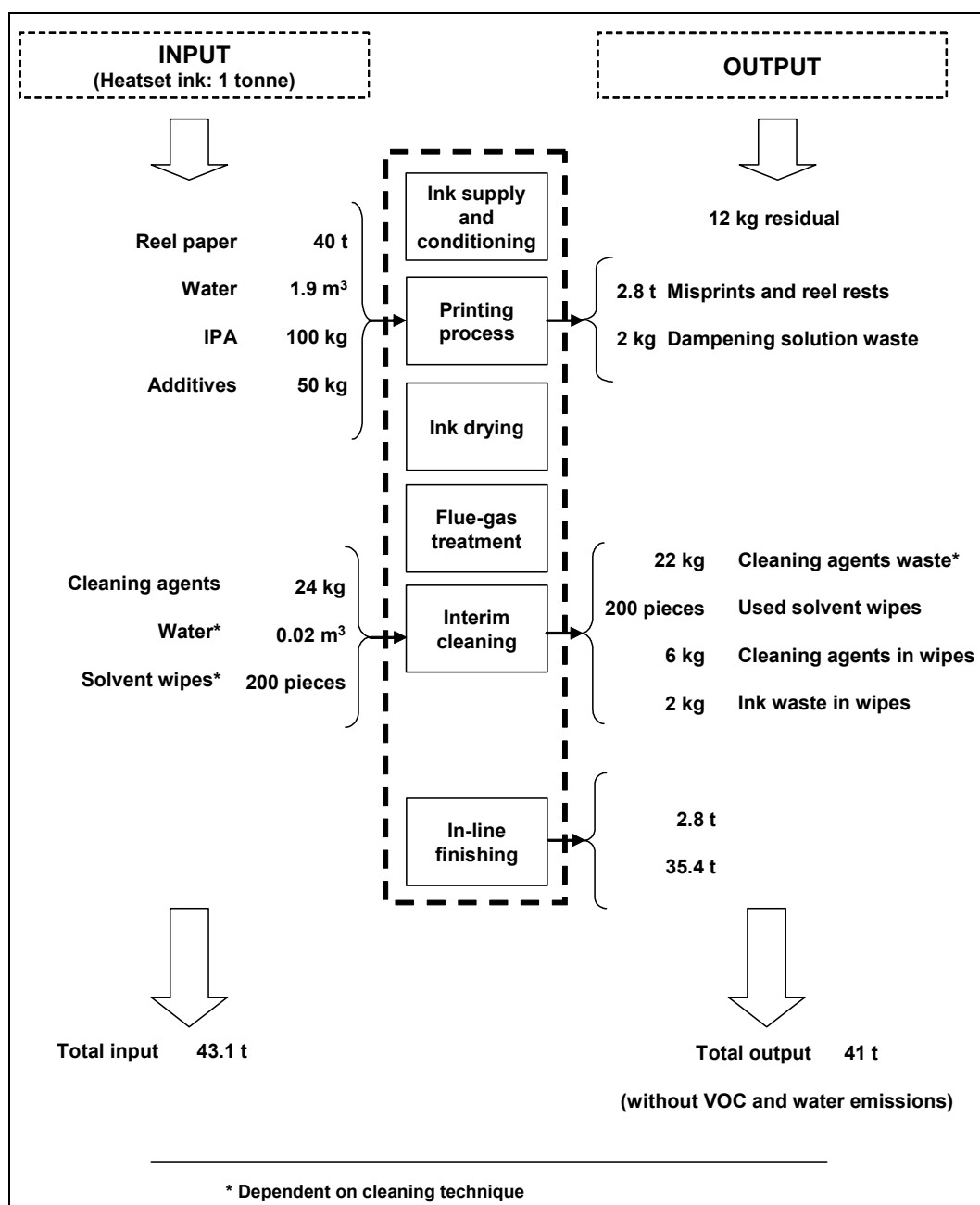


Figure 2.8: Specific input of substances and output of waste in a virtual heatset process [18, UBA Germany, 2003]

A study has been carried in Flanders (Belgium) and the Netherlands in 2003 on nine plants using over 200 t/yr VOCs [115, Intergraf, 2005]. From these, and further experiments, two types of press were identified, those capable of printing with low concentrations of IPA in the dampening solution (new or upgraded presses) and those not capable (existing plants). By trials to optimise the presses, two types of printing jobs were also identified: those that could readily run with low IPA concentrations (favourable), and 'difficult' ones that needed higher IPA concentrations, see Table 2.8. 'Difficult' jobs involve all or some of the following:

- changes in the surface of the paper requiring numerous fine changes to settings of the press
- situations of high ink coverage where IPA prevents the occurrence of white spots
- lower levels of skill, education and experience of operators
- new, wide fast presses were also reported to need higher IPA to meet the demands of running wide plates, wide rollers with small amounts of sag, etc. [178, Verspoor, 2006]

Press type	Characteristics of the jobs to be printed	
Type 1: capable of using low IPA concentration	Favourable (A)	Difficult (B)
Type 2: <u>not</u> capable of using low IPA concentration	Favourable (A)	Difficult (B)

Table 2.8: Combinations of heatset press and job type analysed [115, Intergraf, 2005]

Consumption figures have been derived from the data collected by the Belgian study for dampening solution and cleaning agent consumptions, see Table 2.9.

Situation	IPA or substitute	Cleaning agents	
Press type 1, type A jobs	2 % of ink weight	Mainly K3 (55 - 100 °C)	2 % of ink weight
Press type 1, type B jobs	10 % of ink weight	Mainly K3 (55 - 100 °C)	5 % of ink weight
Press type 2, type A jobs	5 % of ink weight	Mainly K3 (55 - 100 °C)	5 % of ink weight
Press type 2, type B jobs	15 % of ink weight	Mainly K3 (55 - 100 °C)	10 % of ink weight

Table 2.9: Solvent consumption data for heatset press and job type [115, Intergraf, 2005]

Virtual plant calculations have been made in Table 2.10, assuming the minimum possible consumptions of IPA, IPA substitutes and cleaning agents. For illustrative purposes, an ink consumption of 500 t/yr is assumed.

Emission sources	Press 1 jobs A	Press 1 jobs B	Press 2 jobs A	Press 2 jobs B
ink t/yr	500	500	500	500
VOC evaporating from ink %	35 %	35 %	35 %	35 %
VOC evaporating from ink t/yr	175	175	175	175
Emission from ink %	1.5 %	1.5 %	1.5 %	1.5 %
Emissions from ink t/yr	2.6	2.6	2.6	2.6
IPA or VOC in substitute % of ink weight	2 %	10 %	5 %	15 %
IPA or VOC in substitute t/yr	10.0	50.0	25.0	75.0
Fugitive IPA or VOC in substitute %	90 %	90 %	90 %	90 %
Fugitive IPA or VOC in substitute t/yr	9.0	45.0	22.5	67.5
Cleaning agents (CA) % of ink weight	2 %	5 %	5 %	10 %
VOC in CA %	100 %	100 %	100 %	100 %
VOC in CA t/yr	10.0	25.0	25.0	50.0
Emission factor CA	23 %	23 %	23 %	23 %
Emissions from CA t/yr	2.3	5.8	5.8	11.5
Total input t/yr	195	250	225	300
Total emissions t/yr	13.9	53.4	30.9	81.6
% of ink weight	2.8 %	10.7 %	6.2 %	16.3 %
<i>% of input (SED)</i>	<i>7.1 %</i>	<i>21.4 %</i>	<i>13.7 %</i>	<i>27.2 %</i>

Table 2.10: Heatset virtual plant VOC emissions [115, Intergraf, 2005]

2.3.2.2 Consumptions – heatset

[128, TWG, 2005]

2.3.2.2.1 Constituents and additives

2.3.2.2.2 Printing inks

The basic constituents of offset inks are: pigments, binders (resins, varnish, mineral oil), and additives (drying substances). In addition, certain substances (printing oils/thinner, rub resistance pastes, gloss agents, drying retarders, etc.) are added to the inks to adjust their properties [21, Nordic Council of Ministers, 1998].

In heatset, there are only four standard colours. The inks are mainly organic and only a few inorganic pigments are used. The most commonly used are:

- black: carbon black
- inorganic: titanium dioxide, aluminium hydroxide, iron blue
- organic: diarylide yellows, lithol rubine 4B, phthalocyanine blue.

Phthalocyanine blue contains a strongly complex-bound copper. Normal pigments can contain heavy metals in the form of small impurities in amounts counted in parts per million [21, Nordic Council of Ministers, 1998].

A typical formulation of heatset inks is shown in Table 2.11.

Component	Contents	Concentration (wt-%)
Binding agent	Resins, vegetable oils, mineral oils (b.p. 240 – 300 °C)	60 – 85
Colourants	Nearly exclusive organic pigments	10 – 25
Colour auxiliary agents	Siccatives (metal soaps), anti-oxidising agents (e.g. butyl hydroxyl toluene, hydroquinone), anti-skinning agents (e.g. cyclohexanone oxime), complex formers (e.g. EDTA, tartrates)	<10

Table 2.11: Typical basic recipe for heatset web offset printing inks
[18, UBA Germany, 2003],[54, BMLFUW Austria, 2003] [128, TWG, 2005]

The total consumption of heatset inks in the EU-15 is estimated at 125 to 140 kilotonnes per year [4, Intergraf and EGF, 1999]. Data from the virtual heatset offset plant show a consumption of ink of 27.8 kg per tonne of finished product, or 25 kg per tonne gross (including wastage) [18, UBA Germany, 2003]. Experience of three plants over five years showed a consumption of 19 kg per tonne gross [76, TWG, 2004]. For the whole Finnish printing industry, the average ink consumption was 20.6 kg per tonne product [21, Nordic Council of Ministers, 1998]. A typical ink consumption is about 19 to 25 kg per tonne of output.

2.3.2.2.3 Dampening solutions

[128, TWG, 2005]

Undiluted IPA is added to the dampening solution, unless they are replaced by tensides. In heatset offset, the concentration of IPA varies between 5 - 15 % depending on print job [4, Intergraf and EGF, 1999] [76, TWG, 2004].

Some older presses are designed to operate with concentrations of up to 30 % IPA or ethanol, and others with none. The concentration of IPA can be 30 - 50 % over the amount needed, without disturbing the printing process. On the other hand, having too little IPA immediately has a negative effect on the quality [4, Intergraf and EGF, 1999].

Sometimes concentrations of 2 – 8 % of IPA are used in combination with an additive, usually glycol ethers which are added to the dampening solution in concentrations of about 1 %. In some cases, working without IPA can be possible [21, Nordic Council of Ministers, 1998] [4, Intergraf and EGF, 1999].

Table 2.10 shows the variation in IPA concentrations that are used, because of variations in presses and printing jobs.

In Germany, the implementation of the Solvent Emissions Directive has led to concentrations of IPA in heatset processes being limited to a maximum of 8 % [18, UBA Germany, 2003, 76, TWG, 2004].

Solvent consumption data for heatset press and job type data from 2003 are given in Table 2.9.

An inventory in the German heatset printing industry showing the amount of IPA used (before 1999) was in the range of 18 - 21 wt-% (in relationship to the total ink input being 100 %). However, more recent data show a ratio of 10 % in combination with 5 % of other additives from one virtual heatset offset plant. In 2002 in that virtual plant, (see Table 2.5 and Table 2.6) the IPA input is 50 tonnes for printing 20000 tonnes printing substrate. The IPA concentration in the dampening solution is approx. 5 %. 18000 tonnes commercial printing products are produced and the input of IPA is then 2.8 kg per tonne of product and 100 kg per tonne ink used (10 %) [18, UBA Germany, 2003].

Ranges in IPA concentrations of 5 - 20 % are also reported to be common practice in Austria. [54, BMLFUW Austria, 2003].

Of 16 heatset printing plants in Flanders, Belgium, the range of IPA in relation to the ink input by weight, is from 0 - 47 %. In the three plants where no IPA is used, alternatives are applied. Relative to the ink input, two plants each with over 500 employees show IPA consumptions of 56 % and 176 % respectively [32, Aminal, et al., 2002].

In waterless printing processes, no dampening solution is applied and rejection of the ink in the non-image areas is being achieved by a silicone coating [4, Intergraf and EGF, 1999] [76, TWG, 2004].

2.3.2.2.4 Varnishes

No data submitted.

2.3.2.2.5 Cleaning agents

[4, Intergraf and EGF, 1999] [128, TWG, 2005]

Typical cleaning agents used for offset blankets and ink rollers are shown in Table 2.12

The solvent mixtures generally contain aliphatic, cyclical and/or naphthenic hydrocarbons. These are usually free of aromatic compounds for health and safety reasons. However, aromatic hydrocarbons, such as toluene, xylene, and halogenated solvents have been used [21, Nordic Council of Ministers, 1998] [4, Intergraf and EGF, 1999].

For the heatset processes in the EU-15, this is estimated at 13 kilotonnes per year, which is about 10 % of the ink input by weight. [4, Intergraf and EGF, 1999]. However, a range of 4.5 - 6.5 wt-% has also been reported [18, UBA Germany, 2003]. Data from 16 heatset printing plants in Flanders, Belgium, report a range from 0.5 – 11.2 % based on the ink consumption, and one plant even reports a specific use of 110 wt-% [32, Aminal, et al., 2002].

Where in the past very volatile and, in some cases, halogenated solvents were used for cleaning offset presses, there is a definite trend towards using less volatile solvents. This trend results in a substantial decrease of the VOC emissions from cleaning agents, but, on the other hand, increases the amount of hazardous waste. The increase in waste is, however, smaller than the decrease in VOC emissions. Experience shows that, once low volatility cleaning agents have been used for some time, the amount used can be decreased [4, Intergraf and EGF, 1999].

Nowadays, the proportion of cleaning agents used in heatset, sheetfed and generally in offset processes, is shown in Table 2.12.

Cleaning agent	Heatset (1999)	Heatset (2000)	Sheetfed (2000)	Offset (2000)
	Proportion (%)			
Solvent mixtures with a flashpoint <21 °C	12.9	9	21	12 – 33
Solvent mixtures with a flashpoint of 21 – 55 °C	36.3	3	8.5	
Solvent mixtures with a flashpoint of 56 – 100 °C	39.2	76	68.5	61 – 79
High boilers with a flashpoint >100 °C	9.7	12	2	6 – 8.6
Vegetable oil esters with a flashpoint >150 °C	1.9			
Note Column 2 are data from German industry Columns 3 and 4 are data from Flemish industry Column 5 are data from Dutch industry and [76, TWG, 2004]				

Table 2.12: Cleaning agents in heatset and offset processes in general [18, UBA Germany, 2003] [32, Aminal, et al., 2002]

In heatset processes in Austria, 90 % of the cleaning agents used are organic solvents with a vapour pressure >0.01 kPa. Of this amount, 70 % is used for intermediate cleaning which takes about 20 – 80 seconds and (for a 4 blanket-to-blanket units press, 96.5 cm wide) less than 1 litre cleaning solvent. Automatic cleaning of the press between two printing jobs takes about 0.5 l/hr (for a 4-colour double-print press, 96.5 cm wide) [54, BMLFUW Austria, 2003] [76, TWG, 2004].

Solvent consumption data for heatset press and job type data from 2003 are given in Table 2.9.

Automatic cleaning systems use some 10 % less cleaning agent than the amount needed when cleaning is manually carried out [4, Intergraf and EGF, 1999].

Some vegetable cleaning agents contain up to 15 % solvents. However, they are also available without [4, Intergraf and EGF, 1999] [76, TWG, 2004].

Some old presses may have molleton covered dampening rollers, although these are obsolete in the EU-15. These need to be removed from the press for cleaning. Solvents are not needed to clean these rollers, because they can be adequately cleaned using high pressure water sprays, occasionally helped with a small amount of detergent [4, Intergraf and EGF, 1999].

2.3.2.2.6 Energy and resources

[128, TWG, 2005]

Energy consumption of the virtual heatset plant described in Table 2.5 and Table 2.6 are shown in Table 2.13 and Figure 2.9. Energy consumption per tonne of ink is very variable on type of press, job and ink, etc. and not a realistic indicator [76, TWG, 2004].

Energy consumption heatset offset process	Consumption	Consumption
Total	1.355 MWh/t	54.2 MWh/t ink input
Gas	0.685 MWh/t	
Electricity	0.67 MWh/t	
Gas in waste gas treatment	4.60/t VOC in waste gas	
	15.56 GJ gas/t VOC	
	0.3 t LNG/t VOC	

Table 2.13: Energy consumption in virtual heatset plant (from Table 2.7) [18, UBA Germany, 2003]

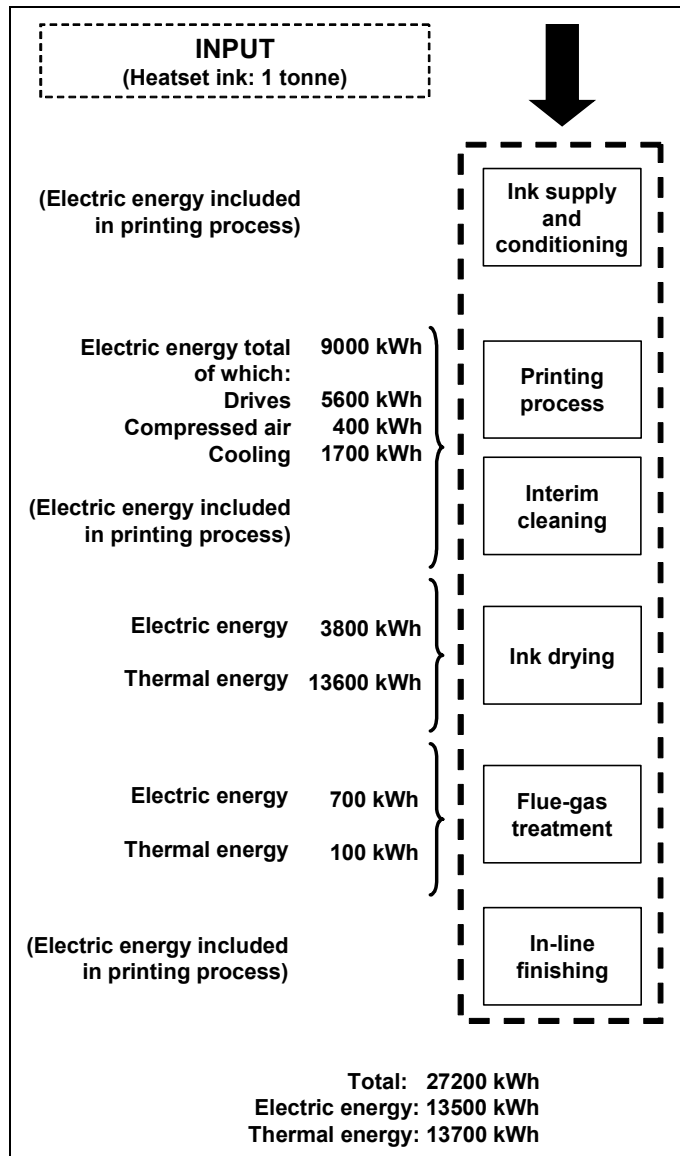


Figure 2.9: Specific energy consumption in a virtual heatset process [18, UBA Germany, 2003]

2.3.2.2.7 Printing substrates and other consumptions

[128, TWG, 2005]

Printing substrates

The substrate used in heatset is typically paper with a specific weight of the paper between 40 - 60 g/m². Often coated LWC grades and uncoated paper are used with a specific weight normally of between 45 – 70 g/m².

Other consumptions

Other inputs are materials such as wipes for cleaning, containers and other packaging materials.

In heatset, four standard colours are used and these are supplied in re-usable containers, which are either intermediate bulk containers (IBC) with a content of approximately 1 tonne, or common 200 litre metal drums [4, Intergraf and EGF, 1999].

Wipes are usually re-usable and weigh about 40 grams. A heatset printing plant reported using about six wipes per tonne printed product, which equals 200 wipes per tonne ink used [4, Intergraf and EGF, 1999, 18, UBA Germany, 2003, 76, TWG, 2004].

2.3.2.3 Emissions – heatset

2.3.2.3.1 Emissions to air – sources and fugitive emissions

[128, TWG, 2005]

The total European unabated VOC emissions from heatset plants are estimated to be in the order of magnitude of 100 kilotonnes per year. Over half of these emissions stem from the IPA in the dampening solution and the rest from the cleaning agents. The emissions from the ink created in the drier are of high boiling oils and are abated, together with an estimated 10 % of both IPA and cleaning agents that are also extracted via the drier where the driers extract air from the press room.

According to the RAINS model, at EU-25 level for 2000, NMVOC emissions from heatset were 40 kt representing 0.38 % of the total NMVOC emissions. The total activity was 123.59 kt with an average emission factor of 3239 g NMVOC/kg which shows this industry already reduces some emissions [130, EGTEI, 2005].

Some data show 50 % of the original VOC emissions will remain unabated [4, Intergraf and EGF, 1999]. Other data show that much lower levels of fugitive VOC emissions in the range of 25 – 30 % are achievable [54, BMLFUW Austria, 2003], with low IPA consumption and the use of low volatility cleaning agents. Even levels of around 23 % are reported to be achieved; see Table 2.7 [76, TWG, 2004].

Fugitive emissions are described as a percentage of the input in the SED. In heatset printing, key techniques for reducing fugitive VOC emissions are the reduction of VOC solvent inputs. Expressing the emission as a percentage of the input therefore does not reflect the changes made. Reduction scheme calculations that overcome this problem are used in Germany and Austria, but not in the SED. A study has been carried out showing that for heatset it is more useful to express emissions as a percentage of the ink consumption [115, Intergraf, 2005]. See Annex 24.2.

The waste gases of heatset presses tend to smell offensively. In many cases, this was the original driving force for installing incinerators in this part of the printing industry [4, Intergraf and EGF, 1999].

In the following paragraphs details about the different emission sources are discussed.

Inks

The total emission of solvents from heatset inks, that normally contain 30 - 35 % solvents in the EU-15, is approximately 45 kilotonnes. Of these solvents, 80 – 90 % evaporate in the drier and are usually treated [4, Intergraf and EGF, 1999, 76, TWG, 2004].

The ink is supplied in bulk and is transported directly to the presses by pumping it through a piping system. This is common practice in very large plants [4, Intergraf and EGF, 1999, 76, TWG, 2004] [128, TWG, 2005]

Dampening solution

The IPA, or sometimes ethanol, added to the dampening solutions, will evaporate during the printing process; approximately 85 - 90 % is fugitive and approximately 10 % (in heatset) will be extracted through the driers and treated [4, Intergraf and EGF, 1999]. However, other sources report that 50 % of the dampening solution applied in heatset processes are captured and treated [54, BMLFUW Austria, 2003]. The amounts of IPA consumed are also partly emitted, and these are reported in Section 2.3.2.2.3.

IPA can be partially substituted by glycol ethers which also evaporate although to a lesser extent than the amount of IPA substituted. However, the ozone forming potential of some glycol ethers may be 10 times greater than that of IPA; the advantages need to be assessed on a weight for weight basis.

Waterless offset printing has no emissions to air from the dampening process [4, Intergraf and EGF, 1999, 76, TWG, 2004].

Cleaning agents

Emissions of the estimated 100 kilotonnes of cleaning agents used in European offset plants are dependent on the sort of cleaning equipment, print job, solvent applied, etc. High or low boiling solvents show very different emission levels. The mass balance of the virtual heatset plant that is shown in Figure 2.6, shows an example of the percentage of solvents that can be emitted to air, partly via an incinerator and partly fugitively.

The percentage of solvent emissions that stem from automatic interim cleaning in heatset processes and that is captured and routed to the waste gas treatment are in the range of ≤ 15 - 50 % [18, UBA Germany, 2003, 54, BMLFUW Austria, 2003].

Solvent emissions in heatset processes from cleaning by hand and basic cleaning, that are captured and routed to the waste gas treatment, are in the range of 0 - 5 %.

Capture

The average VOC concentration in the waste gases from heatset processes is in the range of 1 - 3 g/Nm³ due to the absence of any recirculation of drier air. The waste gases smell so offensively that recirculation would give the printed product an unacceptable smell. The absence of recirculation encourages a proportionately large airflow and incinerator capacity. The low concentration causes a relatively high energy demand [4, Intergraf and EGF, 1999, 18, UBA Germany, 2003]. However, data from a good practice press in Austria (a 4-colour double-sided press which is 96.5 cm wide), extracting between 1000 – 4000 Nm³ air, show a maximum VOC concentration of 8 g/Nm³. For comparison, this is nearly 50 % more than the two very large presses in the virtual plant in Table 2.7.

There are various waste gas treatment options, which are discussed in Section 20.12.

Incineration

Incinerators can be integrated in the driers or can be a central system to which all driers are connected, see Section 20.11. In Austria (where VOC abatement was implemented early), 80 % of the central systems use regenerative incinerators [76, TWG, 2004].

The incineration temperature needs to be 750 - 800 °C. The calorific value of the waste gases may not be enough to attain this temperature unaided [4, Intergraf and EGF, 1999]. However, under the best conditions it can be an autothermic process where regenerative incineration is used [18, UBA Germany, 2003, 76, TWG, 2004].

The three incineration techniques applied in heatset plants show the characteristics as shown in Table 2.14.

Emissions	Unit	Thermal	Catalytic	Regenerative
Total carbon of which methane	mg C/Nm ³	<20	<50 some 25	<30
NO _x	mg/Nm ³	100	20	100
Energy		Thermal	Catalytic	Regenerative
Temperature	°C	750	400	800
Natural gas	m ³ /h	105	20	20
Exhaust temperature	°C	350	200	200
Electricity	kW	100	100	75
Heat loss	kW	2640	1400	1400

Table 2.14: Achievements of applied incineration techniques in heatset plants [4, Intergraf and EGF, 1999, 76, TWG, 2004]

Thermal oxidation can achieve slightly lower VOC emissions; the efficiency is better by some 0.1 %. This is, however, paid for by substantially higher energy consumption. The consumption in natural gas is five times that of the two other systems.

The thermal oxidation applied in the theoretical virtual plant described in Table 2.7 has a VOC reduction efficiency of 99 % and shows the following emission levels. However, this is associated with a very high combustion temperature of 900 °C compared to a more usual 750 - 800 °C [18, UBA Germany, 2003] [76, TWG, 2004]:

- 19 mg VOC/m³
- 40 mg NO_x/m³
- 50 mg CO/m³.

Condensation

Condensation normally has an efficiency level of around 90 % [52, SPIN Netherlands, 1994]. However, it will not meet emission values required by the SED and is not often used [76, TWG, 2004].

Biological treatment

Reported as not being successfully used in this industry. See Section 20.11.8.

2.3.2.3.2 Waste

[128, TWG, 2005]

Papers

The amount of waste paper produced in heatset offset is usually higher than in other printing methods, as a significant amount of paper is used before a proper balance between ink and dampening water is achieved and a good print quality is produced.

The virtual heatset plant described in Section 2.3.2.1 produced 2800 tonnes of waste for 20000 tonnes of substrate, which is equal to a waste of 14 % of the input paper substrate [18, UBA Germany, 2003].

Waterless offset is claimed to produce less waste, as there is no balance between ink and dampening to be achieved.

Inks

The virtual heatset plant described in Section 2.3.2.1 produced 12 kg ink waste per tonne ink used, of which 10 kg are left over inks and 2 kg are inks absorbed into cleaning wipes [18, UBA Germany, 2003].

Dampening solution

During printing, the dampening solution can become contaminated with paper dust and small amounts of ink. These solutions contain AOX and small amounts of metals. Normally, these waste dampening solutions are discharged, and may require pretreatment described in detail in Section 2.3.2.3.3 [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003, 76, TWG, 2004].

Cleaning agent

Large amounts of used cleaning agents may arise, especially in large printing plants where most of the cleaning is done automatically. The estimated amount is some 100 kilotonnes cleaning agents per year in the EU-wide offset printing industry, which is disposed of [4, Intergraf and EGF, 1999] [76, TWG, 2004].

The virtual heatset plant described in Section 2.3.2.1 generated 46 litres waste water with 50 % high boiling solvents for each tonne of ink used [18, UBA Germany, 2003].

Cleaning agents are re-used to a great extent and the disposal of these solvents as hazardous waste may be reduced by some 50 % [4, Intergraf and EGF, 1999].

Wipes

Wipes from cleaning the press contain organic solvents, ink and sometimes varnish. The amount usually varies with run length, and therefore number of changeovers per year. The virtual heatset plant described in Table 2.5 and Table 2.6 used approximately 200 pieces solvent wipes per tonne ink used, contaminated with an average of 10 g ink and 30 g cleaning agent each [18, UBA Germany, 2003] [76, TWG, 2004].

Other wastes

Old printing plates contain metals, primarily aluminium, with traces of other metals, depending on the age of the equipment. Blankets are also discarded. Waste can also contain filters from filtering the dampening solution and discarded UV lamps from the platemaking process. [21, Nordic Council of Ministers, 1998] [76, TWG, 2004].

Standard colours of offset inks can be supplied in re-usable IBC containers or in the common 200 litre metal drums.

2.3.2.3.3 Waste water

Dampening solutions

During printing, the dampening solution gets contaminated with paper dust and small amounts of ink. These solutions then contain AOX in concentrations of >1 mg AOX/l and small amounts of metals such as aluminium, copper, zinc, cobalt and manganese (these last two from drying agents), all together in concentrations of around 0.1 g/l. Normally these waste dampening solutions are discharged, often after treatment [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003].

The additives used in dampening solutions in concentrations of around 3 % may contain small amounts of biocides against algae. Common concentrations of biocides are in the range of 0.1 – 0.2 %, which means that the ultimate concentrations in the dampening solution are negligible [4, Intergraf and EGF, 1999].

Normally, printing plants are not equipped with a waste water treatment plant and discharge directly to the municipal sewerage system. Where discharges cannot be allowed because of excessive levels of contaminations, disposal as hazardous waste is an alternative [4, Intergraf and EGF, 1999].

Cleaning agents

The effluent from cleaning dampening rollers used in water-based printing processes contains hardly any contamination. It may contain some detergents, some substances that can be found in the dampening solution and small amounts of ink. This effluent is normally not treated but discharged directly to the sewerage system [4, Intergraf and EGF, 1999].

2.3.3 Flexible package printing – flexography and gravure

In flexible packaging plants, a combination of two or more of the following processes are used:

- packaging gravure
- flexography
- lamination
- varnishing.

Solvents may be used in all of these processes.

2.3.3.1 Mass balances – flexible packaging

[18, UBA Germany, 2003]

In 1999, the results of an inventory amongst packaging printing plants in Germany were reported. One of the results of this inventory was that the performance data from different units of different plants were compared and used to simulate a virtual plant that could meet the legal requirements, especially those of the Solvent Emissions Directive. In the following section, a mass balance for a good practice plant selected from the inventory is reported, followed by data for the virtual plant.

A good practice plant

In this section, data of a good practice plant from this inventory are reported along with the mass balances of the virtual plant. This virtual plant as explained above is not an existing plant, but made up of well-performing units from different existing plants. Notice that the data from the existing good practice plant do not differ that much from the virtual plant. The operational data of the good practice plant are as follows:

- the plant is operational for six days a week in three shifts. It has three units each with three flexography central impression cylinder presses with a web width of 1.30 metres
- the end-product is printed forms that are wound up after printing and delivered as an intermediate product to brand-name article manufacturers; finishing operations are not done at this plant
- in two units, mainly solvent-based products are applied (i.e. inks and cleaning agents) and in one unit, 85 % of the products used are water-based
- solvents for viscosity control of the inks are piped directly to the inking unit
- for air emissions control, a catalytic waste gas treatment system with heat recovery is installed. The extraction systems of the printing presses are equipped with circulating air techniques which are controlled by measuring the solvent concentration
- the cleaning of the inking unit is done in an enclosed cleaning machine equipped with an integrated solvent recovery
- effluent from cleaning activities is treated by applying ultrafiltration (for water-based inks).

The mass balance of the good practice plant is shown in Table 2.15.

INPUT	Amount	Unit	Notes	OUTPUT	Amount	Unit	Notes
				Products			
				Intermediate printed products	9700	t/yr	Paper and ink
Material				Waste			
Printing substrate	10433	t/yr		Paper/misprints	740	t/yr	
Printing inks; VOC content	576 189	t/yr t/yr	Of which approx. ¼ water-based	Ink residues	41	t/yr	With approx. 10.8 t VOC
Thinners (solvents for viscosity adjustment)	316	t/yr					
Water for cleaning and thinning	666	m ³ /yr		Mixture of cleaning agents and water	15	t/yr	With approx. 9.8 t VOC
				Process effluent	545	m ³ /yr	
Water for cooling and air conditioning	51866	m ³ /yr					
Wipes	144100	items/yr		Wipes	144100	items/yr	With approx. 2.5 t VOC
VOC total	505	t/yr		VOC in waste	23	t/yr	
Energy				Exhaust gas			
Energy in total	3670	MWh/yr		Volume flow	72.45 x 10 ⁶	m ³ /yr	
Gas energy	350	MWh/yr		VOC in purified gas	1.38	t/yr	384 t/yr VOC destroyed
Electric energy	3320	MWh/yr		NO _x in purified gas	4.70	t/yr	
				CO in purified gas	2.72	t/yr	
				Fugitive			
				VOC fugitive	96	t/yr	approx. 19 % of the input
Note: [76, TWG, 2004]: <ul style="list-style-type: none"> • three shifts and six day working are unusual in flexographic printing: the presses are not expensive enough. This is usually associated with a packaging gravure plant • web width 130 cm is rather wider than normal • catalytic incineration: nowadays always regenerative • effluent treated by ultrafiltration is unusual: normally effluent is insignificant. 							

Table 2.15: Mass balance of a good practice flexo printing plant
[18, UBA Germany, 2003, 76, TWG, 2004]

The following points should be noted from the information exchange [76, TWG, 2004] [128, TWG, 2005]

- these data may indicate good practice for one plant for certain jobs and conditions but may not be typical of the industry
- ink residues = 41 t/yr with 10.8 t solvent = 26 %: this is not ink (press-ready ink has 80 % solvent) but sludge from the distillation of cleaning agents
- 385.38 t/yr in the untreated waste gas is an average of 5.3 g/Nm³. This is too high for usual flexo work and is only reached if a high level of varnishing and lamination (which is not shown in Table 2.15) is done with a high air recirculation rate. This also implies that a significant amount of printing is using white ink and therefore not printing on paper
- VOC in purified air is an average of 19 mg/Nm³, which expressed in mg C is some 50 % lower (about 10 mg/Nm³) with an incinerator efficiency of >99.5 %. Industry believe this efficiency is too low to be realistic. However, it is reported as normal good practice in Germany, with raw gas concentrations in the range 1 – 8 g/Nm³ and an outlet concentration below 20 g/Nm³.

It should be noted that when comparing the consumption and emission data of this good practice plant with those from the virtual plant, all auxiliary processes with their additional consumptions and emissions are also recorded. The estimated data of the virtual plant are estimations of the consumption and emissions of each specific unit on its own.

A virtual plant

In order to draw an objective picture of the range of consumption and emission values that are achieved in practice, two different driving styles of the virtual plants are described. On one hand, production with solvent-based inks, and on the other hand mixed production with water-based inks and a solvent-based cover varnish. The virtual plants have the following characteristics as shown in Table 2.16:

Printing machines	Flexography central impression cylinder plant; eight inking units, size 127 x 100 cm, web velocity up to approx. 250 m/min
Driers	Indirect heating of interim drier and bridge drier by heat transfer oil, circulating air technique controlled by monitoring the solvent concentration
Finishing processes	Reel slitter, cross cutter, rewinder
Conditions of production	280 production days/yr, in three shifts; 6525 operating hours/yr with 70 %* production printing time; in total 4560 printing production hours/yr
Products	Paper wrappers 70 g/m ² <u>Solvent-based:</u> six colours, surface coverage 155 %, in application 4.98 g/m, web velocity 150 m/min <u>Mixed process:</u> six colours + cover varnish, surface coverage 255 %, ink application 4.9 g/m ² + cover varnish 2.5 g/m ² , web velocity 150 m/min
* Note: 70 % printing production time is higher than can be achieved in practice [76, TWG, 2004]	

Table 2.16: Machinery and conditions of production of the virtual flexo printing plants [18, UBA Germany, 2003]

The specific consumption and emission values are significantly dependent upon the manufactured products and will increase with:

- decreasing print volume
- increasing number of colour change sequences
- extremely high demands on the printing quality, or difficult printing images
- decreasing paper quality
- increase of surface to cover.

From the virtual plants, mass balances are calculated. Average VOC consumptions and emissions in relation to one tonne ink that is used are shown in Table 2.17 and Table 2.18 as are the average input of material and output of waste of the virtual plants. For a production by gravure, the admixture of thinners (VOC input) and the corresponding VOC emissions stemming from the ink would be 10 – 20 % higher. These values are average values, which can, depending on the above-mentioned parameters, vary in practice by +/- 20 %.

1000 kg printing ink containing 500 kg VOC	Process step	Output
¹ 731 kg thinner (100 % VOC)	Solvent for viscosity adjustment [76, TWG, 2004]	
21875 kg paper	Printing process	160 kg fugitive VOC losses 1900 kg misprints/paper waste 90 kg ink residues
70 kg cleaning agent (100 % VOC) 120 wipes	Interim cleaning	45 kg fugitive VOC losses 120 wipes with approx. 1.4 kg ink residues + 3 kg solvents
	Ink drying	1063 kg VOC in the extracted untreated air ² 6.80 g/m ³ VOC in 133100 Nm ³ after treatment
	Finishing	Waste paper
Total VOC input: 1301 kg		Total VOC output: 205 kg fugitive (16 % of input) 1060 kg treated approx. 2 – 3 kg in treated gas approx. 33 kg in waste
Note: ¹ The figure for thinner is too low: press-ready ink is 72 % solvent [76, TWG, 2004] ² 6.80 g/m ³ VOC is too high for flexo printing, and probably includes laminating and/or varnishing		

Table 2.17: VOC and waste balance of solvent-based virtual flexo printing plant [18, UBA Germany, 2003]

1000 kg printing ink * containing 31 kg VOC	Process step	Output
516 litres water 625 kg print varnish (containing 156 kg VOC) 198 kg thinner (100 % VOC)	Ink conditioning	
21875 kg paper	Printing process	58 kg fugitive VOC losses 1900 kg misprints/paper waste 140 kg ink residues
1200 l water 120 wipes	Interim cleaning	1200 l effluent containing approx. 18 kg COD 120 wipes with approx. 1.4 kg ink residues
	Ink drying	323 kg VOC in the extracted untreated air 1.38 g/m ³ VOC in 234370 m ³ air of 69 °C after treatment
	Finishing	Waste paper
Total VOC input: 385 kg		Total VOC output: 58 kg fugitive (15 % of input) 320 kg treated approx. 3 kg in treated gas approx. 4 kg in waste
* Note: ink appears to be water-based, but this is not clear [76, TWG, 2004]		

Table 2.18: VOC and waste balance of mixed-process virtual flexo plant [18, UBA Germany, 2003]

2.3.3.2 Consumptions – flexible packaging

2.3.3.2.1 Organic solvents

Table 2.19 shows a choice of typical organic solvents that are employed in package printing processes together with their field of application. Table 2.20 shows an overview of typical organic solvents that can be found in package printing processes applying water-based inks, adhesives or varnishes.

Solvent	Vapour pressure (kPa)	Field of application
Ethyl acetate	9.2	Thinner, cleaning agent
Ethanol	5.9	Solvent in ink, cleaning agent
Mixtures of ethanol and ethyl acetate		Mix depends on required drying time
Isopropanol	4.3	Solvent in ink, cleaning agent
Isopropyl acetate	6.1	Viscosity adjuster
Methyl ethyl ketone	10.5	Siccative; often used as solvent in adhesives and some varnishes
n-Butanol	1.2	Retarder
Methoxy propanol	1.1	Retarder
n-Propanol	2.5	Retarder
Ethoxy propanol	0.65	Retarder
Various esters		Plasticiser

Table 2.19: Typical solvents used in solvent-based packaging printing processes [18, UBA Germany, 2003, 76, TWG, 2004]

Solvent	Vapour pressure (kPa)	Field of application
Ethanol	5.9	Solvent in ink, siccative, cleaning agent
Isopropanol	4.3	Solvent in ink, cleaning agent
n-Propanol	2.5	Solvent in ink
Special naphtha	4.0 – 8.5	Cleaning agent (rarely used as most packing is for food)
White spirit	0.15 – 1.0	Cleaning agent (rarely used as most packing is for food)

Table 2.20: Typical solvents used in water-based packaging printing processes [18, UBA Germany, 2003]

Apart from organic solvents in purchased printing inks, other relevant solvent quantities are used in ink thinning (viscosity control) and for several cleaning jobs. Especially in the area of viscosity control, the gravure and flexography processes are different. Table 2.21 presents typical mean values of specific VOC employments.

It is important to note that the solid:solvent ratio in inks 'as bought' will vary enormously from plant to plant. Ink is delivered to certain specifications. In one extreme; it is delivered 'almost press-ready', with a solvent content of close to 75 % (a small final dilution is done at the press). At the other extreme, ink is delivered as a 'paste' with a solvent content of about 30 %. The pastes are mixed and diluted in the ink department to 'almost press-ready'. Again, the final dilution is made at the machine. In addition, a few years ago the 'normal' percentage of solvent in ink 'as bought' was between 50 and 60 %, this is now no longer the case. In larger plants, inks are today bought as 'paste' and diluted in-house [128, TWG, 2005]:

Printing process	VOC used (expressed as % of purchased ink wt-%) in the following areas:						Total VOC used as % of purchased ink wt-%	
	Printing inks ⁽¹⁾		Thinners for inks		Cleaning agents		Average	Range
	Average	Range	Average	Range	Average	Range		
Gravure solvent-based	60	40 – 70	101	70 – 120	17		178	127 – 207
Flexography solvent-based	60	45 – 75	81	50 – 95	14		155	109 – 184
Gravure water-based	5	0 – 20	2	0 – 5	10	0 – 15	17 ⁽²⁾	0 – 40
Flexography water-based	5	0 – 20	2	0 – 5	10	0 – 15	17 ⁽²⁾	0 – 40

Notes: [76, TWG, 2004, 128, TWG, 2005]
⁽¹⁾ the machine-ready ink will always contain about 80 % solvent. An ink bought with a higher solvents content will require less solvent for thinning (viscosity adjustment). Averages for solvent-based inks: gravure tend to be slightly over 80 % and flexo tend to be slightly under 80 %.
⁽²⁾ average for water-based inks of 17 % is too high.

Table 2.21: Specific VOC use in package printing processes [18, UBA Germany, 2003]

Table 2.21 shows, for example, that in a gravure solvent-based printing process, an average of 1.78 kg VOC per kg purchased ink input is used in the production and auxiliary processes of the plant. The range in this example is 1.27 - 2.07 kg VOC per kg purchased ink input.

On-site solvent recovery is only applicable to cleaning agents and will reduce the amount of cleaning agents that have to be purchased. This means that for the specific VOC uses per kg ink input, as mentioned in Table 2.21, the data concerning the column 'cleaning agents' are reduced by about 50 %.

2.3.3.2.2 Printing inks and varnishes

[18, UBA Germany, 2003] [4, Intergraf and EGF, 1999] [21, Nordic Council of Ministers, 1998] [22, Vito, 1998, 128, TWG, 2005]

Types of inks used – solvent-based

The most common solvents used in solvent-based package printing are ethanol and ethyl acetate. Furthermore, flexo printing plants use isopropanol, n-propanol, methoxy propanol and ethoxy propanol, and gravure printing plants also use methyl ethyl ketone, i-propyl-acetate and n-propyl-acetate. The choice of solvent used in the ink depends on the printing substrate.

During printing, the viscosity of the ink is adjusted as required, or is kept at its preset level by adding compatible solvents. Newly mixed inks are always produced slightly too viscous to allow exact adjustment to be made at the press.

Flexo ink is either solvent-based or water-based. Gravure ink is almost always solvent-based and water-based inks are rarely used. Table 2.22 shows an average composition of a basic recipe for solvent-based inks. The ink solvent concentration varies, see Section 2.3.3.2, above. Machine-ready inks contain about 80 % solvent and 20 % solids. Varnishes also contain about 80 % solvents [76, TWG, 2004][128, TWG, 2005]

Component	Contents	Concentration (wt-%)
Binding agent:		
- solvent component	Normal drying solvents: e.g. ethanol, n-propanol, isopropanol	60 – 80
	Fast drying solvents: e.g. ethyl acetate, i- and n-propyl acetate, MEK, naphthas	
	Slow drying solvents: e.g. methoxy propanol, ethoxy propanol	
- binding agent component	Cellulose derivates (e.g. nitro-cellulose), polyvinyl butyrates, PVC, polyamides	10 – 2
Colourants	Inorganic and/or organic pigments	10 – 5
Colour auxiliary agents	e.g. softeners, waxes, slide agents, EDTA (no longer used in Germany)	1 – 6
Physical properties: solids content: 25 – 40 %; net calorific value: >20 MJ/kg; flashpoint <21 °C		

Table 2.22: Average basic recipe for solvent-based flexo printing inks [18, UBA Germany, 2003] [54, BMLFUW Austria, 2003]

A typical formula for a flexo ink to be printed on paper is shown in Table 2.23 and a typical formula for a hydrocarbon solvent-free ink for paper is shown in Table 2.24.

Component	Concentration (wt-%)
Pigment	20
Maleic resin varnish	16
Nitrocellulose varnish	38
Wax	4
Plasticiser	4
Ethanol	11
Isopropyl acetate	7

Table 2.23: Typical flexo ink for paper as bought [4, Intergraf and EGF, 1999]

Component	Concentration (wt-%)
Organic pigment	12
Alcohol-soluble polyamide resin	22
Nitrocellulose (dry weight)	4
Wax	4
Fatty acid amine	1
Ethanol	29
n-propyl alcohol	18
n-propyl acetate	10

Table 2.24: Typical hydrocarbon solvent-free flexo ink for paper as bought [4, Intergraf and EGF, 1999]

Flexo inks for plastic substrates and metallic foils vary considerably from inks that are used on paper. The solvents used have changed over time, partly as a result of food packaging requirements and regulations. Aromatic ink solvents have been replaced by ethanol and ethylacetate and some MEK in adhesives and varnishes [4, Intergraf and EGF, 1999] [143, EC, 2002/4]:

Apart from the general basic recipe shown in Table 2.22, other examples of typical inks used in the gravure printing process can also be found; one of these is shown in Table 2.25. Of course, the ink formulation will vary considerably depending on the printing substrate, the press parameters and end use of the finished product.

Component	Concentration (wt-%)
Pigment	4 – 12
Extender pigment	0 – 8
Resin	10 – 30
Plasticiser/wax/additives	2 – 10
Solvents	40 – 60

Table 2.25: Typical recipe of a gravure ink as bought
[4, Intergraf and EGF, 1999] [76, TWG, 2004]

In general, the solvent choice will depend on many aspects, such as a need to avoid a solvent attack on a film or solvent coating, and to ensure that as little solvent as possible remains in the product, especially with food packaging. Only very rarely is it necessary to deviate from ethanol, ethylacetate and mixtures of the two. Occasionally MEK, acetone, toluene (packaging for medical purposes) or isopropanol (non-food paper product) may be found [4, Intergraf and EGF, 1999, 128, TWG, 2005]:

Types of inks used – water-based

Table 2.26 shows an average composition of a basic recipe for water-based inks applied in gravure printing. In water-based inks, the water concentration in the purchased printing inks is normally in the range of 50 – 60 %. Aqueous dispersions, such as styrene-acrylate copolymer, are mainly used as binding agents. According to the purpose and the desired resistances, acid resins which are transformed into a water-soluble form by saponification with alkaline substances (ammonia or amines), are employed for modification. During the drying process, the amines or ammonia escapes and the binding agent resins once more become insoluble in water [18, UBA Germany, 2003].

As drying additives, ethanol and isopropanol are added in low concentrations of mostly below 5 %. Only in cases of very special demands to the drying velocity, e.g. on thin papers, can this percentage increase up to 25 % [18, UBA Germany, 2003].

In most cases, the recipes contain additives such as anti-foam agents, wetting agents and biocides. Dilution can be made with water [18, UBA Germany, 2003].

Component	Contents	Concentration (wt-%)
Binding agent:		
- aqueous solvent component	Water	50 – 75
- organic solvent component	Alcohols (e.g. ethanol, isopropanol)	0 – 13
- other binding agent component	e.g. polyester and acrylate resins, polyvinyl acetate	10 – 20
- other binding agent component	Ammonia, amino acids	1 – 5
Pigments	Inorganic and/or organic pigments	10 – 20
Colour auxiliary agents	e.g. waxes, (softeners and complex formers are not used in Germany)	1 – 5
	Ssaponification agents	1 – 5
Physical properties: solids content: 25 – 40 %; net calorific value: >10 MJ/kg; approx. pH value: 8		

Table 2.26: Average basic recipe for water-based gravure inks
[18, UBA Germany, 2003] [54, BMLFUW Austria, 2003] [76, TWG, 2004]

A typical recipe of a water-based gravure ink for printing on coated paper, might be as shown in Table 2.27:

Component	Concentration (wt-%)
Acrylic resin	32
Water	30
Pigment	15
Acrylic dispersed phase polymer	15
Alkali	2
Anti-foam	1
Isopropanol	3
Wax dispersant	2

Table 2.27: Typical recipe of a water-based gravure ink for coated paper as bought [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003, 128, TWG, 2005]

A typical, well performing, water-based flexo ink used for printing on paper and cardboard is shown in Table 2.28:

Component	Concentration (wt-%)
Acrylic emulsion	50
Water	20
Pigment	25
Monoethylamine	2
Polyethylene wax	3
Organic anti-foam	<1

Table 2.28: Typical recipe of a water-based flexo ink for paper and cardboard as bought [4, Intergraf and EGF, 1999]

Water-based inks for printing onto polyethylene and polypropylene would typically have much higher acrylic dispersed polymer contents (40 %) and much lower acrylic resin percentages (5 - 10 %).

Cartons are almost always varnished, increasingly with water-based overprint varnishes. A water-based heatseal resistant varnish, suitable for overwrapping with film, might have the formula shown in Table 2.29:

Component	Concentration (wt-%)
Hard acrylic resin	15
Isopropanol	20
Water	15
Acrylic emulsion	35
Amine or ammonium hydroxide	2
Wax emulsion	5
Wax dispersion	5
Release agent	2
Anti-foam	1

Table 2.29: Typical water-based varnish for cartons in gravure printing processes [4, Intergraf and EGF, 1999]

Types of inks used – UV

UV printing inks are increasingly applied in flexo printing. These inks consist of binders, additives, photo-initiators and the dyestuff which are all solid materials and contain no solvent. Drying, or more correctly, curing is the consequence of the cross-linking or polymerisation of the printing film resulting from the printed surface being exposed to short-wave UV light.

Amounts of inks used

The amount of both solvent- and water-based ink consumed depends largely on the colour of the ink and only slightly on the printing substrate or printing method. Table 2.30 shows some average values.

Colours	Ink application (for theoretical complete coverage) (g/m ²)
White	1.5 – 2.0
Spot colours	1.0 – 1.5
Half tone	0.5 – 1.0

Table 2.30: Average ink application values

The surface that is covered with ink, especially in flexible packaging, is determined by several complex customer requirements, such as:

- the quality of the image that has to be printed and the type of printing substrate
- the need to prevent light reaching the product inside (usually food)
- the need for an air-tight barrier and prevention of migration of smells
- for printing materials that are difficult to moisten (e.g. foils), a primer is applied that acts as an adhesive agent and is applied in the first printing run
- for improvement of the effect of the printed colours on transparent plastic or metal foils, the surface is first printed in matt white before applying the final colours
- improving the characteristics of the coloured surface, e.g. UV or abrasion resistance, a full-surface varnishing is employed as a last step in the printing job.

For example, on corrugated cardboard, the surface covered with ink is usually <20 %, while for high quality consumer goods (e.g. chocolate packages) a surface coverage of >400 % is reached by using a series of coatings. So-called ‘flat tints’ reach 100 % coverage for white ink on plastic, and also varnishes and adhesives have a large impact on the total surface covered [76, TWG, 2004].

2.3.3.2.3 Cleaning agents

For cleaning the presses, primarily the same solvents as employed in the inks are used. Plants using water-based ink systems are usually cleaned with water, partly with admixtures of alkaline substances, such as sodium bicarbonate, and tensides. Mixtures of water with water-dilutable organic solvents are also used. In order to remove dried inks from the small cavities in gravure cylinders and anilox rollers, ultrasonic equipment or other solvent-free cleaning techniques may be used. High pressure water jets are also used on anilox rollers [18, UBA Germany, 2003] [4, Intergraf and EGF, 1999] [76, TWG, 2004].

2.3.3.2.4 Adhesives in lamination

Traditionally, most laminating was done with solvent-based systems. Such adhesives gave good levels of gloss and bond strength. Press ready varnishes contained about 80 % solvents. Alternatives to solvent-based systems are the epoxy or the urethane systems, in which two constituents react together to form a very tough film. Mixing of the two-components is required but there will be no solvent emissions. Solvent-free adhesives or UV curing laminating adhesives are also applied. Water-based adhesives may be used when paper needs to be adhered to aluminium or plastic foil. The water evaporates through the paper. Water-based adhesives have the lowest use [4, Intergraf and EGF, 1999] [76, TWG, 2004].

2.3.3.2.5 Energy and resources

Energy

The specific energy consumption of the good practice flexo plant described in Section 2.3.3.1 is 0.4 MWh/tonne product. Note that this good practice plant is equipped with a waste gas treatment with heat recovery [76, TWG, 2004].

The energy balance of the virtual solvent-based flexo plant as described in Table 2.16, in relation to the use of 1 tonne ink, is shown in Table 2.31.

Input based on 1000 kg printing ink	Process step	Output
<i>Included in the printing process</i>	Ink conditioning	
3185 kWh electric drives 1010 kWh electric cooling 580 kWh electric compressed air	Printing process	
<i>Included in the printing process</i>	Interim cleaning	
2800 kWh thermal oil (approx. 51 % intermediate driers and 49 % final or bridge driers)	Ink drying	
985 kWh electric fans		
<i>Included in the printing process</i>	Finishing	
350 kWh electric fans	Waste gas treatment	5785 kWh thermal from energy recovery
Total input: 8910 kWh 6110 kWh electrical 2800 kWh thermal		2985 kWh thermal net gain Total output: 5785 kWh thermal

Table 2.31: Energy balance of the virtual solvent-based flexo printing plant
[18, UBA Germany, 2003] [76, TWG, 2004]

The energy balance of the mixed-process flexo printing virtual plant as described in Table 2.16, in relation to the use of 1 tonne ink, is shown in Table 2.32 [76, TWG, 2004].

Input based on 1000 kg printing ink	Process step	Output
<i>Included in the printing process</i>	Ink conditioning	
3180 kWh electric drives 1010 kWh electric cooling 580 kWh electric compressed air	Printing process	
<i>Included in the printing process</i>	Interim cleaning	
5500 kWh thermal oil (approx. 42 % intermediate driers and 58 % bridge driers) 980 kWh electric fans	Ink drying	
<i>Included in the printing process</i>	Finishing	
1300 kWh thermal 350 kWh electric fans	Waste gas treatment	0
Total input: 13000 kWh 6200 kWh electrical 6800 kWh thermal		Total output: 0

Table 2.32: Energy balance of the mixed-based virtual flexo printing plant [18, UBA Germany, 2003]

UV- and water-based inks need more energy to dry than solvent-based inks. UV inks need UV light to cure it and special equipment on the press. As the high energy supply to the lamps is turned into heat, large installations for cooling are also needed [21, Nordic Council of Ministers, 1998]. For water-based inks, an increase in the energy consumption of the driers of some 10 % is often found [4, Intergraf and EGF, 1999].

2.3.3.3 Emissions – flexible packaging

2.3.3.3.1 Emissions to air

At EU-25 level for 2000 (according to the RAINS model) NMVOC emissions were 127.56 kt representing 1.2 % of total NMVOC emissions. The total activity was 91.69 kt of non-diluted ink and an average emission of 1.4 kg NMVOC/kg non-diluted ink [131, EGTEI, 2005]:

The mass balance shown in Table 2.15, shows that for a flexo printing plant, fugitive VOC emissions of 19 % of the solvent input are achievable although the measurement method is not clear. For the virtual plants described in Table 2.17 and Table 2.18, fugitive emissions of 16 % and 15 % respectively, are calculated to be achievable for a 100 % solvent-based printing plant [18, UBA Germany, 2003].

For packaging gravure, total emissions of 10 % of the total input can be achieved (fugitive and emissions after treatment). However, this requires a high level of emission reduction measures.

A recent report [127, VROM, 2004] showed VOC emissions from flexible packing plants using good practice to be in the order of 7.5 to 12.5 % of the reference emission (calculated according to the SED [123, EC, 1999]). Older plants that have connected only the more concentrated VOC sources to waste gas treatment achieve 10 – 25 % of the reference emission. Lower values may be associated with the extensive use of solvent-free products. Similarly, some plants without abatement equipment can achieve less than 25 % of the reference emission, but as a consequence, not many of these will use more than 200 tonnes of solvent per year.

In total, 29 different emission sources were distinguished. These include not only sources for fugitive emissions but also some sources for waste gas emissions. Distinction was made between four different groups of emission sources: press room (P), incineration (O for 'oxidiser'), cleaning (C) and ink preparation (I).

Table 2.33 below gives, for many sources, a typical emission value, possible reduction measures for that source and a typical emission value after the reduction measures have been taken. Note:

- ‘typical’ emission values are provided to give an impression of the order of magnitude. The emission is expressed as a percentage of the solvent consumption of the plant. Actual emissions values may vary widely
- ‘n.a.’ means that no typical emission value can be given. Emissions from sources such as ‘defects in bypasses’ or ‘solvent content water-based products’ obviously vary enormously from plant to plant
- ‘very small’ means that the total emissions of all the ‘very small’ sources may be less than 1 % of the solvent consumption
- ‘negligible’ means that the emission is either zero or an order of magnitude smaller than the ‘small’ emissions. Their total volume is smaller than the margin of error in the larger emissions.

Group	Activity or source	Typical emission	Possible reduction measures	After reduction
P	Evaporation from the ink fountains during production	5 %	1. Adequate coverage of the ink fountains 2. Use chamber doctor blades 3. Encapsulation of varnishing or lamination units 4. Use of adhesives with reduced solvent content (see relevant techniques in Section 2.4.2) 5. Floor extraction through driers 6. Floor extraction sent to incinerator (see Section 2.4.2.5.2)	2.5 %
	Evaporation from open viscosity adjustment units	Very small	None	Very small
	Leaking driers through defects or drier pressure higher than atmospheric	n.a.	Proper maintenance, correct operation, periodic checks (see Section 20.11.1.2)	Negligible
	Defects in the bypass of the driers (waste gases sent to atmosphere rather than to the incinerator)	n.a.	Give priority, proper maintenance, correct operation, periodic checks, instruction for manual operation if possible, speedy repairs (see Section 20.11.1.2)	n.a.
	Waste gas emissions from presses when these are filled with ink, but not yet printing	Negligible	None	Negligible
	Waste gas emissions from presses when these are printing at minimum speed	0.1 %	None	0.1 %
	Waste gas emissions from presses in the case of defects to production machines	Very small	None	Very small
	Waste gas emissions from presses when printing at make-ready speed. (30 to 60 m/min)	3 – 8 %	Automatic closure of bypass before make-ready speed is reached (see Section 2.4.2.5.5)	Negligible
	Cleaning floors	1 %	1. Prevention of soiling 2. Use of squeezable sweeps 3. Use non volatile cleaning agents (see Sections 20.9 and 20.10.1)	Very small
	Evaporation from open drums	Negligible	Keep closed as much as possible (see Section 20.2.2.1)	Negligible
	Residual solvent packaging materials for food	Very small	None	Very small
	Residual solvent in printed materials that are not packaging for food	3 – 10 %	Improve drying	0.1 %
O	Emissions from the incinerator	0.5 – 1.5 %	(May increase if additional solvent laden air stream are sent to incinerator)	0.5 – 1.5 %

Group	Activity or source	Typical emission	Possible reduction measures	After reduction
	Defects in the incinerator causing waste gases to be sent to the air	n.a. (0.4 % of input per defect day)	High priority: proper maintenance, correct operation, periodic check, instruction for manual operation if possible, speedy repairs (Section 2.4.2.5.2) Equip with computer techniques, connect to supplier (see Section 20.2.3)	Very small
	The use of solvent-based inks, varnishes and adhesives on machines not attached to the incinerator	n.a.	Connect to incinerator at times when incinerator has enough capacity (see Section 20.11.1.4)	n.a.
	The use of solvent-based inks, varnishes and adhesives on driers not attached to the incinerator	n.a.	Refrain from using these driers for solvent-based inks Connect to incinerator at times when incinerator has enough capacity (see Section 20.11.1.4)	n.a.
	Solvent content of water-based products (inks contain approx. 5 % solvent, varnishes and adhesives may be fully solvent-free)	n.a.	Priority: Use water-based products with solvent content as low as possible. Otherwise: none (see relevant techniques in Section 2.4.2)	n.a.
C	Drying process and ventilation in automatic washing machines using solvents	5 %	1. Ventilation to incinerator (Section 2.4.2.5.2) 2. Use non-volatile cleaning agents (see Sections 20.9 and 20.10.1)	Negligible
	Evaporation during manual cleaning operations	1 %	1. Prevent useless evaporation 2. Prevent cleaning and drying by hand after washing automatically 3. Use automatic washing machine as much as possible 4. Use non-volatile cleaning agents as much as possible 5. In press room, prevent contamination of objects that cannot be cleaned in washing machine as much as possible 6. In-depth cleaning of anilox rollers and cylinders with solvent-free methods (see Sections 20.9 and 20.10.1)	0.5 %
	Cleaning and drying by hand after washing automatically	Included	See manual cleaning (see Sections 20.9 and 20.10.1)	Included
	Cleaning with machines other than automatic washing machines	Included	See manual cleaning (see Sections 20.9 and 20.10.1)	Included
	Cleaning of the floors	Included	1. Prevention of soiling 2. Use of squeezable sweeps 3. Use of non-volatile cleaning agents (see Sections 20.9 and 20.10.1)	Included
	Evaporation from open drums (solvent, waste, etc.)	Included	Keep closed	Included
I	Evaporation resulting from the mixing of inks	Very small	Automatic ink mixing systems, drum close to nozzles, quickly close drums after filling (see Sections 20.2.3 and 20.2.2.1)	Very small
	Evaporation resulting from making colour tests	Negligible	None	Negligible
	Cleaning of the floors and other cleaning	1 %	1. Prevention of soiling 2. Use of squeezable sweeps 3. Use of non-volatile cleaning agents (see Sections 20.9 and 20.10.1)	0.5 %
	Evaporation losses from tanks	Negligible	None	Negligible
	Evaporation from open drums	Very small	Keep closed (see Section 20.2.2.1)	Very small

Table 2.33: Reduction of fugitive emissions from flexible packing printing [127, VROM, 2004]

The emissions caused by defects in driers, bypasses or in the incinerator itself may be considerable. The same is true for machines and driers not attached to the incinerator and the solvent content of water-based inks. No typical emission values are given, but the total of the emissions from these sources may easily be several per cent of the annual solvent consumption.

It can be seen that the total of the emissions from all the other sources may vary enormously. If none of the reduction measures mentioned in Table 2.33 are applied, this total may amount to well over 25 % of solvent consumption. If all possible reduction measures are applied, the total of these emissions may be well below 10 % of solvent consumption.

Allowing for several per cent of emissions due to defects and the solvent content of water-based inks, the total emissions can be expected to vary between 30 and 10 % in most plants.

In order to attain a total emission lower than 10 % of solvent consumption, it is necessary to carry out all or most of the following:

- prevent defects to incinerator, bypasses, driers; etc. (see Section 20.11.1.2)
- send waste gases from the driers to the incinerator both automatically and before make-ready press speed is reached (see Section 2.4.2.5.5)
- connect the ventilation exhaust of the automatic washing machines to the incinerator (see Section 2.4.2.5.2)
- reduce emissions due to evaporation from ink fountains during production (see Section 2.4.2.5.2)
- avoid the use of solvent-based products on machines not connected to the abatement equipment
- reduce the residual solvent in printed matter not intended to be used as packaging for food
- reduce the use of volatile solvents for cleaning floors (see Sections 20.9 and 20.10.1).

Inks

For water-based inks, 0.5 - 1.0 % ammonia emissions per kg ink input can be expected. On average, water-based inks contain 0 - 10 % organic solvent (ethanol or IPA) which will, in the end, be emitted [18, UBA Germany, 2003].

There are no emissions to air from UV inks.

Lamination and varnishing

When using solvent-based (SB) materials, the emissions from these processes are higher than from printing. With solvent-based adhesives, a large amount of air has to be moved through the drier to keep the solvent/air ratio well below the lower explosive limit (LEL) [4, Intergraf and EGF, 1999] [76, TWG, 2004].

Increasingly 2-component, solvent-free adhesives and water-based varnishes are used for lamination of plastic foil and varnishing of aluminium respectively. Water-based adhesives are often used to adhere paper to aluminium. Where water-based inks mostly still contain some solvent, water-based adhesives and varnishes are generally solvent-free.

Cleaning

Fugitive solvent emissions arise from cleaning where the quantity depends on the handling.

Waste gas treatment

Modern regenerative incinerators can work without the addition of fuel (autothermic operation) when the solvent concentration in the air to be treated is $>1 \text{ g/m}^3$. At higher concentrations, the incinerator may produce excess heat, which may be recovered and used in production processes. In flexo and packaging gravure plants where the airflow has been optimised, and a large amount of the work is with 100 % coverage (such as white ink, adhesives and varnishes) concentrations of 4 to 6 g/m^3 are attainable, otherwise lower concentrations are found [76, TWG, 2004].

With incineration, emission levels of $<100 \text{ C/Nm}^3$ can be achieved and often levels of 20 - 50 C/Nm^3 , see Section 20.11.4.2 [76, TWG, 2004, 128, TWG, 2005]

Adsorption is also applied, although to a lesser extent, see Section 20.11.6. Adsorption can achieve a removal efficiency of up to 99 % in publication gravure (see Section 2.3.4.3), although this is not usual as it requires a high energy input in regeneration of the absorbent. In the clean gas, concentrations of $<20 \text{ mg/m}^3$ are achieved, The hot steam desorption generates about 3 – 6 m^3 per kg of recovered solvent. In flexible packaging, solvent recovery through adsorption to activated carbon is also applied; frequently in Italy, rarely elsewhere. Where solvent recovery is applied, solvent consumption is limited as far as technically possible to ethyl acetate, in order to reduce the size of the adsorption unit, reduce dehydration problems and reduce the occurrence of azeotropic mixtures of ethylacetate with ethanol and MEK. Hot steam desorption is used less and less in flexible packaging, and currently inert gas desorption is usual. Recovery rates are generally 95 to 95.5 %, with a waste gas concentration of 50 to 150 mgC/m^3 . [14, DFIU and IFARE, 2002] [4, Intergraf and EGF, 1999, 128, TWG, 2005]

2.3.3.3.2 Waste

[128, TWG, 2005]

Printing substrate

Printing substrate is wasted when starting a new printing job and also arises from misprints because of defects and when the edge of the printed web roll requires trimming. The quantity depends on the product produced, however it often accounts for 10 % of the final product in weight [18, UBA Germany, 2003] [76, TWG, 2004].

Ink

Ink losses arise from three areas [4, Intergraf and EGF, 1999]:

- the amount of ink prepared always exceeds the need to avoid presses running out of ink
- ink supplied to the inking unit, but not used, is stored and later used on a repeat job for the same client. Most plants have a large stock of these readymade inks waiting for repeat jobs. Periodically, inks that are not expected to be used again are removed
- the mixing of the ink results in the wrong colour. To correct this mistake, more ink has to be added and, as a result, too much ink is prepared.

Surplus inks are disposed of as waste, or alternatively are distilled in-house. Their solvent content is then recovered and used for cleaning purposes; the ink sludge is disposed of as waste.

However, modern practice with computerised colour-matching systems enables better first time quality resulting in very little ink wastage and minimal leftover batches, which can be used again in slightly different colours (see Section 20.6.3.6). In situations where no computerised systems for mixing the right colour are applied, some 10 – 20 % of the ink purchased ends up as waste. Where computerised systems are used, the amount of waste ink is reduced by at least 25 - 75 % [18, UBA Germany, 2003] [76, TWG, 2004].

Cleaning

Dirty wipes containing solvents, dirty cleaning mixtures of water and solvent, and ink residues stem from interim cleaning. When the cleaning agents are distilled, the resulting waste, i.e. ink sludge, is far less than without recovery [18, UBA Germany, 2003].

When cleaning is done without using solvents, the waste water might be treated and discharged. Cleaning solutions with solvents are normally treated as hazardous waste [4, Intergraf and EGF, 1999] [76, TWG, 2004].

Cleaning agents can be successfully recovered by distillation.

Others

Other wastes are, for example [4, Intergraf and EGF, 1999] [76, TWG, 2004]:

- photopolymer and rubber printing plates: The steel, polyester or aluminium sleeves are re-used repeatedly: the polyester or rubber materials are glued to these
- non-returnable metal containers
- reel cores
- film wastes.

2.3.3.3.3 Waste water

Waste water from water-based ink processes can be treated and disposed of to the sewerage system. The total amount of waste water is highly dependent on the working methods, and on average 2 – 3 m³/t ink is used and discharged, mainly from interim cleaning and cleaning the machinery after a job. The characteristics of this waste water before and after treatment are shown in Table 2.34. Copper is not present to the extent shown in Table 2.34 in inks, and is likely to come from the paper (see Section 2.3.2.3.3) [76, TWG, 2004].

Contaminant	Before treatment (mg/l)	After treatment (mg/l)
AOX	1500	1
Cu	20	
Hydrocarbons	1000 – 5000	10
COD	1000	200

Table 2.34: Characteristics of waste water from water-based ink processes
[18, UBA Germany, 2003]

The amount of ink sludge resulting from the waste water treatment differs depending on the treatment applied. Treatments such as coagulation and flocculation, which are most commonly applied, result in high quantities of sludge compared to ultrafiltration, for example [18, UBA Germany, 2003].

Waste water with water-based ink is normally discharged to the sewerage system, with or without in-house treatment. After treatment, the water may be re-used and the sludge disposed of as waste [4, Intergraf and EGF, 1999] [76, TWG, 2004].

2.3.4 Publication gravure

2.3.4.1 Mass balances – publication gravure

[18, UBA Germany, 2003, 128, TWG, 2005]

In 1999, the results of an inventory amongst publication gravure plants in Germany were reported. One of the results of this inventory was that the performance data from different units of different plants were compared and used to simulate a virtual plant that could meet the legal requirements, especially those of the Solvent Emissions Directive [76, TWG, 2004]. In this section, a mass balance for a good practice plant (selected from the inventory) is reported, followed by data for the virtual plant.

A good practice plant

In this section, data of a good practice plant from this inventory are reported along with the mass balances of the virtual plant. The virtual plant is, as explained above, not an existing plant, but made up of well-performing units from different existing plants. The good practice plant is a modern publication plant with five presses containing forty ink units in total. The products are mainly magazines and catalogues which both need to be of high quality. The operational data of this good practice plant are as shown in Table 2.35:

INPUT	Amount	Unit	Notes	OUTPUT	Amount	Unit	Notes
Material				Products			
Pre-products	3100	t/yr		Pre-products	86367	t/yr	Paper and ink
				Waste			
Printing substrate	91300	t/yr		Substrate/misprints	8005	t/yr	
Printing inks	2210	t/yr	Including varnish	Ink/varnish residues	15.7	t/yr	Hazardous
Water: of which	158150	m ³ /yr	Well water	Sludge	7.5	t/yr	Hazardous
	123100	m ³ /yr	Cooling				
	9000	m ³ /yr	Cylinder preparation	Activated carbon	2.6	t/yr	From adsorbers
	6500	m ³ /yr	Heating	Waste water			
Wipes	600125	Items/yr that are cleaned	Re-usable wipes	To sewage	33200	m ³ /yr	2418 m ³ /yr from electro-varnishing
Energy				Waste gas			
Energy in total	67509	MWh/yr		VOC in purified gas	7.2	t/yr	Average * 35 mg C/m ³
Gas energy	44051	MWh/yr		NO _x from combustion plant	7.6	t/yr	Natural gas combustion
Electric energy	24011	MWh/yr		CO from combustion plant	0.2	t/yr	Natural gas combustion
				Fugitive			
				VOC fugitive	365	t/yr	

* Note: the waste gas average of 35 mg C/m³ is low and will be associated with a high energy demand [76, TWG, 2004].

Table 2.35: Mass balance of a good practice publication gravure plant [18, UBA Germany, 2003] [76, TWG, 2004]

The virtual plant

The VOC balance of the virtual plant by employing emission factors that are typical for the branch, gives the following results shown in Figure 2.10 below. Inks, when bought, contain on average 50 – 55 % of toluene rather than 45 % (gravure varnish contains 45 – 55 % VOC). However, it does not affect the calculations, as after dilution, the figures approximately balance. VOC in ‘clean gas’ equals a recovery efficiency of 99.9 %, which is exceptional and far lower than usual good practice, is technically very difficult to achieve and would create a large energy demand. The average airflow is 19000 Nm³/h, which is unusual in practice and 100000 m³/h would be much more likely [76, TWG, 2004].

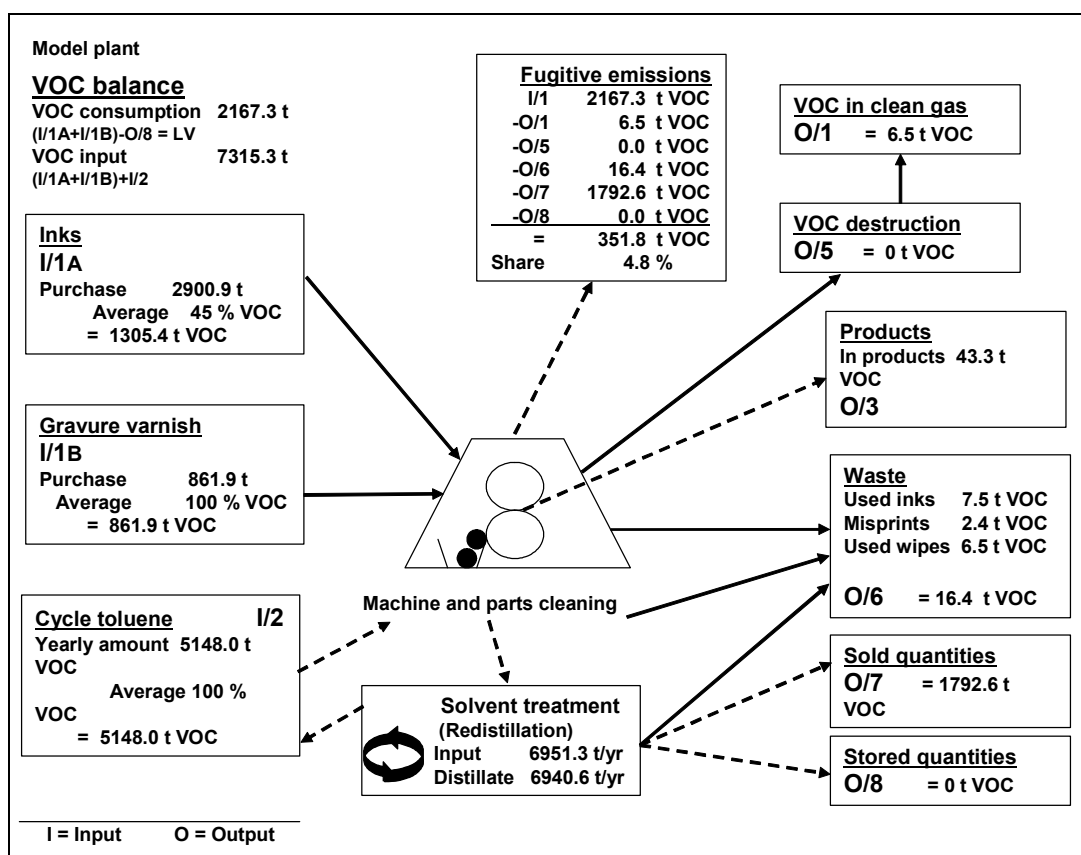


Figure 2.10: VOC balance of a virtual publication gravure plant
 [18, UBA Germany, 2003]

Note. 'Gravure varnish' should read 'Gravure extender'. Gravure extender contains 45 - 55 % toluene not 100 %. This affects the calculations [128, TWG, 2005]

This mass balance is, in theory, achieved by applying the following reduction measures:

- the applied printing inks are retention inks (see explanation below)
- air extraction is applied at collecting places of ink residues and solvent wipes
- periodic cleaning of persistent contaminants is done with dry ice instead of solvents
- the performance of the toluene adsorber is continuously monitored
- the drying air from the toluene adsorber is led through the waste gas scrubber.

In 'retention inks', formation of a skin on the ink surface is delayed by a modified recipe. In this way, a higher percentage of the toluene contained in printing ink can be expelled directly into the ink drying unit of the printing plant [18, UBA Germany, 2003].

Some key VOCs in illustration gravure are shown in Table 2.36. From this table it can be calculated that for each tonne of purchased ink, 1.86 tonnes toluene (partly recovered and partly fresh) is used. Data from two plants show a specific toluene input of 1.96 and 1.48 tonnes respectively for each tonne of purchased ink; see Table 2.37. However, it is not clear if this refers to the ratio of toluene to solids; this is the only accurate basis to compare with ink input [76, TWG, 2004].

Substance	Vapour pressure at 20 °C (kPa)	Specific input (wt-% of purchased ink input)	Use
Toluene	2.9	54.7	Solvent in ink and gravure varnish
		100	Thinner in the printing process
		2.5 - 7.5 [128, TWG, 2005]	Cleaning agent [76, TWG, 2004]
Ethanol	5.9	<1	Siccative for cylinder correction
Turpentine substitute	0.04	<1	Cleaning agent for cylinder correction
Acetone	24.0	<1	Cleaning agent for cylinder correction

Table 2.36: VOCs in publication gravure [18, UBA Germany, 2003]

	Purchased ink input (t/yr)	Total toluene input (fresh and recovered) (t/yr)	Specific toluene input (wt-% of purchased ink input)
Plant 1	1312	2571	196
Plant 2	1475	2179	148

Table 2.37: Specific toluene input of two plants in Flanders, Belgium [32, Aminal, et al., 2002]

Toluene balances of the two gravure printing plants with a total of five presses situated in Flanders (Belgium) are shown in Table 2.38. The fugitive toluene emissions are 10 and 6 % respectively. The technique for achieving zero toluene in the waste of Plant 2 has not been not identified [76, TWG, 2004].

	Plant 1	Plant 2	Unit
Total toluene consumption (fresh and recovered)	2571	2179	t/yr
Toluene in waste	11	0	t/yr
Toluene in sold product	10	10	t/yr
Toluene recovered and re-used on site	1694	1428	t/yr
Toluene recovered and sold	599	613	t/yr
Emissions			
Toluene emissions after treatment	1.1	4	t/yr
Fugitive toluene emissions ⁽¹⁾	265	133	t/yr
Total toluene emission	266.1 (10 %)	137 (6 %)	t/yr (% of consumption)

⁽¹⁾ inclusive of 10 tonnes toluene in the sold product

Table 2.38: Toluene balances of two gravure printing plants [32, Aminal, et al., 2002]

2.3.4.2 Consumptions – publication gravure

2.3.4.2.1 Printing inks

All inks used in publication gravure are toluene-based. Table 2.39 shows an average basic recipe for publication gravure. In the printing plant, inks of this type of recipes are significantly thinned before being used. The toluene concentration of the press-ready ink is in the range of 70 – 80 wt-%.

Component	Contents	Concentration (wt-%)
Binding agent:		
- Solvent component	Toluene	50 – 60
- Binding agent component	e.g. phenol resins, hydrocarbon resins, ethyl cellulose	30 – 40
Colorants	Organic and inorganic pigments	8 – 20
Colour auxiliary agents	e.g. waxes, dispersants, defoamers	1 – 4

Table 2.39: Average basic recipe of purchased publication gravure ink [18, UBA Germany, 2003]

The amount of ink used in the publication printing industry is vast; an average four press plant may use 10000 tonnes of press-ready ink per year and will consequently have a solvent input of about 8000 tonnes. Of this amount, some 7000 tonnes are recovered and either re-used or sold back to the ink manufacturer [4, Intergraf and EGF, 1999].

Water-based inks have been the subject of experiment. A major problem is that, with the existing paper recycling processes, de-inking of the paper is not possible. This, in combination with lower press speeds, print problems with wide web widths and cross-media effects, has led to cessation of their use [4, Intergraf and EGF, 1999] [76, TWG, 2004].

A successful development of publication gravure inks has led to a new generation of toluene-based inks known as ‘retention inks’. Their formulation has been modified in such a way that the toluene evaporates more efficiently in the driers. Although they contain about 5 % more toluene when press-ready, they can lead to less fugitive emissions. These new inks are distributed by several manufacturers [37, CITEPA, 2003] [18, UBA Germany, 2003] [35, Aminimal, et al., 2002].

2.3.4.2.2 Cleaning agents

All inks used in publication gravure are toluene-based. Once dry, they re-dissolve in toluene, which is, therefore, used as the cleaning agent. Data on the amount of cleaning agents used are not available, however, only the relative value in Table 2.36 shows that for each tonne of purchased ink, 2.5 - 7.5 wt-% toluene is used for cleaning [128, TWG, 2005]

2.3.4.2.3 Energy and resources

The specific energy use of the good practice plant shown in Table 2.35 is 0.8 MWh per tonne pre-product.

The toluene recovery process uses some 2 – 8 kg of steam per kg of recovered toluene. Where, in a ‘normal’ four press plant, some 7000 tonnes of toluene are recovered yearly, some 20 to 30000 tonnes of water are necessary. Normally this water is re-used for cooling purposes or, in the case of new recovery installations, combined with new steam boilers and used again as steam for the toluene recovery. As cooling water, about 30 - 50 % water can be saved. In situations where the condensed steam is re-used as boiler water, the savings are up to 100 % [4, Intergraf and EGF, 1999, 32, Aminal, et al., 2002].

2.3.4.2.4 Printing substrates and others

No data submitted.

2.3.4.3 Emissions – publication gravure

[128, TWG, 2005]

2.3.4.3.1 Emissions to air

At EU-25 level for 2000 (according to the RAINS model), NMVOC emissions were 61 kt representing 0.58 % of the total NMVOC emissions. The total activity was 191.48 kt of ink, with an average emission of 0.32 kg NMVOC/kg non-diluted ink which means that this industry already has significantly reduced emissions [132, EGTEI, 2005]:

All publication gravure plants nowadays have toluene recovery installations. In spite of the toluene recovery, part of the toluene input is still emitted. The abatement equipment has limited efficiency, air from the press room or other department where toluene is used may be ventilated to the outside and also other fugitive emissions may occur [4, Intergraf and EGF, 1999]. However, the residual toluene content in the printed product is by far the most significant source of toluene emissions [18, UBA Germany, 2003].

In the standard situation, 85 % of the total toluene input is recovered and 2 - 3 % stays in the product; the rest is fugitive. As guidance for standard situations in Flanders, Belgium; there is an emission factor of 0.13 kg fugitive toluene per kg of the total input (new and re-used toluene) [22, Vito, 1998] [35, Aminal, et al., 2002]. The virtual plant in Figure 2.10 and the plants in Table 2.38 show 0.16, 0.10 and 0.06 kg fugitive toluene per kg of the total input, respectively [76, TWG, 2004].

Currently new, modern plants normally emit between 4 - 10 % of their total solvent input and standard plants between 10 - 15 %. These modern type presses apply retention inks and all ventilation air (from room and driers) is sent to the solvent recovery installation, even when the press is idle. In the standard situation, only the air from drier ventilation of operational presses is sent to the abatement device [37, CITEPA, 2003] [4, Intergraf and EGF, 1999] [11, IMPEL, 2000].

Of the five gravure printing presses present in the two gravure plants in Flanders, Belgium, the air from the driers is continuously led to the solvent recovery installation, whether the presses are operational or not. From one of these presses, the ventilation air of the press room is also sent to the recovery installation. These plants also apply retention inks and with this combination of reduction techniques, they can reduce their total toluene emissions to 6.5 % of the total input [32, Aminal, et al., 2002].

Existing plants in Germany are permitted to emit 10 % of the total toluene input and for new plants this is 5 %. New and existing plants in the Netherlands are allowed to emit 8.5 % of the total toluene input. Dutch plants achieve this by extracting all the air from rooms where toluene is worked and route this to the waste gas treatment system [35, Aminimal, et al., 2002] [29, Netherland, 1996].

Using a range of good practice techniques, emissions for new plants of 4 to 5 % can be achieved, and for existing plants 7.5 to 8.5 % (expressed as a percentage of the total solvent, i.e. toluene input) [76, TWG, 2004].

In the following paragraphs details about the different emission sources are discussed.

Inks

The toluene concentration of the press-ready ink is about 80 wt-%, which will all be emitted and most of it recovered, except for about 2 - 3 % that remains in the product.

Retention inks might reduce fugitive emission by 1 % of the total toluene input [35, Aminimal, et al., 2002] [76, TWG, 2004].

Cleaning agents

Once the ink is dry, they re-dissolve in toluene, which is therefore used as the cleaning agent. Cleaning may give rise to fugitive emissions of toluene, however, data on quantities are not available: The quantities emitted will be included in the reported fugitive or total emissions. They will depend on the ventilation system and its connection to the solvent recovery systems. Cleaning agents are normally distilled and re-used [4, Intergraf and EGF, 1999] [76, TWG, 2004].

Data on emissions from cleaning agents for water-based inks are not available.

Toluene recovery installation

Toluene is easy to recover. It adsorbs well to activated carbon and is retrieved by heating the carbon with steam. The steam and solvent vapours are condensed and separate almost completely. The toluene is part re-used and part sold back to the ink manufacturers [4, Intergraf and EGF, 1999].

A removal efficiency of 99 % is technically achievable. However, there is a balance with increased energy consumption [35, Aminimal, et al., 2002] [76, TWG, 2004].

Monitoring of emissions to air

The Solvent Emissions Directive prescribes an emission limit value at the outlet of the waste gas treatment system of 75 mg C/Nm³ in a 24 hour average and 112.5 mg C/Nm³ in a 1 hour average. In practice, the 1 hour average is the limiting level for the adsorption cycle. It commonly happens that the 24 hour average is approximately 10 – 50 mg C/Nm³, while the 1 hour average is only met three of four times a day. Monitoring the 1 hour average requires continuous measuring of the emission concentration instead of the cheaper and easier longer time period or volume control.

2.3.4.3.2 Waste

Inks

In most cases, the work is done with four standard process colour inks and very little mixing of inks takes place. Presses work in shifts and, if at all, are only stopped during the weekends and for public holidays. Only a small proportion of the ink becomes waste and re-using press returns is normal practice [4, Intergraf and EGF, 1999].

Leftover coloured ink is normally mixed with black ink and thus re-used, saving on black ink. Waste ink can be distilled to recover the toluene. The distillation sludge, which is about 20 % of the original weight of the waste ink, is disposed of. However, because of the small amounts of toluene recovered, distillation is not often applied because of the relatively expensive equipment needed [4, Intergraf and EGF, 1999].

2.3.4.3.3 Waste water

The toluene recovery process uses some 2 to 8 kg of steam per kg of recovered toluene. Where in a 'normal' four press plant some 7000 tonnes of toluene are recovered yearly, some 20000 to 30000 tonnes of water are necessary. The condensed steam will contain toluene to its maximum solubility of approximately 0.05 %, in a range of 0.38 - 0.54 g/l. Toluene is on the list II (the EU black list) of substances for water, from Directive 76/464/EEC [4, Intergraf and EGF, 1999] [11, IMPEL, 2000] [76, TWG, 2004].

The condensed steam is stripped of toluene by bubbling air through it; the toluene concentration in the discharged water is approximately 1 to 10 mg/l. The discharge of the above-mentioned 'normal' plants will be around 0.1 - 0.3 kg toluene per year [4, Intergraf and EGF, 1999] [11, IMPEL, 2000].

2.4 Techniques to consider in the determination of BAT for printing

In these sections, the following printing sectors are addressed:

- heatset offset printing (see Section 2.4.1)
- flexography and packaging gravure (see Section 2.4.2)
- publication gravure printing (see Section 2.4.3).

These processes are the ones most likely to exceed the threshold in Annex 1 (6.7) to the IPPC Directive. On its own, an installation using sheetfed offset is unlikely to exceed the IPPC threshold, but the activity may be used in installations running heatset offset above the IPPC threshold, e.g. for producing magazines. For example, sheetfed offset is used for ('glossy') magazine covers, while the internal pages are printed by heatset offset. While large coldset offset plants are generally low solvent or solvent-free in printing, some large ones use >200 t/yr solvents for cleaning. This has stopped in some countries because of health and safety requirements, but may still occur in others [114, Jepsen, 2005].

Other printing processes may be found in the same installation, or may exceed the threshold for Annex 1 (6.7) to the IPPC Directive. For such activities, the general techniques to consider in the determination of BAT (see Chapter 20) are applicable, as well as techniques in this section that may be appropriate.

The EGTEI synopsis sheets for heatset offset, flexography and packaging gravure, publication gravure printing (see Annex 24.1.1) give some data on the cost-benefit at a European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only a few principle techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations or products. In the printing industries, there is a more complex range of techniques to consider for BAT [130, EGTEI, 2005] [131, EGTEI, 2005] [132, EGTEI, 2005]:

In these three printing sectors, common themes are discussed such as substitution of solvent-based inks, extraction and treatment of waste gas and cleaning. The reason for discussing each sector individually is that the detailed information is sector-specific.

2.4.1 Heatset offset printing

[128, TWG, 2005]

In Chapter 20, techniques are discussed which might also be applicable to the printing industry. In Table 2.40, the general techniques relevant for heatset offset printing are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 2.40: Reference to techniques generally applicable to the sector

2.4.1.1 Conventional heatset inks

Description: The basic constituents of offset inks are: pigments, binders (resins, varnish, mineral oil), and additives (drying substances). In addition, certain substances (printing oils/thinner, rub resistance pastes, gloss agents, drying retarders, etc.) are added to the inks to adjust their properties. The binder content of the inks (high boiling petroleum fractions and vegetable oils) used in heatset web offset printing processes is about 25 to 50 %.

Achieved environmental benefits: The solvent part of these inks is high boiling and is part-evaporated in the driers.

Cross-media effects: Contain mineral oils from non-renewable sources.

Operational data: See Section 2.3.2.2.2.

Applicability: No information submitted.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [4, Intergraf and EGF, 1999]

2.4.1.2 Replacement of conventional heatset inks (substitution)

2.4.1.2.1 Inks based on vegetable oils

Description: Inks based on vegetable oils, such as soy bean oil, can sometimes replace the mineral oils in conventional ink.

Achieved environmental benefits: The main advantage is that vegetable inks are made from renewable sources and the sludge generated when de-inking printed matter will be more biodegradable.

Cleaning can be done with water and detergents.

It is common to regard the mineral oil free inks as cleaner technology, although a full lifecycle assessment is not known. These inks are preferred to mineral oil-based inks according to the Nordic Swan labelling criteria.

Cross-media effects: Vegetable inks have a tendency to adhere strongly to the fibres with the result that they make de-inking difficult.

Operational data: In heatset processes, these inks are not commonly used, see Applicability, below.

Applicability: This technique is not applied in heatset offset, where the mineral oils are evaporated, as the vegetable oils do not evaporate fast enough. They are only used in sheetfed offset, where the oils do not evaporate but harden through oxidation. Vegetable-based inks and varnishes are not applicable to printing newspapers.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [21, Nordic Council of Ministers, 1998] [11, IMPEL, 2000] [53, US EPA et al., 2003] [76, TWG, 2004]

2.4.1.3 Reducing emissions from the dampening solution

It must be noted that where percentages of IPA are discussed, it is not always clear whether per cent by volume or by weight is intended. The difference is important enough to be taken into consideration [76, TWG, 2004].

In addition to technical press requirements, a number of issues significantly affect the possibility of reducing or completely substituting IPA:

- changes in the surface of the printed paper (different kinds of coating, absence of coating, different degrees of calendering, etc.) require changes in numerous fine settings of the press. These changes take press-time and increase the amount of paper lost in make ready. Where IPA is used, such changes in paper surface can be dealt with faster and with less paper loss than where IPA has been reduced or substituted. Where frequent changes in paper surface occur, reduction or substitution of IPA may have a serious negative economic effect
- in situations of high ink coverage (the percentage of the surface that actually carries ink), the use of IPA makes it possible to allow very small areas to remain without ink. In situations of full ink coverage, the use of IPA better prevents the occurrence of small water droplets that cause white spots in fully printed surfaces. Where frequently high ink coverage or full ink coverage needs to be printed, reducing or substituting IPA may thus result in a substantial increase of intermediate cleaning of the blanket cylinder and plate
- where skill, education and experience of press operators is not of a very high level, failure of any experiment toward reducing or substituting IPA is almost unavoidable. Equally, an experienced operator may significantly reduce the chances of successful IPA reduction, by maintaining traditional approaches.

See also general techniques for substitution, Section 20.10.

2.4.1.3.1 Replacement of IPA in the dampening solution (substitution)

Description: Additives exist which allow lower IPA concentrations in the dampening system. Most of these additives are glycol ethers. They are added in concentrations of about 1 %, or sometimes 3 – 5 %, depending on the additive, to the dampening solution. Some additives are intended to totally replace IPA, others are meant for use in combinations with low concentrations of IPA. Ethanol is sometimes used to replace IPA as a seemingly ‘eco-solvent’ (see Cross-media effects, below).

Additives that give good results and have low ozone-forming potential (see Section 20.10.2) are:

- propylene glycol
- glycerol
- di-hydro-3-methyl-2.5-furandion
- butyldiglycol.

Achieved environmental benefits: IPA concentrations of 2 – 8 % (actual figures depend on the measurement method used) are achievable, and in some cases working without IPA becomes possible. Glycol ethers also evaporate and represent VOC emissions, but emissions will be less than that of the substituted IPA. However, this might not help in the purpose of reducing VOC emissions with the aim of preventing ozone formation. The ozone-forming potential of some glycol ethers may be 10 times higher than that of IPA if the same amount evaporates.

Cross-media effects: Some additives were suspected to have serious health and safety consequences, but they are believed not to be on the market currently. Safety data sheets should, therefore, be studied before using the additive. However, it must be pointed out that the additives listed above all have a substantially lower occupational exposure limits than isopropanol.

These additives should only be used where it is clear that evaporation is lower than in the case of isopropanol.

Sometimes ethanol is used for replacing IPA; however, this should be avoided because the ozone-forming potential of ethanol is twice as high as IPA. This, in combination with a vapour pressure that is 1/3 higher than that of IPA, will only have a negative environmental effect.

Operational data: The reduction in IPA consumption is not automatically the result of substitution. The specifications for the products to be printed, the combination of paper ink, the local climate, and the ability of the press room personnel very much determine whether substitution has the desired effect.

Using ceramic, chromium-plated or hydrophilic distributing rollers in combination with hydrophilic plate rollers assists the partial use of replacements for IPA, see Section 2.4.1.3.3

Applicability: Applicable to all heatset offset printing plants.

Economics: Costs for IPA are EUR 0.55 per litre, and costs for the substitute is about EUR 1 - 1.50 per litre. Because the quantity of additives needed to replace IPA is less, the overall costs are the same. However, changing over to another technology always involves costs because of loss of production at the time of change.

Driving forces for implementation: Solvent Emissions Directive. Health and safety: roughly 90 % of the IPA evaporates through the press and never reaches the paper, requiring a high level of ventilation.

Example plants: Impress Group, Lint, Antwerp, Belgium (IPA substituted completely).

Reference literature: [4, Intergraf and EGF, 1999] [21, Nordic Council of Ministers, 1998] [35, Aminal, et al., 2002] [29, Netherland, 1996] [76, TWG, 2004] [128, TWG, 2005]

2.4.1.3.2 Optimising the concentration of IPA in the dampening solution

Description: The IPA concentration in the dampening solution is reduced as far as practically possible. There are several factors:

- more diligence is necessary for the adjustment of the printing press
- to achieve reproducible printing conditions at a reduced IPA concentration, an exact and continuous measurement of the IPA concentration is needed, e.g. by infrared or ultrasound measuring systems
- to assist with printing at low IPA concentrations, adapted inks are used, which are capable of taking up more water than normal heatset inks
- offset plates with adapted coating are capable of being covered with more water than normal heatset plates, while still not humidifying the ink-carrying parts of the plate
- exact adjustment of the water hardness and the pH value, and just monitoring the water quality, is a prerequisite for achieving an IPA concentration as low as possible.

Achieved environmental benefits: In heatset offset, the concentration of IPA varies typically between 8 - 15 %. This means that for existing webfed presses an average reduction of 26 % can be achieved. For new and newly designed webfed presses this is 65 %.

Cross-media effects: None.

Operational data: Measuring IPA concentrations exactly is difficult. The automatic IPA measuring devices on most presses are usually of simple designs, influenced by temperature and the presence of other additives. However, under comparable circumstances, they give comparable results, so they can be used for quality control purposes, even though they do not always correctly indicate the exact IPA concentration. It is not necessary to use sophisticated measuring devices to be able to reduce IPA consumption to a minimum.

Applicability: All heatset offset printing plants applying IPA.

Economics: Costs of a continuous IR measurement system was EUR 70000 – 100000 per press in Finland in 2002.

Driving forces for implementation: Although the SED does not prescribe a maximum % IPA, it does limit fugitive emissions from heatset, and in order to attain that limit, every effort should be made to reduce the IPA concentration in the dampening solution. In Germany the concentration of IPA in heatset processes is limited to a maximum of 8 %.

Example plants: No information submitted.

Reference literature: [4, Intergraf and EGF, 1999, 18, UBA Germany, 2003] [29, Netherland, 1996, 76, TWG, 2004]

2.4.1.3.3 Ceramic, metal and hydrophilic distributing and plate rollers

Description: Applying a ceramic, chromium-plated or hydrophilic distributing roller in combination with hydrophilic plate rollers. Hydrophilic plate rollers are made of soft rubber. These rollers can form a particularly thin and unbroken dampening film on the plate roller with lower IPA concentrations.

These rollers are also successfully applied in situations where IPA is partly substituted.

Achieved environmental benefits: IPA concentrations can be reduced by 2 - 3 %, depending on the starting concentration.

Cross-media effects: Soft rubber is damaged sooner than plate rollers made of hard rubber and needs to be replaced more often, resulting in more waste. Also, ceramic rollers need to be replaced more frequently than chromium-plated steel ones.

Operational data: Whether ceramic or chromium-plated distributing rollers give better results, depends on the type of press. Ceramic rollers require more maintenance and cleaning time.

In one offset plant in Norway where IPA is partly substituted, the level of IPA could be reduced from 15 % to 4 %, which resulted in a reduction of the IPA concentration in the air above the press in the range 77 - 90 %.

Applicability: This technique is commonly applied and is applicable in all printing plants applying IPA. However, ceramic or metal rollers are now used less. Hydrophilic rollers are used, have the same effect, and are cheaper.

Economics: The costs for hydrophilic plate rollers are the same as for hard rubber rollers and vary from EUR 250 - 1000 each. However, they need to be replaced more often. Ceramic rollers cost EUR 2500 - 3000 each. The total costs of replacing distributing rollers for ceramic ones depend on the size of the press. Also ceramic rollers need to be replaced more frequently than chromium-plated ones (costs are from approximately 1997).

Driving forces for implementation: No data submitted.

Example plants: Norwegian plant.

Reference literature: [35, Aminimal, et al., 2002] [4, Intergraf and EGF, 1999] [21, Nordic Council of Ministers, 1998, 76, TWG, 2004]

2.4.1.3.4 Exact adjustment of the inking rollers

Description: Perfect adjustment in the relative position of the rollers and the plate cylinder allows for lower IPA concentrations. Minute maladjustments are a cause for ruptures in the water film. The addition of IPA makes the dampening solution less sensitive to this phenomenon.

Achieved environmental benefits: Enables low IPA concentrations to be used.

Cross-media effects: No information submitted.

Operational data: No information submitted.

Applicability: New presses are generally equipped for exact adjustment of rollers. Retrofitting is not possible.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [115, Intergraf, 2005] [128, TWG, 2005]

2.4.1.3.5 Apply a spray system in the dampening unit

Description: In a spray-dampening system, the nozzles used to spray the dampening solution have an oscillating motion which makes the dampening solution feed more linear compared to conventional systems, such as the roller system.

Achieved environmental benefits: Spraying, instead of applying the solution by a roller system, requires lower concentrations of IPA.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: This technique does not allow an exact dosage of very thin water film and therefore is not applicable to heatset.

This technique is used in newspaper printing (coldset) where more water is used because it helps to remove paper dust. In newspaper printing, no IPA or very low IPA concentrations are achieved. This is only possible because these very thin water films are not necessary since there rarely is a very high ink coverage and the paper can easily absorb all excess. It does not transfer to heatset offset.

Economics: No information submitted.

Driving forces for implementation: SED, H&S and economic reasons (automation of press operation requires the ability to make very fine adjustments).

Example plants: No information submitted.

Reference literature: [21, Nordic Council of Ministers, 1998] [76, TWG, 2004]

2.4.1.3.6 Cooling the dampening solution

Description: The circulation and dosing systems for dampening solutions containing IPA are cooled to about 8 - 15 °C to reduce the evaporation of IPA.

Achieved environmental benefits: 2/3 of the IPA input is already evaporated before it reaches the dampening rollers and the printing plate. At the time the dampening solution reaches the printing plate, the IPA concentration is only about 1 %. Cooling the solution reduces the evaporation rate.

The concentration on the plate is very difficult to measure due to the very thin ink film. The information about the remaining IPA concentration on the plate is disputed in the Intergraf EWP. The conclusion was reached in the late 1980s through model calculations.

Cross-media effects: Cooling requires energy.

Operational data: Most presses are equipped with a cooling system as standard.

Applicability: Commonly applied to heatset offset printing plants.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [35, Aminal, et al., 2002, 76, TWG, 2004] [128, TWG, 2005]

2.4.1.3.7 Cooling the dampening rollers and plate cylinders

Description: Cooling the dampening rollers and plate cylinders reduces the temperature and evaporation of the applied dampening solution.

Achieved environmental benefits: No information submitted.

Cross-media effects: No information submitted.

Operational data: Cooling temperatures are, for example:

- dampening rollers 28 - 29 °C
- plate cylinders 28.5 - 32 °C.

Applicability: Retrofit not generally possible.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [128, TWG, 2005]

2.4.1.3.8 Removal of IPA solutions from the dampening unit

Description: Removing dampening solution from the dampening system during press stops, such as overnight and during weekends. Automatic systems are available.

Achieved environmental benefits: Some reduction in IPA emissions.

Cross-media effects: No information submitted.

Operational data: Nowadays, in most plants, the IPA solution is continuously circulated by pumping in an amount greater than the press uses. The excess is piped back to the reservoir, where IPA additions are made. The technique cannot be usefully applied where presses are run 24 hours per day, which is generally the case in heatset plants exceeding the thresholds in Annex1 (6.7) to the IPPC Directive.

Applicability: Applicable to heatset offset plants.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [35, Aminimal, et al., 2002] [4, Intergraf and EGF, 1999] [11, IMPEL, 2000] [76, TWG, 2004] [128, TWG, 2005]

2.4.1.4 Filtering the dampening solution

Description: The dampening solution is continuously recirculated. A filtering unit can prolong the lifetime for the dampening solution. Where other substances are substituted for IPA, the water becomes contaminated more quickly and filtering during recirculating reduces water consumption and the production of waste (which may be hazardous).

Achieved environmental benefits: Less water is consumed and so less is discharged as waste water.

Cross-media effects: Filtering requires energy.

Operational data: No information submitted.

Applicability: Applicable to all heatset offset printing plants running at low IPA concentrations.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [21, Nordic Council of Ministers, 1998, 76, TWG, 2004] [128, TWG, 2005]

2.4.1.5 Controlling the hardness of the water for the dampening solution

Description: Dampening solutions are centrally prepared, monitored, cooled and filtered, and supplied to all presses in the plant. The hardness of water is a regional variable, which influences the quality of the dampening solution and its emulsification degree in the ink. Treating the raw water by demineralisation and hardness balancing (remineralisation to a predetermined level) makes it easier to define how much additive is needed and improves the quality of the dampening solution.

The treatment can be by ion exchange and/or reverse osmosis. For example, the calcium content of the raw water can be reduced by reverse osmosis and the hardness adjusted to the optimal value, about 70 - 140 ppm as CaCO₃.

Achieved environmental benefits: A more accurate dosing of additives, including IPA, is possible, and cooling and filtering are more efficient. This leads to less use of energy, less waste water and loss of raw materials due to a lower amount of misprints. If IPA is applied, it will lead to less emissions of IPA to air. However, in a centralised system, the IPA concentration (or any other substitute) will be adjusted to the press that needs the highest concentration.

Cross-media effects: Demineralising water requires energy and chemicals. Reverse osmosis requires energy.

Operational data: No information submitted.

Applicability: This technique is applied in large heatset offset plants but may not be beneficial where the water is of a suitable constant composition.

Economics: Installation of this technique in new plants or in plants where a few new presses are installed, is not very expensive. Costs for retrofit are high.

Driving forces for implementation: An automatic system allows better quality control, as well as better control of IPA consumption.

Example plants: No information submitted.

Reference literature: [35, Aminal, et al., 2002] [21, Nordic Council of Ministers, 1998, 76, TWG, 2004]

2.4.1.6 Waterless offset

Description: Waterless offset is an offset printing technique that does not use water/oil separation to ensure that the ink only covers the image carrying parts of the plate: separation is achieved by special plates and inks. In normal offset, the plate is hydrophobic in the image carrying places and hydrophilic elsewhere. Water is used to make sure that the oily inks do not attach to the non-image carrying parts. In waterless offset, the non-image carrying parts have a coating that achieves the same effect. No water is needed.

Achieved environmental benefits: No dampening solution is required, eliminating any emissions from this source, particularly IPA. There is a saving of raw materials (paper and ink), however, these advantages may disappear if additional cleaning is required for longer runs in heatset.

Cross-media effects: As there is no dampening solution, waterless offset requires additional ways to carry off heat from a printing unit and the additional cooling consumes energy. However, no energy is required for the dampening solution.

Ink temperature control systems are used as standard in waterless offset presses. Other additional temperature control systems can be suitable means for better stabilising and controlling the temperature in waterless offset printing. Control systems include: separate ductor roller temperature control systems, multizone temperature control systems, plate cylinder temperature control systems, rubber blanket cylinder temperature control systems and oil cooling and/or bearing cooling systems.

Operational data: The technique has some distinct advantages over ‘normal’ offset. Its printing quality is better and ‘make-ready’ is faster. The process runs smoothly.

Applicability: The technique is generally applicable for high quality full colour jobs and/or short runs: this is typically sheetfed work, although heatset runs are decreasing in length. The technique has been applied in heatset, see ‘example plants’, below.

For heatset presses, the following questions have been raised:

- the waterless process does not trap paper dust, therefore requiring higher quality paper and/or more cleaning. Against this, the paper is not wetted, as it is repeatedly in multiple passes for colour offset printing
- the life of waterless plates is still not well established and is reported to be a maximum of 100000 to 300000 revolutions
- waterless plates are more sensitive to scratching, e.g. during cleaning operations
- waterless systems have a smaller number of rollers, limiting the ink quantity transferred and fine adjustments at the press. The suppliers claim that because no dampening solution is transferred, more ink can be transferred, and a new press has been installed with no ink keys
- the range of ink colours has been limited although the spectrum may now be larger.

Economics: Presses, plates and the inks are more expensive than those used in ‘normal’ offset, however, there are no costs for isopropanol, water and dampening solutions and ‘making ready’ time is shorter implying less costs for paper and ink. However, longer runs may need more plates and cleaning operations.

Driving forces for implementation: Achieves very high quality work. Reduction in chemicals usage improves workplace health and safety.

Example plants: Toppan printing, Hokuseisha, Seikousha, Aika, GAO, Kousolu offset, Sanesu (all these plants are in Japan). In Europe, there are many sheetfed presses, 25 newspaper presses and about five waterless heatset presses: Quebecor, UK; two are in Switzerland (one retrofitted a dampening unit in 2003) and two in Hungary (both were moved from Germany).

Reference literature: [4, Intergraf and EGF, 1999, 35, Aminal, et al., 2002] [18, UBA Germany, 2003] [72, Hamann, 2004] [76, TWG, 2004] [128, TWG, 2005]

2.4.1.7 Waste gas collection and treatment

2.4.1.7.1 Encapsulation of presses or extraction and treatment of air from the press room

Description: Heatset presses are sometimes encapsulated for reasons of temperature control, avoiding draughts and to reduce noise. IPA evaporates within the encapsulation. The air from the encapsulation is extracted by the drier and may be sent to the incinerator, thus destroying all or most IPA emissions.

In some cases, where the presses are not encapsulated, the air in the press room is extracted and removes volatilised isopropanol and high volatility cleaning agents.

Achieved environmental benefits: Treating extracted air will reduce emissions of IPA and high volatility cleaning agents. Encapsulation reduces noise.

Cross-media effects: Extraction fans increase energy consumption and may increase noise levels.

For reasons of health and safety, the concentration of IPA and other solvents usually have to be kept well below occupational exposure limits. This means that the solvent concentration will be far below 1 g/m³ (OEL IPA: 650 mg/m³ (reported by the Netherlands, 2001), most cleaning agents have far lower OELs). At this low VOC concentration in the inlet gas, the waste gas incineration cannot be autothermic, and substantial additional fuel is required. Costs and energy consumptions to deal with the flows extracted from the presses do not outweigh the emission reduction that can be achieved (see Operational data, below).

Operational data: The waste gas treatment systems are usually only designed for the airflow from the driers. A modern drier has a capacity of 4000 - 7000 m³/h; older ones up to 10000 m³/h. In order to also extract the air from the presses, capacities of 50000 m³/h or more are needed. The thermal treatment will need increasing in size and if the air contains less solvent, will also need support fuel.

Applicability: Inks from heatset do not evaporate at room temperature. They are evaporated in the drier and therefore always captured. Where low volatility cleaning agents are used, they also evaporate in the drier. Encapsulating the press with or without treating the press ventilation air has no effect on solvent emissions and it is carried for occupational health and safety reasons.

Encapsulation of the presses and routing the air to waste gas treatment is common practice in publication gravure (for more details see Sections 2.4.3.3.3 et al.). However, it is not practicable in heatset offset as the capacity of existing waste gas treatment systems may not be sufficient or may not be effectively used treating this air with very low VOC concentrations.

Economics: See Cross-media effects, above. To increase the size of an incinerator from say 5000 to 50000 m³/h, the additional investment will be some EUR 450000. Electricity consumption for the main fan would increase accordingly and the fuel consumption would grow from negligible to substantial because autothermic operation would no longer be possible.

Driving forces for implementation: Encapsulation of the presses is to reduce noise and other health and safety requirements. Press room air is always extracted for workplace health and safety.

Example plants: Encapsulation is widely applied. Extraction is generally applied. Treatment of the press room air is not usual.

Reference literature: [21, Nordic Council of Ministers, 1998] [35, Aminal, et al., 2002] [4, Intergraf and EGF, 1999, 76, TWG, 2004] [128, TWG, 2005]

2.4.1.7.2 Extraction and treatment of air from the driers

Description: Heatset processes are always equipped with a system that extracts air from the driers and is usually routed to a waste gas treatment system.

Achieved environmental benefits: Reduction of VOC emissions from driers. Reduction in odour.

Cross-media effects: Extraction requires energy.

Operational data: See Section 20.11.2.5.

Applicability: Generally applied.

Economics: See Section 20.11.2.5.

Driving forces for implementation: Meeting SED levels. Reduction in odour.

Example plants: Generally applied.

Reference literature: [21, Nordic Council of Ministers, 1998] [35, Aminal, et al., 2002] [4, Intergraf and EGF, 1999, 76, TWG, 2004] [128, TWG, 2005]

2.4.1.8 Cleaning

2.4.1.8.1 Replacement (substitution) and control of VOCs used in cleaning

Description: The input of VOCs for cleaning activities can be reduced by combining the following techniques:

- careful handling of the cleaning agent, e.g. closing containers after use
- applying higher flashpoint HBS (Section 20.10.1.3) or VCA (Section 20.10.1.4) for all cleaning activities
- reducing the ozone-forming potential (OFP) of the mix of solvents used, see Section 20.10.2.

Achieved environmental benefits: The VOC input for cleaning can be reduced to <5 % of the ink input or the overall OFP can be reduced.

Cross-media effects: Using the above solvents may mean that more solvent will require treatment and/or disposal, as less solvent evaporates.

Operational data: No information submitted.

Applicability: Vegetable cleaning agents are not applicable in heatset printing, because the rinse-water can break the paper web.

Only the sheetfed letterpress process can easily use VCAs, but in offset printing, vegetable cleaning agents are not an efficient solution in cleaning blanket cylinders and rubber blankets. The VCAs that are currently available work as swelling agents to rubber blankets and the blankets become unfit for use. It must be taken into consideration that even though VCA has considerable environmental benefits, VCAs are BAT for only some production methods.

Economics: No information submitted.

Driving forces for implementation: SED. Occupational health (exposure to solvent vapours). Occupational safety (avoiding explosions in the drier when the paper web with a cleaning agent reaches the drier).

Example plants: No information submitted.

Reference literature: [18, UBA Germany, 2003, 76, TWG, 2004] [128, TWG, 2005]

2.4.1.8.2 Automatic high pressure cleaners for dampening rollers

Description: Dampening rollers can be cleaned by using automatic high pressure cleaners and water. This technique can substitute the traditional cleaning using low flashpoint solvents.

Achieved environmental benefits: No VOC emissions and no solvents consumed.

Cross-media effects: Increased consumption of energy and water. Waste water arises which has to be discharged or treated. Noise levels might increase.

Operational data: The best result is achieved when the ink is scraped off, as much as possible, before cleaning is started.

Applicability: Applicable in offset printing plants using dampening rollers with a molleton covering; however, these are obsolete in heatset in the EU-15. (They occur rarely in sheetfed offset).

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [21, Nordic Council of Ministers, 1998] [128, TWG, 2005]

2.4.1.8.3 Automatic cleaning systems for printing and blanket cylinders

Description: The printing and blanket cylinder in large modern heatset offset presses are normally cleaned automatically.

In most machines, the cleaning agent is collected. Some machines use a sheet of tissue that is fed through the cylinders in the same manner as the web. The cleaning agent is sprayed onto the tissue or the tissue is dipped into the cleaning agent, or rolls of tissue are used that already are impregnated with the cleaning agent. Machines applying tissues for cleaning use less cleaning agent, however, the tissues need to be stored and disposed of carefully to prevent uncontrolled emissions (not necessary where non volatile cleaning agents are used). Other machines spray the cleaning agent onto the paper web to clean the cylinders.

Achieved environmental benefits: Automatic cleaning uses some 10 % less cleaning agents compared to manual cleaning. Fewer wipes are used and, thus, less waste arises.

Automatic cleaning has health and safety advantages. Exposure to vapours and skin contact with cleaning agents is reduced.

Cross-media effects: Automation requires energy. Less waste arises because fewer wipes are used. Liquid wastes may be greater, unless tissue on rolls is used. Liquid waste can be filtered, the solvent can sometimes be re-used.

Operational data: Sometimes the contaminated cleaning agents are absorbed in the paper and so, together with the paper discarded, will result in uncontrolled solvent emissions in downstream processes. In some plants, this contaminated paper is put into a drier to make sure that the solvent emissions are led through the waste gas treatment system. This is not applicable where HBS or low ozone-forming potential solvents are used.

Applicability: Applicable in new and existing plants. Currently, automatic cleaning is standard.

Economics: For one press, the investment is between EUR 60000 – 80000. The investment costs for retrofitting existing presses is much higher than for new presses (1999).

Operating costs are reduced through a shorter cleaning time, a lower consumption of cleaning agent and a reduction of the amount of hazardous waste. In large machines, the cost reduction may outweigh the investment. For small presses, however, it is thought that the environmental advantages do not warrant the investment.

Driving forces for implementation: SED and reduced workforce exposure to cleaning agents.

Example plants: No information submitted.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [21, Nordic Council of Ministers, 1998, 76, TWG, 2004] [128, TWG, 2005]

2.4.2 Flexography and packaging gravure

[128, TWG, 2005]

In Chapter 20, techniques are discussed which might also be applicable to flexography and packaging gravure. In Table 2.41, the general techniques relevant for flexography and packaging gravure are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 2.41: Reference to techniques generally applicable to the sector

2.4.2.1 Conventional solvent-based inks

Description: See Section 2.3.3.2.2.. The most common main solvents are ethanol, ethyl acetate and mixtures of these two, where ethanol is used more in flexo and ethyl acetate more in gravure. Other solvents like isopropanol or MEK may also be used as the main solvent. In addition, many different solvents may occur in small quantities for adjustments to, for instance, drying speed and viscosity or as content of the ink as bought. Today, simplification and standardisation has led to the reduction of the number of different solvents, but in the mid 1990s, up to twenty different solvents could be found in one flexible packaging plant.

Achieved environmental benefits: No information submitted.

Cross-media effects: Over 90 % of the solvents consumed can be emitted.

Operational data: The exact composition also depends on the quality requirements for the packaging material and the resistances that it must have, for example, resistance to acids, high temperatures, water, alcohol, barrier properties such as odour, impermeability for light, etc.

Waste gas treatment is generally used to remove VOCs.

Applicability: No information submitted.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [18, UBA Germany, 2003] [4, Intergraf and EGF, 1999] [21, Nordic Council of Ministers, 1998] [22, Vito, 1998] [76, TWG, 2004] [128, TWG, 2005]

2.4.2.2 Replacement of conventional solvent-based inks (substitution)

2.4.2.2.1 UV curing alternatives

Description: UV curing inks do not contain organic solvents. Curing is achieved by UV radiation.

Achieved environmental benefits: In printing processes where inks based on volatile solvents are used, a significant reduction in solvent emissions can be achieved.

Cross-media effects: In some circumstances, the energy consumption of the UV curing lamps may exceed the usual drier consumption, although one plant reports overall energy saving. The UV lamps contain mercury and require special management as a waste.

These inks contain reactive acrylates, monomers and oligomers, some of which are allergenic.

Operational data: Printing with UV curing inks in flexography requires 'kiss printing'. UV curing inks have much stronger pigments than other inks. The amount of ink to be transferred must be much smaller. Where in 'normal' flexography the substrate is forcefully locked between the image carrier and the impression cylinder, in UV printing this must be far less. Only very little pressure is used. This is one of the main reasons why retrofit is not possible on most existing flexo presses.

In flexography, in the case of web breakages, the end of the broken web may, on its way to the end of the press, pass a few inkpans and transport ink from one inkpan to the next. This must, of course, be cleaned before printing can restart. In 'normal' flexo, this is cumbersome, but in UV flexo, this is nearly impossible because of the heavy pigmentation and the fact that the ink does not dry. When printing UV flexo, the press design must be such that in case of web breakages, the web is immediately stopped, before the end of the web can drag through any inkpan.

A major problem is presented by the difficulty in cleaning presses where UV curing inks are used. The strong pigmentation and the fact that UV inks do not dry anywhere else than on the substrate means that the smallest amount of contamination makes for serious quality problems. Cleaning is very labour intensive because the inks do not easily dissolve in any solvent. The problem is largest where colours need to be changed between jobs. This is normally the case in printing packaging materials.

In a Dutch plant (see Example plants), cleaning between jobs was prohibitively time-consuming and caused unacceptable quality problems. In order to limit cleaning, a patented system was developed that reduces the number of colour changes drastically. Seven standard colours are used to build up the required colours. This means that seven out of eight printing units do not need to be cleaned between jobs. The eighth printing unit is used to add an additional colour if still necessary. For every job that is switched from 'normal' flexo to UV flexo, all image carriers need to be replaced. (In publications, colour photographs are built up from four standard colours. This system, however, cannot produce every colour and brightness necessary in packaging printing.)

Applicability: UV curing inks can be applied in flexo processes for printing paper packaging materials, labels, and carton packaging materials for dairy products. However, manufacturers of packaging materials for food are often reluctant to employ UV curing inks since the migration of minute quantities of some of the ingredients of these inks into the packed food may lead to non-compliance with food contact legislation.

Most paper could be printed with UV inks. The limitation is, however, not the substrate but the existing machinery. Currently, UV curing flexo is used for:

- self adhesive labels (not likely to reach IPPC scope)
- beverage cartons.

In both cases, presses are used that are built specifically for the purpose: labels on small narrow web presses (up to say 25 cm) and beverage cartons on presses with a width of between 100 and 150 cm.

UV curing inks can also be applied to large flexographic printing machines, however, no practical information was submitted.

Economics: In the case of flexo for beverage cartons, the machines are considerably more expensive than 'normal' flexo presses. Better quality can however be obtained, which is needed in answer to market demands.

Where otherwise increased quality requirements tend to lead to a switch from flexo to gravure, the combination of the run length, customer requirements for regular changes in the printed image and the special substrates used for these cartons, make UV curing flexo an appropriate technique in this case.

Driving forces for implementation: Implementation of SED. Workplace health and safety. Economic reasons, where there is a need for higher quality with short runs and the high image carrier cost of packaging gravure needs to be avoided.

Example plants: Thomas Grafische Veredelung GmbH & Co, KG, Germany. Elopak (Terneuzen, the Netherlands).

Reference literature: [21, Nordic Council of Ministers, 1998] [35, Aminimal, et al., 2002, 76, TWG, 2004] [18, UBA Germany, 2003] [128, TWG, 2005]

2.4.2.2.2 Electron beam (EB) curable alternatives

Description: EB curable inks consist of low molecular weight polymers that react with a stream of electrons from a vacuum tube. These inks contain no solvents and do not cure until exposed to light and may, therefore, remain in ink fountains for long periods of time, reducing clean-up needs. The electrons drive the reaction, forming polymers and setting the ink.

Electron beam driers use polymerisation by electron bombardment to dry liquid and powdered coatings.

Achieved environmental benefits: VOC emissions from ink are reduced to zero.

Cross-media effects: No information submitted.

Operational data: Problems reported with EB curable inks include paper degradation and worker exposure to radiation. They are sometimes used for higher gloss coatings and metal decorating applications.

Applicability: Applicable to new presses.

Economics: These driers have high initial costs and low to moderate operating costs.

Driving forces for implementation: Implementation of SED. Workplace health and safety.

Example plants: No information submitted.

Reference literature: [53, US EPA et al., 2003, 76, TWG, 2004]

2.4.2.2.3 Water-based inks

Description: Water-based inks contain reduced amounts of organic solvents. Conventional water-based inks rely on relatively highly acid resins for water dispersibility; more recently developed inks are based on water-dispersible polyester resins. (The latter do not need neutralising agents such as ammonia or amines to maintain their dispersibility properties, and therefore meet flexo requirements).

Achieved environmental benefits: In flexo and packaging gravure, press-ready inks contain about 80 % solvents. These are always mixtures of several solvents, e.g. ethanol and ethyl acetate. Substitution with water-based inks can result in significant reductions in solvent emissions, particularly of fugitive emissions. However, most flexo and packaging gravure printing plants are equipped with waste gas abatement systems and in that situation the achievable reduction in solvent emission is clearly smaller. Where waste gases are efficiently treated and excessive fugitive emissions are avoided, little further gain is made by switching to water-based inks.

Cleaning of water-based inks can be done with water as long as the ink or varnish is not dry.

Water-based inks may require more energy for drying, however, the total plant energy consumption will be reduced because no waste gas treatment system is required (see Section 2.3.3.2.5, and Annex 14 to the ECM BREF).

Cross-media effects: Water-based inks used in flexo and packaging gravure processes still contain ethanol, isopropanol and/or n-propanol.

The amount of energy needed for drying water-based inks is higher than for solvent-based inks. However, the lack of solvents makes it possible to recirculate the drying air more often and thus reduce the effect. In practice, the increase in energy consumption for drying purposes may be about 10 %.

More waste ink is generated.

Operational data: In flexography, most paper packaging materials can successfully be printed with water-based inks. Simple plastic packaging materials such as carrier bags, refuse bags, bread bags and heavy duty bags may also be printed successfully with water-based inks in flexography. Applying ceramic anilox cylinders improves the printing quality.

Flexible food packaging materials may be required to be resistant against acids, solvents, fats or oils coming from the food which is to be packed. Currently, these requirements can only be satisfactorily met with solvent-based inks. High quality products meeting these requirements are often printed in packaging gravure, applying solvent-based inks. However, sometimes white ink, the colour which is used most, can be substituted.

Switching from solvent-based inks to water-based inks in flexography or packaging gravure usually requires a different pretreatment of the carrier material and always new printing plates and cylinders.

Applicability: Water-based inks (not varnishes) are successfully applied in flexo packaging printing processes for printing paper sacks, plastic refuse sacks and carrier bags. However, also in these processes conventional inks still need to be applied in some exceptional situations, e.g. for fluorescent effects, gold or silver colours, or where very high gloss is required.

Where water-based products (inks, varnishes, etc.) are applied on existing presses, the drier systems are often found to lack capacity. This reduces the applicability on existing presses.

Water-based inks are currently not applicable in packaging gravure because a comparable quality cannot be achieved.

Economics: Changing from solvent-based to water-based inks involves substantial changeover costs. For new presses applying water-based inks, the investment is approximately the same as for presses for solvent-based inks. In the case of retrofit, substantial investment may be needed if the drier capacities need to be enlarged.

Since water-based inks are more highly pigmented, less is needed and the operational cost per m² of printed material will generally be somewhat lower than the cost of solvent-based inks.

Where, in the case of water-based inks, printing speed and flexibility can be maintained and the investment in abatement equipment and other solvent related costs can be avoided, substantial savings may result.

Driving forces for implementation: Where operators opt for reduction schemes to comply with SED, this route may be an option (See Economics, above).

Example plants: Several.

Reference literature: [21, Nordic Council of Ministers, 1998] [4, Intergraf and EGF, 1999] [11, IMPEL, 2000] [35, Aminal, et al., 2002] [53, US EPA et al., 2003] [128, TWG, 2005]

2.4.2.3 Conventional solvent-based varnishes and adhesives

Description: See Section 2.3.3.2.2. Solvent-based systems are used. The most common solvents are ethanol, ethyl acetate and MEK.

Achieved environmental benefits: No information submitted.

Cross-media effects: High solvents emissions.

Operational data: Exact composition depends on the substrate to be printed. Waste gas treatment is usually applied.

Applicability: No information submitted.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [18, UBA Germany, 2003] [4, Intergraf and EGF, 1999] [21, Nordic Council of Ministers, 1998] [22, Vito, 1998] [128, TWG, 2005]

2.4.2.4 Substitutes for conventional varnishes and adhesives

2.4.2.4.1 Water-based varnishes and adhesives

Description: Water-based varnishes and adhesives are generally solvent-free.

Achieved environmental benefits: Press-ready varnishes and adhesives contain about 80 % solvents. There may be mixtures of several solvents, e.g. ethanol, ethyl acetate and MEK or single solvent systems. Substitution with water-based products can result in significant reductions in solvent emissions, particularly fugitives. However, most flexo and packaging gravure printing plants are equipped with waste gas abatement systems and in that situation the achievable reduction in solvent emission is clearly smaller. Where waste gases are efficiently abated and excessive fugitive emissions are avoided, no further gain is made by switching to water-based inks.

Cleaning of water-based varnishes and adhesives can be done with water as long as they are not dry. However, ethanol, IPA, etc. are usually used for cleaning.

Water-based varnishes and adhesives require a lot of energy for drying, however, the total energy consumption will be reduced because no waste gas treatment system is required (see water-based inks, Section 2.4.2.2.3).

The same is valid for the amount of waste water that will on the one hand increase, but in situations where a waste gas adsorption and solvent system is no longer used, the overall amount of waste water will decrease.

Cross-media effects: The energy consumption for increased drying of the water-based products is somewhat higher and more waste is generated. The amount of energy needed for drying water-based inks is higher than for water-based varnishes and adhesives. However, the lack of solvents makes it possible to recirculate the drying air more often and thus reduce the effect. In practice, the increase in energy consumption for drying purposes may be about 10 %.

Operational data: There are a large number of different quality requirements and resistances that apply to a packaging material and therefore the applicability of alternatives for traditional solvent-based inks, varnishes and adhesives is never obvious. For example, the varnish may be required to have a certain resistance against slip in order to accommodate the specifics of the packaging machines, which can only be achieved by applying solvent-based varnishes. They also show a lower chemical resistance compared to solvent-based adhesives besides the lower adhesive starting and composite strength; for these reasons, water-based cannot be used for all types of applications.

In the special lamination process where a thin paper is attached to plastic or aluminium, water-based products are suitable because the water can evaporate through the paper. For the lamination of two non-porous films, water-based products are less suitable because they require a longer drying time before the films can be put together. In these situations, solvent-based or 2-component solvent-free adhesives are used.

Applicability: Applicable in all printing and laminating processes in the manufacturing of flexible packaging. It is commonly applied in flexo and packaging gravure plants. However, they cannot replace the solvent-based varnishes in all situations.

Where on existing presses water-based products (inks, varnishes, etc.) are applied, the drier systems are often found to lack capacity. This reduces the applicability on existing presses.

Economics: No general valid statement on costs can be made.

Driving forces for implementation: Occupational health and safety. SED.

Example plants: No information submitted.

Reference literature: [21, Nordic Council of Ministers, 1998] [35, Aminimal, et al., 2002] [14, DFIU and IFARE, 2002] [128, TWG, 2005]

2.4.2.4.2 High solid alternatives

Description: Traditional solvent-based adhesives contain 80 % solvents, where high solid adhesives contain some 60 % solvent. Where the original adhesives need 4 kg solvent for each kg of solids, the alternative only needs 1.5 kg. In this case, a reduction of solvent consumption of more than 60 % is attained.

Achieved environmental benefits: Reduction of solvent emissions.

Cross-media effects: Waste gas treatment techniques may still be necessary.

Operational data: High solid adhesives are applied in lamination processes for flexible packaging. They are applied in the high performance sector for mechanically, thermally or chemically stressed packages and in the production of composites changing in material within one lamination installation.

Applicability: Applicable in new and existing plants.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [14, DFIU and IFARE, 2002, 76, TWG, 2004]

2.4.2.4.3 UV curing alternatives

Description: UV curing varnishes and adhesives used for lamination do not contain organic solvents.

Achieved environmental benefits: Where varnishes or adhesives based on volatile solvents are used, a significant reduction in solvent emissions can be achieved.

Cross-media effects: UV curing varnishes and adhesives require energy to be dried by specific UV driers. However, this is unlikely to be more than for drying conventional solvent-based systems. In addition, the lamps used contain mercury and require special treatment as waste.

UV curing varnishes and adhesives contain reactive acrylates, monomers and oligomers, some of which are allergenic.

Operational data: In the flexible packaging industry next to printing, laminates containing a number of different plastic films and aluminium foil are often made. UV curing adhesives are applied here, however, only for standard composites up to a medium quality level.

Applicability: Applicable in new and existing plants and installations.

Economics: No general valid statement on costs can be made.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [21, Nordic Council of Ministers, 1998] [35, Aminal, et al., 2002] [14, DFIU and IFARE, 2002, 76, TWG, 2004] [128, TWG, 2005]

2.4.2.4.4 Solvent-free alternatives

Description: Solvent-free adhesives are 2-component adhesives with a 100 % solid content, often containing isocyanates.

Achieved environmental benefits: Solvent emissions from adhesive applications are reduced to zero.

Cross-media effects: No information submitted.

Operational data: These are commonly applied in the flexo and packaging gravure industry in the lamination processes on non-porous substrates such as plastic and aluminium.

A general problem of these solvent-free systems is the application of thin, uniform adhesive films. As opposed to the solvent-based adhesives where layer thickness can be controlled by the viscosity, the control has to be carried out by mechanical rolling processes. The adhesive layer might show slightly increased surface irregularities compared to solvent-based adhesives.

Many complex laminates can be produced with 2-component systems. They require special machinery.

Applicability: No information submitted.

Economics: No information submitted.

Driving forces for implementation: SED. Occupational health and safety. Client's product specifications.

Example plants: No information submitted.

Reference literature: [21, Nordic Council of Ministers, 1998] [35, Aminimal, et al., 2002] [14, DFIU and IFARE, 2002]

2.4.2.4.5 Co-extrusion

Description: With co-extrusion, the printed substrate is covered with a warm, liquefied plastic film and subsequently cooled down. This film replaces the necessary varnish, or when used between two different layers of different carriers, it acts as an adhesive.

Achieved environmental benefits: Solvent emissions are eliminated.

Cross-media effects: Co-extrusion requires energy.

Operational data: Applied in flexible packaging.

Applicability: No information submitted.

Economics: No information submitted.

Driving forces for implementation: SED. Occupational health and safety. Client's product specifications.

Example plants: No information submitted.

Reference literature: [35, Aminimal, et al., 2002] [128, TWG, 2005]

2.4.2.5 Waste gas treatment

2.4.2.5.1 Encapsulation/enclosure

Description: See Section 20.11.2.1.

In flexible packaging, the driers are always enclosed. They work at sub-atmospheric pressure to avoid sending solvent-laden air into the press room. They thus always extract a part (often some 20 %) of their inlet air from the press room. The waste gases are emitted through a stack or sent to abatement equipment.

Solvents not only evaporate in the drier, they also evaporate from ink fountains, viscosity adjusters, containers, etc. These solvents must be extracted locally for health and safety reason, in order not to exceed occupational exposure limits (OEL).

Local extraction is normally not sent to abatement equipment due to the low solvent concentration.

Achieved environmental benefits: See Section 20.11.2.1. Enclosure or encapsulation reduces the volumes of air to be extracted, and therefore reduces the size of extraction fan motors and waste gas treatment where applied.

Reducing solvent emissions. Solvent emissions from washing machines may be several per cent of the total solvent consumption.

Cross-media effects: Safety needs to be assured. At the times that the solvent concentration in the ventilation air from the washing machine is at its highest, adequate dilution with waste gases from production machinery or otherwise is necessary to prevent explosions.

Operational data: Automatic cleaning machines need to be ventilated before unloading. During a few minutes, a relatively small airflow (a few thousand m³/h) is heavily laden with solvent vapours. This airflow is sent to the abatement equipment.

Applicability: Driers are always enclosed. Enclosure of ink fountains, viscosity adjusters, containers, etc., are increasingly used to meet SED requirements. Retrofit is not possible (machine control needs to be completely automated).

Economics: No information submitted.

Driving forces for implementation: Implementation of the SED. Occupational health and safety.

Example plants: No information submitted.

Reference literature: [76, TWG, 2004] [128, TWG, 2005]

2.4.2.5.2 Extraction and treatment of air from the presses and other production areas

Description: Solvents evaporating from the presses, such as from containers for ink, varnishes and adhesives, from venting automatic cleaning machines (see Section 2.4.2.6.2) and escaping capture by the driers, are extracted locally and subsequently treated.

The following can be applied:

- encapsulating, laminating and varnishing machines and ventilating the enclosure by the drier extraction rather than local extraction
- sending local extraction around production machinery to abatement
- ensuring fugitive emissions from ink fountains are captured and treated. This reduces the need for local extraction of open areas
- installation and use of chamber doctor blades (see Section 2.2.3.2)
- sending washing machine ventilation to abatement (see Section 20.9.10).

Achieved environmental benefits: Reduction of VOC emissions. Assures the capture and treatment of fugitive emissions from ink fountains and washing machines.

Automatic washing machines need to be ventilated before they can be unloaded (see Section 2.4.2.6.2). This ventilation is often not sent to the abatement equipment.

Cross-media effects: Extraction requires energy, but this local extraction takes place to prevent high occupational exposure levels. The issue is whether or not to send the extracted air to the waste gas treatment (usually an incinerator). However, since the incinerator may need to be larger, the main fan of this incinerator would also be much larger. This would substantially increase the amount of energy required. The increased airflow with a low solvent content will increase the amount of support fuel required by an incinerator.

Operational data: Modern packaging gravure presses are, apart from extraction of the driers, equipped with floor extraction and/or extraction from the ink containers to the waste gas treatment system. This extracted air may contain about 1 g solvent/m³, but this will depend on other measures taken to reduce fugitive emissions, and may be lower. These additional extraction systems are placed between the printing units. For flexo presses equipped with a central impression cylinder (see Figure 2.2), the available space between the printing units is too small to install an extraction system.

Modern standalone varnishing and lamination units are usually equipped for this.

Applicability: Not applicable on existing flexo presses equipped with a central impression cylinder. In-built in new standalone varnishing and lamination units.

The venting of automatic washing machines is commonly applied where incineration has recently been installed. Generally not applicable where solvents are recovered for re-use, since recovered solvents are used for cleaning that cannot be re-used in inks, varnishes or adhesives.

Economics: Depends mainly on the capacity of the waste gas treatment system. In packaging gravure, costs for retrofit are over EUR 100000.

Where locally extracted air is always sent to the incinerator, the incinerator would need to have some 20 % additional capacity. A newly built incinerator would therefore be about EUR 150000 to 300000 more expensive, assuming the original capacity would be between 75000 and 150000 m³/h. Retrofitting an incinerator to enlarge its capacity by 20 % is often technically not possible or far more expensive (2004).

Driving forces for implementation: Implementation of SED.

Example plants: No information submitted.

Reference literature: [21, Nordic Council of Ministers, 1998] [35, Aminal, et al., 2002] [4, Intergraf and EGF, 1999, 76, TWG, 2004] [128, TWG, 2005]

2.4.2.5.3 Peak volume bypass and peak/trough smoothing: extraction and treatment of air from the presses and production areas

See Section 20.11.2.4.

2.4.2.5.4 Maintenance of waste gas treatment equipment, bypasses, collection systems, etc.

Description: Ensure planned maintenance and speedy repairs are carried out, see Section 20.2.6.

Achieved environmental benefits: Defects in incineration equipment can give rise to VOC emissions of up to 0.4 % of the annual input per day (assuming 250 working days a year).

Cross-media effects: No information submitted.

Operational data: In seven IPPC-size Dutch flexible packaging plants, the downtime of incinerators varied between 1 and 14 working days. The average was almost 7.5 days, i.e. about 3 to 8 % of total annual input. These data are from 2004.

Applicability: All plants.

Economics: No information submitted.

Driving forces for implementation: SED.

Example plants: No information submitted.

Reference literature: [76, TWG, 2004]

2.4.2.5.5 Automatic and timely closure of a bypass system

Description: Waste gases from the driers should be sent to the incinerator automatically before make-ready press speed is reached (30 to 60 m/min).

Achieved environmental benefits: A 5 to 15 % reduction in emissions can be achieved.

Cross-media effects: No information submitted.

Operational data: No information submitted.

Applicability: No information submitted.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [76, TWG, 2004] [128, TWG, 2005]

2.4.2.6 Cleaning

2.4.2.6.1 Replacement of VOCs with less volatile solvents for cleaning floors (substitution)

Description: See Section 20.9.

Achieved environmental benefits: A reduction in the emission of VOCs of 1 – 2 % can be achieved from a situation where floors are cleaned by wetting with buckets of solvents. However, where some preventative measures are already taken, such as reducing the dirtying of the floors and controlling solvent use, the reduction in emissions is less.

Cross-media effects: No information submitted.

Operational data: No information submitted.

Applicability: No information submitted.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [128, TWG, 2005].

2.4.2.6.2 Cleaning machine parts and equipment in automatic cleaning/washing machines

See Section 20.9.10

2.4.2.6.3 Cleaning of machine parts with high pressure water spray

See Section 20.9.12

2.4.3 Publication gravure printing

In Chapter 20, techniques are discussed which might also be applicable to publication gravure. In Table 2.42, the general techniques relevant for publication gravure are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 2.42: Reference to techniques generally applicable to the sector

2.4.3.1 Conventional solvent-based inks

Description: Conventional inks used in publication gravure, are toluene-based. In the printing plant, inks are significantly thinned before being used. The toluene concentration of the press-ready ink is in the range of 70 - 80 wt-%.

Achieved environmental benefits: No information submitted.

Cross-media effects: No information submitted.

Operational data: No information submitted.

Applicability: No information submitted.

Economics: With a high press speed, solvent recovery is possible.

Driving forces for implementation: Most stable process. Easiest de-inking of printed paper for recycling.

Example plants: No information submitted.

Reference literature: [18, UBA Germany, 2003] [128, TWG, 2005]

2.4.3.2 Substitutes for conventional solvent-based inks

2.4.3.2.1 Water-based alternatives

Description: Water-based inks only contain some organic solvents. Conventional water-based inks rely on relatively high acid resins for water dispersibility; more recently developed inks are based on water-dispersible polyester resins. The latter ones do not need neutralising agents such as ammonia or amines to maintain their dispersibility properties.

Achieved environmental benefits: The currently applied inks are based on toluene and huge reductions in the use of toluene can, theoretically, be achieved. However, all publication plants are equipped with waste gas treatment systems and toluene emissions are already significantly reduced. An LCA study carried out in Germany has not given any clear indication that water-based gravure inks can be considered a cleaner technology solution for existing plants; rather the opposite.

Cleaning of water-based inks can be done with water. However, if the ink or varnish dries, then solvents have to be used.

Cross-media effects: The energy consumption for forced drying of the water-based ink is higher and more waste is generated.

It is difficult to de-ink paper products and wastes in normal de-inking plants. This inhibits the recycling of products.

Operational data: The print quality with water-based inks is lower than with conventional inks.

Applicability: They are not applied in publication gravure printing processes because of practical problems.

Economics: For changing from solvent-based inks to water-based inks, high costs are involved. For new plants or presses, investment costs for applying water-based inks are more or less the same as for solvent-based inks.

The cost for retrofitting one publication gravure press is EUR 1 million. At the start, operational costs are 20 % higher than for conventional printing because of the learning period, however, in the end they will be more or less equal.

In addition, productivity because of lower press speeds and print problems on wider web widths is only about 70 % of normal.

Driving forces for implementation: No information submitted.

Example plants: RotoSmeets, Deventer, the Netherlands, is one of several publication gravure plants that experimented with water-based inks, without achieving acceptable results.

Reference literature: [21, Nordic Council of Ministers, 1998] [4, Intergraf and EGF, 1999] [11, IMPEL, 2000] [35, Aminal, et al., 2002] [53, US EPA et al., 2003, 76, TWG, 2004]

2.4.3.2.2 Using retention inks

Description: Retention inks have a modified formulation that slows the film formation and allows evaporation of the toluene over a longer period of time. The result is that a higher percentage of the toluene can be expelled directly into the ink drying unit and can be captured. Less toluene will remain in the product.

Achieved environmental benefits: The remaining toluene load in the product, measured directly at the delivery area of the press, can be reduced by 30 – 50 %.

Diffuse emissions can be reduced by approx. 1 % of the total input. This corresponds to a reduction of 20 % of the total emissions from a good practice gravure plant (where total emissions are 5 to 6 % of the total input, including from waste gas treatment: input is as defined in the SED) [18, UBA Germany, 2003].

These benefits can only be achieved where the waste gas from the driers are extracted and treated.

Cross-media effects: Where adsorption is used, more energy is reported to be needed to desorb the higher load of toluene produced from the driers.

Operational data: No information submitted.

Applicability: Applicable for all publication gravure processes, except where special inks are required that do not have a retention ink counterpart.

In the EU-15, 70 % of the publication gravure inks used are now retention inks, and in Germany, 100 %.

Economics: The price of retention inks is the same as conventional inks, however, less ink is needed (although this is not an ink reduction technique).

The savings for each kg of toluene recovered are about EUR 0.50.

Driving forces for implementation: Less toluene in the final product.

Example plants: Large number of plants throughout Europe.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [35, Aminal, et al., 2002] [76, TWG, 2004] [128, TWG, 2005]

2.4.3.3 Waste gas treatment

2.4.3.3.1 Increased temperature in the press room

Description: With higher temperatures in the press room, more toluene will evaporate from the residues in the printed product. A prerequisite for this technique to be effective is that the air in the press room is extracted and that the extraction system is connected to a waste gas treatment system.

Achieved environmental benefits: Reduction of fugitive emissions stemming from the printed products. In this way, fugitive emissions are reported to be reduced by approx. 1 %.

Cross-media effects: Energy consumption may be higher if the press room requires heating.

Operational data: Applying the mass balance of the virtual gravure plant in Section 2.3.4.3.1 with a total of about 352 t of fugitive emissions, approximately 3.5 t could be saved by additional extraction from the paper web. The total residual solvent, however, is 43.3 t. Consequently, the higher press room temperature supposedly reduces the solvent content in the product by more than 8 %. Tests in a rotogravure plant in north Germany, raising the drying temperature from about 40 to 90 °C has proved to be unable to achieve a reduction of this extent.

Applicability: No information submitted.

Economics: Possible higher running costs. These may be offset as the savings for each kg of toluene recovered are about EUR 0.50.

Driving forces for implementation: No information submitted.

Example plants: Not known to be applied in EU-15.

Reference literature: [35, Aminal, et al., 2002, 76, TWG, 2004] [128, TWG, 2005]

2.4.3.3.2 Increasing drying time

Description: Increasing drying time and maintaining the same speed can be achieved by increasing the length of the drier.

Achieved environmental benefits: With a prolonged retention time, more toluene will have the time to evaporate inside the drier which will be routed to the waste gas treatment system.

Cross-media effects: Increased capacity of the driers will increase energy consumption. Noise levels might also increase.

Operational data: No information submitted.

Applicability: Only applicable to new presses; retrofit is not possible.

Economics: The savings for each kg of toluene recovered are about EUR 0.50.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [4, Intergraf and EGF, 1999] [76, TWG, 2004]

2.4.3.3.3 Discontinuous air extraction from the driers

Description: When the press is running, the air in the driers is extracted and routed to the waste gas treatment system (i.e. only the air from the driers, and only when the press is running). The press is not enclosed and the amount of ventilation air around the press that is routed through the driers is small. The ventilation air in the press room is not routed through the waste gas treatment system.

Achieved environmental benefits: A level of fugitive emissions of 15 - 20 % of the total toluene input can be achieved. The air from the driers has a high load of toluene, which makes the adsorption of toluene very efficient. Because the capacity of the waste gas treatment system is laid out only for the air coming from the driers, the system is relatively small and can achieve a good balance between reduction of VOCs and use of energy.

Cross-media effects: High levels of VOC around the press and in the press room might be found. Extra ventilation because of workers health and safety might be necessary. Noise levels might increase.

Operational data: No information submitted.

Applicability: This technique is now outdated as it fails to meet the requirements of the SED.

Economics: The savings for each kg of toluene recovered are about EUR 0.50.

Driving forces for implementation: Workplace health and safety.

Example plants: No information submitted.

Reference literature: [4, Intergraf and EGF, 1999, 35, Aminal, et al., 2002, 76, TWG, 2004]

2.4.3.3.4 Continuous air extraction from the driers

Description: The air in the driers is extracted and routed to the waste gas treatment system as in Section 2.4.3.3.3 above. However, in addition to when the press is running, the drier air is also extracted and treated when the press contains ink, but is otherwise idle. The press is not enclosed and the amount of ventilation air around the press that is routed through the driers is small. However, it is significantly more than with only discontinuous air extraction as addressed in Section 2.4.3.3.3. The ventilation air in the press room is not routed through the waste gas treatment system.

Achieved environmental benefits: Lower toluene emissions than in Section 2.4.3.3.3.

Cross-media effects: Noise levels might increase and increased energy is required for the extraction and recovery of toluene. Air with small concentrations of toluene is routed through the waste gas treatment system. Generally, this results in lower efficiency of the recovery installation.

Operational data: No information submitted.

Applicability: No information submitted.

Economics: The savings for each kg of toluene recovered are about EUR 0.50. Running costs are higher than those noted in Section 2.4.3.3.3.

Driving forces for implementation: Implementation of SED. Occupational health and safety.

Example plants: No information submitted.

Reference literature: [76, TWG, 2004]

2.4.3.3.5 Enclosed press and ventilation air is routed to the waste gas treatment system discontinuously

Description: The press is completely enclosed. The ventilation air inside the enclosure is extracted via the driers and routed to the waste gas treatment system discontinuously, i.e. only when the press is running (as in Section 2.4.3.3.3). Normally there is negative pressure inside the enclosure to prevent air escaping to the press room.

Achieved environmental benefits: Lower toluene emissions and lower energy consumption for extraction than in Section 2.4.3.3.4.

Cross-media effects: No information submitted.

Operational data: No information submitted.

Applicability: No information submitted.

Economics: The savings for each kg of toluene recovered are about EUR 0.50. Capital costs are higher than those noted in Section 2.4.3.3.4.

Driving forces for implementation: Implementation of SED. Occupational health and safety.

Example plants: No information submitted.

Reference literature: [76, TWG, 2004]

2.4.3.3.6 Enclosed press and ventilation air is routed to the waste gas treatment system continuously

Description: The press is completely enclosed. The ventilation air inside the enclosure is extracted via the driers and routed to the waste gas treatment system continuously; including when the press contains ink but is otherwise idle (i.e. as Section 2.4.3.3.4, but ventilation air is also extracted to recovery). Normally there is negative pressure inside the enclosure to prevent air escaping to the press room.

Achieved environmental benefits: Total toluene emissions can be reduced to 5 – 8.5 % of the total toluene input.

Cross-media effects: Air with small concentrations of toluene is routed through the waste gas treatment system. Generally, this results in lower efficiency of the recovery installation. Increased energy consumption to Section 2.4.3.3.5.

Operational data: In the Netherlands, all large plants have been applying this technique since 1996.

Applicability: Commonly applied.

Economics: To install a new press, additional costs for enclosure and continuous routing of the solvent-laden air through a waste gas treatment system adapted to the larger airflow is some EUR 0.5 million. The additional operational costs are about EUR 100000 per year per press.

The savings for each kg of toluene recovered are about EUR 0.50.

Retrofitting non-encapsulated presses in combination with a small capacity waste gas treatment system is prohibitively expensive.

Driving forces for implementation: Implementation of SED. Occupational health and safety.

Example plants: Two Flemish printing plants and all relevant Dutch plants.

Reference literature: [4, Intergraf and EGF, 1999] [29, Netherland, 1996, 76, TWG, 2004]

2.4.3.3.7 Discontinuous air extraction from the press, the driers and the press room

Description: The extracted air from the press room is routed to the waste gas treatment system, along with the air from the driers and from the encapsulated press. However, the air is extracted only when the presses are running.

There are facilities where personnel controlling the printing process are situated in separate control rooms. In these situations, the separate press room where the machines are sited can be seen as the encapsulation of the press. The air from this room is extracted and routed to the waste gas treatment system. This situation may be similar to that described in Section 2.4.3.3.5.

Achieved environmental benefits: Low toluene emissions.

Cross-media effects: Increased energy consumption for extraction and toluene recovery.

Operational data: All publication gravure plants are equipped with a waste gas treatment system; however, the capacity of the existing system might not be sufficient to also deal with the airflow from the press room.

Applicability: No information submitted.

Economics: The savings for each kg of toluene recovered are about EUR 0.50.

Driving forces for implementation: Implementation of SED. Occupational workplace health and safety.

Example plants: No information submitted.

Reference literature: [76, TWG, 2004]

2.4.3.3.8 Continuous air extraction from the press, the driers and the press room

Description: The air from the driers and from the encapsulated press is routed to the waste gas treatment system continuously. In addition the extracted air from the press room is also diverted to the recovery plant.

There are facilities where personnel controlling the printing process are situated in separate control rooms. In these situations, the separate press room where the machines are sited can be seen as the encapsulation of the press. The air from this room is extracted and routed to the waste gas treatment system. This situation may be similar to that described in Section 2.4.3.3.6.

Achieved environmental benefits: Total emissions can be reduced to a level of approximately 5 – 8.5 % of the total toluene input.

Together with applying retention inks, an emission level of 6.5 % of the total input can be achieved by the two Flemish printing plants.

Cross-media effects: No information submitted.

Operational data: All publication gravure plants are equipped with a waste gas treatment system, however, the capacity of the existing system might not be sufficient to also deal with the airflow from the press room.

For the two Flemish plants, it is thought that this technique shows a good balance of an achievable emission level of 6.5 %, avoiding excessive energy consumption.

Applicability: This technique is commonly applied in new plants. In the Netherlands, all large plants have been applying this technique since 1996. Retrofit might be prohibitively expensive because it requires almost a complete replacement of the gas treatment system and new piping work needs to be installed.

Economics: Extra investment cost, compared to the situation where only the driers are connected to the waste gas treatment system, is about EUR 0.5 million per press. Additional operational costs are about EUR 100000 per year per press.

The savings for each kg of toluene recovered are about EUR 0.50.

Driving forces for implementation: Implementation of SED. Occupational workplace health and safety.

Example plants: Two plants in Flanders, Belgium, and all large Dutch plants.

Reference literature: [35, Aminal, et al., 2002] [29, Netherland, 1996, 76, TWG, 2004]

2.4.3.3.9 Closed air loop ventilation

Description: The exhaust air from the waste gas treatment system is returned to the driers or the press room. This requires a waste gas treatment system with a much higher capacity than normal. The frequency of the adsorption/desorption cycle is very short to achieve very low toluene levels in the recycled air stream. Before sending the exhaust air stream to the building again, the air has to be cooled.

Achieved environmental benefits: Depending on the size of the press, the total emission might be reduced to 20 - 75 t/yr.

Cross-media effects: A higher frequency of the adsorption/desorption cycle creates more waste water and requires more use of energy. More energy is also needed because the capacity of the waste gas treatment system is higher. However, several energy reduction or re-use options are commonly installed.

Operational data: No information submitted.

Applicability: Applicable to new presses in combination with a new waste gas treatment system. The technique is also applicable to existing presses when a new waste gas treatment system has to be installed. Retrofitting an existing waste gas system is too expensive.

A new three metre press in a plant in the Netherlands, including a new waste gas treatment system, applying closed air loop ventilation achieved a toluene emission reduction of 75 t/yr. For the two Flemish plants, with presses which are smaller and slower, the achievable reduction may be 20 t/yr for each press, however, the technique is not installed at these plants because the costs for retrofit are too high.

Economics: For a three metre press, additional investment costs, on top of the costs for a new waste gas treatment system, are EUR 5 million. The operational costs are the same when energy saving techniques are installed. Costs per tonne of avoided toluene emission are about EUR 10000, based on a loan for a period of 10 years with an interest rate of 7 % (1999).

The savings for each kg of toluene recovered are about EUR 0.50.

Driving forces for implementation: Implementation of SED; workplace health and safety.

Example plants: Etten Leur, the Netherlands.

Reference literature: [18, UBA Germany, 2003] [35, Aminal, et al., 2002] [4, Intergraf and EGF, 1999, 76, TWG, 2004]

2.4.3.3.10 Air-knives on the printed web

Description: Air-knives prevent the web from carrying solvent-laden air out of the driers.

Achieved environmental benefits: Fugitive solvent emissions are reduced.

Cross-media effects: Noise levels might increase along with an increase in energy consumption.

Operational data: No information submitted.

Applicability: Applicable to webfed printing processes using forced air drying systems.

Economics: Relatively low cost; increased energy costs.

Driving forces for implementation: Implementation of SED. Occupational health and safety.

Example plants: This technique is commonly applied in publication gravure.

Reference literature: [4, Intergraf and EGF, 1999]

2.4.3.4 Cleaning

2.4.3.4.1 In-press cleaning of printing cylinders

Description: The printing cylinders in publication gravure presses are cleaned automatically in the press.

Achieved environmental benefits: No information submitted.

Cross-media effects: No information submitted.

Operational data: Applied in publication gravure.

Applicability: Only for new presses.

Economics: No information submitted.

Driving forces for implementation: No information submitted.

Example plants: No information submitted.

Reference literature: [4, Intergraf and EGF, 1999]

3 MANUFACTURE OF WINDING WIRE

[12, UBA Germany, 2002] [54, BMLFUW Austria, 2003] [64, EWWG, 2004]
[76, TWG, 2004] [128, TWG, 2005]

3.1 General information on the winding wire industry

The manufacturing of winding wires involves a unique type of surface treatment using solvents; basically involving the application of an electrical insulation layer (enamel) onto the surface of a copper wire, although in some cases the substrate may be aluminium wire. This insulation layer is applied for functional purposes rather than just for decoration or protection, with the enamel layer needing to provide high and prolonged dielectric strength throughout the whole lifetime of the wire on a coil core. The surface also needs a well defined lubricant layer covering to ensure good coiling performance and a smooth laying of the wire.

It should be noted that all information and emission values in all specific winding wire sections are given for copper winding wires, because of their predominant market share. In the case of aluminium wire manufacturing, all specific emission limits and achievable emission figures need to be adapted according to the smaller specific weight of the product using a conversion factor of 3.29 according to the ratio of the specific weights of copper and aluminium (8.9 and 2.7 g/cm³ respectively).

Table 3.1 gives figures for the production of enamelled wires in Europe over the period 1970 to 2000 and the correlated use of organic solvents.

Year	Production (t)	Consumption of organic solvents (t)	Specific consumption of organic solvents (t/t)
1970	150000	11250	0.075
1990	286000	20020	0.070
2000	390000	25350	0.065

Table 3.1: European production figures for enamelled wires and the correlated consumption of organic solvents from 1970 to 2000
[64, EWWG, 2004]

According to ESIG, the total consumption of solvents in Europe is about 4.5 million t/yr. From Table 3.1, it can be seen that the share of the winding wire industry is 0.6 % of this.

The European winding wire industry comprises about 40 installations and nearly 4600 workers. A typical installation falling under IPPC has 50 to 250 employees; with most being family owned.

As electric and electronic products are manufactured and sold worldwide, the winding wires used in these products are manufactured according to international standards. Insulating materials are classified in the technical terms of delivery in the EN 60317 standard series. As a consequence, the wires are manufactured to the customer's specifications for their approved type of product, and the manufacturer is not free to select the type of coating. Winding wires can be produced in many hundreds of dimensions, but they are generally grouped as follows:

Wire type	Above (mm)	Up to and including (mm)
Ultrafine wires	-	0.040
Fine wires	0.040	0.10
Medium wires	0.10	1.0
Thick wires	1.0	6.0

Table 3.2: Groupings of winding wire types
[64, EWWG, 2004]

Additionally there are rectangular shaped winding wires from small size to big sizes of about 80 mm².

3.1.1 Product characteristics and end use applications

The enamelled wire is useful for its very thin, high specification insulating film, which allows close packed and energy efficient winding wires to be produced, which can operate at high temperatures. The insulation consists of one or more layer(s) of enamel or tape(s) or a combination of both. The choice of the insulation material results in typical electrical properties like breakdown voltage, loss factor, corona resistance, partial discharge behaviour. Thermal stability of the wire coating materials is characterised by a temperature index. Other specific requirements for insulating coating systems for wires are mechanical strength, chemical resistance, and overload current stability. Contemporary electrical insulating systems already meet these requirements within thin layers (see CEN Standard EN 60317 series for details). Electrical properties especially make winding wires a unique product not comparable with other products under the scope of this document.

The main use of winding wire is in magnetic wires in windings and coils. These are used in a wide range of applications such as miniature coils for medical devices, entertainment electronics (microphones, audio and video heads, etc.), ultrafine wires in watches, and as windings for electrical motors, relays and power transformers. In electrical equipment, the winding wires operate under voltage and conduct currents. The electrical insulation directly affects the functionality and also the safety of the equipment. The electrical properties of the insulation material and the application systems is an essential point to consider when discussing BAT.

During the last few years, many attempts have been made to introduce alternative insulating materials and application systems in order to reduce the use of solvents. Many of these have failed because of insufficient insulation properties, although there are some successful examples throughout the world, e.g. using creosol-free enamels, electrophoresis, powder coating on strips, UV curing coating, and extrusion coating. However, these have not yet been taken up as general standards.

3.2 Applied processes and techniques in winding wire manufacturing

[12, UBA Germany, 2002] [54, BMLFUW Austria, 2003] [64, EWWG, 2004] [76, TWG, 2004] [76, TWG, 2004]

This is a small industry and in Europe there are only about three producers of the machines used to make winding wires. The same technology will therefore be found in nearly all installations. The manufacturing process for enamelled wires is generally linear: after the production of the bare copper wire by drawing or rolling, thermal cleaning or annealing of the bare wire is carried out, both of which are solvent-free processes. Enamel coating, drying and curing of the resin and then lubricant application are the following steps. Solvent use only occurs during enamel coating, and, depending on the specific process, lubricant application; drying and curing also gives rise to solvent emissions.

3.2.1 Typical manufacturing process for enamelled wires

A typical manufacturing process for enamelled wires is shown in Figure 3.1.

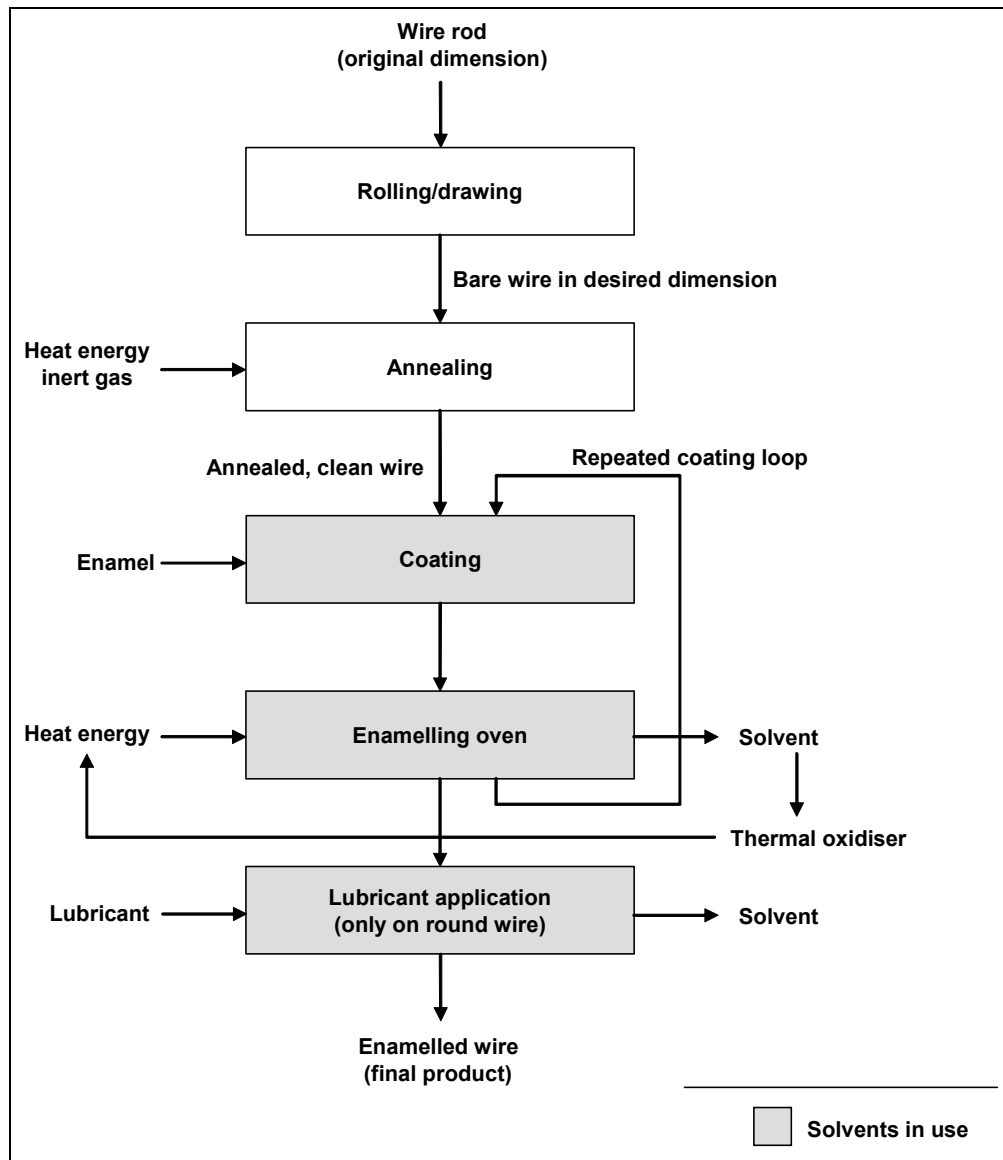


Figure 3.1: Typical manufacturing process for enamelled wires
[64, EWWG, 2004]

Rolling and drawing

These are deformation processes. Rolling is a continuous or stepwise forming process under compressive conditions. The material can be rolled at ambient or elevated temperatures. Wires for enamelled and other insulated winding wires are preferably manufactured by a drawing process. The wire is drawn through dies which reduce its size and extend its length. Fine wires require several drawing stages to reach the desired dimension. The drawing process applies tractive and pressure stress to the drawn material.

Annealing

The wire drawing process is followed by annealing where the wire passes through heated tubes (containing an inert atmosphere to prevent oxidation) and leading to recrystallisation and softening of the wire.

Enamel coating

The next process step is enamel application followed by the drying and curing of the enamel film. The coating is normally applied to the moving wire by passing the wire continuously through a bath of enamel and metering the amount by an accurately sized die or by controlled application through felt pads. Each layer applied is typically 1 - 10 µm thick, depending on the wire diameter, to allow the solvents to evaporate as the wire moves through the enamelling oven.

Drying and curing

The coated wire then passes into the enamelling chamber, which consists of a heated chamber (horizontally or vertically arranged) where the solvent is evaporated before moving into a higher temperature zone (400 - 700 °C) where the film is cured. The wire may then go back into the coating circuit for an additional layer of coating. In this continuous coating process, up to 30 applications of enamel may be applied until the desired layer thickness is obtained.

Recirculated airflow ovens are in use for contemporary wire coating processes. The direction of the recirculating airflow can be with or against the direction of the moving wire. Recirculating the airflow has the advantage that the vented volumes can be decreased. The solvent evaporation process leads to evaporation of the solvent and the air/solvent mix is usually treated in a catalytic oxidiser which ensures that residual solvent concentrations are below legal threshold limits (typically 20 – 30 mg organic C/Nm³). The process heat from the thermal oxidiser can be used in the drying process for the heat up of the circulating airflow (loop).

In gas heated machines, solvent-laden air is passed directly into a gas burner, where the design of the burner allows intimate mixing of the secondary air and oxidation occurs. To ensure that the solvent concentration does not rise beyond the lower explosive limit, it is important that excess air is supplied. Using electrical heating, the solvent-laden air is passed over heating elements to reach a temperature in excess of 500 °C. This is generally sufficient to achieve complete oxidation. In all cases, electrically heated machines use precious metal catalysts. The efficiency of oxidation is sufficient to ensure that emission control limits for VOC emissions are always achieved. After thermal or catalytic oxidation of the solvents, the air stream is recirculated to provide complete or partial heating of the enamelling chamber. Exhaust gas velocities may be lower than other industries to ensure a maximum energy efficiency balance from the use of recirculated air. It is important that any oxidation takes place where the air stream is recirculated. Oxidation in the stack will produce only hotter exhaust air.

Contemporary ovens in use for very fine enamelled wires work with radiation or a combined radiation and circulating airflow.

The enamelling chamber is typically maintained under negative pressure to allow capture of any fugitive emissions from the enamel supply system and to contain any degradation products or products of combustion from entering the workplace air. An enclosure around the enamel applicator further reduces fugitive emissions from liquid enamel.

Lubricant application

Depending on the final product requirements, the enamelled wire may be lubricated before being wound onto a reel. Several lubricants contain different volatile organic solvents.

Typically paraffin is applied from an organic solvent with a solvent content from 98 to 99.9 %. Lubricants, as concentrated emulsions, with a solvent content of between 50 – 95 %, water-based emulsions or even solvent-free hot melts are also used in this industry, though with limited success. With respect to the use of solvent-free alternatives, customer quality requirements with respect to thickness and evenness of the lubricant film have to be respected. The lubricant is generally specified by customers. Generally, it can be stated that high quality requirements and thin wires are less appropriate for solvent-free lubricants. Wherever possible, customers should be encouraged to use products such as self lubricating enamels or solid wax.

An alternative to solvent application may be the application of a molten lubricant to the wire surface by a lubricant wetted felt or by feeding the finished enamelled wire with a lubricant filament that melts due to the residual heat of the wire. The later technique applies the lubricant by looping the filament 2–3 times around the enamelled wire and moving it in the same direction as the wire, although at a lower velocity. Both techniques are not yet suitable for applying lubricants to fine wires with diameters of less than 0.1 mm.

3.3 Current consumption and emission levels in winding wire manufacturing

3.3.1 Mass balances

[12, UBA Germany, 2002] [54, BMLFUW Austria, 2003]

The range of diameters of the wires produced (between 0.01 - 6.0 mm) results in a large variation between production quantity (tonnes wire) and product surface coated (m²). As a consequence, the technologies and varnishes applied for fine wires are different from those for larger diameter wires.

Mass balances of two different types of existing installations in Germany are shown below; the data in Table 3.3 and Table 3.4 are given as specific values related to 1000 kg final product. These data are very similar to the consumption and emission levels of two production plants in Austria.

The first plant from which the consumption and emission data are shown in Table 3.3 can be described as follows:

- installation M: produces medium wires, predominantly with a diameter of 0.6 mm, three shift operations over 320 to 340 days per year, typical capacity 90 t wire per line/per year.

Input		Output	
Raw materials			
Cu-wire (8 mm)	1070 kg	Product (Cu-wire 0.6 mm)	970 kg
		Wire residues (bare and coated)	100 kg
Varnishes and solvents			
Polymer in varnish	38 kg	Varnish on product	30 kg
		Polymer losses	8 kg
Solvents	71.5 kg	Solvents in waste	4.7 kg
		Catalytic oxidation of VOCs ⁽¹⁾	58.6 kg
		Emitted VOCs	8.2 kg
		NO _x CO CO ₂	(2)
Process materials			
Water	~ 1000 kg	Water	~ 1000 kg
Wax	0.1 kg	Wax	0.1 kg
Drawing compound	0.3 kg	Drawing compound waste, wet	3.5 kg
Energy			
Energy	2.1 MWh ⁽³⁾		
¹⁾ This value is not an emission amount but the share of VOC input that is used for energy recovery by thermal or catalytic oxidation. ²⁾ No representative emission values are available that allow for the calculation of specific emission factors. Single measurements have shown that concentrations of up to several thousand mg/m ³ are obtained. NO _x and CO values are highly related to the increasing input of nitrogen compounds from the varnish systems (NMP). ³⁾ The value strongly depends on the product (isolation) system.			

Table 3.3: Mass balance from a plant producing medium sized winding wires
[12, UBA Germany, 2002] [54, BMLFUW Austria, 2003]

The second plant from which the consumption and emission data are shown in Table 3.4 can be described as follows:

- installation F: produces fine wires, predominantly with a diameter of 0.08 mm, three shift operations over 320 to 340 days per year, typical capacity 30 t wire per line/per year.

Input		Output	
Raw materials			
Cu-wire (8 mm)	1100 kg	Product (Cu-wire 0.08 mm)	962 kg
		Wire residues (bare and coated)	138 kg
Varnishes and solvents			
Polymer in varnish	58 kg	Varnish on product	38 kg
		Polymer losses	20 kg
Solvents	186 kg	Solvents in waste	6 kg
		Catalytic oxidation of VOCs ⁽¹⁾	165 kg
		Emitted VOCs	15 kg
		NO _x CO CO ₂	(2)
Process materials			
Water	~ 1000 kg	Water	~ 1000 kg
Wax	0.1 kg	Wax	0.1 kg
Drawing compound	0.3 kg	Drawing compound waste, wet	6.5 kg
Energy			
Energy	4.5 MWh		
¹⁾ This value is not an emission amount but the share of VOC input that is used for energy recovery by thermal or catalytic oxidation. ²⁾ No representative emission values are available that allow the calculation of specific emission factors. Single measurements have shown that concentrations up to several thousand mg/m ³ are obtained. NO _x and CO values are highly related to the increasing input of nitrogen compounds from the varnish systems (NMP).			

Table 3.4: Mass balance from a plant producing fine winding wires [12, UBA Germany, 2002] [54, BMLFUW Austria, 2003]

An installation for producing winding wire is made up of several machines. Usually the machines of an existing plant correspond to different technical grades that may have an influence on the overall emission from the installation. Important parameters in this context are:

- the technology applied at each single machine
- the wire diameter that is produced
- the quality that is produced.

Generally, fine wires are related to higher specific VOC emissions (calculated as g VOC per kg product) compared to thicker wires. This is due to the relationship product weight/product surface and to the achievable share of VOCs in varnishes and lubricants. To give an example: a wire with a diameter of 0.02 mm results in VOC emissions that are four times higher than that produced by a wire with 0.1 mm diameter. Analysis of recent measurements in fine wire and ultrafine wire installations shows a disproportionately high VOC emission from both lubricant application and from the enamelling process for specific application techniques with a very high solvent content. Nevertheless, the impact on the overall value of VOC emission seems to be negligible due to the very small percentage of these products compared to the total winding wire production tonnage.

The emission values in Table 3.3 and Table 3.4 show that these two existing installations cannot, at present, meet the limit values as specified in the Solvent Emissions Directive. It is important to know that the major share of the VOC emissions are due to lubricant application.

3.3.2 Consumptions

[80, EWWG, 2004] [12, UBA Germany, 2002] [76, TWG, 2004]

The process steps in the application of solvents are coating, including the curing of the coating, and the application of the lubricant.

3.3.2.1 Coatings

Table 3.5 shows the different coating systems applied and their average solvent content in relation to the type of winding wire produced. The coating systems that are marked with an asterisk (*) contain n-methyl-pyrrolidone (NMP) as the volatile organic compound. For many years there has been an ongoing discussion with the supplier of NMP requiring enamel systems on replacing NMP with non-nitrogen solvent. This has been tried in different ways, but the results have not been technically acceptable up until now. For the mentioned insulation systems, the use of NMP is unavoidable today and in the near future according to enamel manufacturers. The market for the electromagnetic components using enamelled wires needs to be aware of the requirements of technical and security specifications, products for which the insulation has to meet the requirements of high thermal, mechanical and electrical performance specified in the thermal class.

Product	Insulating coating system	Share of total production (%)	Average solvent content (%)
Solderable round wires	Polyurethane	13	65 – 80
High temperature round wires	Epoxy, polyester, polyamide, polyimide, polyester-imide with additional polyamide-imide layers (*)	70	55 – 75
Self bonding round wires	As above (first and second lines in this table) with additional bonding layers of aliphatic or aromatic polyamide (*)	11	55 – 75
Rectangular wires	Depending on temperature class: polyvinylacetal, polyester-imide, polyamide-imide with an additional bonding layer (*)	6	60 – 80
Total		100	55 – 75

* Coating systems may partially contain NMP (n-methyl pyrrolidine) as a VOC

Table 3.5: Main winding wire products and applied coating systems
[12, UBA Germany, 2002] [76, TWG, 2004]

The solid content of wire coatings usually varies between 20 and 45 %; the remaining 55 - 80 % is organic solvent. For ultrafine wires, (with diameters in the ten micron range) high solvent contents of up to 75 % are necessary, whereas with increasing diameters of the wire less solvent is needed in the coating application, i.e. around 55 %. The choice of solvent for the coating application depends on the coating type.

In order to achieve the required insulation performance, complex coating systems are usually made up of speciality polymers dissolved in special solvent blends. Organic compounds which are strong solvents (cresol/NMP) are required to dissolve the high molecular weight polymers (polyester-imide and polyamide-imide) and cannot be replaced by other solvents with lower solvency and less environmental impact. The most commonly used solvents within the industry are cresylic acids (cresols) with xylene used as diluent, naphtha or other aromatics, or NMP. These are all high boiling point/low vapour pressure solvents designed for production at high temperatures and therefore with very low evaporation rates at ambient temperatures.

Currently a handful of possible coating technique alternatives have been developed:

- hot melt coatings
- medium and high solids coatings
- cresol-free coatings
- waterborne coatings
- electrocoat applicable coatings
- 2-component coatings
- powder polyester coatings
- UV curing coatings
- extrusion coatings with thermoplastic materials.

However, for many reasons, such as lack of quality performance, as well as economical, technological or safety aspects, these alternatives have not yet succeeded against the classical winding wire coatings.

3.3.2.2 Lubricants

Several lubricants contain different volatile organic solvents, however paraffin (wax) is typically applied with an organic solvent content of 98 - 99.9 %. Alternatives such as concentrated lubricant emulsions, with a solvent content of between 50 - 95 %, water-based emulsions or solvent-free hot melts, are also used, however, with limited success.

3.3.3 Emissions

[80, EWWG, 2004] [128, TWG, 2005]

3.3.3.1 Emissions to air

VOC, NO_x and CO emissions

The values in Table 3.6 are examples of measurements in a few installations that give an indication of current emission levels of VOC, NO_x and CO:

	M installations¹ (g/kg)	F installations² (g/kg)
VOC	~ 8	~ 15
NO _x ³	~ 10	~ 12.5
CO	~ 8.5	~ 15
Note: ¹ M installations: these are data from installations that produce medium sized wires (diameter of >0.1 mm). ² F installations: these are data from installations that produce fine wires (with an average diameter of ≤ 0.10 mm). ³ There are no fine wire sites using exclusively NMP-containing materials. The higher values are derived from measurements on production lines using exclusively insulation material containing NMP (see Section 3.3.2.1 and discussion on NO _x , later in this section). (See also Table 3.3 and Table 3.4)		

Table 3.6: Examples of measurements of emissions to air
[80, EWWG, 2004]

Many attempts have been made to reach a low level of CO and NO_x emissions; however, running the enamelling machine efficiently and the destruction of VOC are given priority together.

VOC emissions At an EU-25 level for the year 2000 (according to the RAINS model), NMVOC emissions were 5.4 kt, representing 0.05% of total NMVOC emissions. Total activity was 420 kt of winding wire coated, and the average emission factor is about 12.3 kg NMVOC/t of wire coated meaning that emissions from this sector are already partly treated in EU25 (based on an unabated emission factor is 17 g/kg in 1990). VOC emissions are proportionately lower from the drying processes, due to the waste gas treatment. The major remaining source of VOCs is from the application of the lubricants. In Table 3.6, fine wires are produced by applying a final wax coating with white spirit. The white spirit dries off and consequently VOC emissions are higher. However, in the case of thicker wires, new low solvent techniques can be used. However, these techniques are not readily usable on fine wires of 0.01 - 0.1 mm (see Section 3.4.5.6) [128, TWG, 2005].

Solvent emissions from the industry have been steadily reduced for over 40 years, and a baseline figure of 13 g/kg for 1995 has been estimated (when analysis of emissions started). The industry proposed a reduction target for emissions of 5 g/kg for wires with diameters of >0.1 mm by 2007 and of 10 g/kg for fine wires (with an average diameter ≤0.1 mm). This was based on an industry study using best practice technologies described in this Chapter and modified by experience of the difficulty of reducing the solvents used in fine wire production (for example, see Section 3.4.5.6). This equates to a reduction of up to 60 % (and up to 70 % compared with estimates of the situation in 1990). [55, Europacable, 1997]

Oxides of nitrogen (NO_x) See Section 20.11.9. [140, Tempany, 2006, 163, EWWG, 2005, 193, Tempany, et al., 2006] are produced as a result of the oxidation of VOCs in waste gases and give rise to the cross-media conflict between abating VOCs and creating NO_x. One source of NO_x emissions is the direct result of oxidation of the nitrogenated solvents used in the production of certain enamel systems (see Table 3.5). The concentration of NO_x is proportional to the destruction of VOCs for the products that contain the nitrogenated solvents. Only a part of the nitrogen contained in NMP is converted to nitrogen oxides, at a ratio of 90 % NO and 10 % NO₂. The other major source of NO_x is the oxidation of atmospheric nitrogen during combustion of VOCs in the oven. When using enamels containing nitrogen, emission values of NO_x can be well over 150 mg/Nm³ depending on the specific airflow conditions in the enamelling machine and the number of machines using solvents containing nitrogen. In other cases with different airflows and NMP usage on process machines, the levels are 150 mg/Nm³ and indistinguishable from satisfactory NO_x levels associated with combustion (see the CWW BREF [67, EIPPCB, 2003]). This is a common problem for all installations over Europe. Enamels based on nitrogen-free solvents, such as polyvinyl-acetal, result in wires of low heat class, and do not meet the specifications required by the customers that the polyamide-imide products attain. NO_x emissions after catalytic oxidation do not currently undergo treatment.

Installation(s)	Group of 34 enamelling ovens	Group of 165 enamelling ovens	Installation 1 enamelling	Installation 2
Short description of the installation	Exhaust gases collected in three tubes leading to one stack (flue) Special local conditions: industrial area, close to a power station	Exhaust gases collected by hoods over single sources in four stacks (flues), 35 - 50 m high In order to avoid odour emissions (olfactory trouble with neighbourhood), a large amount of air from the production hall is extracted together with the gas from the oven Sources are spread over an area of about 10000 m ² Special local conditions: mixed industrial and residential zone (climatic spa)	80 % of all product lines used NMP during measuring period Dilution of the exhaust gas in the hood: 1/10 from oven, 9/10 from hall Estimation: 2/3 of the NO _x is caused by nitrogen input (NMP), 1/3 caused by thermal process	Measurement on ventilator on the roof (ventilation of production hall and air from the cooling of the enamelling oven) NO _x emissions caused by small, uncontrollable process source. Number of fans: more than 100, spread over the production area of 10000 m ²
Volume flow (Nm³/h)	3700, 7000, 34500	53600 – 98000 in each of the stacks average mean value: 68480	60 - 810	
Temperature (°C)	~ 80 gas temperature at the entrance of the stack	70 - 110 gas temperature at the entrance of the stack	250 - 550 temperature of undiluted exhaust gas at the source	30 - 45 temperature of air
Concentration (mg NO_x/Nm³)	19 60 34	Average: 51.3	550 – 1500 Average: 615	Average value: 12
Mass flow NO_x (kg NO_x/h)		Total: 14.07	Average: 0.0835 from a single source	Total: 4 mean single sources: <0.040

Table 3.7: Winding wires: Further examples of NO_x emissions [193, Temppany, et al., 2006]

The total amount of NO_x emitted by the industry is estimated to be between 1 and 2.7 ktonnes a year (based on 2000 EUROSTAT figures).

Carbon monoxide is formed by the partial combustion of the enamel components during catalytic incineration in the enamelling machine. Carbon monoxide is a consequence of the destruction of solvent rather than of the burner efficiency. The concentration of carbon monoxide is dependent on the dwell time within the burner rather than the burner being incorrectly set. If the combustion efficiency is increased, the CO emissions would be reduced, but with a corresponding increase in CO₂ and NO_x emissions.

An enamelling machine is not controlled according to CO emissions but under completely different conditions, and these are:

- ensuring the correct temperature within the enamelling machine in order to achieve the optimum properties from the enamel film. Increasing the burner temperature would require dilution air to reduce the temperature in the enamelling chamber overall. This would require a greater amount of energy and is not considered to be the best environmental option
- using excess air to prevent the lower explosive limit from being exceeded and so preventing explosions within the machine. Reducing the airflow to increase the residence time is, therefore, not an option.

Attempts have been made to limit the emission of carbon monoxide by using secondary catalysts; however, meeting the emission limits will remain an issue because of the relatively short life of the catalysts and the corresponding financial implications.

Dust emissions

As the films applied to the wire are extremely thin (in the order of 10 µm) any dust present in the enamelling process would cause very serious surface quality problems. As any emission to the air is only a portion of the recirculated air, there will be no dust emissions expected.

With respect to the current consumption and emission values, there are no major differences in all the European countries because of the same machinery and the fully integrated abatement technique in all kind of enamelling machines.

3.3.3.2 Emissions to water

The water used in a winding wire plant normally is used in closed circuits. Emissions to water from the enamelling process are low; however water use should be kept as low as possible and this is commonly done by:

- minimising the flow through cooling baths and recycling the water through filters and de-ionisers when practicable
- using conductivity meters to optimise the treatment and conserve water in cooling towers
- prolonging the life of waterborne wire drawing lubricant emulsions by using filtration, centrifugation where practicable and ensuring efficient management of the lubricant to prevent premature ageing by stagnation and bacterial degradation.

3.3.3.3 Waste

The main sources of waste are from the drawing process and in the enamelling stage of the winding wire production [128, TWG, 2005].

Drawing:

- the drawing emulsion is used in a closed loop system, it is continuously cleaned using a paper filter or a hydrocyclone separator. In order to reduce waste amounts, emulsion treatment (reconditioning) is carried out with demineralised water; water is evaporated during the process and waste amounts are minimised
- the filters of the drawing emulsion circuit contain a certain amount of copper particles from the drawing process. They are recycled externally for the copper content.

Enamelling:

- varnish application. In order to reduce varnish losses, the varnish is applied in varnish baths, during die stripping using the varnish circuit and by dosed varnish using felt application
- recycling of bare or enamelled wires. The production scrap (bare and enamelled wires) is recycled to 100 %
- used solvents, residual enamels and cleaning wipes containing solvent are collected and disposed of (usually by incineration).

3.4 Techniques to consider in the determination of BAT in winding wire manufacturing

3.4.1 General techniques in winding wire manufacturing

[128, TWG, 2005]

In Chapter 20, techniques are discussed which might also be applicable to winding wire manufacturing. In Table 3.8, the general techniques relevant for winding wire manufacturing are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1, and the applicability is discussed in this section, below.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvent	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6 (not 20.6.3)
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Design, optimisation and management of extraction and abatement techniques	20.11.1
System selection, design and optimisation	20.11.1.1
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Treatment of used solvents for re-use	20.13.2
Disposable cleaning wipes	20.13.3
Re-usable cleaning wipes	20.13.4
Recovery of used solvents from wipes	20.13.5
Re-usable containers	20.13.6
Noise abatement	20.16

Table 3.8: Reference to techniques generally applicable to the sector

The EGTEI synopsis sheet for the coating of winding wires (see Annex 24.1.1) gives some data on the cost-benefit at a European level for some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or the technical characteristics of individual installations and products. [133, EGTEI, 2005] [128, TWG, 2005]

Techniques described in the sub-clauses of Section 20.6.3 are not applicable in the winding wire manufacturing. The enamelling compound is supplied in the final state by the manufacturer of the compound according to the requested content of solvent and polymer; there is no mixing operation in the winding wire installation and no dilution or addition of solvents during the manufacturing process of the enamelled wires.

Section 20.7: Due to the specialist and integrated nature of the process equipment for the coating of winding wires (described in Sections 3.1, 3.2 and 3.4), the general techniques covering only single aspects are technically not applicable to the integrated winding wire machines.

Section 20.8: Drying is not applicable to winding wire installations, because of the industry specification for a high temperature for the enamelling process used.

Section 20.10: Substitution is not applicable because the mixture of the specified enamels cannot be modified without changing the mixture. The performance of the insulating layer is fixed in international standards and specified by the customers. All substitutions described in the sub-clauses of Section 3.4 were performed in close co-operation with the customers, most of them failed to meet the requirements as stated in the specific sub-clause.

Sections 20.11.2 to 20.11.8: The given techniques are not applicable to the winding wire industry. The waste gas treatment used in the in-line process in winding wire installations is given in detail in Chapter 3. The industry specific enamelling machines do not allow the modification or replacement of some parts of the system. The gas loop in the driers is already optimised for recirculation and heat recovery, as well as VOC oxidation. The section on catalytic oxidation contains no additional information to this winding wire specific section. Biological treatment is not applicable because of the high waste gas temperatures.

Section 20.11.9: NO_x abatement techniques notes that SCR and SNCR have not been applied to the winding wire industry for economical reasons. Water-based scrubbers would have to either be fitted to every oven/line or have a very large waste gas capture systems. They have not been applied in this sector and the quantities of NO_x emitted do not currently appear to justify the technical and economic investment.

Section 20.12: Waste water treatment is not applied, because the only the drawing process is water-based and uses a closed loop of the drawing emulsion.

Section 20.13.7 is not applied because of not using activated carbon.

Section 20.13.8 is not applied, because there is no waste water treatment in this kind of installation.

Section 20.14 and 20.15: Dust and odour abatement are already addressed by the in-line machine technique.

Techniques to consider in the determination of BAT in the winding wire industry and attempts for substitution of techniques and materials are given in the following sub-clauses (3.4.x).

3.4.2 Energy management

3.4.2.1 Wire cooling with room air or exterior air

Description: After the drying and curing of the enamel coating, the wire has to be cooled down before the wire can be routed back for another layer of enamel or for applying the lubricant. Room air or exterior air can be used for this. During winter seasons, room and exterior air will usually be mixed to avoid condensation of water in the cooling system.

Achieved environmental benefits: Reduced energy consumption as room or exterior air does not have to be cooled or undergo any treatment before it can be applied.

Cross-media effects: No data submitted.

Operational data: Commonly applied in winding wire manufacturing.

Applicability: Applicable to new and existing plants and commonly applied in all European winding wire plants.

Economics: Very low cost technique.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [12, UBA Germany, 2002] [64, EWWG, 2004]

3.4.3 Conventional solvent-based processes

3.4.3.1 Applying conventional solvent-based coating baths with die application and coating circuit

Description: Applying conventional solvent-based enamel coating baths with die application and coating circuit is commonly applied in the winding wire industry. The amount of coating (or enamel) is metered by dies for consecutive layers. Dies are cleaned with solvent before re-use.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Applicable to new and existing plants. This technique is commonly applied in winding wire manufacturing.

Economics: This is the most cost effective way of achieving a very accurate application of enamel.

Driving forces for implementation: No data submitted.

Example plants: All plants in Europe.

Reference literature: [12, UBA Germany, 2002] [64, EWWG, 2004]

3.4.3.2 Applying conventional solvent-based coatings with dosed coating supply and felt application

Description: Applying conventional solvent-based coatings with dosed coating supply and felt application is commonly applied.

Felts contaminated with wire enamel have a limited life and cannot be reclaimed so are, therefore, treated as hazardous waste.

Achieved environmental benefits: Reduced VOC emissions.

Cross-media effects: No data submitted.

Operational data: This technique is commonly applied in winding wire manufacturing.

Applicability: Applicable to new and existing plants. For fine wire manufacturing, this is the application system which is typically used.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: All plants in Europe.

Reference literature: [12, UBA Germany, 2002] [64, EWWG, 2004] [76, TWG, 2004] [128, TWG, 2005]

3.4.3.3 Applying conventional solvent-based lubricants using felts

Description: Application of a well defined layer of lubricant is a customer's requirement and has been used for many years. Some customers ask for a specific lubricant or supply the desired lubricant to the winding wire manufacturer themselves. The lubricant layer is not a protection layer for the insulated copper wire, but an absolutely necessary tool for the coil winding operation at the premises of the customer. Too little or too much lubricant makes the winding wire sticky and makes close coiling impossible. As a result, the motor or transformer coil is not filled up by copper to the optimum to make them energy efficient. The thickness of the lubricant layer is nearly mono-molecular and a typical value is about 30 - 60 mg/m² for medium or thick wires and 5 - 10 mg/m² for fine wires with a diameter below 0.10 mm.

Achieved environmental benefits: No data submitted.

Cross-media effects: High VOC emissions.

Operational data: This technique enables the manufacturing of energy efficient motors and transformers. However, this is a benefit that is achieved in general and not specifically in the plant where the wire is produced.

This technique is commonly applied in winding wire manufacturing, resulting in the desired uniformly smooth layer of lubricant.

Applicability: This technique is commonly applied in the production of round wires.

Economics: Low investment and running costs compared to the alternative techniques.

Driving forces for implementation: No data submitted.

Example plants: Nearly all plants around the world.

Reference literature: [12, UBA Germany, 2002] [64, EWWG, 2004] [76, TWG, 2004] [128, TWG, 2005]

3.4.4 Conventional water-based emulsions

Description: Water-based emulsions are commonly applied in order to cool the wire and to reduce friction during drawing. Depending on the size of the wire in the machine, the grease content is between 0.1 up to 20 %. The lifetime of the emulsion has been doubled during the last decade, by filtering the emulsion and recovering the copper particles.

Achieved environmental benefits: The drawing process is completely solvent-free.

Cross-media effects: No data submitted.

Operational data: Mineral oil is not used as a solvent, but to generate the emulsion in deionised water, which is used in a closed loop system.

Applicability: A well introduced technique. Applicable to new and existing plants.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: All plants in Europe.

Reference literature: [64, EWWG, 2004] [128, TWG, 2005]

3.4.5 Replacement of conventional solvent-based materials (substitution)

These sections describe possible alternatives for conventional enamel coatings (see Sections 3.4.3.1 and 3.4.3.2) and lubricants (see Section 3.4.3.3).

3.4.5.1 High solids enamel coatings

Description: During the last 20 years, the solids content in general has been increased from 30 to about 45 % (resulting in a solvent reduction from 70 to 55 %), and from 20 - 30 % solid content for wire sizes finer than 0.10 mm with a corresponding solvent reduction from 80 to 70 % due to the application of felts. Further progress should be possible in order to reduce the use of the expensive solvents.

Achieved environmental benefits: A relatively significant reduction in solvent emissions.

Cross-media effects: A very high solids content requires additional high energy input for the production process and, therefore, a higher energy input for heating; however, more waste is produced.

Operational data: A greatly increased solids content shows a tendency to inferior quality levels of insulation films; see Section 3.4.6.2. It is also more complicated to achieve the right thickness of each layer of the insulation. Experience shows a direct correlation between the solids content and the amount of scrap produced. Therefore, it was necessary to deliberately reduce the solids content because of the amount of material wasted.

Applicability: Applicable to new and existing plants.

Economics: Low cost benefit. Reduction of costs for the solvent in the enamels, but less energy is recovered from incinerating the solvents in the waste gas.

Driving forces for implementation: Cost reduction.

Example plants: All plants are applying coating systems with +/- 30 to 45 % solids content.

Reference literature: [64, EWWG, 2004] [76, TWG, 2004] [128, TWG, 2005]

3.4.5.2 Water-based enamel coatings

Description: Tests were performed with acrylic enamels some years ago. They did not meet the required IEC standard and the increasing requirements for electrical and mechanical performance needed by the customer. A small amount of solvent (up to 15 % alcoholics and aminos) is necessary to maintain surface performance.

Achieved environmental benefits: A significant reduction of solvent emissions.

Cross-media effects: Emissions to water, and a huge increase of energy input needed due to drying and energy recovery from the incinerator is omitted.

Operational data: First experiences show a need for greater material input and a longer drying time. Due to the high costs and technological aspects this alternative is not yet proven as suitable.

Applicability: This is not currently applicable.

Economics: Low cost benefit. Retrofitting is a high cost operation because all pipes have to be replaced by stainless steel material. Also the drying zone has to be changed (longer/warmer).

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [64, EWWG, 2004] [128, TWG, 2005]

3.4.5.3 UV curing enamel coatings

Description: UV curing enamel coatings might be a possible alternative for conventional solvent-based enamel coatings.

Achieved environmental benefits: Solvent emissions from the coating system are reduced to zero.

Cross-media effects: UV lamps are needed for the drying. High energy consumption.

Operational data: The existing materials will not meet the required specifications. Great problems are anticipated in order that the correct thickness is reached, and the creation of blisters will cause a bad electrical performance.

Due to the lack of performance, high costs, and technological and safety aspects, this alternative is not yet proven as suitable.

Applicability: Until now, this method/process has not been used. There are currently some development activities which are supported by the EU; however, results are not encouraging at this time.

Economics: Low cost benefit. Retrofitting is an expensive operation. High material costs are also expected.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [12, UBA Germany, 2002] [64, EWWG, 2004] [128, TWG, 2005]

3.4.5.4 Cresol-free enamel coatings

Description: Enamels containing cresols are corrosive and/or toxic, e.g. PVF (polyvinyl acetoformal) is classified as toxic. Cresols could be replaced by diglycol or similar components.

Achieved environmental benefits:

Cross-media effects: Cresol-free enamel coatings are not essentially better for human health, because they may cause bad odour, and they may also be corrosive and toxic.

Operational data: No data submitted.

Applicability: Due to the lack of quality and electrical performance, they are not a suitable alternative yet.

Economics: Low cost benefit. This alternative coating, based on cresol-free solvents, is more expensive and present reduced quality.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [64, EWWG, 2004, 76, TWG, 2004] [128, TWG, 2005]

3.4.5.5 Powder polyester enamel coatings

Description: Powder polyester coatings exist, but are only applicable to low temperature class winding wire.

Achieved environmental benefits: Solvent emissions from the coating systems are reduced to zero.

Cross-media effects: Increased explosion risk.

Operational data: Due to the lack of performance (poor thermal resistance, bad adherence and, therefore, insufficient mechanical and electrical properties) and high investment costs, this alternative is not yet proven as suitable.

When applying this technique, there is no longer any flexibility in production.

Applicability: This is currently not applied. Tests were performed in the 1980s, but the development was stopped after an explosion occurred.

Economics: Low cost benefit. Retrofitting is an expensive operation.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [64, EWWG, 2004] [128, TWG, 2005]

3.4.5.6 Solvent-free lubricants

Description: Solvent-free lubricants can be applied by means of lubrication filaments or felts. Two alternative systems are in use in some factories: molten lubricant is applied to the wire surface by a lubricant wetted felt or by feeding the finished enamelled wire with a lubricant filament that melts due to the residual heat of the wire. The latter technique applies the lubricant by looping the filament two to three times around the enamelled wire and moving it in the same direction, although at a lower velocity.

Achieved environmental benefits: Solvent emissions from lubrication are avoided. For non-fine wires, yarn can reduce VOC emissions to 3 – 4 g/kg product.

Cross-media effects: Waste generation is created from used yarn, and, until now, there have been no possibilities for recycling.

Operational data: The lubricant is not a means of preservation for the winding wire but a well defined means for specific performance of the wire required and approved by the customer. The application systems have to ensure that the small required amount of lubricant is homogeneously applied to the surface of the wire. For typical values see Section 3.4.3.3. Solvent-free lubricant application systems cannot be applied to wires less than 0.15 mm, because the friction generated between wire and lubricant is higher than normal, resulting in more wire breaks. Subsequently more scrap is generated when manufacturing wires less than 0.15 mm.

The quality requirements of the customer, regarding the thickness and evenness of the lubricant film, have to be recognised when dealing with solvent-free alternatives. The lubricant is usually specified by customers. Generally, it can be said that high quality requirements and thin wires are less appropriate for solvent-free lubricants.

There is also a need for supervision and maintenance of the application system and there is also a danger of malfunction. Compared to the conventional system, these alternatives are not effective or simple enough to be reliable.

Applicability: Applicable to new and existing plants. Most plants have some lines (although a few have up to 20 % of their lines) with solvent-free lubricant applicators. Until now, this technique has only been used for specific customers. General application of this is not possible these days because of customer requirements. This technique is applicable only to a restricted wire diameter range, i.e. 0.15 - 1.5 mm (i.e. not feasible for fine wires).

Economics: An economic gain is that solvents are omitted. The alternative systems using a soaked yarn has been under development already for several years. These systems require high investment costs for each line and have running costs comparable to the solvent solution. A break in the yarn will cause a large amount of scrap.

Driving forces for implementation: Customers' requirements to use the alternative and to improve the working environment.

Example plants: No data submitted.

Reference literature: [12, UBA Germany, 2002] [64, EWWG, 2004] [76, TWG, 2004] [128, TWG, 2005]

3.4.6 Replacement of conventional solvent-based coating processes (substitution)

These sections describe techniques where conventional enamel application systems are replaced by different systems (e.g. using different production machinery).

3.4.6.1 Extrusion enamel coatings

Description: This technique, with high thickness insulation, is under development. It is required for very special applications. It is applied to produce fully insulated wires that have, for example, very high insulation thickness and to avoid corona effects. The production line is completely different because the materials differ significantly from solvent-based ones. The product is more like a cable than a winding wire.

Achieved environmental benefits: Solvent emissions from the coating system are reduced to zero.

Cross-media effects: Additional energy is needed for running the extruder. Re-use or recycling of insulation material is not possible resulting in an increase of waste material.

Operational data: The polymer makes the wire springy which leads to looser windings with a lower energy efficiency.

Due to the lack of performance, high costs, and technological and safety aspects, this alternative is not yet proven as suitable.

Applicability: This technique is not applicable for wire sizes below 0.15 mm, as the wire will break because of the viscosity of the molten polymer. Until now, this process has not been applied in winding wire plants.

Economics: Low cost benefit. The cost of the polymer is approximately 10 times the cost of current wire enamel.

Driving forces for implementation: No data submitted.

Example plants: A few plants around the world are applying this technique. However, these are not winding wire plants.

Reference literature: [64, EWWG, 2004] [76, TWG, 2004]

3.4.6.2 Hot melt enamel coatings

Description: A thermosetting material is applied to the copper conductor. This substitute is thermoplastic until 100 °C, and then the resin is maintained as liquid at approximately 80 °C and can be applied with dies onto the copper conductor.

Tests have been performed, especially with wire diameters >0.355 mm, but all wires could not satisfy the typical and increasing demands of modern wire processing regarding adherence and flexibility, heat-shock, cut-through, thermal resistance, resistance to abrasion and centricity of insulation film. Due to the nearly 100 % solids content and the resulting number of fewer insulation layers, it is not possible to realise small tolerances of film thicknesses in a precise way. Fewer layers and bad centricity cause worsening to the dielectric strength of the insulation film.

Achieved environmental benefits: Since this is an almost solvent-free process, a significant reduction in solvent emissions can be achieved.

Cross-media effects: The hot melts still contain small quantities of alcoholic substances which cause a flue smell by oxidation and cracking during the enamelling process. A high input of electrical energy is required for curing.

Operational data: The application of the hot melts requires temperatures of about 80 to 100 °C in the resin circulating pumps, which could result in some problems in the working area for the workers.

No recovery of energy is possible from the oven, due to the lack of solvent.

Applicability: Not the whole range of current products can be produced by using hot melts. There is no solution for a direct (1:1) replacement of the existing insulating systems. Tests have been performed since the mid 1990s without success. This technique is not applicable for wire sizes below 0.15 mm, as the wire will break because of the viscosity of the molten polymer. Due to the lack of performance, high costs, and technological and safety aspects, this alternative is not yet proven as suitable.

Economics: Low cost benefit. The machinery has to be completely changed from the existing one. New insulation materials have to be developed, tested by the winding wire manufacturer and approved by the customers.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [64, EWWG, 2004] [76, TWG, 2004] [128, TWG, 2005]

3.4.6.3 2-component epoxy enamel coatings

Description: The only alternative coating with two components is the epoxy system; however for many products, the temperature range is not sufficient.

Achieved environmental benefits: Solvent emissions from the coating systems are reduced to zero. Forced drying is redundant.

Cross-media effects: 2-component epoxy systems may have an increased issue to the health and safety of the workers.

Operational data: It is a completely different enamel application system (production machinery). It is also a difficult production technique, with a high risk of damage to the machinery.

Applicability: This is currently not applied because, due to the lack of performance and high costs, this alternative is not yet proven as suitable. It is also only applicable for a small part of the product range (temperature class), because the product is too rigid.

Economics: Low cost benefit. Retrofitting is an expensive operation, because it requires completely different machinery.

Driving forces for implementation: No data submitted.

Example plants: None.

Reference literature: [64, EWWG, 2004] [128, TWG, 2005]

3.4.6.4 Electrocoat enamel coatings

Description: Electrocoat coating material is different from the ones currently used and needs completely different machinery for production. The thermal index of insulation films is limited to 130 °C. However, well over 50 % of the application of the wires demands a thermal resistance of up to 200 °C.

Achieved environmental benefits: Significant reduction of solvent emissions.

Cross-media effects: High energy consumption.

Operational data: With the application of water-based enamels, the thickness of the coating is self restricting and does not meet the increasing demands for wire processing of customers. In addition to this, the high number of layers could not be applied.

Experiences show bad adherence to the copper wire, bad mechanical properties, and bad surface properties, which all result in an inadequate electrical performance. Due to the lack of performance, high costs, and technological and safety aspects, this alternative is not yet proven suitable.

Applicability: This technique is only used for very thin coatings.

Economics: Low cost benefit. Introduction of such an application system will need high investment costs and, in addition, the production speed is very low for this continuous running process.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [12, UBA Germany, 2002] [64, EWWG, 2004] [76, TWG, 2004] [128, TWG, 2005]

3.4.6.5 Self-lubricating coatings

Description: The external layer of the coating system also contains lubricant (a special wax).

Achieved environmental benefits: Solvent emissions from a separate lubrication step are avoided.

Cross-media effects: No data submitted.

Operational data: Current minor experiences show that this self-lubricating coating needs an additional application of a different lubricant to prevent friction during coiling operations.

Applicability: Until now, this technique has only been used for specific customers and it is under development in other places. General application of this is not possible these days because of customer requirements. For fine wire, the achievable coefficient of friction is worse than that of solvent-based systems. It could be a resolution for solvent emission problems within the next five years. However, this alternative is not applicable to flat wire manufacturing.

Economics: There is likely to be a zero impact as the enamel cost is higher but the cost of the solvent-based lubricant is eliminated.

Driving forces for implementation: Compliance with the Solvent Emissions Directive.

Example plants: No data submitted.

Reference literature: [12, UBA Germany, 2002] [64, EWWG, 2004] [76, TWG, 2004]

3.4.7 Waste gas treatment

3.4.7.1 Waste gas from enamelling

Description: Air used for drying (e.g. evaporation or curing process) of the enamel coating on the wire, is extracted (see Section 20.11.2) and sent to a catalytical oxidiser (see Section 20.11.4.6). The treated hot air is routed back to the enamelling oven. The solvent destruction provides approximately 50 % of the energy required for the enamelling process. A certain proportion of this cleaned air is continually vented to the air.

The combustion temperature is normally in the range of 500 - 750 °C.

More energy is saved if the extracted hot air is utilised by heat regenerators for heating:

- the incoming laden room air at the entrance of the curing oven
- the bare wire annealer
- the steam generator.

The waste gas from the abatement technique connected to the enamelling ovens for reducing VOC may contain high levels of NO_x (see Section 3.3.3.1). However, no abatement techniques are applied, as they are not currently considered technically or economically viable in the sector.

Achieved environmental benefits: The catalytic oxidiser achieves a removal efficiency of 97 %. Typically achieved emission levels in the production of winding wires are 5 g VOC/kg product for wires with a diameter of, on average, below 0.10 mm, and 10 g VOC/kg product for wires with a diameter of, on average, above 0.10 mm. The solvent destruction provides about 50 % of the energy required. Energy consumption is also reduced because less fresh air needs to be heated.

Cross-media effects: Emissions of NO_x, CO and CO₂.

Operational data: Reduction of the waste gas flow is limited by the need to avoid fugitive emissions from both open ends of the enamelling ovens and to prevent the risk of fire and explosions. A reasonable level of security is assured if the contaminated air contains a quantity of enough clean or circulated air to avoid LEL.

Applicability: Applicable to new and existing plants. This technique is commonly applied as an integrated part of the oven. Single parts of the machinery are not substitutable and, therefore, retrofitting the oven is not possible.

Economics: Continuous catalyst treatment of the circulating process air in the curing ovens saves electrical energy (about 50 %) by solvent oxidation.

Driving forces for implementation: The saving of energy and a reduction of waste gas odours and VOC emissions.

Example plants: All plants.

Reference literature: [12, UBA Germany, 2002] [64, EWWG, 2004] [65, UKDEFRA, 2003] [76, TWG, 2004] [128, TWG, 2005]

3.4.7.2 Lubrication

Description: The fugitive emissions from lubrication are an important source of the VOC emissions from the winding wire industry. Nevertheless, extraction and treatment of these emissions is not technically or economically feasible (see Operational data and Economics below). To reduce these fugitive emissions, during the last 10 - 15 years, a large number of lines have been modified to substitute conventional solvent-based lubricants by solvent-free materials (see Section 3.4.5.6).

Achieved environmental benefits: Reduction in VOCs where solvent-free materials have replaced alternatives containing solvents.

Cross-media effects: Continuing VOC emissions in conventional systems.

Operational data: To dry the wire in the room air, it has to travel horizontally over several metres. This is a large area for applying an extraction system. The lubricant drying process must not be carried out by passing through the enamelling oven as the wax content of the lubricant would burn off due to the high temperatures. Also, guiding the waste gases directly into the enamelling oven, which is running in a nearly closed circuit of hot air, is not feasible because of the huge amount of cold air. The layout of the oven would have to be modified totally (new machines) to cope with this volume of air and reducing only a limited amount of the fugitive emissions. For example, reduction of only 60 % of the fugitive emissions while ventilating some hundred m³/h with relatively low concentrations of VOCs (50 – 100 ppm).

Applicability: Extraction of solvents from the lubrication process is not commonly applied. It has been tested in Sweden and Italy with unsuccessful results.

Economics: To extract the fugitive emissions from the lubricant application is very expensive when modifying the ovens, and it is very expensive to use a central treatment facility to remove or incinerate the solvents. Recent reports for thermal incineration and for a piping system result in installation costs of EUR 300000 - 350000 for the whole factory and additionally, operating costs of EUR 40000 - 50000 per year.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [64, EWWG, 2004] [66, UBA Germany, 2003] [76, TWG, 2004] [128, TWG, 2005]

4 MANUFACTURING OF ABRASIVES

[12, UBA Germany, 2002, 76, TWG, 2004] [128, TWG, 2005]

4.1 General information on the abrasives industry

4.1.1 Areas of application

Grinding is one of the oldest production processes. A principal characteristic of grinding is the effect of numerous, non-orientated cutting materials in the workpiece. Contemporary abrasive materials are synthetic corundum or silicon carbide often cubic boron nitride (CBN) or diamond.

A large variety of workpiece materials can be processed such as ferrous and non-ferrous metals, glass, ceramics, natural stone, concrete, plastics and wood. The application field of grinding is wide and includes activities such as rough grinding of cast iron or high accuracy grinding of tubular needles for medical purposes. Numerous products in tool manufacturing, construction of vehicles, aircraft, power plants or furniture only obtain their finish and high quality surface through grinding.

4.1.2 Production and sales

In Germany, currently more than 100 companies are manufacturing all kinds of abrasives. Therefore, around 70 enterprises are represented by the association of German abrasive manufacturers (VDS – Verband Deutscher Schleifmittelwerke).

According to VDS data, the German abrasive industry plays a leading role in Europe. Table 4.1 gives a rough overview of its economical importance.

	EUR million
Production of bonded abrasives	~ 305
Imports	~ 82
Exports	~ 170
Production of coated abrasives	~ 385
Imports	~ 205
Exports	~ 310

Table 4.1: Abrasive production in 1999 in Germany
[12, UBA Germany, 2002]

4.1.3 Characterisation of the product 'abrasive' and its quality demands

Basically, the production of abrasives can be distinguished between bonded abrasives 'grinding wheels' and coated abrasives 'abrasive paper and tissues'. Loose abrasives exist, which do not have any solid linkage to a backing (e.g. polishing pastes).

Figure 4.1 shows a simplified overview on the development and allocation of the different kind of abrasives.

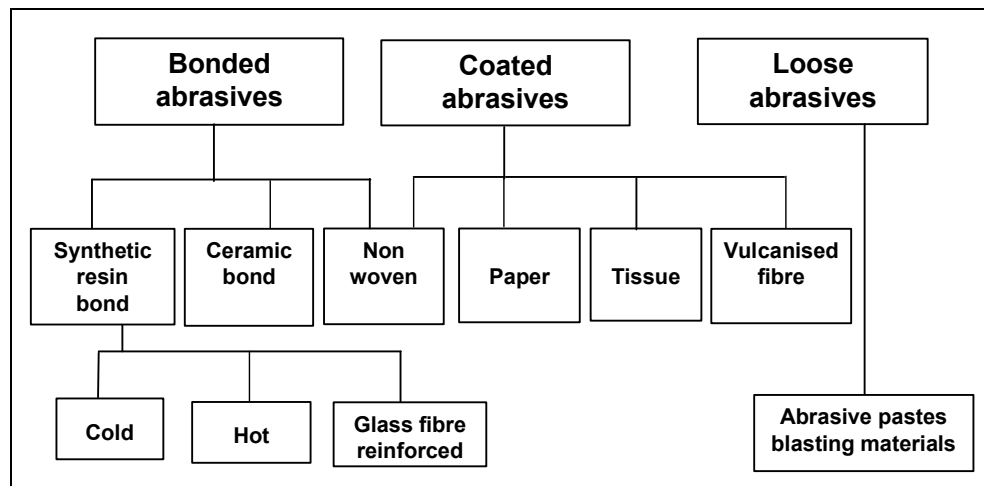


Figure 4.1: Overview on different types of abrasives
[12, UBA Germany, 2002]

Organic solvents are partially used in the fabrication of bonded and loose abrasives. It can be assumed that the German installations do not represent an activity in the sense of the IPPC Directive Annex I point 6.7. Consequently, production processes related to these activities will not be mentioned in the following paragraphs.

The activity of manufacturing coated abrasives may be subject to the IPPC Directive due to the use of considerable amounts of organic solvents and the threshold limits as set in the Directive. Coated abrasives are a basic material for many grinding machines with elements such as blades, stripes, page discs or assembled from those elements (e.g. peel shims, fan grinding wheels, belts). According to the purpose of use and basic material, a large number of bonding systems can be differentiated.

Non-woven abrasives take a special position between coated abrasives and bonded abrasives as they can be both used as an abrasive body as well as an abrasive element. They consist of polyamide fibres, e.g. to which the grinding material is fixed via bonding material. The production processes are comparable to the production of coated abrasives.

Coated abrasives are composed of:

- backing, e.g. paper, finished fabric, vulcanised fibre, film
- bonding material, e.g. glue systems, phenolic resin, epoxy resin, polyurethane, urea resin
- abrasive grain, e.g. flint, silicon carbide, corundum, zirconia alumina, seldom used: diamond and CBN.

4.1.3.1 Backing

The term ‘coated abrasives’ refers to the importance of the backing. According to the purpose of use and the strain of a flexible abrasive, the backing has to show specific properties. For hand grinding or sanding, special flexibility and high buckling resistance are both required. For high performance grinding with abrasive belts, abrasive discs and cylindrical sleeves, excellent mechanical properties such as swell-resistance, tenacity, resistance against abrasion or alternating stress, are required.

To meet all these requirements, the following groups of backing materials are particularly used:

- paper
- fabric
- combination of paper/fabric
- vulcanised fibre.

Table 4.2 shows an example of a classification of the used backing materials:

	Weight class equipped (g/m ²)
A-paper	≤ 85
B-paper	86 – 110
C-paper	111 – 135
D-paper	136 – 220
E-paper	221 – 270
F-paper	271 – 350
G-paper	351 – 500
H-paper	>500
A-paper water resistant	≤ 115
C-paper water resistant	>115
Heavy cotton/X-weight	370 – 400
Flexible cotton/J-tissue	270 – 290
High flexible cotton/J-flex-tissue	200 – 220
Heavy polyester/X-tissue	475 – 505
Very heavy polyester/Y-tissue	630 – 665

Table 4.2: Selected backing materials for coated abrasives
[12, UBA Germany, 2002]

Paper

The papers used in the production of coated abrasives consist of extremely firm and tenacious fibres. They are processed in different qualities, weights, sizes and widths according to the reason for their use. They can be distinguished between:

- flexible
- single layer paper with a homogenous tensile strength in any direction of straining
- heavy, multilayer cylinder paper which has an especially high stability in any direction of rolling (long direction).

All types of backings (A to F shown in Table 4.2) are adjusted to dry grinding. A- and C-papers with water resistant preservation (latex or varnish) are appropriate for wet grinding.

Abrasives on A-, B-, and C-papers are used in offhand grinding and for hand operated grinding machines (e.g. a grinding pencil). D- and E-papers are necessary as backings for stationery/fixed grinding machines up to the highest demand.

Textile backing

Textile backing is used for coated abrasives that are processed into wide bands or used in belt, surface and plunge grinding. They consist of fabric as a result of the high strain they are exposed to. These so-called 'technical fabrics' are made of raw cotton (woven or stitch bonded). They can be distinguished between heavy X-tissue and light J-tissue. This differentiation is made due to the thread layer that means the number of fibres used as the warp and weft. Heavy X-tissue has a comparatively low thread count, compared to the light J-tissue.

Before being treated with abrasive grains, the tissue has to be subjected to a special treatment. The raw tissue is first downsized and dyed and afterwards shrunk to its final density. The fabric is finished on its thrust face with adhesives, synthetic resins/plastics or similar substances and finally flattened.

Vulcanised fibre

Numerous industrial manufacturing processes require special high performance abrasives with a high wear resistance. In this case, vulcanised fibre is used as backing material. Vulcanised fibre is a very hard, multilayer fibre material. In the course of its fabrication, numerous non-woven-like paper webs are connected through flattening with a contact adhesive. Vulcanised fibre can be manufactured in every thickness. In the abrasive industry, the vulcanised fibre thicknesses of 0.8, 0.6 and 0.4 mm are the most important. The wider material is used for high wear resistance and the thinner material for larger flexibility. Abrasives applied mechanically to vulcanised fibre backing have an extremely high resistance to stress. They are applied in almost all industrial branches, e.g. in automotive, machines, ship or apparatus engineering.

4.1.3.2 Bonding material

The efficiency of coated abrasives depends, to a large extent, on the bond (grain adhesion) of the abrasive grain. Consequently, bonding materials play an important role. In order to achieve a good adhesion of the grain and other required properties, the bonding materials are successively applied in several layers.

The following bonding materials are the most important:

- hide glue
- synthetic resin
- varnish.

With consideration of the used bonding agents, the following types of bonding systems are differentiated:

- glue bond (solvent-free). The bond consists of hide glue and the backing of paper or fabric. These coated abrasives are used for lower shear forces or if the long lasting utilisation of the material is not important (e.g. for the treatment of lubricating materials)
- partially synthetic resin bond (resin over glue, solvent-free). The abrasive bond system consists of a hide glue make coat and a size coat of synthetic resin. Abrasive papers or fabrics can be used universally, especially for medium grinding operations. Due to the elastic make coat of hide glue and the resistant size coat of synthetic resins, the qualities are very suitable for the surfacing of formed workpieces
- synthetic resin bond (solvent-free where possible). Abrasives for high stock removal capacity are bonded with synthetic resins. The abrasive grains are bound exceptionally well to fix to the backing by the comparatively strong resin bond. They are resistant to very high cutting forces. High performance rates can be obtained

- varnish, waterproof bond (solvent-based). Numerous workpieces and specific application methods require water-based cooling or rinsing agents. Therefore, the above-mentioned methods cannot be used because either the bonding material or the finishing will be dissolved by the cooling agent. In these cases, totally waterproof tissue qualities are required. As bonding materials, special synthetic resins are used. Such waterproof abrasives are applied for the wet grinding of steel, glass, ceramics, natural or artificial stone and plastics. For example, when grinding primers, fillers and clear or pigmented lacquers, often clogging or dusty grinding residues result. These load or glaze the abrasive. Therefore, it is necessary to work with waterproof abrasive papers in wet grinding. These papers have a flexible paper backing, which is impregnated with latex or lacquer to make them water resistant. The make- and size coat is made with special resins and lacquers. Waterproof abrasive papers are not only water resistant but also resistant against loading and glazing.

4.1.3.3 Abrasive grain

Aluminium oxide

Table 4.3 shows typical values of alumina applied as inert abrasive grain.

	Corundum (%)	Semi special fused alumina (%)	Special fused alumina rose (%)	Special fused alumina red (%)	Special fused alumina white (%)	Ceramic corundum	Zircon corundum (%)
Al ₂ O ₃	95.83	97.69	99.52	97.50	99.50	99.6	60.0
ZrO ₂	-	-	-	-	-	-	39.0
SiO ₂	0.60	0.38	-	0.02	0.05	0.07	0.30
TiO ₂	3.12	1.45	-	-	0.02	0.2	0.25
Fe ₂ O ₃	0.10	0.15	0.05	0.05	0.05	0.02	0.25
Na ₂ O	-	-	0.18	0.3	0.30	0.01	0.03
CaO	0.05	0.03	-	-	0.05	0.01	0.09
MgO	0.20	0.15	-	-	0.01	0.015	0.02
CrO ₂			0.25	2.0			
Others	0.10	0.15	-	0.13	0.02	0.075	0.06
Colour	Dark brown	Light brown	Rose	Ruby red	White	White	Light grey

Table 4.3: Alumina applied as inert abrasive grain (typical values)
[12, UBA Germany, 2002]

Silicon carbide

Table 4.4 shows typical values of silicon carbide applied as abrasive grain.

	Black SiC (%)	Green SiC (%)
SiC	98.26	99.66
Free Carbon (C)	0.19	0.29
Fe	0.10	0.02
Si	0.19	0.03
Others	1.26	-

Table 4.4: Silicon carbide applied as abrasive grain (typical values)
[12, UBA Germany, 2002]

Table 4.5 shows the use of solvent attributed to the different products.

Base	Product	Formed part	Application	Bonding material systems	Solvent
A-Paper	Dry grinding paper	Sheets, rolls	Lacquer and wood grinding (paint)	Hide glue, synthetic resin bond	No
B-Paper	Dry grinding paper	Sheets, rolls	Lacquer and wood grinding (paint)	Hide glue, synthetic resin bond	No
C-Paper	Dry grinding paper	Sheets, rolls, belts	Lacquer, wood and metal grinding (machine)	Partial or complete synthetic resin bond	No
D-Paper	Dry grinding paper	Sheets, rolls, belts	Lacquer, wood and metal grinding (machine)	Partial or complete synthetic resin bond	No
E-Paper	Dry grinding paper	Sheets, rolls, belts	Lacquer, wood and metal grinding (machine)	Partial or complete synthetic resin bond	No
F-Paper	Dry grinding paper	Sheets, rolls, belts	Lacquer, wood and metal grinding (machine)	Partial or complete synthetic resin bond	No
A-Paper waterproof	Wet grinding paper	Sheets	Common grinding of lacquer (hand)	Synthetic resin bond	Yes
C-Paper waterproof	Wet grinding paper	Sheets, belts	Common grinding of lacquer (hand) Machine grinding	Synthetic resin bond	Yes
X-tissue cotton	Dry grinding; wet grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machines)	Synthetic resin bond	Partially
J-tissue cotton	Dry grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machine)	Synthetic resin bond	Partially
J-flex-tissue	Dry grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machine)	Synthetic resin bond	Partially
X-tissue polyester	Dry grinding; wet grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machine)	Synthetic resin bond	Partially
Y-tissue polyester	Dry grinding; wet grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machine)	Synthetic resin bond	Partially

Table 4.5: Use of solvents in manufacturing attributed to products [12, UBA Germany, 2002]

4.1.4 Quality requirements

The most important quality criterion is the retaining of the standardised grain size. Toughness, hardness, low dust content, no components of quartz or fibrous parts, and the grain structure are also important. Quality requirements that arise from customers are:

- range of flexibility
- non-allergenic properties for hand-wet grinding
- the amount of grains applied to the abrasive for very fine grains.

Due to these requirements, the use of organic solvents is currently necessary in the case of abrasives for wet grinding.

4.2 Applied processes and techniques in abrasives manufacturing

4.2.1 Process overview

Coated abrasives are produced in the following way:

- coating of a backing with bonding materials
- electrostatic or mechanical grain coating as specified in Section 4.1.3
- pre-drying
- repeated coating with bonding materials
- drying.

Differences in the procedures include the type of drying ovens (festoon drier or tensionless drier), the application procedure and the waste gas treatment (biological treatment, thermal combustion or without any treatment).

Solvent coatings are more frequently used in the production of jumbo rolls to self-adhesive products or endless abrasive belts.

Coated abrasives with constant quality are manufactured in production plants with high production levels. Such plants usually consist of the following units:

- base coat part (maker)
- pre-drier
- size coat part (sizer)
- drier
- spooler.

In the first step, the reverse side of the backing is printed in the so-called 'maker' with the required information (e.g. brand and quality labels). Afterwards, the make coat is applied on the front side of the backing. Then it is coated with abrasive grains. In the second part of the plant – the pre-drier – hot air dries or hardens the make coat. In the third production unit – the 'sizer' – the backing that is now coated with abrasive grains is furnished with a size coat. In the fourth unit, the hot air heated drier can be found and the finished abrasive material runs through it for a specific time. After this procedure, the material leaves the plant dried and cured and is rolled up into large rolls (jumbo rolls).

A multitude of electronic and thermal measuring units control the whole procedure and ascertain specific tolerance limits. Among other things, this refers to the grain coating of the backing.

4.2.2 Detailed process steps

Figure 4.2 shows an overview of a typical plant.

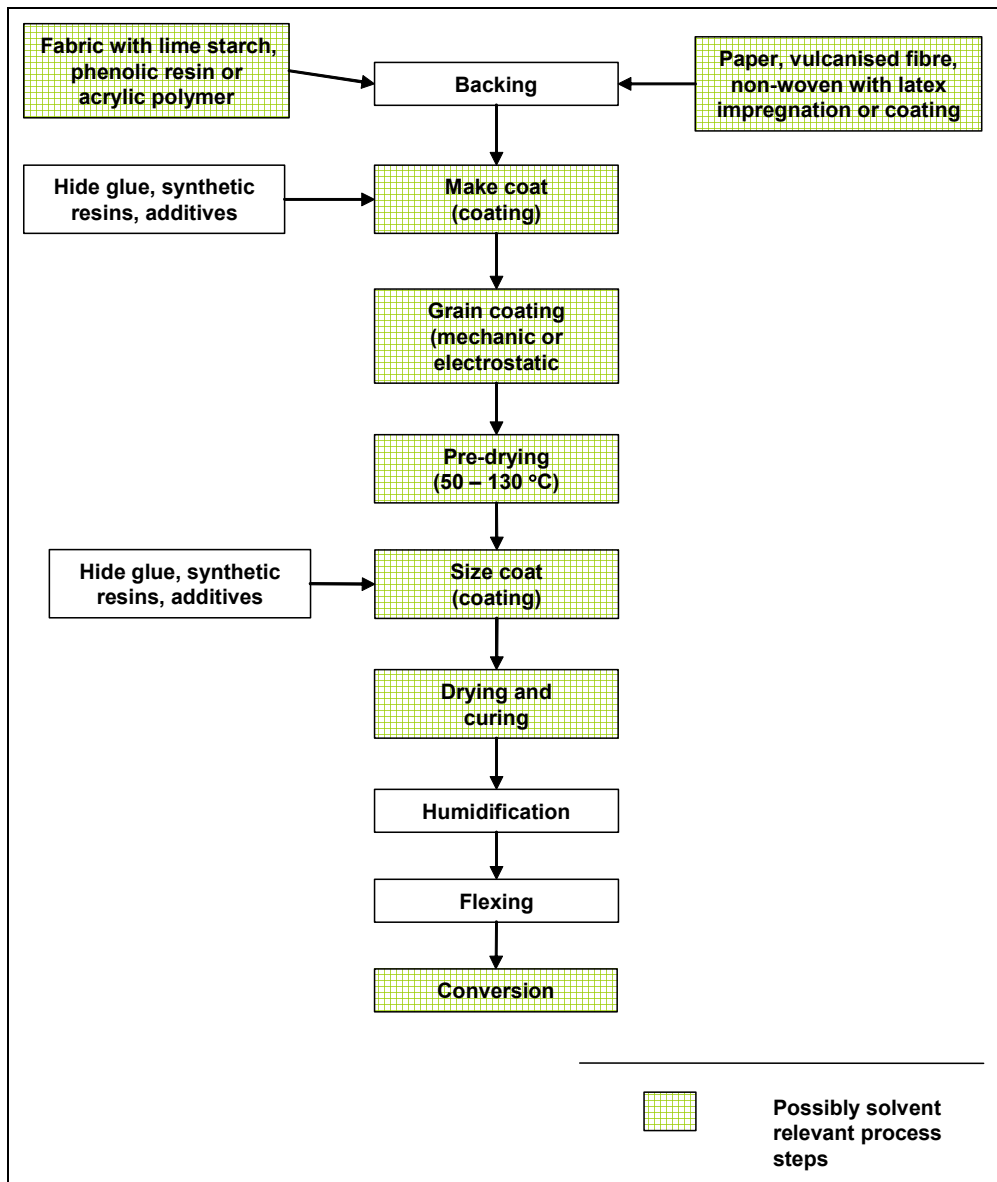


Figure 4.2: Schematic process flow for coated abrasives [12, UBA Germany, 2002]

4.2.2.1 Pretreatment of backings

The pretreatment is an optional process step in an abrasive production plant.

Paper

Depending on the further application of the paper, the pretreatment differs. For example, the backing for waterproof abrasive papers is impregnated with long chain alkyd resins. Latex dispersion sometimes used in combination with water dilutable phenolic resins (for better heat resistance) may be a solvent-free alternative.

Fabrics

The following fabrics are used as backing:

- cotton
- synthetic
- mixed (cotton and synthetic).

The modification of the bonding material for the tissue depends on the requested (mechanical) flexibility of the product. Phenolic resins, caoutchouc (natural rubber) or dispersions of synthetics are the common materials for this purpose.

Vulcanised fibre

Vulcanised fibre is commonly not pretreated.

4.2.2.2 Coating of the backing with bonding materials

The backings are coated with the bonding material in a coating machine, e.g. by means of a spreader roll (application of the make coat).

Depending on the application profile of the abrasive, there are different bonding materials. In addition to natural products such as hide glue and starch or resins (e.g. epoxy, urea, alkyd and polyurethane resins), phenolic resins are mostly applied. The advantages of phenolic resins compared to other bonding materials are a better adherence, a lower sensitivity against humidity and a higher thermal resistance. Aqueous phenolic resins are often preferred to the slightly more flexible products with a solvent content because of their easier handling process.

The drying and hardening process is carried out in the festoon pre-drier. The backing material runs in large loops over sticks through the various temperature zones of the drier or hardener, which is heated with circulating hot air. Thus, a specific dwell time corresponding to the bonding material is guaranteed.

If necessary, the web is stretched at the end of the drier. For the final imbedding and fixing (size coating), several binding layers may be applied.

The conclusive hardening of phenolic resins is carried out at temperatures up to a range of 100 to 140 °C, depending on the bonding and the abrasive grain. This procedure takes place in a drying channel (such as in predrying) or after spooling in the hardening oven.

4.2.2.3 Coating of the backing with grain**Electrostatic grain coating**

The backing runs through an electrostatic field. The side with the make coat is positioned downwards. At the same time, the abrasive grain runs for a certain distance under the coated backing on a conveyor belt. When the abrasive grain enters the electrostatic field, it is charged and thus attracted by the backing above. It reaches the coated backing and trickles into the make coat. During this process, the grains are oriented with its sharp ends vertical to the backing. As a consequence, the abrasive obtains outstanding cutting characteristics.

Mechanical grain coating

Before the electrostatic grain coating, the coated abrasives were coated with the so-called 'gravity grain coating'. This procedure is still in use in some special fields. The abrasive grain falls over a hopper and free falls onto the make coat coated backing. Most of the grain clings in the binding layer. The surplus grain falls into a collecting funnel when the direction of the backing web is changed. From there, the abrasive grain can be recycled and used again.

Other coatings

For special applications where fine grain sizes are needed, the abrasives are coated in a third procedure – the elutriating process. The grain, polish powder or filling material is directly added to the bonding material. In a sizer, the well mixed mass runs over reverse rolls and is applied to the backing material. The application of a make coat is not necessary here.

4.2.2.4 Flexing

After the spooler, the rolls of abrasive tissue, paper or fibre (jumbos) have to be further treated in order to guarantee the quality of the products depending on its further purpose. To this end, the rigid coating with grain and bonding materials is rendered flexible after hardening and conditioning. Depending on the kind of abrasive used, there are several particular methods for flexing. They can be differentiated between 90°-flexing and cross-flexing. For the 90°-flexing, the non-sprinkled side of the abrasive is drawn over a flexing roll.

The degree of flexing depends on the radius of the flexing roll. The flexing is realised according to the specific purpose and properties of each abrasive. When the layer of the bond material and the abrasive grain is broken due to the very high flexing, this leads to reduced abrasive capacity of the product.

4.2.3 Components of installations and required differentiation

The described processes are typically realised in installations with the components listed in Table 4.6:

Unrolling	Unroll stands with a working width of 900 to 1650 mm and a speed of 10 to 50 m/min are in use
Printing	Usually two to three printing rolls are used
Roll coating (alternative: spraying)	Realised through a two printing roller with ladle tank or alternatively with jet spraying
Grain coating field (electrostatic or mechanic)	Use of a grain coating field with plate capacitor (around 30 kV or more voltage) or grain coating hopper (hopper gate on the backing)
Drier (loop drier or tensionless drier)	Temperature of 35 to 110 °C (in the loop drier, the coated web runs through in loops; in the tensionless drier, the web is transported flat without contact through the drier)
Humidification	Usually at the end of the drier in a vapour zone
Spooling	Realised through a running lap winder
End drying	Use of a small dimensioned drier, usually with the capacity for single jumbo rolls
Exhaust air treatment	Application of dust separators and thermal or regenerative post-combustion at 700 °C (or higher) with or without energy recovery (depending onsite-specific circumstances and energy or heat demand)
Water treatment	Biological water treatment plant or bioreactor
Flexing	Flex machines consisting of unrolling, flexing rods (the web runs with the back side in a narrow angle over the flexing rod in order to make the product flexible), roll up
Conversion	Glueing of abrasive belts to overlapping endless belts is prepared in machines for cutting into sections before glueing under pressure and heat in pressure units. PU-glues containing solvent may be used. Cutting and punching devices produce sheets, discs and rolls

Table 4.6: Components of installation and differentiation
[12, UBA Germany, 2002]

System differentiations related to explosion protection

It is usually necessary to install explosion protection equipment around the applying units and the open run of webs. The applying units and the open run of webs are equipped with properly working suction units. Monitoring takes place by suitable measures appropriate to the site-specific conditions.

Where required, all electrical equipment is explosion protected according to these guidelines. All loop driving devices are situated outside the loop zone. The loop zone is exclusively indirectly heated.

The maximum speed of the production line is controlled to 50 % of the LEL of the substance with the lowest flashpoint.

In order to achieve a negative pressure and to guarantee the 50 % LEL, the drier is constantly driven with a determined exhaust air amount.

The waste gas streams are collected and led to the waste gas treatment installation. The air streams are monitored. The grain coating room is equipped with an extraction unit and monitored as well.

The coating machines along with the electrostatic grain coating installations are protected by fire extinguishing systems.

The pre- and the main drier are completely protected by inner fire extinguishing systems (dry ascending pipes).

4.3 Current consumption and emission levels in abrasives manufacturing

4.3.1 Mass balances

In Table 4.7, Table 4.8 and Table 4.9, mass balances of three existing plants are shown. Table 4.7 shows the mass balance of an abrasive production plant with a typical product mix of different binding types:

- hide glue (solvent-free)
- partial synthetic resin (solvent-free)
- synthetic resin (almost solvent-free).

The balance has been established on real values with specific values related to 10 kilotonnes final product per year. The capacity of this plant corresponds approximately to this amount. The output values are half hour mean values.

Input		Output	
Raw materials ⁽¹⁾			
Paper/fabric	4701 t/yr	Product	10000 t/yr
Abrasive grain	3214 t/yr	Waste for combustion	77 t/yr
Bonding material including phenols and other synthetic resins	2436 t/yr	Waste for disposal	37 t/yr
		Hazardous waste	116 t/yr
Solvents ⁽²⁾			
Water	827 t/yr	Water	827 t/yr
Organic solvents ⁽³⁾	275 t/yr	Fugitive emissions of VOC	38 t/yr
		TOC after thermal post-combustion	<20 mg/m ³
		NO _x after thermal post-combustion	<100 mg/m ³
		CO after thermal post-combustion	<100 mg/m ³
		Relative oxygen of a thermal or regenerative post-combustion	18 – 21 %
Energy (in kWh/yr)			
Electric current	3007243		
Gas	21871076		
Hot water	16379075		
Note: [76, TWG, 2004]			
⁽¹⁾ The input of raw material adds up to 10351 t and the output only to 10230 t (mass balance is not closed)			
⁽²⁾ Similarly with the organic solvent (input 1102 t, output 865 t)			
⁽³⁾ Differences in the mass balances are due to the combustion of solvents and other additives in the waste gas treatment systems [128, TWG, 2005]			

Table 4.7: Mass balance of abrasive manufacturing in plant 1 [12, UBA Germany, 2002]

Table 4.8 shows the mass balance of plant 2, where only fabric is assembled by means of preservation. The manufactured fabric is used as backing for coated abrasives. Light and heavy cotton and also heavy polyester fabrics are impregnated. The values shown are exclusively values of the fabric impregnation. The mass balance has been established on real values with specific values related to 10 kilotonnes final product per year. The capacity of this plant is about 5 kilotonnes final product per year. The corresponding abrasive production is carried out in plant 3, which is described in Table 4.9.

Input		Output	
Raw materials⁽¹⁾			
Raw fabric	8101 t/yr	Impregnated fabric	10000 t/yr
Corresponding to m ² /yr	24261025	Corresponding to m ² /yr	24261025
Phenolic resins	1002 t/yr	Hazardous waste	185 t/yr
Latices	2104 t/yr	Waste for disposal	133 t/yr
Hide glue/starch	585 t/yr	Waste for further treatment	484 t/yr
Additives	670 t/yr	Paper waste	117 t/yr
Solvents⁽²⁾			
Organic solvents ⁽³⁾	125 t/yr	Fugitive emissions of VOC	12 t/yr
		TOC after thermal post-combustion	<20 mg/m ³
		NO _x after thermal post-combustion	<100 mg/m ³
		CO after thermal post-combustion	<100 mg/m ³
		Dust	<10 mg/m ³
		Relative oxygen of a thermal or regenerative post-combustion	18 – 21 %
Accessory agents			
Water (m ³ /yr)	101630	Waste water	
		Manufacturing	46750 m ³ /yr
		Cooling	8794 m ³ /yr
		Vapour	21752 m ³ /yr
		Sanitary	7692 m ³ /yr
		Cleaning	16639 m ³ /yr
Energy (in kWh/yr)			
Energy	46258325		
Note: [76, TWG, 2004]			
⁽¹⁾ The input of raw material adds up to 12462 t and the output only to 10919 t (mass balance is not closed)			
⁽²⁾ The same with the organic solvent (input 125 t, output 12 t).			
⁽³⁾ Differences in the mass balances are due to the combustion of solvents and other additives in the waste gas treatment systems [128, TWG, 2005]			

Table 4.8: Mass balance of impregnation plant for the manufacturing of abrasives in plant 2 [12, UBA Germany, 2002]

Table 4.9 shows the mass balance of plant 3, which is a production site for coated abrasives. It comprises several machines, however without pretreatment of the backings. The production includes hand grinding and dry grinding papers, waterproof paper and tissue abrasives, light and medium as well as heavy fabric qualities and abrasive non-woven products. The balance has been established on real values with specific values related to 5000000 m²/yr final product. The capacity of this plant is slightly above this amount. Output values are half hour mean values.

Input ⁽¹⁾		Output ⁽¹⁾	
Raw material			
Impregnated backing	5000000 m ² /yr	Product	5000000 m ² /yr
Abrasive grain	992 t/yr		
Solvents			
Organic solvents ⁽²⁾	259 t/yr	Fugitive emissions of VOC	30.1 t/yr
		TOC after thermal post-combustion	<20 mg/m ³
		NO _x after thermal post-combustion	<100 mg/m ³
		CO after thermal post-combustion	<100 mg/m ³
		Dust	<10 mg/m ³
		Relative oxygen of a thermal or regenerative post-combustion	18 – 21 %
Phenolic and other resins	520 t/yr		
Latices	22.2 t/yr		
Accessory agents			
Water	32063 m ³ /yr		
Energy			
Gas and current	34831581 kWh/yr		
Note: [76, TWG, 2004]			
⁽¹⁾ The mass balance is not closed			
⁽²⁾ Differences in the mass balances are due to the combustion of solvents and other additives in the waste gas treatment systems [128, TWG, 2005]			

Table 4.9: Mass balance of abrasive manufacturing in plant 3 [12, UBA Germany, 2002]

4.3.2 Consumptions

See Section 4.3.1 for the consumption of raw materials, solvents, water and energy.

4.3.3 Emissions

4.3.3.1 Emissions to air

General background on industries using adhesives

In the SED, the manufacture of abrasives is grouped with other industries using adhesives. Other relevant industries that are:

- addressed in this document: the production of adhesive tapes, abrasives, the transportation sector (passenger cars, commercial vehicles, rail vehicles, and aircraft), and the wood material and furniture industry
- not addressed in this document: composite foils, mobile homes, the manufacture of shoes and leather goods.

Abrasive manufacture cannot be disaggregated from the following data, but it does provide some background. At EU-25 level in 2000 (according to the RAINS model) NMVOC emissions were 257.6 kt representing 2.4% of total NMVOC emissions. Total activity was 680 kt of adhesives used, and the average emission factor is about 378.8 g NMVOC/kg of adhesives meaning that emissions from this sector are already partly treated* in EU-25 (the untreated* emission factor being 780 g/kg). EGTEI estimate reductions achievable across all the industries using solvent to be 76 to 98 %; however, it is not known how representative this is of abrasive manufacture. (*Treated/untreated in this context means not only waste gas treatment but also other measures to reduce VOC emissions).

Specific data for the manufacture of abrasives

Examples of emissions from three plants in Germany are given in Section 4.3.1.

After waste gas treatment, the emission levels achieved are <20 mg organic carbon/m³, 100 mg CO/m³ and 100 mg NO_x/m³. The maximum limits for phenol and formaldehyde (20 mg/m³) are also kept.

4.3.3.2 Emissions to water

Waste water arises from the cleaning of machine parts, mainly containing phenol and fluoride. The following waste water treatments are normally carried out before discharge to a municipal waste water treatment plant:

- neutralisation
- fluoride precipitation
- filtration
- biological treatment.

The techniques mentioned above are described in detail in the STM BREF [59, EIPPCB, 2006] and in the CWW BREF [67, EIPPCB, 2003].

The following emission levels or lower are achieved:

- total phenol 75 mg/l
- volatile in steam phenol 20 mg/l
- fluoride 40 mg/l
- sulphate 200 mg/l
- iron 1 mg/l
- aluminium 1 mg/l
- zinc 1 mg/l.

4.3.3.3 Waste

According to the product spectrum, waste arises during conversion in the form of cuttings (e.g. edges, punchings). In some cases, a proportion of these cuttings may be separated, recut and sold.

4.4 Techniques to consider in the determination of BAT for the manufacturing of abrasives

In Chapter 20, techniques are discussed which might also be applicable to the manufacturing of abrasives. In Table 4.10, the general techniques relevant for the manufacturing of abrasives are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 4.10: Reference to techniques generally applicable to the sector

The EGTEI synopsis sheet for the industrial application of adhesives (see Annex 24.1.1) gives some data on the cost-benefit at a European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations and products [134, EGTEI, 2005].

4.4.1 Conventional solvent-based bonding materials

Description: Solvent-based bonding materials are applied where workpieces and application methods require water cooling, e.g. for wet grinding of steel, glass, ceramic, natural or artificial stone and plastics. The required waterproof qualities of the abrasive paper can only be achieved by using solvent-based bonding materials.

Phenolic resin is the most commonly used resin. Others are epoxy resins, polyurethane and urea resins. No information has been made available on the organic solvent content.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: It is common practice to treat the waste gases containing solvent.

Applicability: This technique is commonly applied. Solvent-based bonding materials are necessary for the production of wet grinding abrasives.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [12, UBA Germany, 2002] [76, TWG, 2004]

4.4.2 Substitution of conventional solvent-based bonding materials

4.4.2.1 Solvent-free bonding materials

Description: Solvent-free bonding materials are hide glue and starch, and partial synthetic resins. In the case of fabrics, they can be recognised for specific product qualities. However, resins are usually applied, because they have a better adherence, a lower sensitivity against humidity and a higher thermal resistance. Water-based phenolic resins are often preferred to the slightly more flexible products with solvent content, because of their easier handling process.

The waterproof qualities required for abrasive paper can only be achieved by using solvent-based bonding materials.

Achieved environmental benefits: Solvent emissions are omitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Solvent-based bonding materials are necessary for the production of wet grinding abrasives. They are commonly applied for the production of dry grinding papers.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [12, UBA Germany, 2002] [76, TWG, 2004]

4.4.3 Drying

4.4.3.1 Convection drying

For a general description, see Section 20.8.1.1. Loop or tensionless driers are commonly applied at a temperature of 35 - 110 °C. In the loop drier, the coated web runs through in loops. In the tensionless drier, the web is transported flat and without contact through the drier.

[12, UBA Germany, 2002]

4.4.3.2 Electromagnetic drying

For a general description, see Section 20.8.1.4. Electromagnetic drying, i.e. high frequency drying (HF), is commonly applied to water-based coatings.

[12, UBA Germany, 2002]

4.4.4 Waste gas treatment

4.4.4.1 Increase of the internal solvent concentration

For a general description, see Section 20.11.3.1. This is commonly applied to increase the solvent reduction efficiency of the waste gas treatment system. The maximum speed of the production line is at 50 % LEL of the substance with the lowest flashpoint. To this end, the speed is electronically blocked. In order to achieve negative pressure and to guarantee the 50 % LEL, the drier is constantly driven with a determined amount of exhaust air.

[12, UBA Germany, 2002]

4.4.4.2 Containment and collection of waste gases

For a general description, see Section 20.11.2. The waste gas from the places where the web runs open, the units applying bonding material and the drier are collected and routed to the waste gas treatment system. Fugitive solvent emissions are reduced to a range of 9.6 - 13.8 % of the total solvent input.

[12, UBA Germany, 2002] [128, TWG, 2005]

4.4.4.3 Dry filter systems

For a general description, see Section 20.11.3.6. Several types of bag filters are applied. The emission values obtained depend on the dust characteristics, filter construction and the filter itself. A static dust concentration of $<10 \text{ mg/m}^3$ is achievable. However, typically this is 20 mg/m^3 .

[12, UBA Germany, 2002]

4.4.4.4 Thermal oxidation

For a general description, see Section 20.11.4.2. At exhaust air volumes of up to $66000 \text{ Nm}^3/\text{h}$, the installations achieve emission values of $<20 \text{ mg VOC/m}^3$ (the half hour mean value).

[12, UBA Germany, 2002]

4.4.4.5 Regenerative thermal oxidation

For a general description, see Sections 20.11.4.4 and 20.11.4.5. This is commonly applied to treat waste gases from the driers, the places where the web runs open and to the units applying bonding material.

During production, the regenerative oxidiser can work normally autothermal (above $2 - 3 \text{ g/m}^3$ organic solvent in the waste gas). At exhaust air volumes of up to $66000 \text{ Nm}^3/\text{h}$, the installations achieve emission values of $<20 \text{ mg C/m}^3$, $<100 \text{ mg CO/m}^3$ and $100 \text{ mg NO}_x/\text{m}^3$ (the half hour mean values). Levels for phenol and formaldehyde of $<20 \text{ mg/m}^3$ are achieved.

[12, UBA Germany, 2002]

4.4.4.6 Biological treatment

For a general description, see Section 20.11.8. This technique is sometimes applied to the waste gas from the drying ovens.

[12, UBA Germany, 2002]

4.4.5 Waste water treatment

See Section 4.3.3.2.

5 MANUFACTURING OF ADHESIVE TAPE

[14, DFIU and IFARE, 2002] [76, TWG, 2004, 128, TWG, 2005] [184, AFERA, 2005]

5.1 General information on the manufacturing of adhesive tape

Adhesive tapes are used in many different industries such as packaging, vehicle production, electrical equipment, construction, furniture and paper industries as well as for the do-it-yourself market. Each industry has a wide range of different requirements for product applications and properties that have to be met. In the vehicle industry for example, adhesive tapes are used for attachment of parts onto outer surfaces of car bodies, for abrasion protection, for caulking small openings, for wrapping cables, for masking during painting and for supporting functions during assembly.

Depending on the use, widely different requirements concerning product properties have to be met, such as adhesive strength, resistance against temperature, mechanical rigidity, tensile strength, shear adhesion, etc. VOC emissions in the production of adhesive tapes originate from the application of solvent-based adhesive systems and the application of auxiliary material containing solvent such as release agents and primers.

Due to the range of products and production techniques, installations usually specialise in certain types of products. Some installations, specialise in using adhesive systems based on solvents. In these installations, significant amounts of VOC are used as solvents in the adhesive systems, in auxiliary materials such as release agents and primers and as cleaning agents. In most cases, the amount of solvents used exceeds the threshold of 200 t/yr.

In 2003, 45 installations in Europe produced about 3300 million m² of these solvent-based adhesive tapes. They share a proportion of about 40 % in the total European adhesive tape production.

The other part of the European adhesive tape market is covered by product groups for other purposes or with other properties. They are produced in installations using adhesives based on hot melt, water-based dispersions and UV cross-linking adhesives. These installations use no or only very small amounts of VOC (usually for cleaning).

5.1.1 Applications of pressure-sensitive adhesives

The selection of the solvent-based adhesive system depends on the technical application of the adhesive tapes. Table 5.1 gives an overview of different applications of adhesive tapes and the adhesives most commonly used.

Tape use	Application	Solvent-based pressure-sensitive adhesive
Packaging	Adhesive labels, adhesive tapes for packaging	Natural rubber adhesives, (SB)
Automotive industry	Transfer adhesive tapes for decorative strips and flank protection strips, insulating slabs, assembly aids for wheel case covers and skirt side panels, adhesive tapes for winding wire harnesses	Natural rubber adhesives, esters of acrylic acid and acrylates
Construction industry	Foamed plastic adhesive tapes for sealing of windows, caulking of construction splices and expansion joints, carpeting adhesive tapes, etc.	Acrylate dispersions
Medicine	Medical tapes, adhesive plasters	Pure acrylates, polyacrylates
Furniture industry	Transfer adhesive tapes for mirrors, etc.	Acrylate adhesives

Table 5.1: Applications of solvent-based pressure-sensitive adhesives for adhesive tapes [14, DFIU and IFARE, 2002] [128, TWG, 2005]

5.2 Applied processes and techniques in adhesive tape manufacturing

5.2.1 Construction of adhesive tapes

Solvent-based adhesive tapes consist of a substrate, a coupling agent, a pressure-sensitive adhesive and releasing agents. The substrates used are: paper (widely used), fabrics, polyvinyl chloride foils, polyester, polyamide and aluminium. Products can be classified as transfer adhesive tapes (double-sided adhesive tapes), adhesive tapes for packaging purposes and adhesive tapes for coating purposes.

For the production of one-sided adhesive tapes, a pressure-sensitive adhesive is applied onto a substrate. Adhesion of the adhesive layer onto the substrate is improved by a physical surface preparation or an application of primers. For the production of double-sided adhesive tapes, a pressure-sensitive adhesive is applied onto both sides of the substrate. A releasing agent is applied onto one of the adhesive layers in order to avoid contact between the adhesive layers.

5.2.2 Materials for the production of adhesive tapes

Pressure-sensitive adhesives are organic compounds with a high self strength that have a high adhesive strength with different surfaces at the same time. Unlike other adhesive systems, the plastic adhesive film is also active in dry conditions. The adhesive shows visco-elastic behaviour and can be considered as a fluid with a very high viscosity. A classification of pressure-sensitive adhesives is shown in Table 5.2.

Type of adhesive	Caoutchouc adhesive	Acrylate adhesive	Other pressure-sensitive adhesives
Adhesives using solvents in production			
Dissolution in organic solvents	Natural rubber (NR), butadiene styrene (SBR), styrene isoprene styrene block copolymer (SIS)	Pure acrylate, polyacrylate	Polyurethane, neoprene
Adhesives not using solvents in production			
Dispersion in water	Styrene butadiene styrene block copolymer (SBS), SBR latex, carboxylated (CSBR)	Pure acrylate, polyacrylate	Polyvinyl acetate, acrylate, ethylene vinyl acetate (EVA)
Hot melt	Styrene isoprene styrene block copolymer (SIS), butadiene styrene copolymer (SBR), styrene butadiene styrene block copolymer (SBS)	Polyacrylate	No application
Systems with 100 % solids content, radiation curing or as two part system	Natural rubber (NR), butadiene styrene copolymer (SBR), styrene isoprene styrene block copolymer (SIS)	Pure acrylate, polyacrylate	Polyurethane, polyester, two part polyurethane

Table 5.2: Pressure-sensitive adhesives for the production of adhesive tapes
[14, DFIU and IFARE, 2002]

Caoutchouc adhesives and resins

Caoutchouc adhesives that are technically processed are natural rubber (NR) and synthetic caoutchouc adhesives such as butadiene styrene (SBR), styrene isoprene styrene (SIS).

For the production of natural caoutchouc systems, caoutchouc is dissolved in organic solvents together with resins influencing cohesiveness and adhesion (so-called ‘tackifiers’). Other additives, such as agents preventing the ageing processes are also added. These adhesives are mainly used for plasters, but also for double-sided adhesive tapes, adhesive tapes for packaging and coating adhesive tapes.

Acrylate adhesives

Adhesive tapes are coated with acrylate adhesives especially for long-term or exterior use. Acrylate adhesives dominate the field of assembly application due to their higher thermal and chemical resistance as well as higher cohesion compared to caoutchouc adhesives. Solvent-based adhesives are dissolved in organic solvents (e.g. benzene, ethyl acetate or toluene). The solvent-based acrylate adhesives possess higher cohesiveness than water-based.

Other pressure-sensitive adhesives

Thermoplastic elastomers, polyurethanes, as well as neoprene are also used for the production of adhesive tapes for special applications.

Solvents

Solvents for pressure-sensitive adhesives are aromatic and aliphatic solvents with a boiling point of between 60 and 120 °C as well as mixtures of these components. Solvent proportions in adhesives ready for application range between 60 and 75 %. High solid systems with solid proportions over about 60 % are used in some cases.

Non-solvent adhesive tapes

(Note the comments in Section 5.1 about installations using specific processes).

Synthetic caoutchoucs are applied as hot melts without solvents. For the production of such synthetic caoutchoucs, resins and other auxiliary materials are mixed in the melt, for example, in continuously working extruders and then coated as a melt. The thermoplastic behaviour of the compound is reversible.

Acrylate adhesives can also be applied as water-based dispersions, as 100 % solid systems (as UV cross-linking compounds).

Auxiliary materials

Coupling agents allow a failure-free unwinding and restripping of the adhesive tape by increasing the adhesion between the pressure-sensitive adhesive and the substrate. The coupling can be realised by application of a primer layer. Primers are applied dissolved in organic solvents. Common low emission techniques for surface treatment are corona discharge, flammng and low pressure plasma surface preparation.

Releasing agents

Releasing agents are used to prevent adhesion of the pressure-sensitive adhesive to the surface of the adhesive tape. Silicones are applied as releasing agents for acrylate adhesives and synthetic caoutchoucs. For natural caoutchouc adhesives, systems containing stearyl groups are also in use. Most of the releasing agents are applied as solutions.

Impregnating agents

Impregnating agents are applied for surface refinement of smooth, absorbent papers in order to increase the wet strength and mechanical rigidity. For this process, polymer dispersions containing water are used based on SBR acrylate, acrylate as well as acrylate-natural caoutchouc systems for special applications.

Cleaning agents

Usually, the same solvents are used for the different cleaning activities as are used in the adhesive systems, both for cleaning during production or for maintenance.

5.2.3 Production process of adhesive tapes

[128, TWG, 2005] [184, AFERA, 2005]

The production process can be subdivided into three main steps:

- coating: surface treatment of the substrate and the coating of the sheet-like substrate with the adhesive
- drying (cross-linking) of the adhesive
- winding.

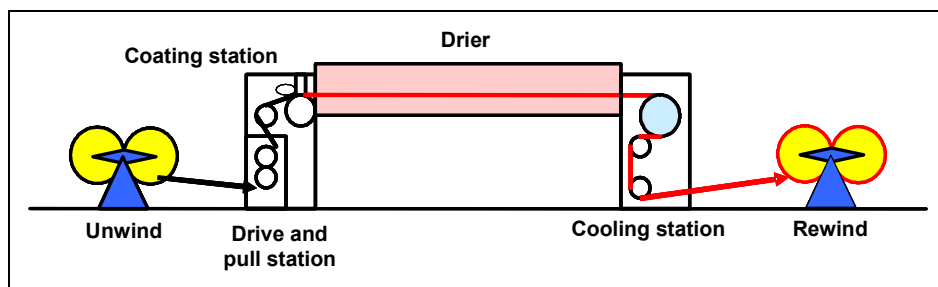


Figure 5.1: Schematic layout of an adhesive tape production line

[184, AFERA, 2005]

In addition, in (nearly) all solvent-based installations, the following auxiliary processes are installed:

- storing the adhesive components
- adhesive mixing
- waste gas treatment (of gas of the drier)
- slitting the rewound tape.

This section describes the production steps of adhesive tape production which may have an impact on the environment.

Coating

The application of a solvent-based pressure-sensitive adhesive can be carried out by different application techniques. Doctor knife systems or reverse-roll-coat systems as shown in Figure 5.2 are commonly used.

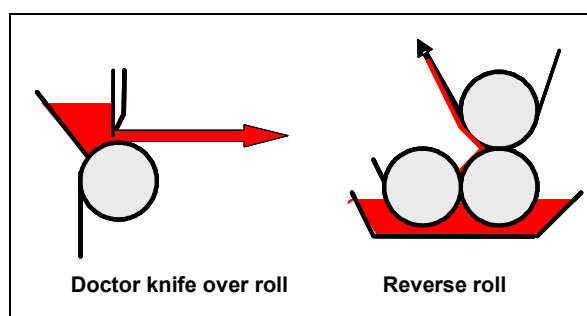


Figure 5.2: Different types of adhesive application units
[184, AFERA, 2005]

The adhesive material can be applied directly onto the substrate. An alternative is the transfer technique, where the pressure-sensitive adhesive is dried onto the releasing material and cross-linked. Afterwards, the adhesive film is transferred onto the substrate by lamination, therefore the substrate has to be protected from damage during the drying process. Lamination can be carried out with coating directly to a transfer release liner and laminating with a backing as shown in Figure 5.3.

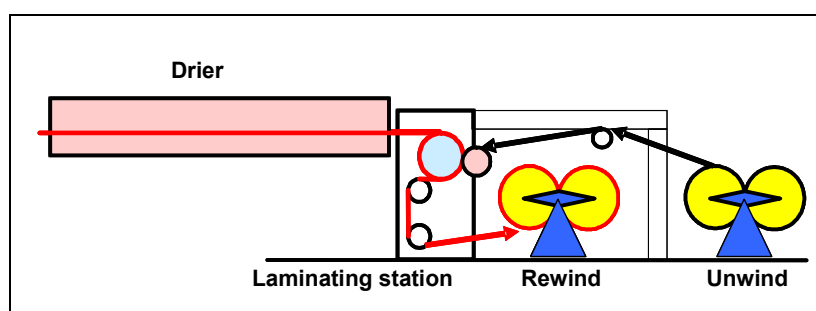


Figure 5.3: Lamination unit
[184, AFERA, 2005]

The formulation of the adhesives is often situated close to the application process. Different mixing facilities are used for different types of adhesives:

- granulated rubber, resins and other additives are put into a kneader filled with solvent. This is a slow batch processing for adhesives with a high viscosity
- granulated rubber, resins and other additives are put into a high speed mixer filled with solvent. The mixer has different mixing blades inside. This is a short batch process for a lower viscosity adhesive
- acrylic adhesive is made in batches in polymerisation stations. The reaction is based on a catalyst in the mixer, and is controlled by temperature and pressure.

Fugitive VOC emissions in these first steps of production may arise from the following processes or units:

- storing of solvents or pre-products containing solvent
- formulation of the adhesives in the mixing units
- leading the adhesives to the application machine
- the application unit of the primer
- the adhesives application unit.

Some of the fugitive emissions from these sources are captured and led to a waste gas treatment unit.

Waste results from mixed but used adhesives and from cleaning of the mixing facilities.

Normally there is no waste water from these processes.

Drying

Solvent-based adhesives are dried thermally by convection driers and infrared driers. Any cross-linking can be carried out chemically or by UV radiation in order to improve technical properties. The air of the convection driers is heated with gas, oil or steam via heat exchangers.

The main drier equipment for solvent-based systems is differentiated by airflow and material transportation:

- in a tangential airflow drier, the material is transported by rolls
- in a single side drier with nozzles over rolls, the material is transported by driven rolls
- in a transport belt drier, the material is transported by a belt
- in an air floating drier, the material is transported by specially designed air nozzles
- in a festoon drier long loops are hung on poles which move slowly through a sealed room.

The VOC evaporating from the adhesive layer during drying is captured with part of the exhaust air from drier. For safety reasons, a maximum solvent concentration is maintained in the exhaust air, calculated using EN 1539. The safe working level maintained is 50 % of the lower explosion limit. A reduction of the solvent concentration of the drier's air is controlled by the air flowrate. If gas-tight inert gas driers are used, higher solvent loads are possible. The load depends on the solvents used and the drying temperature.

The exhaust air of the driers is usually cleaned by solvent recovery. This is carried out by condensation in the pre-drying stage (captured fugitive emissions from the mixing and application units) and by adsorption on activated carbon in the drying stage. Solvents are recaptured by steam desorption and trapping.

There is no waste from the processes of drying and waste gas treatment. Minor amounts of waste water result from the desorption process in the waste gas treatment.

Winding

Before rewinding, the tape has to be cooled down in a cooling unit with cooling rolls. The cooling is done by the use of cooling water.

After cooling, the tape is rewound on large rolls ready for transport to the slitting process.

The solvent proportions remaining in finished double-sided adhesive tapes produced with solvent-based adhesives account for between 0.1 and 2 % based on the amount of solvent used. Solvents remaining in the products are either slowly lost due to diffusion processes or they remain in the adhesive layer functioning as a plasticiser.

At this stage of the production process, waste may result from faulty charges and as slitting rest. The amount of waste normally remains below 10 % of the material input.

There is no waste water.

5.3 Current consumption and emission levels adhesive tape manufacturing

[128, TWG, 2005] [184, AFERA, 2005]

General background on industries using adhesives

In the SED, the manufacture of adhesive tapes is grouped with other using industries adhesives. Other relevant industries that are:

- addressed in this document: the production of adhesive tapes, abrasives, the transportation sector (passenger cars, commercial vehicles, rail vehicles, and aircraft), and the wood material and furniture industry
- not addressed in this document: composite foils, mobile homes, the manufacture of shoes and leather goods.

Adhesive tape manufacture cannot be disaggregated from the following data, but it does provide some background. At a EU-25 level in 2000 (according to the RAINS model) NMVOC emissions were 257.6 kt representing 2.4% of total NMVOC emissions. Total activity was 680 kt of adhesives used, and the average emission factor is about 378.8 g NMVOC/kg of adhesives meaning that emissions from this sector are already partly treated* in EU-25 (the untreated* emission factor being 780 g/kg). The EGTEI data estimate reductions achievable across all the solvent using industries to be 76 to 98 %. It is not known how representative this is of adhesive tape manufacture. (*Treated/untreated in this context means not only waste gas treatment but also other measures to reduce VOC emissions).

Specific data for the production of adhesive tapes

The following tables and figures show basic consumption data and a mass balance for a modern reference plant producing high quality solvent-based adhesive tapes for very specific industrial uses.

Production time	20 shifts a week
Products	About 50 million m ² /year with about 75 % high coating weight

Table 5.3: Conditions of production for a solvent-based adhesive tape production plant

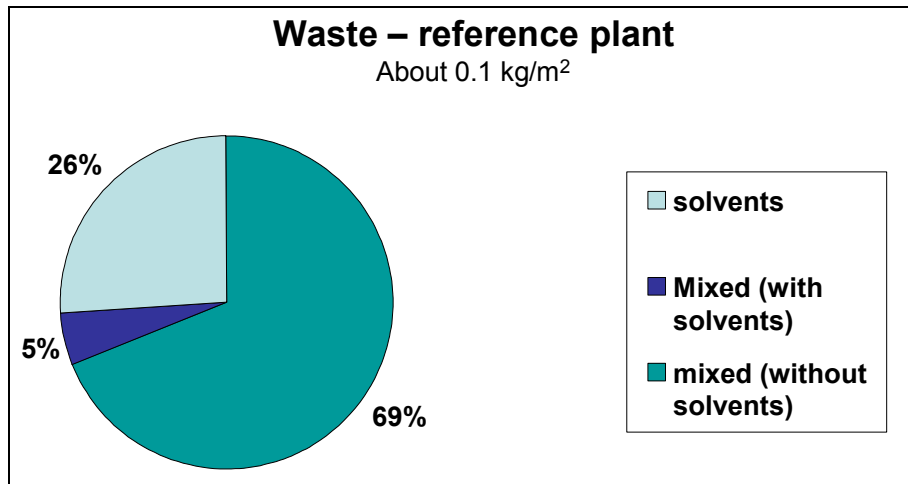


Figure 5.4: Waste generation (2004)
[184, AFERA, 2005]

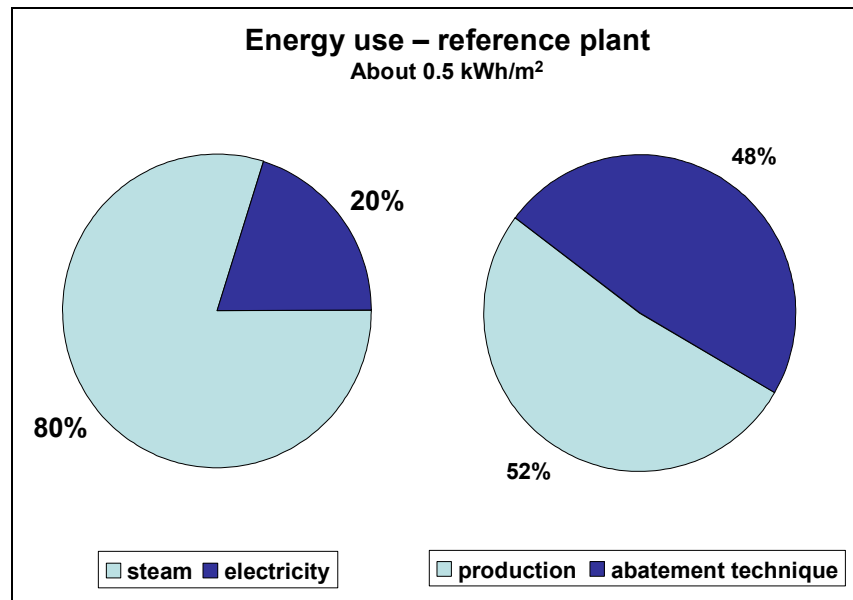


Figure 5.5: Energy consumption (2004)
[184, AFERA, 2005]

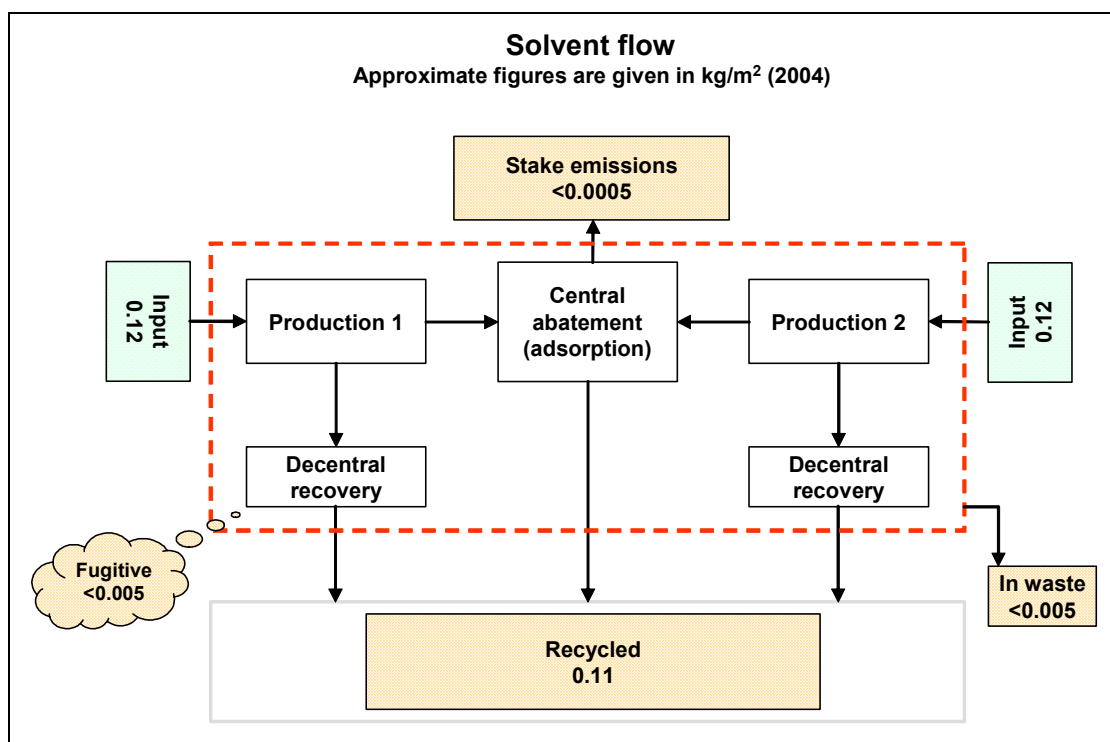


Figure 5.6: Solvent flow (2004)
[184, AFERA, 2005]

The amount of waste is reduced by:

- process optimisation by risk analysis (the FMEA process: failure mode and effects analysis) avoiding quality problems
- continuous process control to avoid non-conforming products
- optimisation of adhesive mixing to avoid excess materials with limited shelf life
- an efficient solvent recovery system.

A reduction of the energy consumption is gained by:

- the use of heat exchangers in the driers
- optimised insulation of the driers.

The specific consumption and emission values are significantly dependent on the types of manufactured tapes (type of solvent, substrate, coating weight) and will decrease with:

- a decreasing number of different products during the production period (longer campaigns)
- a lower share of double sided tapes in the production.

Table 5.4 shows the specific consumption figures of the reference plant in comparison with average data from other solvent-based productions.

	Solvent used kg/m ²	Energy used kWh/m ²	Waste generated kg/m ²
Average data (min – max) (normal production)	0.04 (0.02 - 0.12)	0.5 (0.25 - 1.1)	0.03 (0.005 - 0.1)
Reference plant (special production)	0.12	0.5	0.10

Note: This table very clearly expresses the higher specific consumption of specialised production (as in the reference plant) compared with the average level of commodities produced in other solvent-based plants.

Table 5.4: Benchmark comparison for solvent and energy used and waste generated

5.3.1 VOC emission balance

The VOC balance for the described reference plant is presented in Figure 5.7 below.

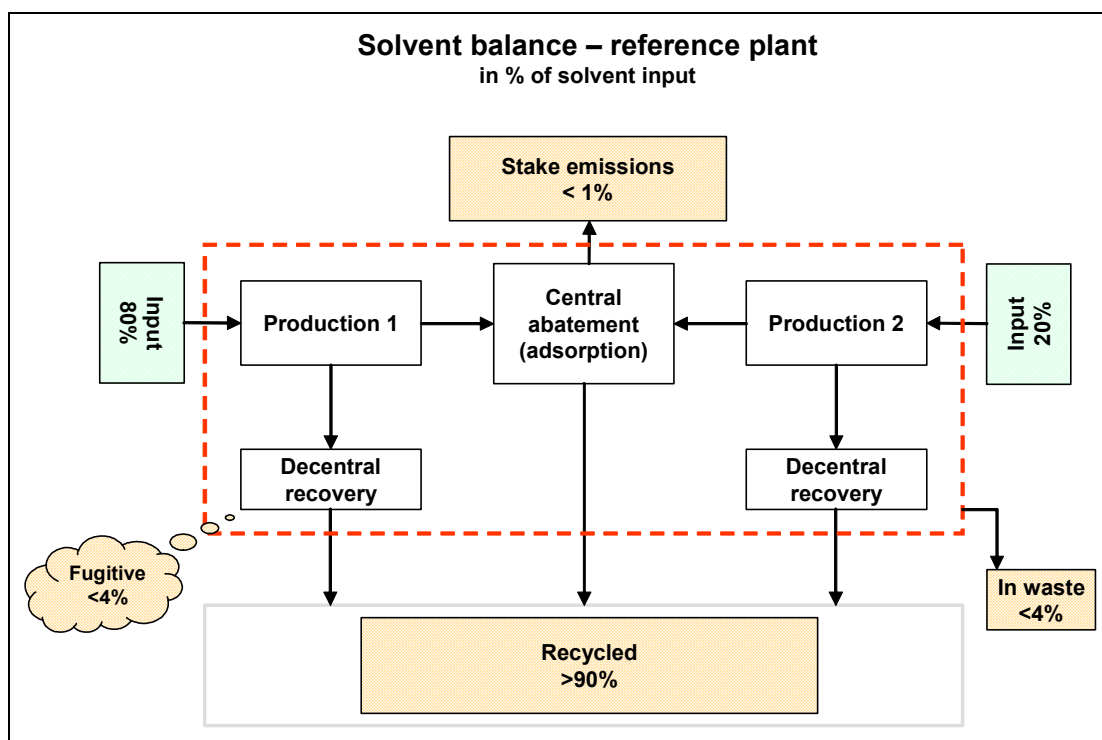


Figure 5.7: VOC balance of the reference plant
[184, AFERA, 2005]

As can be seen from this VOC balance, the emission limits for such installations are low and emission values of 5 wt-% or less can be achieved. Important elements for gaining good emission values are:

- using non-solvent techniques for manufacturing suitable products (currently lower quality ranges of packaging and masking tapes, and double-sided tapes)
- capturing of emissions from solvent storing and adhesive mixing
- encapsulation of the whole coating machine and leading all emissions from all fugitive sources to the waste gas treatment. Waste gas treatment can be one or a combination of:
 - condensation, after a pre-drying step (see Sections 5.4.5.1 and 20.11.5.3, and Sections 5.4.4.1 and 20.8.1.2)
 - absorption with a recovery of >90 % and emissions of <1 % (see Sections 5.4.5.2, 20.11.6.1 and 20.13.7.1)
 - oxidation with energy recovery (see Sections 5.4.5.2, 20.11.6.1 and 20.13.7.1)
 - additional specific capturing of VOC emissions direct from the coating units (see Section 20.11.4)
- decreasing the number of different products during the production period (longer campaigns) avoiding the need for interim cleaning.

5.4 Techniques to consider in the determination of BAT for the manufacturing of adhesive tape

In Chapter 20, techniques are discussed which might also be applicable to the manufacturing of adhesive tape. In Table 5.5, the general techniques relevant for the manufacturing of adhesive tape are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

The EGTEI synopsis sheet for the industrial application of adhesives (see Annex 24.1.1) gives some data on the cost-benefit at a European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations and products [134, EGTEI, 2005].

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
On-site recovery of the used activated carbon	20.13.7.1
Odour abatement	20.15
Noise abatement	20.16

Table 5.5: Reference to techniques generally applicable to the sector

5.4.1 Conventional solvent-based adhesives

Description: Solvent-based adhesives have to be applied for achieving specific properties, e.g. to meet high stress resistance. There are no solvent-free adhesives currently available that show equivalent properties.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Applicable in new and existing plants and installations.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Widely used.

Reference literature: [14, DFIU and IFARE, 2002]

5.4.2 Replacement of conventional solvent-based adhesives (substitution)

It is important to note that these are only options for producing limited types of tapes and for a new or upgraded plant, as these substitutions require a complete change of equipment [128, TWG, 2005]

5.4.2.1 Hot melts adhesives

Description: Hot melts do not contain solvents.

Achieved environmental benefits: Solvent emissions are eliminated.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Applicable in new and existing plants and installations. In the manufacturing of adhesive tapes, hot melts are suitable for the lower quality range of packaging and masking tapes as well as for double-sided tapes.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [14, DFIU and IFARE, 2002]

5.4.2.2 Water-based adhesives

Description: Water-based adhesives do not contain organic solvents.

Achieved environmental benefits: Solvent emissions are eliminated.

Cross-media effects: Higher energy is required for drying.

Operational data: No data submitted.

Applicability: Applicable in new and existing plants and installations. In the manufacturing of adhesive tapes, water-based adhesives are suitable for the lower quality range of packaging and masking tapes as well as for double-sided tapes.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [14, DFIU and IFARE, 2002]

5.4.2.3 UV curing adhesives

Description: UV curing adhesives do not contain solvents.

Achieved environmental benefits: Solvent emissions are eliminated.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Applicable in new and existing plants and installations. In the manufacturing of adhesive tapes, UV curing adhesives are suitable for the lower quality range of transfer and packaging as well as for masking tapes.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [14, DFIU and IFARE, 2002]

5.4.3 Replacement of conventional solvent-based adhesives manufacturing (substitution)

5.4.3.1 Solvent-free manufacturing of adhesive tape

Description: A new production process for the manufacturing of technical adhesive tapes was scaled up to a full size production line in one plant in Europe. The new process is based on hot melt technology which is adopted for the very specific needs of existing solvent-based products for industrial uses. This has been made possible by product modifications, product campaign mergers and intensive product and application support for costumers to ensure acceptance of the new products and their fitness in use.

Achieved environmental benefits: In comparison to solvent-based processes, solvent emissions, solvent use and process water use are reduced to zero. The primary energy consumption is reduced to 33 %.

Cross-media effects: This technique involves the cross-linking of polymers leading to ozone generation. Ozone emissions are destroyed by an eliminator (catalyst) achieving emission values of 0.05 ppm.

Operational data: A range of products can be manufactured with an adhesive application of 30 – 110 g/m². Integrated automated processes without manual operation gives high materials efficiency. Table 5.6 shows a comparison between a natural rubber process using solvents and a solvent-free natural rubber process for one plant. Actual figures will vary depending on the products manufactured.

Energy	Solvent-based process	Solvent-free process
Steam (t) for regenerating activated carbon (kWh)	25145	0
corresponding to fuel oil use (t)	14.75 million approx. 1700	0
Electricity (kWh)	6.71 million	4.5 million
corresponding to fuel oil use (t)	approx. 1650	approx. 1100
Process water use (m ³)	approx. 25000	0
Total energy use (kWh)	21.46 million	4.5 million
Total equivalent fuel oil use (t)	approx. 3350	approx. 1100
Note: The energy consumption is related to a production output of 100 million m ²		

Table 5.6: Comparison between a natural rubber process using solvents and a solvent-free natural rubber process

Applicability: Not all existing products can be produced by this new installation. It is necessary to redefine the product specification together with the client if a change to this technique is envisaged.

The application of this new technique requires fundamental changes in all parts of an installation. It is only an option for new installations or for one undergoing extensive upgrading.

Gaining the efficiency advantages described requires a homogenous production portfolio.

Economics: The capital investment for the new installation was EUR 13.4 million. Savings in energy are about 66 %. There is no expenditure on waste gas treatment, monitoring, and other compliance with emission controls, etc., as these are not necessary.

Economical operation of this technology can only be achieved for large scale installations.

Driving forces for implementation: Solvent Emissions Directive 1999/13/EC. Adoption of new technology to respond to current and new market requirements.

Example plants: Tesa AG, Hamburg, Germany.

Reference Literature: [76, TWG, 2004, 128, TWG, 2005] [184, AFERA, 2005]

5.4.4 Drying

5.4.4.1 Inert gas convection drying

For a general description, see Section 20.8.1.2. This technique is commonly applied as a pre-drying step in adhesive tape manufacturing.
[14, DFIU and IFARE, 2002]

5.4.4.2 Infrared radiation curing

For a general description, see Section 20.8.2.1. This drier is commonly used in adhesive tape manufacturing and is suitable for dispersions and also for solvent-based adhesives if explosion protection is needed.
[13, DFIU and IFARE, 2002] [14, DFIU and IFARE, 2002]

5.4.4.3 Ultraviolet (UV) curing

For a general description, see Section 20.8.2.3. UV curing is increasingly applied in the production of adhesive tapes. It is used especially for newer acrylate hot melts. It is also used for radiation curing adhesives, where the final reticulation and the adjustment of the technically required cohesiveness and adhesive strength are initiated by UV radiation. [13, DFIU and IFARE, 2002] [14, DFIU and IFARE, 2002]

5.4.4.4 Electron beam curing (EB)

For a general description, see Section 20.8.2.4. EB curing is increasingly applied in the production of adhesive tapes, however, less than UV curing (see Section 5.4.4.3) due to higher investment costs. Also, compared to UV curing, changes in substrate properties are possible. [13, DFIU and IFARE, 2002] [14, DFIU and IFARE, 2002]

5.4.5 Waste gas treatment

5.4.5.1 Condensation (refrigeration)

For a general description, see Section 20.11.5.3. Used solvents can be recovered by applying condensation in a recuperative heat exchanging device and cooling (5 to -30 °C) by a refrigerant compressor. In adhesive tape manufacturing, condensation is applied after a pre-drying step using an inert gas nozzle drier (see Sections 5.4.4.1 and 20.8.1.2) and before the main drying process. This is followed by an adsorption step for the waste gas. [14, DFIU and IFARE, 2002]

5.4.5.2 Adsorption to activated carbon and recovery on-site

For a general description, see Sections 20.11.6.1 and 20.13.7.1. The waste gas loaded with solvents flows through adsorbers that are generally constructed as several parallel connected tanks. The tanks are filled with activated carbon. If one adsorber is saturated, the waste gas is routed to the adjacent adsorber. For regeneration, the adsorbed solvents are first desorbed due to a rise in temperature initiated by steam supply. The water-solvent mixture being formed is then condensed and parted by phase separation. Emission concentrations of 70 - 90 mg/m³ are achieved in the cleaned gas. [14, DFIU and IFARE, 2002]

6 COATING OF CARS

[13, DFIU and IFARE, 2002, 68, ACEA, 2004] [117, ACEA, 2005] [128, TWG, 2005]

6.1 General information on the car industry

6.1.1 Production and sale figures

This chapter discusses the large-scale coating of passengers cars, in categories M1 (according to Directive 70/156/EWG) and the integrated environmental protection measures used. Some N1 vehicles (vans) which are produced in the same installations, may be based on cars and use similar production techniques.

The vehicle industry is one of the major manufacturing industries in Europe. In 2005, the whole of Europe (including Russia) produced 20.8 million motor vehicles, making Europe the world's largest producer with 39.6 % of the world total. Western Europe (EU-15 + EFTA) produced 16.5 million vehicles in 2005, which was 32 % of world production. About 1.2 million people are directly employed in vehicle manufacture and 0.8 million in manufacturing vehicle components (which contribute to industries in Chapters 13 and 16), accounting for 7 % of the EU-15 manufacturing industry (2003). The European industry contributes EUR 33500 million to the EU's trade balance.

Western Europe produced 14.3 million passenger cars, of which ACEA⁴ members account for about 12.9 million with a turnover in Europe of EUR 452000 million. There are 154 car production plants in the whole of Europe (ACEA members: 106). In the EU-25, 18 countries have vehicle production plants. The top vehicle producing countries in Europe are shown in Table 6.1. Despite this dynamic overall situation, the industry is highly competitive, with over-capacity in Europe and production moving to Eastern Europe (including the new EU MS), as well as to Asia. Plants are closing or cutting production in some countries (see Table 6.1 and its notes) [152, ACEA, 2006].

Vehicle assembly capacity in '000 of units		2004	Estimate for 2009
1	Germany	6190	6398
2	France	4356	4500
3	Spain ²	3329	3318
4	UK ²	2632	2613
5	Russia	1874	2113
6	Italy	1803	1802
7	Belgium	1133	1222
8	Turkey	1003	1105
9	Poland ¹	847	654
10	Czech Republic ¹	534	854
Notes:			
(1) Changes by 2009: Poland drops out of the top 10; Czech Republic becomes 9 th ; Slovakia 10 th at 811000 units			
(2) Since this table was derived, in the UK, one large plant closed in 2005, and one will close in 2007. Other plants will cut shifts. One plant in Spain will cut production in about 2007.			

**Table 6.1: Europe's top vehicle producers
(Automotive News Europe 19 Nov 2004)**

⁴ ACEA: European Motor Manufacturers Association

Investment cycles are a key factor for vehicle manufacturers. Clearly, the optimal time to make environmental investments is when the renewal of equipment takes place within the normal investment cycle. Generally, major investment cannot be made into an existing installation, except when opportunities for major modifications of the paintshop facilities arise. These opportunities tend to occur after the normal lifetime of the paintshop (between 20 and 40 years) or when there is a step change in production volumes, which is often associated with a new product launch.

Investment opportunities for existing installations are limited because the capital investment required is extremely high, between EUR 100 million and 500 million for a complete paintshop or, (if constraints such as time and space etc. allow) for the replacement of one spray booth, between EUR 15 million and 35 million. These investments are usually depreciated over 20 years.

Investment timing will depend on several factors, such as:

- new model programme
- age of existing equipment and design
- availability of time and/or space to upgrade
- size of the investment
- previous investments.

The average age of a car in Europe is 8 years, driving 15000 km a year. The durability of the car body is a major issue, and improvements in coating bodies and components in the last 20+ years has played a major part in extending car life from about 5 years, improving the lifetime sustainability.

The manufacture of cars represents a significant part of its consumptions and emissions during its life cycle. Energy consumption can be 5 to 15 % (according to different sources). Solvent emissions were about 300 gm/m² in the 1970s and have been steadily reduced by the techniques discussed in this chapter.

6.2 Applied processes and techniques in the car industry

6.2.1 Quality requirements

The following requirements have to be fulfilled by the coated car bodies and, therefore, by the paints:

- long-term protection against corrosion, weather, chemical influence (e.g. bird droppings, acid rain), chipping protection, sun, abrasion in car washes, etc.
- ideal optical surface properties: polish, colour depth, free of cloudiness, faultlessness, therefore producing homogeneity and a consistency in colouring and formation of effects (such as metallic finishes, etc.).

These high requirements can only be achieved by at least three, often four or maybe even five paint layers designed to complement each other. These are applied on body parts pressed and assembled from pretreated steels to increase the long-term corrosion resistance [59, EIPPCB, 2006]. In Europe, the following paint layer construction has become predominant:

- pretreatments are applied on plastics and body parts assembled from metals (e.g. steels are pretreated with phosphate to increase long-term corrosion resistance)
- cathodic electrocoating prime coating
- underbody protection/seam sealing
- primer
- topcoat (can be made up of base coat and clear coat)
- cavity conservation and, if necessary, conservation for transport.

First of all, the pretreatment removes dirt and oils from the pressed bodies and applies an anticorrosion phosphate treatment, which also assists subsequent paint adhesion. The cathodic electrocoat provides corrosion protection for interior and exterior areas including all cavities, overlapping regions and connections. The primer offers optical properties (masking of the sub-surface, gradient), protection against chipping and regulates adhesive strength. Topcoats may be one-layer or two-layer systems (base coat and clear coat), e.g. with metallic colours, painting effects (pearl shine) and sometimes with unicoloured paints. The topcoat provides optical properties (polish, colour, luminance) and offers essential protection against chemical and physical environmental attack (solar radiation, rain, chemicals, fuel, washers, mechanical stress) [76, TWG, 2004, 128, TWG, 2005].

6.2.2 Serial coating

In spite of serial coating processes being different between each factory (even of the same producer) certain common properties can be listed. The main steps include precleaning, phosphatisation, passivation, cathodic immersion prime coating, underbody protection and seam sealing, application of the primer, drying of the primer, application of topcoat and mostly of a clear coat (one- or two-layers), drying of the topcoat, cavity conservation, if necessary conservation for transport and repair of possible damage to the paint before assembly. Generally throughout Europe, two-layer topcoats with a base coat and clear coat instead of one-layer coats are applied. A general process procedure is shown in Figure 6.1.

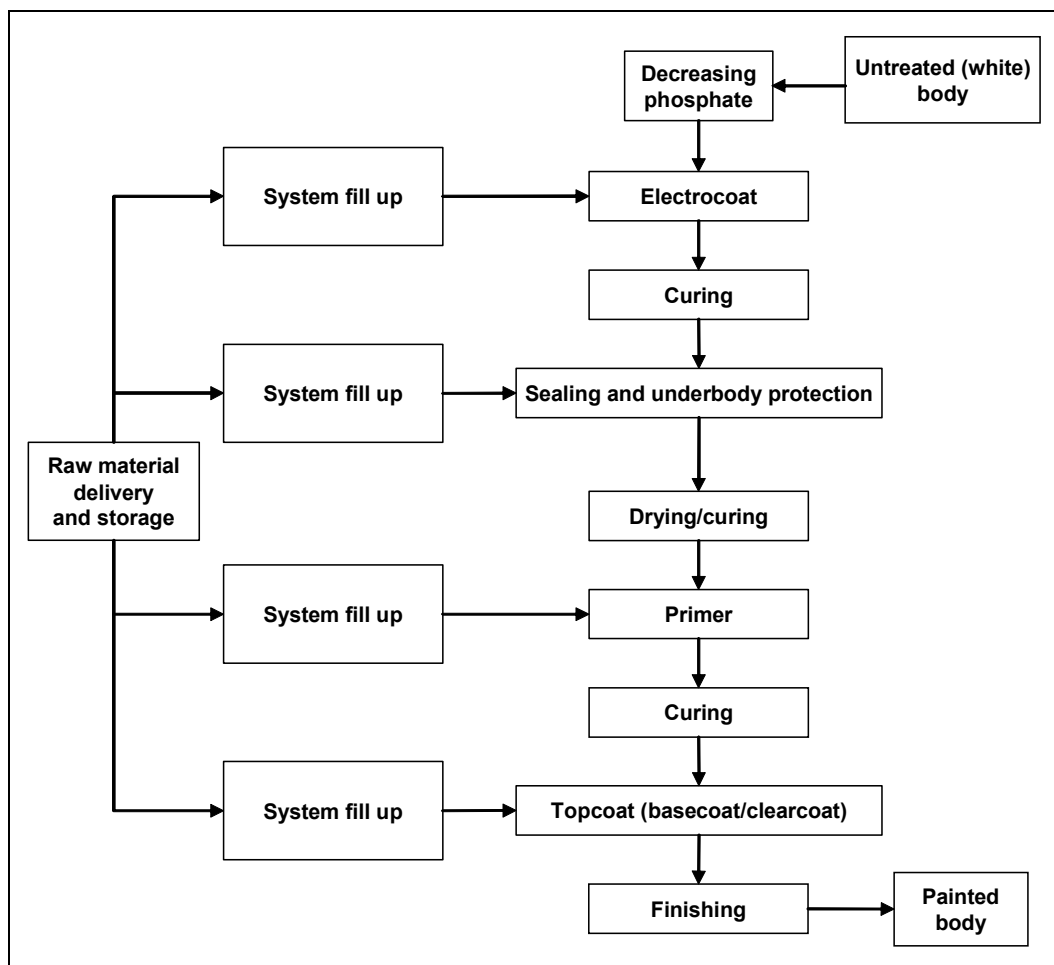


Figure 6.1: Scheme of a typical vehicle body paint process [68, ACEA, 2004]

6.2.3 Applied coating materials

These are described in the coating processes, see Sections 6.2.4, 6.4.1 and 20.7.

6.2.4 Coating processes

6.2.4.1 Coating application techniques

Serial painting of bodies in white (BIW)⁵ includes electrocoat (cathodic immersion), sealing, prime coating, topcoat application and wax processes. Prime and topcoat processes utilise spray application techniques (predominantly electrostatic for external surfaces), which take place in specifically designed spray booths, with controlled dust proportion in the air, temperature and humidity. Topcoat booths are usually constructed with flash-off zones to optimise paint performance. The first flash-off being positioned between base coat and clear coat application, (for water-based paints, this process is usually accelerated by hot air and/or infrared radiators – ‘forced flash-off’) and the second, after clear coat and before entry into the stoving oven. Paint overspray is treated by means of thoroughly mixing the booth exhaust air with water (or alternative solution) in the venturi cleaner beneath the grating of the booth [76, TWG, 2004, 128, TWG, 2005].

In spraying, the most important nebulising techniques include [76, TWG, 2004]:

- compressed air spraying (effects such as metallics and interior)
- high rotation electrostatic spraying
- spraying by robots
- electrostatically assisted spraying with compressed air
- hot spraying
- rotational nebulising
- airless spraying.

6.2.4.2 Description of the process steps

Due to intensive research and development (ongoing) by the automotive industry, various advanced coating techniques are used throughout Europe. They are described in the following paragraphs [76, TWG, 2004].

6.2.4.2.1 Pretreatment

Pretreatment techniques for degreasing, phosphating and other conversion coatings, with their rinsing and other associated techniques are discussed in the STM BREF [59, EIPPCB, 2006].

At the first step, the bodies in white are degreased and subsequently well rinsed. The degreasing removes oils, greases, soaps, dirt particles, sanding residues, substances and other contaminants. It is carried out at a temperature of about 50 – 60 °C using aqueous, alkaline cleaning agents that may also contain phosphates and surfactants.

⁵ BIW is a standard term in the industry and refers to the bare metal shell of the vehicle before it has been degreased, dipped and painted.

Phosphating follows, creating a substructure for corrosion protection and adhesion stability of the paint system. A phosphate layer with a thickness of about 1.5 μm is achieved by spraying or by immersion with a water-based solution. It may contain other metals, e.g. widely used tri-metal systems containing zinc, manganese and nickel, as well as calcium, phosphoric acid and oxidants, e.g. nitrite, nitrate, chlorate, hydrogen peroxide and hydroxylamine salt as an accelerator. After another rinsing process, the phosphating layer may be additionally passivated (such as with Cr(VI) or Cr(III) solution). Further rinsing is carried out, finishing with demineralised water. The phosphated body is usually dried, at a temperature of 50 – 60 °C, and is immediately transferred to the electrocoating zone (see Section 6.2.4.2.2).

Waste waters can be treated in typical waste water treatment plants (more information can be found in the STM BREF [59, EIPPCB, 2006]).

Sludges formed in the process solutions require removal as part of the solution maintenance and are treated as wastes [76, TWG, 2004].

6.2.4.2.2 Electrocoating

This is known by a variety of names: e-coating, cathodic immersion, electrophoretic painting, etc. Nowadays, electrocoating is used almost universally throughout Europe as the primer coating for passenger cars, due to high quality requirements for corrosion protection. The water-based paint is applied by immersion and generally contains about 14 – 22 wt-% solids and about 2 – 6 wt-% solvent, and the pigments are lead-free. The solids are usually a latex polymer dispersed in an acetic acid base (called ultrafiltrate, see below) and are applied in a process that is similar to electroplating.

Paint particles which have not been electrically deposited are removed by rinsing with ultrafiltrate. To minimise paint losses, the multiple rinsing systems (cascade rinses) are used and the solids and the liquid regenerated by ultrafiltration. The high solids part is returned to the immersion bath achieving a closed loop for the solids (more information can be found in the STM BREF [59, EIPPCB, 2006]). The electrocoat requires curing, for example at 150 - 180 °C. Low-bake materials are under development. Except for the deletion of small imperfections, the priming is not subsequently sanded.

Waste waters from rinsing can be treated in typical waste water treatment plants [76, TWG, 2004] (more information can be found in the STM BREF [59, EIPPCB, 2006]).

6.2.4.2.3 Seam sealing and underbody protection

Before applying the primer, joints and folds need to be sealed. This is carried out partly by hand, partly by robots normally using various PVC materials applied with special guns. Also, the subsequent underbody protection coating is based on PVC plastisols (100 – 1200 μm) or on polyurethane. Generally it is applied by robots using airless techniques. An additional chipping protection is also partly applied onto critical areas by a sharply bordered airless spray jet. At some sites, materials for both underbody and chipping protection as well as for seam and cavity sealing, are applied in later steps of the production, sometimes after finishing the top layer at the final assembly section.

In a plant in Germany, the application of underbody protection is carried out by robots and is partly carried out on turned car bodies. This technique can only be applied in the case of a suitable underbody structure and stable longitudinal girders. Advantages are a reduction of overspray because of lower spraying pressure and a uniform, reproducible coating. Furthermore, the technology has ergonomical advantages for subsequent manual operations (Volkswagen AG, Wolfsburg).

The sealing and underbody protection materials are in some cases dried/cured prior to further processing. However, curing is increasingly carried out in the primer ovens, saving energy.

Before the application of the primer, the body is cleaned with a dust-attracting wipe, by blowing with ionised air or increasingly also with rolls of emu feathers, because particles can still have a detrimental effect on the future topcoating layer.

6.2.4.2.4 Application of the primer

The primer has the following functions:

- filling of small unevennesses of the subsurface and preparation of the topcoat application
- guarantee of adhesion stability and achievement of a layer thickness required for achieving the desired quality
- protection against stone chipping
- UV protection for underlying electro-immersion layers.

Besides conventional primers containing solvents, water-based primers are also used. In the primer sector, the exterior surface coatings are generally applied electrostatically by high rotation nebulisers; if necessary, the primer is applied manually to some places (e.g. interior sections). After the passage to a short flashing-off area for solvent elimination, the primed bodies reach the filler drier (up to 140 - 160 °C: it has to be less than the electrocoat temperature).

A reduction of the consumption of the subsequent base coat can be achieved by adjusting the primer colour to that of the base coat. In some cases, the base coat can be abandoned completely for interior applications.

For a couple of years, powder coat primers have been used in the US and in Austria (DaimlerChrysler, Graz). However, long-term experiences have shown that the required surface quality was not achievable this way (among other things, this is because of the high layer thickness) and high material consumption. However, one plant in Europe is now using powder primers successfully in five to six colours. Powder coatings slurried in water (powder slurries) that are processed like liquid paint are still at the development stage. They are currently used in top coating (see Section 6.4) [76, TWG, 2004].

6.2.4.2.5 Cleaning

Before applying the topcoat, a complete cleaning is absolutely necessary. The following processes are commonly used: ionised air, blower, feather dusting, complete cleaning of the body including drying and cooling processes [76, TWG, 2004].

6.2.4.2.6 Types of topcoatings and their application

Topcoats can be 1-, 2- or more coats.

1-coat topcoat

This procedure of 1-coat topcoating is only currently used in special cases with unicolours, and even in these cases, because of the durability and optical surface quality, more and more 2- or more layer coatings are used. For the coating of light commercial vehicles, 1-coat topcoats are still common, because customers require special colours.

1-coat topcoats can range from classical one part alkyl, polyester or acrylate burning-in systems towards higher cross-linking 1- or 2-component paints, often with isocyanate cross-linking.

These systems exist for both water-dilutable as well as paints containing solvent. Only extremely light and weather durable compounds are used as pigments.

The topcoat material is applied predominantly with automatic, electrostatically assisted high rotation nebulisers, allowing fast changes of colour within only a few seconds. Pre- or after-spray of difficult to access parts is done manually (pneumatically). The required dry coat layer thickness (1-coat topcoat) of 35 - 50 μm is applied in one or two steps, if necessary with short intermediate flashing-off periods. Afterwards, the coating is burned in at about 130 - 140 $^{\circ}\text{C}$ (depending on the bonding agent) in the topcoat drier.

2-coat (or 3-) topcoat

In 2-coat topcoating, a colouring base coat is applied and is subsequently covered with clear coat. Unicolours are therefore more attractive as they gain in optical deepness; the coating is significantly more durable. Effect coatings and metallic coatings are applied in two steps: firstly, by high rotation electrostatic bells; secondly, pneumatically or electro-pneumatically.

The base coat is applied with a layer thickness of only 12 to 35 μm . The effective thickness depends on the masking efficiency of the colouring. Different primer colours can be used in order to increase the masking capability. Pearly coloured base coats containing glimmer or other special effect pigments as essential pigments generally do not mask and hence need an additional base coat layer as subsurface. This is typically a white base coat, whereas for an emphasis of interference effects, dark base coats are also used ('3-coat topcoating'). Further new effect techniques, like the colouring of base coats or clear coats with soluble colours or the usage of clear coats containing fluor (more strongly dirt-repellent) are only briefly mentioned here.

Unlike primers and base coat, there are no widely used water-based alternatives for conventional clear coats. Solvent proportions of conventional clear coats amount to about 53 to 57 %. High solids versions have a VOC content of 37 - 42 %. Many manufacturers use 2-component solvent-based clear coats with an increased non-volatile content of 60 - 75 % (with high solids). This layer is of milk-like white at first, it clears while drying and then the final colour appears. Modified bonding agents and curing systems as well as new component mixing technologies to enable the use of 2-part clear coats are currently under development in order to reduce emissions originating from clear coats.

At first, the interior surfaces of doors, engine compartments, tailgates and if necessary of the interiors are painted either manually or by robots. Following unicoloured base coats, clear coats and effect base coats (in the latter case only the first spraying process) can be applied principally with electrostatically assisted high rotation devices or pneumatic pistols. When using an electrostatically assisted device for applying metallic and pearl coatings, an additional pneumatically applied coating is necessary.

When using a waterborne base coat, an intermediate drying step is necessary. For conventional base coats, a short period of air circulation drying (the so-called 'wet-on-wet' technique) is sufficient.

Coloured coats (mainly base coats) require colour changes. Colour blocks are often less than two cars average. Even when the best techniques for recovery are in place, purging/rinsing of bells and guns contributes significantly to emissions when solvent-based paints are used. For water-based coats, purge liquids usually comprise 90 % water [76, TWG, 2004].

6.2.4.2.7 Drying and curing

Drying speeds up vaporisation of solvents of the applied paint layer and includes curing of the paint layer by chemical reactions. Three types of drying can be distinguished:

- physical drying: the coating material is applied in a liquid state and solidifies to a solid coat by evaporation of the solvents
- chemical curing: the film that is usually already solidified after physical drying is cross-linked by chemical reactions. These reactions occur at higher temperatures and, therefore, need a specific thermal input. Additional heat can accelerate the reaction process within certain limits
- curing by reaction-drying: two or more reactive components are mixed in preset proportions before or during the application and they result in a solid film by chemical reaction. The systems may either be solvent-based or solvent-free. Usually, the reaction starts at an ambient temperature, and it can also be accelerated by heating.

In practice, convection driers, radiation driers or a combination of both systems are used, depending on quality requirements of the coating. The car bodies, heated during the drying process, generally have to be cooled prior to further processing. Therefore, they are cooled with air in cooling zones.

6.2.4.2.8 Cavity conservation

The conservation of cavities consists of an application of a wax film sealed into the cavities (which exist for constructional reasons) of the girders and doors of the body for corrosion protection. It can be carried out according to the following two techniques:

- spraying: for every cavity there is at least one application hole (40 – 50 such holes in a body). Reproducible dosaging is achieved by preprogramming the volume applied. The spraying technique usually uses a material with 60 - 70 % wax content, which may be in aqueous emulsion. Spraying is at ambient temperature, followed by an oven to liquefy the wax to run into all areas
- flooding with solvent-free hot wax: hot wax (paraffin at 120 °C) is flowed into the cavities through automatically racked flooding nozzles. The cavities are filled according to the specifications. After the flooding process, the surplus wax flows through the leak openings back to the flooding basin and is re-used in the circulation of wax supply. The body is heated before flooding (50 to 80 °C) in order to obtain a remaining layer as thin as possible. This technique operates solvent-free.

6.2.4.2.9 Rework

In spite of all the elaborate measures to prevent problems with dust, coating defects (dust dried in coats, mechanical damage, substances that interfere with wetting, etc.) are not completely avoidable. Faults are rectified by immediate sanding of the spot, and completely or partly topcoated, depending on the extent of the defect.

6.2.4.2.10 Transport conservation

For protection of the vehicle during its transport, a variety of methods are used. Most manufacturers apply a wax protection layer: this can be solvent- or water-based. The solvent content (about 70 %) generally depends on the corrosion protection required and to some extent on the age of the application facilities available. These wax application facilities are not an integral part of the painting line, and may be located after the final assembly of the vehicle. If water-based wax is used, forced drying is required. Increasingly, foils are used for transport protection or the transport conservation is completely omitted [76, TWG, 2004].

6.3 Current consumption and emission levels in the car industry

The vehicle manufacturers' data for VOC mass emission figures from individual paintshops are generally comparable across Europe because they are standardised in line with the SED. However, data from sources such as materials/equipment suppliers or from outside the EU may not be comparable due to technical differences (e.g. colour change, cleaning solvents). Other consumptions and emissions are not readily comparable due to the diverging interpretation of the IPPC 'installation' among Member States. Nevertheless, the integrated approach in IPPC is very important and the impacts of each technique on other emissions and emissions to other media should also be considered in detail.

6.3.1 Mass balances

No information submitted.

6.3.2 Consumptions

6.3.2.1 Materials

Table 6.2 shows consumption of paint in grams per painted m² of the car's body surface area, where the VOC emission and the surface area are as measured according to the techniques described in detail in Annex 24.5. The consumption depends on the different paint systems and application systems, etc. It should be remembered that this is for information only, and cannot be a 'pick list' to select a paint system on the basis of consumption efficiency only. The paint process in each installation is highly complex and fully integrated comprising many integrated steps: each step influences others and different figures apply according to application techniques. Decisions about best options therefore cannot be taken on the basis of selecting each step individually.

Painting material ⁽⁴⁾	Specific material consumption (g paint/m ²) ⁽¹⁾⁽⁶⁾ except ⁽³⁾
Electrocoating: water-based, 5 wt-% organic solvents, solid content of 14 - 18 %	70 – 80
Primer: solvent-based, 45 wt-% organic solvents, electrostatically assisted spray application	10 – 15
Primer: water-based, 8 wt-% organic solvents, solid content of 50 – 55 %, electrostatically assisted spray application	10 – 20
1-coat topcoat: solvent-based, 45 wt-% organic solvents, electrostatically assisted spray application	35 – 60
Base coat: solvent-based, 75 wt-% organic solvents, ⁽⁵⁾ electrostatically assisted spray application (60 %) and compressed air spray application (40 %)	45 – 55 ⁽²⁾
Base coat: water-based, 13 wt-% organic solvents, solid content 17 - 35 %, electrostatically assisted spray application (60 %) and compressed air spray application (40 %) ⁽⁵⁾	45 – 60 ⁽²⁾
Clear coat: solvent-based, 45 wt-% organic solvents, electrostatically assisted spray application	20 – 30
Clear coat: water-based, 14 wt-% organic solvents, solids content of 42 - 49 %, electrostatically assisted spray application	35 – 45
Clear coat: powder-slurry, about 1 wt-% organic solvents, solids content of 38 % electrostatically assisted spray application	42 – 46
Clear coat: powder-based, solvent-free, electrostatically assisted spray application	100 – 110
Underbody protection and seam sealing	6 – 12 kg/car body ⁽³⁾
Transport and delivery protection	6
⁽¹⁾ Electrocoated area as defined in the SED. This unit is valid for all cited paint systems except the underbody protection and the seam sealing; for the latter no area-related unit can be given ⁽²⁾ For base coats with a solids content of 20 – 25 wt-% during processing ⁽³⁾ kg/car body not g/m ² ⁽⁴⁾ Electrostatic applications expect to have higher application rates and pneumatic lower, ⁽⁵⁾ The percentages relate to proportion of the film thickness achieved by the base coat film applied: 60 % relates to using electrostatic high rotation bells (e.g. 9 μ) versus 40 % by pneumatic application (e.g. 6 μ). Repairs by pneumatic spraying show visible differences of metallic finishes applied by electrostatic coating, so serial coating using pneumatic sprays makes repairs during lifetime easier. ⁽⁶⁾ Measured according to the techniques described in detail in Annex 24.5.	

Table 6.2: Specific paint consumption of several paint systems
[13, DFU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

6.3.2.2 Water

The main water using areas are:

- pretreatment (degreasing)
- conversion coatings (phosphating and passivation)
- electrocoating
- cleaning of the spray booth exhaust air.

The primary use of water is in rinsing off materials prior to the next process: a small amount is used for topping up from evaporation, and making new solutions. Water management and saving techniques for these are described in detail in the STM BREF [59, EIPPCB, 2006]. These include multistage rinsing, techniques to minimise water use, recovery of water and raw materials, and are equally applicable to electrocoating. Consumption ranges associated with BAT given in the STM BREF are: 3 – 20 l/m²/rinse stage.

The painting department of a major German company has reduced water consumption by about 70 % down to 3 litres/m² due to the use of all possible water saving techniques, such as closed loops and multiple stage cascade systems in the rinsing zones of the pretreatment and the electrocoating primer installations. This included installing a new phosphating plant. Assuming this included three rinse stages (one each for degreasing, phosphating, electrocoating), then the consumption range associated with BAT given in the STM BREF would be 9 - 60 l/m².

Spray booths have a curtain of water catching overspray. These are normally a closed loop of the water circulating in the booth, with paint coagulation. The waste is a sludge-like coagulate and little waste water is generated. The booths require emptying occasionally for cleaning, and need some water to replace evaporative losses.

Water can be used for cooling. This is discussed in the CV BREF [126, EIPPCB].

6.3.2.3 Energy

Typical energy consumption of car paintshops	
Production capacity	200000 cars/year
Coating system	Water-based filler and base coat, solvent-based 2K clear coat
Energy consumption of paintshop	Units range
Total energy consumption (plant)	380000 – 580000 MWh
Energy consumption of paintshop (60 % gas)	160000 – 240000 MWh
Paintshop as % of total plant energy	38 – 52 %
Energy consumption of paint processes	
	Range
Pretreatment	7 – 11 %
E-coating	10 – 15 %
Seam sealing/underbody protection	12 – 18 %
Filler	12 – 18 %
Base coat	15 – 22 %
Clear coat	22 – 33 %
Cavity sealing	2 – 2 %
Total	80 – 120 %
Sources: Ökobilanz Lackierprozess (2003) (Krinke), Pers. Mittl. Hr. Engelmann, Oct 2005, ACEA 2005	

Table 6.3: Typical energy consumption of car paintshops [128, TWG, 2005]

The painting process is one of the most energy intensive steps and is probably the most environmentally significant in vehicle production after considering solvent use and emissions. Table 6.3 gives typical values for car paintshops, showing the energy consumption is 38 – 52 % of the energy consumption for an entire assembly plant (excluding other production activities sometimes located in the same plant, such as foundries, engine block manufacture and production of other component production). Details of the energy consumption for a specific sequence of processes and of individual process steps depend on the type of processes and the individual production line capacities. Because of this, data are often not comparable, even between different production lines within the same site. Detailed data often do not exist or are not published.

6.3.3 Emissions

6.3.3.1 Emissions to air

In the production of cars, VOCs represents the most significant emission source. The activity emits NMVOC originating from the spray booths, the drying ovens and the cleaning of application equipment. NMVOC emissions from this sector may vary significantly from country to country. At EU-25 level for 2000 (according to the RAINS model), NMVOC emissions were 74.2 kt representing 0.7% of total NMVOC emissions. Total activity was 18367150 vehicles coated, and the average emission factor was about 4 kg NMVOC/vehicle. This shows that emissions from this sector are already partly treated* in the EU-25 (the untreated* emission factor is country specific but can be as high as 10 kg/vehicle). This figure equates to an EU-25 average of about 40 - 67 g VOC/m², compared with the untreated situation of about 100 - 167 g VOC/m² (both ranges depend on the model size). The industry has invested significantly in solvent reduction activities and before introducing reduction measures (e.g. in the 1970s), typical emission levels were between 200 and 300 g/m² (measured according to the SED) [117, ACEA, 2005]. (*Treated/untreated in this context means not only waste gas treatments but also all other measures to reduce VOC emissions). The emissions and surface areas are calculated according to Annex 24.5.

The SED set a VOC mass emission limit for vehicle painting installations of 60 g/m² for existing installations and 45 g/m² for new installations. The deadline for achieving the mass emission limit for existing plants is 31 October 2007. In early 2005, 27 plants in Europe operated above the 60 g/m² limit and have upgrade programmes in place to achieve the limit within the deadline [117, ACEA, 2005].

Most Member States apply the SED limits, but there are lower emission limits applied in some Member States. Germany, for instance, has a long tradition of implementing VOC legislation, which has required industry to reduce emissions over 20 years from 60 to 35 g/m² for solid paint. Similar legislation applies in Austria and the Czech Republic [128, TWG, 2005].

Usually, application and drying of primer and topcoat/clear coat contribute to approximately 80 % of the VOC emissions originating from the painting sector of car production. The topcoat refinishing (rectification), cleaning procedures as well as additional sources (e.g. coating of small parts, application of underbody protection) are responsible for the remaining 20 %. Approximately 70 to 90 % of the total VOC emissions generated during the application and drying procedure, originate from the painting booth; the remaining 10 - 30 % from the drier. The indicated percentage rates depend generally on the solvent types used, the painting systems and the application efficiency factor of the technique. Waste air from the drier loaded with VOC is supplied to a thermal waste gas cleaning system.

The figures in this section are related to the e-coat surface of the car body (see Annex 24.5) where the total surface is typically 65 - 95 m² (mini to medium family car), where primer, base coat and topcoat are applied to about 10 - 15 m² painted surface. Current, average specific emissions of volatile organic compounds for the German car industry is about 35 - 45 g/m² electrocoated surface. It corresponds to an average solvent consumption of 2.5 to 4 kg per vehicle (depending upon each model and individual requirements). Austria estimates VOC emissions of 21 - 27 g/m², and about 1.8 kg per vehicle with NO_x 40 - 80 mg/Nm³, CO 25 - 80 mg/Nm³, particles (TPB) <3 mg/Nm³. For the European car industry likewise, emission values of between 35 and 45 g/m² are achieved, in particular for plants in Sweden and the Netherlands as well as for some plants in Belgium, the United Kingdom, France, Italy, Portugal and the Czech Republic. However, this level has not been achieved for many plants in Europe where the VOC emissions reach values of between 60 and 120 g/m². Figure 6.2 shows the range of VOC emissions from 65 paintshops in Europe.

For two major companies (one in Sweden and one in Germany), the emissions are substantially lower, down to 10 g/m² or below. These are new (or recent) plants using a combination of greenfield sites or complete rebuild, novel green techniques and/or technologies that give finishes that do not meet other manufacturers' quality requirements for finish, durability, chemical resistance, etc. [128, TWG, 2005].

Besides the VOC emissions, paint particles (possibly containing heavy metals) also have to be considered. Particle emissions from overspray are generally well below 5 mg/Nm³ which is ensured by the use of wet and dry separators within the spray booths.

The efficiency of eliminating VOC emissions is dependent on the techniques used, which include application efficiency, paint VOC content, vapour capture and waste gas treatment, see Section 20.11.4. After thermal treatment, cleaned gas concentrations of 10 mg C/m³ are commonly achieved. A relatively good cost benefit is achieved for the first half of the VOC emissions, often reducing for the rest. The efficiencies of thermal oxidation are 90 % for drying ovens. When combined with carbon absorption, it is 80 % for the primer application, 70 % for the base coat, and 75 % for the clear coat [68, ACEA, 2004, 128, TWG, 2005]. For waste gas treatment in Germany (incineration), emission values well below 10 mg C/Nm³, and for NO_x and CO about 100 mg/m³ are achieved although the incineration temperature was lowered from 730 to 700 °C and energy consumption was reduced.

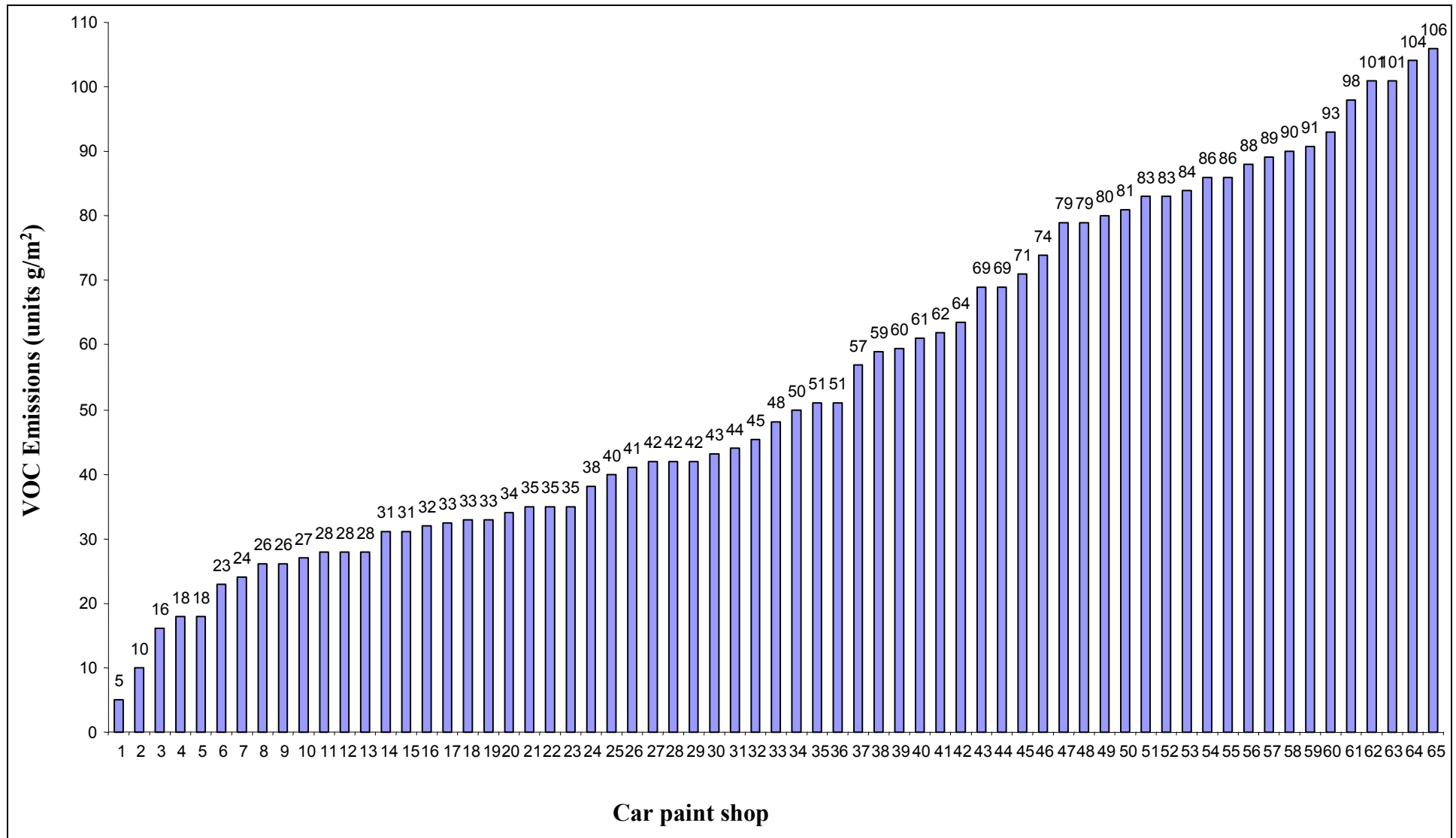


Figure 6.2: Range of VOC emissions from 65 car paintshops in Europe [68, ACEA, 2004]

6.3.3.2 Emissions to water

Waste water of the pretreatment and the immersion prime coating

Waste water originates from the pretreatment of the bodies by degreasing, phosphating passivation and also from the electrocoat primer process. The waste waters are predominantly from rinsing the bodies between treatments, therefore removing the materials from the previous process. The components of pretreatment (degreasing), conversion coatings and passivation, as well as water management and saving techniques applicable to all are described in detail in the STM BREF [59, EIPPCB, 2006]. These include multistage rinsing, techniques to minimise water use, recovering water and raw materials, and are equally applicable to electrocoating.

Electrocoating can be operated with multiple (cascade) rinses, with separation and recovery of the paint solids and the liquid (ultrafiltrate) being returned for rinsing. Although these are usually closed loop for the paint solids, some rinse-water may be lost (containing traces of paint, water-based solvents, etc.) and there is a need for periodic cleaning. At present, unleaded electro-immersion paint is considered as good practice. However, new risk materials, e.g. organotin compounds, arise with some lead-free products and may occur in waste water treatment.

The waste water is treated in a waste water treatment plant and then discharged to a municipal waste water treatment plant for further treatment which is described in detail in the STM BREF [59, EIPPCB, 2006], along with emission values associated with BAT.

Waste water from coating processes

Generally, other waste water is generated by the wet cleaning-out of paint overspray as:

- a mix of paint, water and coagulating agent residues
- a mix of paint, water and solvent generated by cleaning the nebuliser units and paint supply conduits
- a mix of paint and water generated by cleaning the painting booths.

During the spraying application of paint in spraying booths, overspray is generated and is caught in wet cleaners. This is required to minimise emissions of paint as particulate matter. The water for these scrubbers is recirculated in a closed loop, and the paint sludge is separated and has to be removed periodically for maintenance. The same methods are used for the separation of both solvent-based and water-based paints.

The organic solvents contained in solvent-based paints are mostly very volatile with low solubility in water. Water-based paints have a substantially smaller solvent proportion which, however, is almost completely soluble in water. If these solvents have a very low vapour pressure, they can accumulate in the water. Solvents for water-based paints accumulate in the water circulating in the spray booth only up to the equilibrium state (usual concentrations are about 0.5 %). The rinsing water of the spray booth is held in a closed loop and is renewed periodically, such as twice a year or less frequently. Moreover, waste water is generated by the cleaning of the heat exchangers of the spray booth exhaust air and the heat rotors as well as by the humidification of the input air supplied to the spray booth [76, TWG, 2004].

6.3.3.3 Waste

Substantial wastes originating from pretreatment/cathodic immersion prime coating and the painting of vehicle bodies include:

- solvent waste: the primary source of solvent wastes are recovered solvents, old solvents, solvent leftovers, used and contaminated cleaning agents are generated, among other things, by the cleaning and setting up of solvent-based paint systems, by tool, device or spray booth cleaning and possibly by the waste gas cleaning of painting and drying
- paint leftovers and old paints: due to their changed physical and/or chemical characteristics, paint leftovers and old paints that are no longer usable and have to be disposed of as waste material. Out of specification and/or surplus batches and dried paints are likewise waste. Differentiation can be made between non-cured paint leftovers with solvent content and cured old lacquers/paint residues without solvents. Water-based paints and powder coatings are also included
- paint sludge: during spray painting, non-separated overspray is captured in water and the coagulated lacquer particles are removed from the water. Coagulation agents are added to the water for separation and for improved cleaning-out processes, hence paint sludge is generated
- used adsorption agents: if waste gas cleaning methods are used such as adsorption onto charcoal, solvent-loaded charcoal is generated that has to be disposed of
- phosphate sludge resulting from pretreatment
- PVC wastes generated by the application of underbody protection
- filters and filter pads
- used cellulose wipes and cleaning wipes: solvent-saturated cellulose and cleaning wipes are generated in cleaning operations of the application devices. They are partly polluted with paint.

6.4 Techniques to consider in the determination of BAT for the coating of cars

In Chapter 20, techniques are discussed which might also be applicable to the automotive industry, for categories M1 and N1. In Section 20.7, techniques relevant to paint application are discussed. These techniques will also be applicable to cars. In Table 6.4, the general techniques relevant for cars that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

The EGTEI synopsis sheet for the coating of cars (see Annex 24.1.1) gives some data on the cost-benefit at a European level of some techniques for the reduction of VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations and products [135, EGTEI, 2005].

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 6.4: Reference to techniques generally applicable to the sector

6.4.1 Coating systems

The paint process in the vehicle manufacturing industry is a highly complex and fully integrated operation consisting of many interdependent steps. As each step influences all others, decisions made about one step can impact on all or part of the process. Equally, some combinations of techniques may be incompatible with each other. Also, an existing application system may limit the choice of coatings. Therefore, when considering techniques for determining BAT, it is not meaningful to select each step separately.

For instance, various examples of combinations of techniques are given in Table 6.5 below. These configurations are intended to be informative and are not to be considered the only options:

Example	Primer	Base coat	Clear coat
A	<ul style="list-style-type: none"> • SB • WB • None • Powder Primer 	<ul style="list-style-type: none"> • WB 	<ul style="list-style-type: none"> • WB • Powder • Powder slurry
B	<ul style="list-style-type: none"> • WB 	<ul style="list-style-type: none"> • WB 	<ul style="list-style-type: none"> • SB
C	<ul style="list-style-type: none"> • SB • SB with booth air abatement • WB 	<ul style="list-style-type: none"> • WB • SB • SB with booth air abatement 	<ul style="list-style-type: none"> • SB • SB with booth air abatement
Key: SB = solvent-based, WB = water-based			

Table 6.5: Examples of combinations of coatings for cars
[117, ACEA, 2005]

6.4.2 Conventional solvent-based materials

Description: Conventional solvent-based paints have the following solvent contents by weight: 35 – 45 % for primers, 40 – 50 % for top coats, and 30 – 35 % for high solid topcoats, 70 - 80 % for base coats and 50 – 55 % for clear coats. The solvent (mainly VOC) is present for viscosity, film formation and reduced energy evaporation.

The application involves a closed delivery system to an application gun. Application can be both manual or automatic (or both) in a purpose built spray booth with downdraft and exhaust ventilation.

Achieved environmental benefits: Compared to water-based paint systems, direct energy requirements for each car is 15 % lower (990 MJ/car compared to 1100 MJ/car for water-based coatings) due to the better climatization and accelerated flash-off of solvent-based systems. However, this does not include energy consumption for abatement of spray booth exhaust air which is about 200 to 400 MJ/car. See Section 6.3.2.3 and Table 6.3.

Cross-media effects: As a baseline, all solvent materials without emission controls 20 to 30 years ago resulted in 100 - 300 g/m². Modern systems achieve 43 - 72g/m² for a primer/base coat/clear coat system.

Typically, the solvents in the waste gas from ovens are incinerated as they account for about 15 % of the total VOC emissions from a site using conventional paint systems. Where possible, the heat generated energy is recovered and used, e.g. for heating the driers. However, to achieve low levels, thermal treatments need additional fuel, see Section 20.11.4.

Operational data: Curing times are shorter than those required for water-based systems, therefore, faster line speeds can be achieved in smaller areas due to reduced oven times. Solvent-based systems can also operate over a wider temperature and humidity range. Stainless steel equipment is not required.

Modifications to solvent-based operations to achieve lower VOC emissions can be achieved with reduced downtime (as opposed to a refit needed with a material change).

This technique does not meet the lower emission requirements necessary in some parts of Europe, and will not achieve even mid-range performance, e.g. as indicated in Figure 6.2.

Applicability: Solvent-based paints can be used in all phases of the painting operation (primer, solid topcoat, base coat, clear coat and repair), and can be used on metals and plastics. They can be applied to new and existing paintshops where space is limited and where changes in the paint materials may not be technically possible.

Economics: No data submitted.

Driving forces for implementation: Economic and technical restraints on existing paintshops may make conventional solvent technology a preferred option for certain facilities.

Example plants: No data submitted.

Reference literature: [68, ACEA, 2004] [76, TWG, 2004] [128, TWG, 2005]

6.4.3 Substitution of solvent-based materials

6.4.3.1 Water-based paint systems

Description: See Section 20.7.2.3 for a general description of water-based paint systems. In electrocoating, the application of water dilutable or water dispersible paints use materials with a solvent content of 1 – 6 % and usually 1 – 2 wt-%.

Electrocoating materials are delivered in a closed system and applied using dip techniques. For primer and base coat applications, water-based paints contain water dilutable or water dispersible film forming agents (alkyd, polyester, acrylate, melamine and epoxy resin). Primer and base coat materials are delivered in a closed system and applied using spray techniques. Conventional water-based systems contain the following solvent contents by weight: 5 - 10 % for primer and 10 - 15 % for base coat.

Achieved environmental benefits: Typical VOC emission factors for the water-based phases of the paintshop include 1 – 2 g/m² for the primer, 6 – 8 g/m² for the base coat (7 – 9 % for products with reduced flash-off time, see Section 20.7.2.4 and 2-component types) with no emission controls.

Cross-media effects: The direct energy requirements per car are approximately 13 - 17 % more than solvent operations partly due to the requirement to dry each layer between coating applications (intercoat flash-off).

Energy generation from some solvent incineration systems is lost.

Material consumption for waterborne material has been reported to be comparable to solvent-based paints between 0 and 11 % higher for primer and between 0 and 25 % higher for base coat.

Water consumption is also higher and the sludge separation in waste water treatment is more difficult.

Operational data: Energy requirements are typically 1100 MJ per car. For data on specific processes, see Section 6.3.2.3 and Table 6.3. Influences on operations: production volume, local climatic conditions, abatement techniques used, air volume requirements, length of booths, booth operating criteria such as temperature and paint application techniques.

Applicability: Waterborne materials can be used as electrocoat, primer, base coat and in some repair operations. They can be used on metals and plastic materials. However, they cannot be used with one-coat one-bake solid colours as they would need to be sealed with a clear coat. Waterborne materials have been developed for clear coat applications, but have not been taken up widely for cars due to their poor appearance and quality. However, note that limitations of appearance and quality of topcoats is independent of whether they are water-based or solvent-based, but depends on resin technology (alkyd or acrylic) and pigment stability under UV light impact (for example, solvent-based alkyd topcoats have poor appearance).

Waterborne solid colour topcoats have been used commercially for years for commercial vehicles and drivers cabs. In one case, a light commercial vehicle is painted with a water-based one-coat layer without an additional clear coat.

There are difficulties in retrofitting waterborne systems into conventional solvent-based paintshops due to cost and physical constraints. The need for extended ovens with intercoat flash-off zones to meet additional curing requirements means that paintshops designed and installed for solvent-based systems may not have the space to accommodate a water-based system. Other requirements are that the paint supply pipes and systems are in stainless steel. Additional costs associated with the operational requirements, materials and equipment installation mean that water-based systems are often restricted to new paintshops, or those already equipped with the necessary systems. Water-based booths have to operate under tighter temperature and humidity controls. Because curing times are longer for water-based systems, the line speed is usually slower than for other systems.

Economics: Material costs for waterborne paints are 0 - 20 % higher compared to solvent-based paints, depending on economies of scale. In one of the reference plants (below), no cost difference is seen. Associated energy costs are higher than solvent-based materials due to extended drying requirements. Water-based technology cannot be fitted into conventional paintshops without significant investment associated with equipment installation and building costs. For example, in large paintshops (over 100000 units per year) typical costs for a complete new spray booth installation would be between EUR 15 million and 35 million; costs for water-based spray booths may be 10 - 20 % higher. These figures do not include building costs, which can be substantial depending on local conditions. This, combined with technical constraints, means that water-based technology is usually only fitted during major upgrades or in new paintshops. Since 1994, most new paintshops in EU countries have been designed for waterborne base coats. Retrofit products are available in the form of base coats with reduced flash-off time (see Section 20.7.2.4).

Overall costs, when taking into account decreased abatement costs, are typically lower for waterborne coatings.

Driving forces for implementation: Reduction of VOC emissions to the air.

Example plants: Volkswagen, Wolfsburg, Germany; Renault, Flins sur Seine, France; GM, Eisenach, Germany; Opel, Eisenach, Germany.

Reference literature: [68, ACEA, 2004] [13, DFIU and IFARE, 2002] [128, TWG, 2005]

6.4.3.2 Powder coating

Description: Powder coatings are solvent-free systems that require electrostatic application procedures and are, therefore, primarily suitable for metal bodies. Powder coatings are typically based on acrylic resins with either an acid or an anhydride. They can be used in primer or clear coat applications. Powder application takes place in a purpose built spray booth with downdraft and exhaust ventilation and can be by automatic or hand spray applications. See also Section 20.7.2.6.

Achieved environmental benefits: Powder coat technology has zero VOC emission and does not require water use for particulate abatement. The use of reclaimed powder enables material re-use of up to 97 %. Energy requirements are lower than waterborne material and are comparable with solvent-based technology. Drying by combinations of infrared and air circulation drying techniques reduce energy consumption.

Cross-media effects: Energy generation due to solvent incineration is omitted.

Operational data: The powder paint technique allows reduced reprocessing of the booth air compared to conventional installations. There have been problems with a yellowish colouration of the clear coat application in the final product. The main problem is that control of the film thickness is difficult: a greater layer thickness will be created than is necessary (approx. 65 µm), which results in higher paint consumption; however, increasingly nowadays, thinner layers (approx. 55 µm) are also achievable.

Applicability: Powder coat technology is currently applicable for primer and clear coat application. Powder primers are now available and used in one plant in Europe (with up to five to six coloured primers). Powder clear coat is used in Europe by one car manufacturer.

Economics: When changing from existing solvent technology to retrofitting powder technology, high capital costs are involved, because powder technology is a completely different technology and requires a total refit of facilities, equipment and materials. However, a reduction of operating costs can be observed; present estimations describe a reduction of at least 12 % in energy costs over either water-based or solvent-based with abatement costs.

Driving forces for implementation: Reducing VOC emissions.

Example plants: BMW AG in Dingolfing, Germany.

Reference literature: [68, ACEA, 2004] [13, DFIU and IFARE, 2002] [63, Vito, 2003] [76, TWG, 2004] [128, TWG, 2005].

6.4.3.3 Powder slurry coating

Description: Powder slurries are powders dispersed and stabilised in water and are applied using conventional equipment for liquid paints. They can be used in clear coat applications.

Achieved environmental benefits: Significant reduction in VOC emissions. Significant energy savings are achieved by replacing the conventional 2-component clear coat by the wet-on-wet applied powder slurry clear coat. With the wet-on-wet application, the intermediate drying step can be missed out.

Cross-media effects: Energy generation due to solvent incineration is omitted.

Operational data: To meet the quality criteria, the spray booth must operate under tight temperature (20 - 24 °C) and humidity (65 - 75 %) controls. A thinner film (45 µm) can be achieved compared to dry powder coating.

The powder slurry clear coat, which has been in use at DaimlerChrysler AG since 1997, is almost solvent-free and is applied by using the wet-on-wet application technique.

Applicability: Powder slurry is not employed in general industrial processes for vehicle coating, although two leading suppliers offer powder slurry systems. Powder slurry requires the application of an adapted colour coat layer to ensure wet-on-wet compatibility. Before powder slurry can be baked, water must evaporate from the wet film, therefore, a forced flash-off is required. It is used in two plants in Europe.

Economics: No data submitted.

Driving forces for implementation: Reduced VOC emissions.

Example plants: DaimlerChrysler AG (Austria) and Rastatt (Germany).

Reference literature: [68, ACEA, 2004] [13, DFIU and IFARE, 2002] [76, TWG, 2004].

6.4.4 Paint application techniques and equipment

The following paint application techniques and equipment are commercially applied:

- paint application by immersion, see Section 20.7.3.4 and for more detail Section 6.4.4.1
- conventional high and low pressure spraying, see Section 20.7.3.8
- high volume low pressure spraying (HVLP), see Section 20.7.3.9
- electrostatic atomising spraying processes, see Section 20.7.3.14
- electrostatically assisted high rotation bells, see Section 20.7.3.15
- electrostatically assisted compressed air, airless and air assisted spraying, see Section 20.7.3.17
- powder coatings – electrostatically assisted spraying, see Section 20.7.3.18.

6.4.4.1 Paint application by immersion

Description: Pretreated vehicle bodies are electrically charged while being passed through a bath of electro-immersion coating. The coatings are typically water-based and are diluted with deionised water. The solvent content is typically in the range 2 - 6 wt-%, and usually 1 – 2 wt-%.

The dip electrocoating process covers all vehicle surfaces interior and exterior. The calculated e-coat area is typically between 60 and 100 m² per vehicle, depending on size and design (see Annex 24.5). See also Section 20.7.3.4.

Achieved environmental benefits: Due to the low solvent content of this material and the fact that the material is not atomised as with spray operations, VOC emission levels are very low. Typical emissions are <0.2 kg VOC/car, which equates to between 2 – 4 g VOC/m², depending on the electrocoated surface area of the car being painted. With abatement of waste gas from the oven, >1 g VOC/m² can be achieved.

In addition to the paint consumption being low, a small amount of waste is generated. Dip coating represents a very high application efficiency and because of the low material usage generates very little waste.

Cross-media effects: No data submitted.

Operational data: Application takes place in a purpose built facility with exhaust ventilation. The primed bodies must pass through an oven before subsequent coatings are applied.

Applicability: This technique can be used for whole vehicle bodies and metal components including surface panels that are difficult to reach. At present, the immersion technique is widely used, but only for the application of the primer (cataphoretic application). The optical quality of the lacquer finish is very important in car production, therefore only spraying techniques are used for the application of fillers and topcoats.

Economics: No data submitted.

Driving forces for implementation: Quality and corrosion protection.

Example plants: No data submitted.

Reference literature: [68, ACEA, 2004] [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

6.4.5 Spray booths

The following techniques are commonly applied:

- wet separation spray booths, see Section 20.7.4.1
- water emulsion techniques in spray booths, see Section 20.7.4.3.

6.4.6 Minimisation of raw material consumption

The following techniques are commonly applied:

- batch painting/colour grouping, see Section 20.6.3.6
- pig-clearing systems, see Section 20.6.3.7.

6.4.6.1 Recovery of used solvents

Description: See Section 20.13.1. Modern paint supply equipment including recovery of the purge solvents are commonly applied. Recovery is by piping the cleaning agents from the application equipment to the storage tanks.

Achieved environmental benefits: Typically 80 - 90 % cleaning and purge solvents can be recovered, either on site or off site, for re-use.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: The installation of a typical solvent recovery system costs EUR 0.4 million per spray booth.

A saving will be achieved because of a reduced consumption of solvents and reduced amounts of hazardous waste. In large plants, the savings will approximately outweigh the investment.

Driving forces for implementation: No data submitted.

Example plants: Ford, Europe.

Reference literature: [4, Intergraf and EGF, 1999] [13, DFIU and IFARE, 2002] [62, CITEPA, 2003] [68, ACEA, 2004, 76, TWG, 2004]

6.4.7 Drying techniques

The following techniques are commonly applied:

- drying via circulating air with or without dehumidified air, see Section 20.8.1.1.
- infrared radiation curing, see Section 20.8.2.1.

6.4.8 Waste gas treatment

The following techniques are commonly applied:

- venturi system, see Section 20.11.3.5
- scrubber, see Section 20.11.3.6
- dry filter systems, see Section 20.11.3.8
- electrostatic filter, see Section 20.11.3.7
- internal solvent concentration as the pre-procedure for waste gas treatment, see Section 20.11.3.1
- external solvent concentration as the pre-procedure for waste gas treatment, see Section 20.11.3.2
- dedicated waste gas treatment system integrated in the drier, see Section 20.11.1.6
- adsorption: fixed-bed adsorption, fluidised bed adsorption and rotor (wheel) absorption, see Section 20.11.6
- oxidation: recuperative, catalytic, and regenerative oxidation, see Section 20.11.4.

6.4.9 Waste water treatment

The following techniques are commonly applied:

- cascade rinsing, see Section 20.7.5.1
- use of ion exchanger, see Section 20.7.5.2
- ultra and nanofiltration, see Section 20.12.6.

7 COATING OF VANS, TRUCKS, AND TRUCK CABS

[13, DFIU and IFARE, 2002] [128, TWG, 2005] [118, ACEA, 2005] [181, ACEA, 2003]

The painting processes for the coating of vans, trucks and truck cabs show significant deviations compared to the serial painting of cars due to the use of different coating materials, processes, application techniques and layer constructions. Although optical surface qualities are as important as for cars, corrosion protection is more important than in other sectors.

This chapter addresses the integrated environmental protection measures used in the painting of cabs and chassis for trucks of the categories N2 and N3 (according to Directive 70/156/EWG). Driving cabs for trucks or truck cabs are defined as cabs and include integrated housings for technical equipment.

7.1 General information on the coating of vans, trucks and truck cabs

See Section 6.1 for overall details of size, turnover, etc. of the vehicle manufacturing industry. In the EU in 2005, 1640769 light commercial vehicles and 549468 heavy trucks were produced, generating revenues of nearly EUR 70000 million and accounting for 250000 jobs directly. There are about 109 sites producing commercial vehicles in the whole of Europe (including Russia) [152, ACEA, 2006].

7.2 Applied processes and techniques in the coating of vans, trucks and truck cabs

7.2.1 Drivers cabs and light commercial vehicles

[185, May, et al., 2006]

Similar to the serial coating of passenger cars, the applied coating systems can vary from plant to plant. Commercial vehicle manufacturers use either serial coating systems (with drying temperatures of about 140 °C) or 2-component paints for repair purposes (with drying temperature of 80 °C); a combination of both systems is also often used.

The pretreatment of the cabs includes cleaning, degreasing with subsequent rinsing, zinc phosphating with rinsing, followed by passivation and rinsing with demineralised water. A lead-free dip e-coat is applied. After two rinsing cycles in ultrafiltrate and with demineralised water, the drivers cabs are dried in a drier, which is equipped with a post combustion unit. Then the application of underbody protection, anti-noise materials and seam sealing takes place. The vehicle body is prepared for the applications of paint by optional filing and relative cleaning.

Subsequently, a filler is applied onto the inner and outer surfaces of the drivers cab and is dried in a drier. The layer thickness varies from 25 to 30 µm. Afterwards, the paint is applied onto the interior and exterior surfaces both via automated and manual spray applications (electrostatic and pneumatic). The layer thickness varies from 25 to 35 µm. The painting booths are equipped with a wet separator for abatement of the overspray; the repair booths can be equipped with a dry separator. Drying is then carried out in an oven.

The layer thickness of the base coats amounts to 10 - 20 µm, that of the subsequently applied clear coat amounts about 40 ± 5 µm, 1-coat topcoats are applied with a layer thickness of 30 - 40 µm.

The current production of truck cabs is composed of more than 90 % solid coat finish and the remaining volumes are metallic finish; for vans, production is more than 85 % solid coat finish and the remaining volumes are metallic finish. Waterborne single layer topcoat has gained acceptance and is used at DaimlerChrysler Düsseldorf, Germany and Ludwigsfelde, Germany, MAN Steyr, Austria and Munich, Germany, Volvo Umea, Sweden, Fiat Sevel, Italy (1K high-bake or 2K low-bake). This is likely to gain in acceptance.

Commonly applied or conventional systems for the coating of drivers cabs are:
[8, IFARE and CITEPA, 2002]

- electrocoat: water-based (8 wt-% solvent content)
- primer: solvent-based (50 wt-% solvent content)
- topcoat: solvent-based solids coat (45 wt-% solvent content); solvent-based base coat (75 wt-% solvent content); and solvent-based clear coat (45 wt-% solvent content).

Alternative systems are:

- electrocoat: water-based (8 wt-% solvent content)
- primer: water-based (15 wt-% solvent content)
- topcoat: solvent-based solids coat high solid (40 wt-% solvent content); solvent-based base coat high solid (65 wt-% solvent content); and solvent-based clear coat high solid (40 wt-% solvent content); electrostatic application.

and:

- electrocoat: water-based (8 wt-% solvent content)
- primer: water-based (15 wt-% solvent content)
- topcoat: water-based solids coat (15 wt-% solvent content) and solventborne solids coat high solid (40 wt-% solvent content) (for special colours); water-based base coat (15 wt-% solvent content); and solvent-based clear coat high solid (40 wt-% solvent content) [152, ACEA, 2006].

7.2.2 Coating of truck chassis

[185, May, et al., 2006]

Truck chassis are assembled from profiles and parts (like axles and air tanks) that are already electrocoated or painted with a conventional primer. A water-based material with a solvent content of 5 - 10 % is for paints for dip coating (e-coat). Conventional primers can be used with powder coat, waterborne (10 - 15% solvent content) and solventborne primers (45 - 55 % solvent).

After pre-assembling the chassis, the surface quality is checked and imperfections are locally repaired with a primer coat. Some areas are masked. Locally some solvent- or water-based cleaning is undertaken manually to remove dirt, oils and other foreign matter. Subsequently, a 1-coat topcoat is applied, so the chassis are automatically transported through the installation by a conveyor system. The chassis are painted manually due to their variations in size and structure. First, the paint is applied onto the underside, then on the topside. For high runners, water-based (2-component) topcoats are used for about 95 % of chassis. For special colours, 2-component solventborne acrylate paints are applied. The applied layer thickness varies from 40 to >60 µm.

The material is applied using HVLP, conventional, airmix or airless spray guns. Overspray is intercepted via a wet dust collector with automated discharge of the paint sludge. For drying, the coated chassis are first transported to a flash-off zone with a maximum temperature of 40 °C and low air velocity. Afterwards, the paint is dried in a forced air drier at air temperatures of 85 - 90 °C. After drying, the chassis are cooled down to ambient temperature and demasked.

Commonly applied or conventional system for the coating of truck chassis are:
[152, ACEA, 2006]

- electrocoat: water-based (5 - 10 wt-% solvent content)
- primer: solvent-based (45 - 55 wt-% solvent content); electrostatic application
- topcoat: solids coat (45 - 55 wt-% solvent content); electrostatic application.

Alternative systems are:

- electrocoat: water-based (5 - 10wt-% solvent content)
- repair primer: solvent-based (45 - 55 wt-% solvent content)
- topcoat: solids coat (45 - 55 wt-% solvent content)

and:

- electrocoat: water-based (5 - 10 wt-% solvent content)
- repair primer: water-based (8 - 13 wt-% solvent content)
- topcoat: solids coat (45 - 55 wt-% solvent content)

and:

- electrocoat: water-based (5 - 10 wt-% solvent content)
- primer: water-based (8 - 13 wt-% solvent content)
- topcoat: water-based solids coat (8 - 13 wt-% solvent content); conventional, HVLP, airmix or airless application.

7.2.3 Painting of axles

(See Chapter 13). Axles for trucks and commercial vehicles are generally coated with water-based paints. The greatest proportion of the applied solvents is emitted since emission reduction measures are not applied or only the drier is connected to a post-combustion unit.

7.3 Current consumption and emission levels in the coating of vans, trucks and truck cabs

7.3.1 Mass balances

No information submitted.

7.3.2 Consumptions

7.3.2.1 Materials

An overview of the specific consumption values of paints for the painting of new drivers cabs is given in Table 7.1. The consumption depends on the different paint systems and application systems, etc. It should be remembered that this is for guidance only, and cannot be a 'pick list' to select a paint system of the basis of consumption efficiency only. The paint process in each installation is highly complex and fully integrated comprising many integrated steps: each step influences others and different figures apply according to application techniques. Decisions about best options therefore cannot be taken on the basis of selecting each step individually.

Painting material	Specific material consumption (g paint/m ²)	
	Truck cabs	Vans
Electrocoat: water-based (5 wt-% solvent content)	128	128
Primer: solvent-based (50 wt-% solvent content)	20	24
Primer: water-based (15 wt-% solvent content)	20	24
Topcoat: solvent-based solids coat (45 wt-% solvent content)	134	160
Topcoat: solvent-based solids coat high solid (40 wt-% solvent content)	117	140
Topcoat: water-based solids coat (15 wt-% solvent content)	134	160
Topcoat: solvent-based base coat (75 wt-% solvent content)	122	146
Topcoat: solvent-based base coat high solid (65 wt-% solvent content)	116	139
Topcoat: water-based base coat (15 wt-% solvent content)	122	146
Topcoat: solvent-based clear coat (45 wt-% solvent content)	72	86
Topcoat: solvent-based clear coat high solid (40 wt-% solvent content)	63	76

Table 7.1: Specific consumption values for paints for the coating of new drivers cabs [185, May, et al., 2006]

7.3.2.2 Water

As in the coating of cars, the main water using areas in the painting of truck cabs and vans are:

- pretreatment (degreasing)
- conversion coating (phosphating and passivation)
- electrocoating.

The primary use of water is in rinsing stages; less water is lost by evaporation and used for making new solutions. Water management and saving techniques are described in detail in Chapter 20. These include multistage rinsing, techniques to minimise water use, recovery of water and raw materials. Water consumption for the painting of truck cabs or vans varies from 35 to 80 l/m² [185, May, et al., 2006].

7.3.2.3 Energy

Table 7.2 gives an overview of the gas consumption for the painting of vans, truck chassis and drivers cabs.

	Painting of truck cabs and vans	Painting of chassis
Gas consumption	0.7 - 1 Nm ³ /m ² surface painted area	0.7 - 1 Nm ³ /m ² surface painted area

Table 7.2: Overview of the gas consumption of chassis, and drivers cabs and vans [185, May, et al., 2006]

7.3.3 Emissions

7.3.3.1 Emissions to air

VOC emissions from the painting of vans, trucks and truck cabs is 9.4 % of the total for the automotive industry [118, ACEA, 2005] and are higher per square metre than those from coating processes in car production for the following reasons:

- lower production volumes than cars (typically 150000 to 300000 units), so investments for reducing emission of VOC will be relatively higher, which results in a high cost per tonne VOC avoided compared with the sector of passenger cars (M1)
- less automation because of relatively high investment costs versus annual volumes, the larger area to be covered and the larger reach required to access the whole painted area. This, with difficult geometries and sizes, results in lower transfer efficiency than M1 and higher emissions
- larger size of vehicles requires larger spray booths and ovens and hence larger air volumes to be treated in case of abatement techniques. This makes abatement less economically feasible
- techniques available for passenger cars are often not available or need to be tailored at very high costs because of the large size of the vehicles painted and the smaller production volumes
- colour range much larger (300 – 800 different colours, corporate fleet requirements):
 - waterborne systems not available for multicoloured vehicles and for the number of different colours; or cannot meet customer specifications
 - more rinsing because of large number of colours
 - more purging required because batch painting cannot be used
 - small batches of paint, used infrequently, so the rest of the material needs to be disposed of
 - some colours require higher film build for convertibility reasons and therefore either multicoloured primers need to be used, or double painting is required
 - multicoloured vehicles means more coats and hence more emissions
- larger surface areas are more prone to damage and defects, so more repairs
- increased demand for metallic paints increases VOC emissions (metallics are solvent-based)
- more constraints on technologies due to different type of materials/add-ons to be painted on the same line
- more interior painting (less covering with panels compared to passenger cars).

Figure 7.1 shows some values for VOC emissions from van, truck and truck cab assembly plants in Europe. The surface areas and emissions are measured according to Annex 24.5.

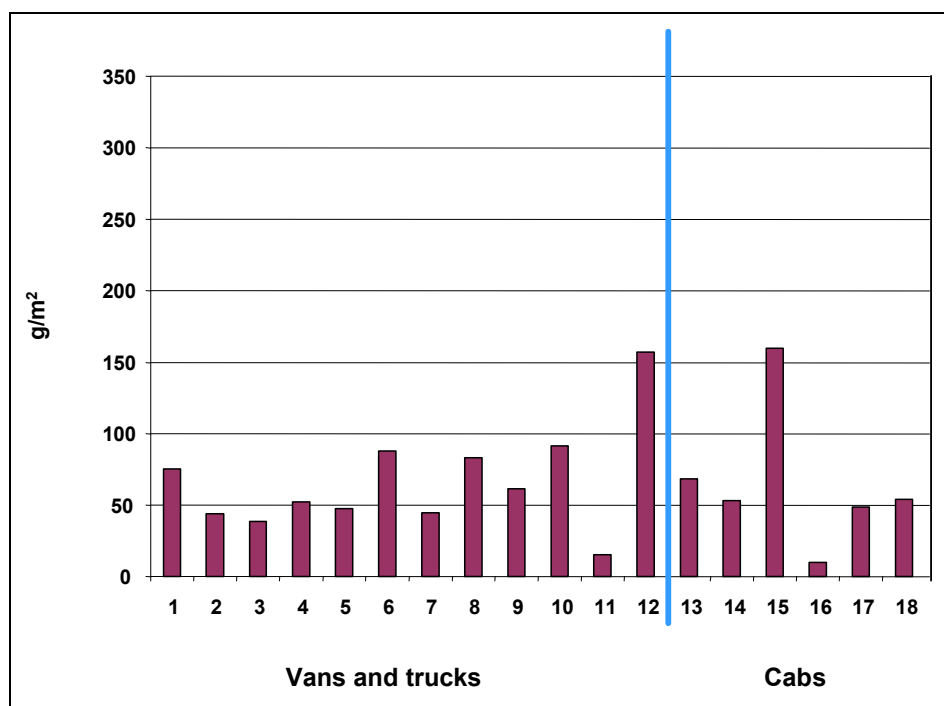


Figure 7.1: VOC emissions for several van, truck and cab assembly plants in Europe [118, ACEA, 2005]

Emissions from cleaning can be reduced to $<20 \text{ g/m}^2$ by using good practice in housekeeping, cleaning, and substitution techniques such as those referred to in Sections 20.2.2, 20.9 and 20.10 [122, Dupont and May, 2005].

7.3.3.2 Emissions to water

Information is given in Section 6.3.3.2 on emissions from water-based processes, such as pretreatments, e-coating, wet scrubber systems for paint spray booths, etc. No specific data relating to vans, trucks and truck cabs was available.

7.3.3.3 Waste

The following wastes are generated by pretreatment, electrophoric dip coating and painting of chassis and drivers cabs:

- paint containers
- decanted paint sludge
- contaminated organic solvents
- waste paints
- masking paper (only from painting of chassis)
- water with painting material.

7.4 Techniques to consider in the determination of BAT for the coating of vans, trucks and truck cabs

In Chapter 20, techniques are discussed which might also be applicable to the coating of trucks and commercial vehicles. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to the coating of trucks and commercial vehicles. In Table 7.3, the general techniques relevant for the coating of trucks and commercial vehicles that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

The EGTEI synopsis sheets for the coating of vans, trucks and truck cabs (see Annex 24.1.1) give some data on the cost-benefit at a European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations or products [136, EGTEI, 2005] [137, EGTEI, 2005].

The paint process in the vehicle manufacturing industry is a highly complex and fully integrated operation consisting of many interdependent steps. As each step influences all others, decisions made about one step can impact on all or part of the process. Equally, some combinations of techniques may be incompatible with each other. Also, an existing application system may limit the choice of coatings. Therefore, when considering techniques for determining BAT, it is not meaningful to select each step separately.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 7.3: Reference to techniques generally applicable to the sector

7.4.1 Conventional solvent-based materials

Description: For the general description, see Section 20.7.2.1. Solvent-based paint systems are applied on drivers cabs as:

- filler: 50 wt-% solvents
- 1-coat topcoat: 45 wt-% solvents
- base coat: 75 wt-% solvents
- clear coat: 45 wt-% solvents.

Achieved environmental benefits: No data submitted.

Cross-media effects: This type of coating system has an approximate range of VOC emissions before abatement of 193 to 233 VOC/m².

Operational data: In metallic paints, the base coat and clear coat are always solvent-based. The layer thickness of the base coats amounts to 10 - 20 µm, and that of the subsequently applied clear coat amounts to approx. 40 ± 5 µm. 1-coat topcoats are applied with a layer thickness of 30 - 40 µm.

For cabs, waste gas from the driers is usually connected to a post-combustion unit, while the spray booth waste gas is not usually treated (only at one site).

However, after painting axles, the greatest portion of the applied solvent is emitted without being treated, since emission reduction measures are not applied, or the drier is connected to a post-combustion unit.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Volvo in Umea (Sweden), combines incineration with zeolite filtration for solvent recovery. The emissions are less than 1 kg per cab.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005] [185, May, et al., 2006]

7.4.2 Replacement of solvent-based materials (substitution)

7.4.2.1 Water-based paint systems

Description: For the general description, see Section 20.7.2.3. Water-based paint systems are applied for:

- electrocoat: 8 wt-% organic solvent
- filler/primer: 15 wt-% organic solvent
- base coat: 15 wt-% organic solvent.

The VOC emissions total for these coats is in the range 31 to 36 g VOC/m² without topcoat and prior to any abatement. About 25 different water-based (2-component) topcoats are used for approx. 95 % of the chassis.

Achieved environmental benefits: No data submitted.

Cross-media effects: Since water-based paints allow lower application efficiencies, an increased paint consumption has to be taken into account. It is reported that:

- the primer consumption for water-based coatings is about 5 % higher than for conventional solvent-based primers
- the base coat consumption for water-based coatings is about 10 % higher than for conventional solvent-based base coats.

Operational data: The DaimlerChrysler AG company in Kassel, Germany has been operating an installation that uses water-based paints for the coating of axles since 1998. Due to these measures, 160000 litres of solvents are saved yearly.

Applicability: Replacement of solvent-based primer and enamels involve changing the spray booths and the automatic spraying devices; this expense varies widely depending on the plant arrangement. In many cases, because additional space is needed to make the spray booths longer, a new plant has to be installed in a new building.

Economics: The cost of replacing one simple spray booth and related automatic spraying devices (i.e. a primer spray booth) varies from EUR 13 million to 25 million. The installation of a new plant in a new building varies, depending on the plant size, from EUR 60 million for a 25000 cabs/year plant to EUR 140 million for a 50000 vans/year plant.

Driving forces for implementation: SED.

Example plants: Water-based 1-coat topcoats are applied by MAN (Munich, Germany) and DaimlerChrysler AG (Kassel, Germany).

Reference literature: [13, DFIU and IFARE, 2002] [8, IFARE and CITEPA, 2002] [128, TWG, 2005] [185, May, et al., 2006]

7.4.3 Paint application techniques and equipment

7.4.3.1 Electrocoating

For a general description, see Section 20.7.3.4. All electrocoatings (e-coat) used are water-based; their content of organic solvents is typically 8 wt-% and they are lead-free. Truck chassis are assembled from profiles that have already undergone the electrocoating dip process. At present, the immersion technique is widely used for the application of electrocoatings. Electrocoating implies high investment and material costs.
[13, DFIU and IFARE, 2002]

7.4.3.2 High volume low pressure spraying (HVLP)

For a general description, see Section 20.7.3.9. Primer is applied onto the interior and exterior surfaces of the driver's cab, via manually operated HVLP spray guns.

On truck chassis, water-based material is applied using HVLP spray guns. The applied layer thickness varies from 40 to 60 μm . Overspray is intercepted via a wet scrubber system with automated discharge of the paint sludge to the decanter.
[13, DFIU and IFARE, 2002] [128, TWG, 2005]

7.4.3.3 Electrostatically atomising spray processes

For a general description, see Section 20.7.3.14. 1-coat topcoat: 45 wt-% organic solvents, with specific VOC emissions of 60 - 72 g VOC/m² that is applied by using electrostatic spraying.

7.4.3.4 Electrostatically assisted high rotation bells

For a general description, see Section 20.7.3.15. After the filler/primer is applied, a second layer is applied onto the outside surfaces via automated electrostatic spray applications via high rotation bells. The layer thickness varies from 25 - 35 µm. A manual paint application is only carried out for special orders.

Solvent-based base coat is usually applied by using an electrostatic spray application (50 %) and a regular spray application (50 %). Clear coat is applied by using electrostatic spraying.

In metallic paints, the base coat and clear coat are solvent-based. The base coat is about 10 - 20 µm thick, the subsequent clear coat 40 ± 5 µm thick and single layer topcoats are 30 - 40 µm thick.

[13, DFIU and IFARE, 2002]

7.4.3.5 Wet separation spray booths

For a general description, see Section 20.7.4.1. These are commonly applied.

[13, DFIU and IFARE, 2002]

7.4.4 Waste gas treatment

7.4.4.1 Oxidation

For a general description, see Section 20.11.4. After rinsing at the end of the electrocoating process, the vans, trucks, cabs and chassis are dried in a drier that is usually equipped with an oxidiser.

Where solvent-based paints are applied, drying over sand spray booths are usually equipped with an oxidiser. However, spray booths might be equipped with activated carbon adsorption combined with an oxidiser.

[13, DFIU and IFARE, 2002] [8, IFARE and CITEPA, 2002]

The investment for the above emission reduction measures depends on the plant size.

For a truck cabs paintshop with a throughput of 25000 units/year, the investment for the installation of post-combustion units on the driers amounts to approximately EUR 3 million, which, per painted vehicle, corresponds approximately to EUR 12. In addition to this, energy costs of about EUR 300000/year are generated, which, per painted vehicle, is approx. EUR 12.

For a van paintshop with a throughput of 50000 units/year, the investment for the installation of post-combustion units on the driers amount to approximately EUR 4 million, which, per painted vehicle, corresponds to approximately EUR 8. In addition to this, an additional energy cost of about EUR 400000/year is generated, which, per painted vehicle, is approximately EUR 8.

[185, May, et al., 2006]

7.4.4.2 Adsorption to activated carbon

For a general description, see Section 20.11.6. If solvent-based paints are applied, waste gas from spray booths and driers can be pretreated, e.g. in an adsorption wheel followed by a post combustion unit.

For a truck cabs paintshop with a throughput of 25000 units/year, the investment for the installation of an adsorption regenerative device and a relative post-combustion unit for partial treatment of the spray booths VOC emissions, amounts to approximately EUR 12 million, which, per painted vehicle, corresponds approximately to EUR 60. In addition to this, energy costs of about EUR 650000/year are generated, which, per painted vehicle, is approximately EUR 26.

For a vans paintshop with a throughput of 50000 units/year, the investment for the installation of post-combustion units on the driers amounts to approximately EUR 15 million, which, per painted vehicle, corresponds to approximately EUR 30. In addition to this, an additional energy cost of about EUR 1.2 million/year is generated, which, per painted vehicle, is approximately EUR 24.

[185, May, et al., 2006]

7.4.5 Waste water treatment

The following techniques are commonly applied:

- ultra and nanofiltration is commonly applied to the electrocoating dip baths, see Section 20.12.6
- cascade rinsing, see Section 20.7.5.1
- use of ion exchanger, see Section 20.7.5.2
- continuous discharge of paint sludge, see Section 20.7.5.6
- decantation system, see Section 20.7.5.7.

8 COATING OF BUSES

[13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005] [118, ACEA, 2005] [186, May, et al., 2006]

8.1 General information on the coating of buses

This chapter addresses the integrated environmental protection measures used in the painting of bodies and chassis for buses of the category M2 and M3 (according to Directive 70/156/EWG). In 2005, 30514 buses and coaches were built in the EU. There are about 46 installations across the whole of geographic Europe (including Russia). Turnover relating to buses is included in that for vans and trucks, and all together they are referred to as commercial vehicles. Additional background information can be found in Section 6.1 on the vehicle building industry and on commercial vehicles in Section 7.1 [152, ACEA, 2006].

8.2 Applied processes and techniques in the coating of buses

8.2.1 Pretreatment

The vehicle bodies are generally treated by applying conventional pretreatment processes such as degreasing and phosphating before the painting takes place. After the pretreatment processes, the ground coat is applied via spray application or dip coating.

8.2.2 Ground coating/dip coating

One German production plant uses cathodic dip coating for the application of a ground coating onto the vehicle bodies. To remove grease, oils, grinding residues and other impurities, the vehicle body shells are previously cleaned in a aqueous-alkaline process (at a temperature of 60 °C). Then rinsing takes place.

To prepare the surface for the following phosphatisation, activation takes place. Applying the conversion layer onto the vehicle bodies (at a temperature in the range of 50 - 55 °C) ensures corrosion protection and the adherence of the coating layer which is applied later. To seal the phosphate layer, the body surface is passivated. The bodies are rinsed several times at an ambient temperature with demineralised water, then the cathodic dip coating is applied. The material used is water-based with an organic solvents content of about 3 wt-%. Subsequently, the primed bodies are rinsed automatically and manually with demineralised water and are dried at 175 °C (temperature of the substrate) in a drier equipped with a post combustion unit, before they are taken to a cooling zone.

VOC emissions could be reduced by up to 60 % by the implementation of the cathodic dip coating. This process was implemented in 1990. In addition to dip coating with water-based materials, the spray application of solvent-based 2-component epoxy materials is also still common. These materials contain about 40 - 50 % solvents and are applied via a manual spray application.

8.2.3 Underbody protection and seam sealing

After the cleaning of the bus bodies, seam sealing takes place inside and outside as well as in the underbody area. Only after the seam sealing does the application of the underbody protection take place. Underbody protection material is either a 2-component polyurethane or a water dilutable lacquer. Seam sealing and the application of underbody protection is carried out manually.

8.2.4 Application of the primer

The primer prepares the surface for the subsequent finish coating. With it, unevenness is filled out and imperfections of the ground coat layer are sealed so that adherence and corrosion protection is ensured. The primer also increases the mechanical resistance of the bus surface.

At present, only solvent-based primers are applied for the coating of buses in Germany. The application is carried out manually, and dried afterwards. In the DaimlerChrysler Neu-Ulm (Germany) plant the primer is applied automatically with high rotating bells and robots. In this case, coloured primers can be used, to avoid the need for two layers of topcoat for colours with low covering qualities.

8.2.5 Application of the topcoat

Due to the individual colour design in the production of buses, different layer concepts are used. Although different labels or motifs are applied at a later stage, all buses go through the same painting steps. Either single layer topcoatings (1-coat topcoats) or double layer topcoatings, consisting of topcoat and clear coat. For colours with a low cover strength (such as yellow or red), two layers are applied, and the topcoats are applied manually. This is not required if coloured primers are used.

Since not all colours are available as water-based paints, solvent-based topcoats are exclusively applied at present. For the application of labels or other motifs, foil coatings are used. Even if foil coatings reduce the paint consumption, this does not essentially reduce the VOC emissions since adhesives containing solvents are utilised. Painting processes for buses are carried out manually, which restricts the use of powder coatings.

8.2.6 Cavity sealing

For the completion of corrosion protection, surfaces with cavities in the body structure have to be sealed by applying a wax layer. A solvent-based wax with a solvent content of about 60 % is used as a cavity sealant.

8.2.7 Alternative systems and abatement techniques

In some cases, water-based paints for the coating of buses are applied (cataphoric dip coating and underbody protection). With one exception, water-based paints are not applied as topcoats. In only one installation, city buses are completely coated with water-based paints. Powder coating is still not used for the serial coating of buses. The application of primary emission reduction measures is still very limited for the painting of buses (as a result of manual application, small volume units and specific customers requests).

For emission reduction, end-of-pipe measures such as post combustion units are utilised for treatment of waste gases from the driers, thus only a small portion of VOC emissions are collected and treated. No experiences have been reported with more efficient emission reduction measures such as combination of adsorption via activated carbon and post-combustion units for the treatment of waste gases from painting booths and driers.

8.2.8 Examples of coating installations for buses

Examples of coating installations for buses are the companies of DaimlerChrysler AG in Mannheim and Neu-Ulm, Germany. The production capacities of these installations amount to nearly 2500 and 3000 buses respectively per year. In Mannheim, the vehicle bodies of city buses and touring buses (coaches) are produced and ground coated by cathodic dip coating.

Touring buses are transported to Neu-Ulm after they have undergone a dip coat application, and are cleaned with hot water and then dried. After that, the coating is applied. Painting steps are similar in both installations. Primarily, spray application is carried out. For underbody protection, a water-based 2-component epoxy resin is processed. To obtain a smooth surface, the vehicle bodies are filled and ground after the flaps have been mounted. Afterwards, a water- or solvent-based primer (2-component epoxy) is applied and ground over again.

In the painting booth, an acrylic priming paint is sprayed onto the body. The material is dried at a temperature of 90 °C. After a further grinding process, the topcoat (2-component material) and then the clear coat is sprayed on. More than 6000 different colours are available as base coats. The buses pass through painting booths and driers up to 15 times, until all labels and motifs have been applied. Pictures and labels are applied via spray applications or even with airbrush techniques, as well as with foil coating.

There are situations where no secondary measures are applied, however, generally thermal oxidation is applied to waste gas from the drying ovens.

As a speciality at the company of DaimlerChrysler AG in Mannheim, a polyurethane material is used for the reduction of structure-borne noise. This material is used instead of PVC noise-dampening matting which are generally bonded with solvent-based adhesives with an average solvent content of about 65 %. The polyurethane material is sprayed onto the vehicle body with a layer thickness from 3 – 8 mm. This implementation is also a contribution to working safety, since less accidents occur and no VOCs are emitted.

This noise protection material is processed inside the buses. Afterwards, a 2-component polyurethane material is applied as an alternative floor covering. In general, a PVC floor covering is utilised in city buses. The material is cut to size and bonded via solvent-based adhesives. As an alternative, a solvent-free polyurethane material is applied via airless spraying. This technique has already been realised for 145 buses (2002). Unlike previous PVC floorings, this surface does not have seams that might not be water tight and, therefore, no corrosion of the vehicle body can occur.

For touring buses, different floor coverings are used; these materials are partly bonded via dispersion adhesives. Also double sided adhesive foils are used.

In summary, the most commonly applied techniques are [8, IFARE and CITEPA, 2002] [138, EGTEI, 2005]:

- electrocoat: water-based (5 wt-% solvent content)
- primer: solvent-based (45 wt-% solvent content); electrostatic application
- topcoat: high solids coat (45 wt-% solvent content); electrostatic application, solvent-based base coat (75 wt-% solvent content); pneumatic application (50 %) and electrostatic application (50 %), solvent-based clear coat (45 wt-% solvent content); electrostatic application.

Alternative systems which are less commonly applied are:

- electrocoat: water-based (5 wt-% solvent content)
- primer: water-based (8 wt-% solvent content); electrostatic application
- topcoat: high solids coat (45 wt-% solvent content), pneumatic application; solvent-based base coat (75 wt-% solvent content), pneumatic application; and solvent-based clear coat (45 wt-% solvent content); pneumatic application.

and:

- electrocoat: water-based (5 wt-% solvent content)
- primer: solvent-based (45 wt-% solvent content); electrostatic application
- topcoat: high solids coat (45 wt-% solvent content); pneumatic application, water-based base coat (13 wt-% solvent content); pneumatic application, and solvent-based clear coat (45 wt-% solvent content); pneumatic application.

and:

- electrocoat: water-based (5 wt-% solvent content)
- primer: water-based (8 wt-% solvent content); electrostatic application
- topcoat: high solids coat (45 wt-% solvent content); pneumatic application, water-based base coat (13 wt-% solvent content); pneumatic application, and solvent-based clear coat (45 wt-% solvent content); pneumatic application.

Alternatively, emissions are reduced by using spray painting operations with reduced air pressure. Generally electrostatic applications are only used for the primer application.

8.3 Current consumption and emission levels in the coating of buses

[13, DFIU and IFARE, 2002]

8.3.1 Mass balances

No information submitted.

8.3.2 Consumptions

8.3.2.1 Materials

Normally a surface of about 200 m² per bus is coated. Table 8.1 shows specific material consumptions for separate coating layers.

Material (wt-%)	Specific material consumption (g paint/m ²)
Cataphoric dip coating, water-based material, 3 – 4 % of organic solvents	120 – 135
Seam sealing and underbody protection (water-based, manual application)	No data available
Primer (solvent-based: 45 % of organic solvents, manual application)	18 – 22
Primer (water-based: 8 % of organic solvents, manual application)	22 – 26
1-coat topcoat solvent-based: 45 % organic solvents, manual application)	10 – 40
Base coat (solvent-based: 75 % organic solvents, manual application)	90 – 100
Base coat (water-based: 13 % organic solvents, manual application)	100 – 110
Clear coat (solvent-based: 45 % organic solvents, manual application)	50 – 65

Table 8.1: Specific material consumptions for different layers
[57, Rentz, et al., 1999]

8.3.2.2 Water

As in the coating of cars, vans, trucks and cabs, the main water using areas for buses are:

- pretreatment (degreasing)
- conversion coating (phosphating and passivation)
- electrocoating.

The primary use of water is in rinsing stages; less water is lost by evaporation and used for making new solutions. Water management and saving techniques are described in detail in Chapter 20. These include multistage rinsing, techniques to minimise water use, recovering water and raw materials.

8.3.2.3 Energy

Similar to the serial coating of passenger cars, the highest energy demand is caused by the heating of painting booths and driers. Data for the energy demand are not provided.

Spray booth heat consumption as installed: 1200 to 1400 kW, electrical power installed 150 to 170 kW.

Oven: heat capacity installed 500 to 700 kW, electrical power 45 kW.

8.3.3 Emissions

8.3.3.1 Emissions to air

VOC emissions from the painting of buses is 0.6 % of the total for the automotive industry [118, ACEA, 2005] and are higher per square metre than those from the serial coating of passenger cars for the same reasons as for trucks, see Section 7.3.3.1.

In the plants described in Section 8.2.8, the VOC emissions amount to approximately 225 g/m² without consideration of emission reduction measures for waste gases from the driers. VOC emission values for several bus plants in Europe are given in Figure 8.1:

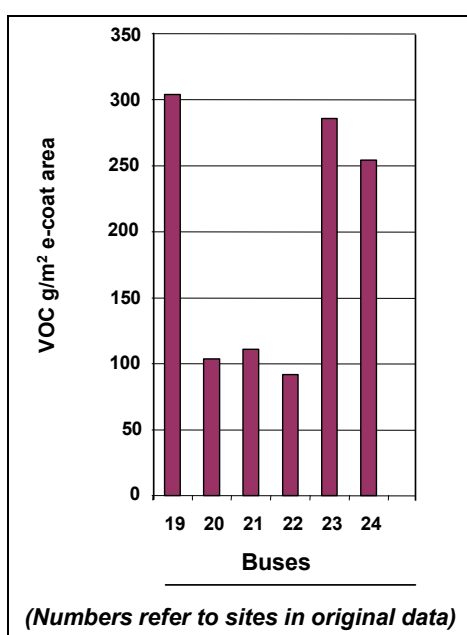


Figure 8.1: VOC emissions for several bus assembly plants in Europe [118, ACEA, 2005]

Emissions from cleaning can be reduced to $<20 \text{ g/m}^2$ by using good practice in housekeeping, cleaning, and substitution techniques such as those referred to in Sections 20.2.2, 20.9 and 20.10 [122, Dupont and May, 2005].

Dust emissions from overspray are commonly below the emission value of 3 mg/m^3 .

8.3.3.2 Emissions to water

For deposition of overspray, painting booths are generally equipped with venturi washers. The generated paint sludge is used for energy recovery.

8.3.3.3 Waste

Paint sludges generated by overspray are discarded and can be incinerated with energy recovery. Organic solvents that are used for the cleaning of tools and painting booths are generally (externally) recycled or discarded and can be incinerated with energy recovery.

8.4 Techniques to consider in the determination of BAT for the coating of buses

In Chapter 20, techniques are discussed which might also be applicable to the coating of buses. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to the coating of buses. In Table 8.2, the general techniques relevant for the coating of buses that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

The EGTEI synopsis sheet for the coating of buses (see Annex 24.1.1) gives some data on the cost-benefit at a European level of some techniques for the reduction of VOCs. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations and products [138, EGTEI, 2005].

The paint process in the vehicle manufacturing industry is a highly complex and fully integrated operation consisting of many interdependent steps. As each step influences all others, decisions made about one step can impact on all or part of the process. Equally, some combinations of techniques may be incompatible with each other. Also, an existing application system may limit the choice of coatings. Therefore, when considering techniques for determining BAT, it is not meaningful to select each step separately.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 8.2: Reference to techniques generally applicable to the sector

8.4.1 Conventional solvent-based materials

Description: Conventional solvent-based paints have the following solvent contents by weight: 45 % for the primer, 45 % for the 1-coat topcoats, 75 % for base coats and 45 % for clear coats. The application is carried out manually with an application gun. Typically, the solvents in the waste gas from the driers are reduced or destroyed (see Section 20.11), depending on the throughput of the installation and the emission levels.

Achieved environmental benefits: Compared to water-based paint systems, direct energy requirements are lower due to the better climatisation and accelerated flash-off of solvent-based systems. However, this does not include energy consumption for the abatement of solvents in waste gases.

Cross-media effects: In the plants described in Section 8.2.8, the VOC emissions amount to approximately 225 g/m² without consideration of emission reduction measures for waste gases from the driers

Operational data: Curing times are shorter than those required for water-based systems, therefore, faster line speeds can be achieved in smaller areas due to reduced oven times. Solvent-based systems can also operate over a wider temperature and humidity range. Stainless steel equipment is not required.

Applicability: Solvent-based paints can be used in all phases of the painting operation (primer, solid topcoat, base coat, clear coat and repair), and can be used on metals and plastics. They may be applied to new and existing paintshops where space and cost are prohibitive for the use of alternatives and where material changes may not be technically possible.

Economics: No data submitted.

Driving forces for implementation: Economic and technical restraints on existing paintshops and certain new paintshops make solvent-based materials a preferred option for certain facilities. Increasing quality targets are also driving the use of solvent-based materials.

Example plants: DaimlerChrysler Mannheim, DaimlerChrysler Neu-Ulm both in Germany.

Reference literature: [13, DFIU and IFARE, 2002] [68, ACEA, 2004] [76, TWG, 2004] [186, May, et al., 2006]

8.4.2 Replacement of solvent-based materials (substitution)

8.4.2.1 Water-based paint systems

Description: For the general description, see Section 20.7.2.3. The following water-based paint systems are applied for the coating of buses:

- electro coat: 3 – 4 wt-%
- primer: 8 wt-% solvent content
- base coat: 13 wt-% solvent content.

Achieved environmental benefits: Significant reduction in VOC use and emissions can be achieved. By using electrocoat, the primer operation can be omitted, which leads to a solvent emission reduction of 90 to 130 g/m².

Cross-media effects: Electrocoat containing lead should not be used, because of the dust emissions during grinding operations.

Operational data: No data submitted.

Applicability: With one exception, water-based paints are not applied as topcoats and in only one installation are city buses completely coated with water-based paints.

Economics: The electrocoat process is only economically feasible for installations with a very high throughput (>5000 buses).

Driving forces for implementation: No data submitted.

Example plants: Daimler Chrysler, Mannheim, Germany; Iveco Italy.

Reference literature: [13, DFIU and IFARE, 2002] [186, May, et al., 2006]

8.4.2.2 High solid paints

Description: For the general description, see Section 20.7.2.2. High solid-based paint is only applied in the 1-coat topcoat and has a solvent content of 40 wt-%. The difference to the normal topcoats with 45 wt-% solvent content is only marginal.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002, 76, TWG, 2004] [186, May, et al., 2006]

8.4.3 Paint application techniques and equipment

The spraying of buses is done manually, by using pneumatic and electrostatic spraying techniques. Electrostatic spraying is only use for primer. However, no further information was made available, on which of the following spraying techniques and equipment are applied:

- conventional high and low pressure spraying, see Section 20.7.3.8
- high volume low pressure spraying (HVLP), see Section 20.7.3.9
- electrostatically atomising spray processes, see Section 20.7.3.14
- electrostatically assisted high rotation bells, see Section 20.7.3.15
- electrostatically assisted compressed air, airless and air assisted spraying, see Section 20.7.3.17
- wet separation spray booth, see Section 20.7.4.1
- water emulsion techniques in spray booths, see Section 20.7.4.3.

8.4.3.1 Electrocoating (e-coat)

Description: See Section 20.7.3.4. All electrocoatings used are water-based; their content of organic solvents is typically 3 – 4 wt-%.

Achieved environmental benefits: Typically the specific VOC emission is in the range 6 – 7 gVOC/m², depending on the surface of the body.

Cross-media effects: None.

Operational data: The advantages of electrocoating are consistent and complete coatings (also in cavities), no forming of edge runners, a high efficiency and the possibility for fully automated processes. Disadvantages are the essential high maintenance requirements of the paint tanks as well as for quality assurance.

Applicability: At present, electrocoating is widely used in coatings of cars, vans and trucks, but is only applied at a small number of bus assembly plants.

Economics: Electrocoating implies high investment cost and higher material costs.

Driving forces for implementation: No data submitted.

Example plants: Daimler Chrysler Mannheim, Germany; Iveco, Italy.

Reference literature: [13, DFIU and IFARE, 2002] [186, May, et al., 2006]

9 COATING OF TRAINS

[13, DFIU and IFARE, 2002] [76, TWG, 2004]

9.1 General information on the coating of trains

Besides high optical qualities of the paint, a good corrosion protection is also required for rail vehicles. The applied coating system must resist climatic impacts, aggressive cleaning agents (used for the removal of graffiti) as well as abrasion from sliding contacts. Locomotives that are operated by the German Deutsche Bahn AG are repainted every eight years.

9.2 Applied processes and techniques in the coating of trains

The selection of the coating system, materials, colour and layer thickness is determined by the customer. Because of large volume flows and discontinuous operations, waste gas treatment is not used in small installations. However, in some large installations, the treatment of the waste gases from the driers is common practice.

The coating processes of rail vehicles can be divided into the coating of new vehicles and maintenance operations. The coating systems are identical for both processes. Both activities usually take place where the rail vehicles are manufactured. The characteristics of the maintenance operations with environmental impacts are outlined in the following paragraphs and are also valid for new construction:

- reparation of the paintwork in the finishing department or during maintenance operations: The paintwork is partly sanded and renewed
- complete lacquer finish of old rail vehicles: As a function of the lacquer condition, the paint is sanded down to the ground coat or completely removed by blasting
- paint removal and new paint finish: After the reconstruction of rail vehicles, old paint is removed via blasting or sanded down to the ground coat layer. Then, a new coating is applied. In general, paint removal is done manually via grit blasting. For paint removal from aluminium and stainless steel (e.g. superstructures), corundum is used as the blasting shot. For normal steel, steel itself is utilised as the blasting agent. After blasting, the dust is removed from the surface by blowing with compressed air. Usually, all blasting materials are recycled.

The process of constructing and painting new rail vehicles is described in more detail in the following paragraphs. As the applied painting processes of construction and maintenance operations are identical, this is also valid for maintenance processes.

Table 9.1 shows the coating systems used for rail vehicle bodies according to the regulations of the Deutsche Bahn AG as an example for a possible layer construction.

Area	Layer construction	Material ⁽¹⁾	Layer thickness of dried material (µm)
Complete rail vehicle body <u>Outside surfaces:</u> Front and side wall including door and window housing, roof and also head areas made of glass fibre reinforced plastic	Pretreatment	Blasting	
	Ground coat	EP, wb	60
	Knifing filler	sb	60
	Primer	PUR or EP primer, wb	60
		PUR primer, sb (alternative)	40
	Topcoat	PUR, sb	40
		PUR, wb	20 – 30
Base coat,wb		40	
PUR, sb and anti-graffiti paint, sb		40	
Roof	Primary coat	EP,wb	80
	Topcoat	EP, wb, thick film	140
		EP, sb, thick film (alternative)	140
Base frame, floor, underbody	Primary coat	EP, wb	60
	Topcoat	EP, wb, thick film EP, sb, thick film or 1-component underbody protection (alternative)	140 140 – 200
Bogie frame	Primary coat	EP, wb	60
		EP, sb (alternative)	60
	Topcoat	EP, wb, thick layer	140
		EP, sb, thick layer (alternative)	140
<u>Interior surfaces:</u> floor, roof, side and front wall	Primary coat	EP, wb	
	Topcoat	EP, wb, thick layer	
		EP, sb, thick layer (alternative)	
	Seam sealant	Sealing agent	
	Acoustic Insulation	Artificial resins, wb	

⁽¹⁾ sb: solvent-based, wb: water-based, EP: epoxy, PUR: polyurethane

Table 9.1: Layer construction for rail vehicles according to the regulations of the Deutsche Bahn AG [13, DFIU and IFARE, 2002]

Pretreatment of the wagon bodies

Optional degreasing via aqueous-alkaline cleaning agents is carried out after assembly (especially for aluminium). Subsequently, the interior and the exterior surfaces are cleaned via blasting. The blasting agent is partially recycled.

Ground coat application (onto exterior areas and interior surfaces)

Ground coat is applied onto the entire wagon. Paint application is carried out manually via an airless spray application. Besides conventional paints, water-based, 2-component, chromate-free paints, based on epoxy resins are also available. The solvent content of these materials varies from 3 - 5 %. Approximately 60 - 100 µm are applied onto the roof and approximately 200 µm on the sidewalls. Component parts such as luggage racks are coated with solvent-based paints or powder coatings.

Filling

After the ground coat is dried, a filler is manually applied via palette knives. The material has a solvent content of about 16 % (of which 8 % is reactive and not relevant for emission). After curing the material, sanding of the sidewalls takes place. Grinding dust is removed by blowing with compressed air and by using cleaning agents. Usually, the filler material is only applied onto welding seams (minimum filler application).

Primer application (generally only onto exterior surfaces)

The primer is applied onto the sidewalls via an airmix spray application. As a primer, either a 2-component, amine hardening, water-based epoxy material (containing 3 % of organic solvents) or a solvent-based polyurethane (containing 35 % of organic solvents) is used. The layer thickness amounts to about 60 µm. The drying time is about two to three hours. If a drier is used (80 °C), the drying takes about 45 minutes. The temperature of the substrate may not exceed 45 °C for completed wagons due to the electronic equipment.

Topcoat application (generally only onto exterior surfaces)

Depending upon the kind of the track, several layers of topcoat are applied (see Table 9.1). For the Deutsche Bahn AG, six different colours are used for city rail vehicles. Among these, three colours are utilised for coating the sidewalls, one for the roof, one for the underbody and one for the bogie frames. The lacquer is applied via airmix spray applications. In between the paint applications, evaporation takes place (one hour). After the last layer is applied, the paint is dried at temperatures of 50 - 60 °C. After two hours, the finished surfaces are masked and the next paint layer is applied. The layer thickness of the paint that is applied onto the sidewalls amounts to 40 µm. It can be up to 120 µm depending on the number of paint layers. About 120 µm is applied onto the roof.

Predominantly, solvent-based topcoats and clear coats are processed. Customers do not often accept them. Good performance is needed from coating systems. This is important especially for high speed trains (300 km/h), for regular cleaning and removal of graffiti. Although water-based materials are already available, solvent-based topcoats are still preferred for the reasons mentioned earlier, and sometimes prescribed by specifications.

Underbody protection

The underbody is coated with a water-based underbody protection via an airless spray application. A minimum layer thickness of 120 - 200 µm is applied.

9.3 Current consumption and emission levels in the coating of trains

9.3.1 Mass balances

No data submitted.

9.3.2 Consumptions

9.3.2.1 Materials

In Table 9.2, the material consumption for specific paint layers is listed. The total solvent input (from thinners, cleaning agents and paints) of the inspected installation was 177.6 t in 1999. Data for individual films of paint could not be determined.

Paint/substrate	Consumption (kg)
Ground coat	200
Primer	35 – 40
Topcoat:	
Roofs	35
Windows	35
Braids, decor strips	5
Sidewall underneath windows	15
Underbody protection	150 – 200

Table 9.2: Material consumption per coated wagon
[13, DFIU and IFARE, 2002]

9.3.2.2 Water

No data supplied.

9.3.2.3 Energy

Due to discontinuous operation of the installation and different geometries of the rail vehicles, the energy demand per coated surface cannot be specified.

9.3.3 Emissions

9.3.3.1 Emissions to air

Only dust from overspray and blasting is deposited. Emission values of less than 3 mg/m³ are achieved. VOC from coating processes are emitted to the air as direct or fugitive emissions. In some installations, which are subject to approval, thermal oxidation units are already used for treating the waste gases from the driers. Emission values of less than 50 mg/m³ are achieved.

However, as spray booths are extremely large and exhaust air volumes are around 200000 m³/h, dry filtering systems are preferred.

If a standard, solvent-based paint system without waste gas cleaning is applied, about 326 g VOC/m² are emitted. From the total solvent input of 187.6 tonne into the inspected plant, 134.08 tonne were emitted and 53.52 tonne was disposed of as waste (a thermal combustion unit is not installed).

By the implementation of the following measures, emission values of <110 g VOC/m² are achieved:

- material specific techniques:
 - application of water-based ground coats, primers and topcoats
 - only for two-layer lacquer finishes, an application of a conventional clear coat
 - water-based primers and underbody protection in combination with thick layer materials
 - water-based primers and fillers
 - minimum use of knifing fillers and use low styrene content filler
 - processing of pre-coated (coil-coated) materials for new construction of rail vehicles
- process specific techniques:
 - reduction of painted surfaces, for example, by the use of adhesive foils for decorative designs or as graffiti protection
 - efficient application devices: HVLP, airless and air assisted airless spraying
 - recycling of cleaning agents via distillation of solvent containing paint wastes and paint sludge
 - use of automated supply of coagulant for wet precipitation for increased service life of the water.

9.3.3.2 Emissions to water

Waste water is generated by the wet precipitation of overspray and the cleaning of application devices. More detailed data could not be determined.

9.3.3.3 Waste

Amongst other things, the following wastes are generated from the painting of rail vehicles:

- paint sludge
- air filters
- cleaning agents
- masking paper
- waste paints
- paint containers
- blasting agents.

9.4 Techniques to consider in the determination of BAT for the coating of trains

In Chapter 20, techniques are discussed which might also be applicable to the coating of trains. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to the coating of trains. In Table 9.3, the general techniques relevant for the coating of trains that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 9.3: Reference to techniques generally applicable to the sector

9.4.1 Conventional solvent-based materials

Description: Conventional solvent-based paints are: filler (based on polyurethane), primer, topcoats and clear coats.

Typically, the solvents in the waste gas from the driers and spray booths are not treated. In some situations, waste gases from the driers are treated by thermal oxidation.

A reported VOC emission factor when applying solvent-based systems (without emission controls) is 326 g/m².

Achieved environmental benefits: None are reported.

Cross-media effects: Higher VOC emissions than other coating systems.

Operational data: Curing times are shorter than those required for water-based systems. Therefore, faster line speeds can be achieved in smaller areas due to reduced oven lengths. Solvent-based systems can also operate over a wider temperature and humidity range. Stainless steel equipment is not required. It is common practice to treat the waste gases containing solvent.

Applicability: Solvent-based paints can be used in all phases of the painting operation (ground coat, filler, solid topcoat, base coat, clear coat and repair). They can be used on metals and plastics. They can be applied to new and existing paintshops where space and cost are prohibitive and where material changes may not be technically possible.

Economics: No data submitted.

Driving forces for implementation: Economic and technical restraints on existing paintshops and certain new paintshops make solvent technology a preferred option for certain facilities. Increasing quality targets are also driving the use of solvent technology.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [68, ACEA, 2004] [76, TWG, 2004] [128, TWG, 2005]

9.4.2 Substitution of solvent-based materials

9.4.2.1 Water-based paints

Description: For a general description, see Section 20.7.2.3. The following water-based paint systems are applied for the coating of trains:

- ground coat: 3 - 5 wt-% organic solvent, 2-component, chromate-free, based on epoxy
- filler: 3 wt-% solvent content, 2-component, based on epoxy
- topcoat
- underbody protection layer.

Achieved environmental benefits: Reduction of VOC emissions.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Water-based paints are normally not applied as topcoats. However, Deutsche Bahn AG uses water-based ground coats, fillers and topcoats for maintenance operations.

Even though water-based topcoats (1-coat topcoat and metallic) with equal properties are available, they are still not accepted by the customers and, therefore, applied only sporadically.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Deutsche Bahn AG, Germany.

Reference literature: [13, DFIU and IFARE, 2002]

9.4.2.2 High solid paints

Description: For a general description, see Section 20.7.2.2.

Achieved environmental benefits: Reduction of VOC emissions.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: High solid paints are only applied in the 1-coat topcoat and have a solvent content of 45 wt-%.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004]

9.4.2.3 Coil coated materials

Description: For a general description, see Section 20.7.2.8. Coil coated materials can be applied to parts replacing the spraying processes.

Achieved environmental benefits: Significant reduction of VOC emissions dependent on the spraying activities that are replaced by applying coil coated materials.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Coil coated materials are being used increasingly for the production of trains, carriages and wagons.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

9.4.3 Paint application techniques and equipment

9.4.3.1 Conventional high and low pressure spraying

For a general description, see Section 20.7.3.8. This paint application technique is commonly applied.

9.4.3.2 High volume low pressure spraying (HVLP)

For a general description, see Section 20.7.3.9. This paint application technique is commonly applied.

9.4.3.3 Airless spraying

For a general description, see Section 20.7.3.11. This paint application technique is commonly applied.

9.4.3.4 Electrostatically assisted compressed air, airless and air assisted spraying

For a general description, see Section 20.7.3.17. This paint application technique is commonly applied.

9.4.3.5 Wet separation spray booths

For a general description, see Section 20.7.4.1.

9.4.4 Minimisation of raw material consumption

Automated mixing systems, i.e. online mixing for 2-component products, are used. For a general description, see Section 20.6.3.1.

9.4.5 Waste water treatment

9.4.5.1 Ultra and nanofiltration

For a general description, see Section 20.12.6. Ultra and nanofiltration are both applied. [13, DFIU and IFARE, 2002]

9.4.6 Waste gas treatment

9.4.6.1 Venturi particle separation

For a general description, see Section 12.4.5.1. Venturi systems are used to improve the efficiency of the absorption equipment (see Section 9.4.6.2). [13, DFIU and IFARE, 2002]

9.4.6.2 Scrubber

For a general description, see Section 20.11.3.8. Spray booths are applied, see Section 20.7.4.1. However, no information was made available on how waste gases are treated. Emission values of $<3 \text{ mg/m}^3$ of dust from the spray booths are reported. [13, DFIU and IFARE, 2002]

9.4.6.3 Dry filter systems

For a general description, see Section 20.11.3.6. Emission values of $<3 \text{ mg/m}^3$ of dust from the spray booths are reported. [13, DFIU and IFARE, 2002]

9.4.6.4 Electrostatic filter

For a general description, see Section 20.11.3.7. Emission values of $<3 \text{ mg/m}^3$ of dust from the spray booths are reported. [13, DFIU and IFARE, 2002]

9.4.6.5 Thermal oxidation

For a general description, see Section 20.11.4.2. In some installations, thermal oxidation units are used for treating the waste gas from the driers. However, only 20 % of the total solvent input is emitted from the driers. The other 80 % of the solvents are emitted as fugitive emissions or end up in the waste. Waste gas from spray booths is not treated. [13, DFIU and IFARE, 2002]

10 COATING OF AGRICULTURAL AND CONSTRUCTION EQUIPMENT

[13, DFIU and IFARE, 2002] [87, ISACOAT, 2004] [128, TWG, 2005]

10.1 General information on the coating of agricultural and construction equipment

The machinery produced in this industry are vehicles (e.g. tractors, earth movers, etc.), or equipment used for specific purposes, which may or may not be mobile (e.g. screens or sieves). To cover the whole range of activities, the term agricultural and construction equipment is used here. Most companies manufacture their machines during the whole year while selling them mainly in spring. Due to the heavy seasonal fluctuations of the business, machines are placed outdoors with the impact of UV radiation, rain, marine atmosphere, sometimes for almost a year between manufacturing and vending, so gloss and colour retention, adhesion and corrosion protection are critical issues. However, the main task is corrosion prevention. In use, the coating has to sustain heavy mechanical and chemical stress. Chemical corrosion occurs due to aggressive liquids arising from the materials handled (e.g. potatoes, manures) and moisture. The life of the coating does not generally survive as long as the vehicle. Optical qualities of the surface are less critical than for cars.

Large enterprises are typically those manufacturing self-driving machines. Due to relatively high technological and optical demands, pretreatment and coating processes are quite sophisticated. Paint consumption is above 50 tonnes per year, associated with a solvent consumption of between 5 and 50 tonnes per year.

10.2 Applied processes and techniques in the coating of agricultural and construction equipment

Common issues for all kinds of coating of agricultural and other machinery:

- complex and large three-dimensional objects
- relatively thick metal sheets which are processed by laser-cutting, welding, etc.
- necessity of pretreatment due to processing rough edges, residues, rust and oil on metal surfaces
- multiple substrates (steel, cast metal, wood, thermoplastics, duroplastics, fibre-enforced plastics, pre-assembled parts)
- pneumatic, airmix and airless application, electrostatically assisted application, dipping, or/and electrocoating are possible
- limited baking conditions due to mass or pre-assembled thermosensitive parts
- one main solid topcoat colour (typical for the brand) and a few additional colours (design)
- single or dual layer system (primer plus topcoat on visible external surfaces, or single layer topcoat)
- high quality of finish with regard to corrosion protection (edges), gloss and colour retention, chemical resistance, adhesion, etc.

The typical process in central Europe for large self-driving machines (combine harvesters, potato seeders/harvesters) includes electrocoating (anodic single layer or cathodic primer) and topcoat application over primer (2-component high solids solventborne, sprayed on partial surface areas, or waterborne topcoat, applied by dipping). However, traditional technologies are still widely spread, especially for smaller machines.

Primers and single layer topcoats have to reach all parts of the machines. Due to the complex structure of objects, dipping of components before assembly is therefore the preferred process option, and can be automated. If installations are not available because low capacity cannot justify the investment, spray application is feasible with some drawbacks on quality issues. In order to reach the internal surfaces of machines, airmix application is preferred. For external surfaces, electrostatic support of the application is feasible and widely used.

Traditional technologies

Primers: polyvinyl butyrate (PVB) based, or acid hardened alkyd (phosphoric acid), for spray operations; or dipping with solventborne materials (organic solvents or chlorinated hydrocarbons, based on alkyd resins).

Single layer topcoat: dipping with solventborne materials is widely used; alkyd coatings contain organic solvents, even chlorinated hydrocarbons are still used.

Topcoat: traditionally solventborne polyester/alkyd.

New technologies

Primer: 2-component epoxy-based, solventborne or waterborne, for spraying; or waterborne coatings for conventional and electrocoating; resins are mainly polybutadiene (anodic electrocoat) or epoxy.

Single layer topcoat: waterborne coatings are available for conventional and electrocoating; resins are mainly acrylic due to demands for UV stability.

Topcoats: isocyanate hardened acrylate/polyester (medium solids, high solids, or waterborne), or one component acrylic (waterborne, high bake), for spraying; or polyester or acrylic coatings (waterborne) for conventional dipping. Powder coat has been used successfully.

Usually, there is only one colour primer and a maximum of four colours for liquid topcoats. So for epoxy primer as for isocyanate hardened topcoats, 2-component mixing machines are technically and economically feasible.

10.3 Current consumption and emission levels in the coating of agricultural and construction equipment

10.3.1 Mass balances

No data submitted.

10.3.2 Consumptions

10.3.2.1 Materials

No data submitted.

10.3.2.2 Water

No data submitted.

10.3.2.3 Energy

No data submitted.

10.3.3 Emissions

This industry is classed as ‘other coatings’ in the SED [123, EC, 1999](see Annex 24.6).

10.3.3.1 Emissions to air

Waste gas from painting booths and driers is treated by post-combustion; concentrations below 20 mg C/m³ in the clean gas are achieved. Therefore, VOC emissions result primarily from diffuse sources, such as evaporation zones located in front of driers.

10.3.3.2 Emissions to water

The rinsing tanks used for the pretreatment of workpieces generate waste water. In an installation, about 18 - 20 m³ per day of waste water is generated. This amount can be halved by the implementation of the cascade technique. Due to the ultrafiltration unit, the dip coating installation does not generate waste water.

10.3.3.3 Waste

For a recycling of dip coat material from subsequent rinsing tanks, ultrafiltration can be used. The amount of waste paint containers can be reduced by the use of large returnable containers for standard topcoats.

10.4 Techniques to consider in the determination of BAT on the coating of agricultural and construction equipment

In Chapter 20, techniques are discussed which might also be applicable to the coating of agricultural and construction equipment. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to the coating of agricultural and construction equipment. In Table 10.1, the general techniques relevant for the coating of agricultural and construction equipment that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 10.1: Reference to techniques generally applicable to the sector

10.4.1 Conventional solvent-based materials

Description: Conventional solvent-based coatings for spraying can be acid hardened alkyd, polyester, PVB, 1-coat topcoat or 2-component topcoat (50 % organic solvents). For dipping, chlorinated hydrocarbons are still used as well as non-chlorinated solvents with alkyd resins. See Section 20.7.2.1.

Achieved environmental benefits: No data submitted.

Cross-media effects: Chlorinated hydrocarbons with the risk phrases R45, R46, R49, R60 and R61 are harmful to human health. Those with the risk phrase R59 are ozone depleting substances.

Operational data: Dipping is still commonly applied. Manual spraying with electrostatic HVLP spray guns gives a layer thickness of approx. 25 µm. The overspray is deposited dry. Drying takes place in a convectional drier in which waste gases are treated by a post-combustion unit.

Applicability: No data submitted.

Economics: Costs for traditional coating materials (chlorinated dip coatings, PVB-based coatings) used to be extremely low in terms of kilograms or litres compared to alternatives like epoxy-based primers and electrocoating. Nevertheless, it can be shown, that in terms of cost per square metre or per coated object, the total process cost of new technologies is fairly competitive (including material consumption, capital cost and depreciation, workforce, energy and other process costs). This is especially true if an adequate use of the installed capacity can be achieved.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002, 76, TWG, 2004] [87, ISACOAT, 2004] [128, TWG, 2005]

10.4.2 Replacement (substitution) and reduction of solvent-based materials

10.4.2.1 Water-based paint systems

Description: For the general description, see Section 20.7.2.3. Water-based paint systems are applied for:

- electrocoat: 2 – 6 wt-% solvent content
- 1-coat topcoat: 11 wt-% solvent content.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Water-based paint systems are commonly applied in electrocoating and in the 1-coat topcoat.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

10.4.2.2 Powder coating

Description See Section 20.7.2.6. One manufacturer has replaced the conventional top coating process with a solvent-based coat by powder application. An innovative new bath care and rinse-water system is used with aqueous cleaning before further surface treatment. After the pretreatment, the workpieces are coated with a water-based dip coat at first, thereafter with a powder topcoat.

Achieved environmental benefits: Reduced VOC emissions, and solvent and energy consumption. Table 10.2 shows solvent and energy consumption data from two installations, i.e. old and new.

	Old installation	New installation
Solvent consumption	41 g/m ²	13.6 g/m ³
Total energy	49.97 MWh/yr	27.73 MWh/yr
Specific energy for drying	6.84 kWh/m ²	5.48 kWh/m ²

Table 10.2: Solvent and energy consumption data from two installations, i.e. old and new

Cross-media effects: No data submitted.

Operational data: The surface is coated before assembly of the vehicle takes place. The waste gas of the preceding cathodic immersion prime coat and of the driers after the primer and powder coating is led through a regenerative oxidiser. Emission values below 20 mg C/m³ are reached.

Applicability: Applicable in new installations.

Economics: Capital investment for a new powder coating installation is EUR 1.35 million. The process works highly economically.

Driving forces for implementation: IPPC Directive, Solvent Emissions Directive 1999/13/EG.

Example plants: CLAAS Selbstfahrende Erntemaschinen GmbH, Germany.

Reference literature: [13, DFIU and IFARE, 2002] [104, UBA - DE, 2004]

10.4.2.3 Coil coated material

See Section 20.7.2.8. Some manufacturers apply electrocoating and topcoating before assembly takes place; coil coated materials might be an option here.
[13, DFIU and IFARE, 2002]

10.4.3 Paint application techniques and equipment

The spraying of agricultural and construction equipment is done manually, by dipping, using conventional pneumatic and electrostatic HVLP spraying techniques, see Section 20.7.3.8 and Section 20.7.3.9 respectively. However, no further information was made available on which of the following spraying techniques and equipment are applied:

- electrostatically atomising spray processes, see Section 20.7.3.14
- electrostatically assisted high rotation bells, see Section 20.7.3.15
- electrostatically assisted compressed air, airless and air assisted spraying, see Section 20.7.3.17
- processing of powder coatings – electrostatically assisted spraying, see Section 20.7.3.18
- wet separation spray booth, see Section 20.7.4.1
- water emulsion techniques in spray booths, see Section 20.7.4.3.

10.4.3.1 Conventional dipping

Description: See Section 20.7.3.3. Dipping is used for the application of 1-coat topcoats. Layers of 85 µm are commonly achieved.

Achieved environmental benefits: No data submitted.

Cross-media effects: Compared to spraying, thicker coating layers are achieved which might consequently result in a higher consumption of raw material, even if efficiency is low due to spray applications. With dipping, a thickness of 85 µm is usually achieved, and a layer thickness of 50 µm can be achieved when applying spray coating (HVLP).

Operational data: Some manufacturers apply topcoats (and electrocoats) onto workpieces before assembly takes place. In addition to other advantages, more automated processes can be used. However, dip coating needs a certain minimum throughput (coated surface) in relation to the tank volume in order to avoid durations of more than a year for the complete replacement of the tank content.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002, 87, ISACOAT, 2004]

10.4.3.2 Electrocoating (e-coat)

Description: See Section 20.7.3.4. All electrocoatings used are water-based; their content of organic solvents is typically 2 – 6 wt-% and they are lead-free.

Achieved environmental benefits: An efficiency of approx. 98 % can be achieved.

Cross-media effects: In the coating of agricultural and construction equipment, it was found that the energy demand for phosphating and ground coat applications via dip coating was significantly higher than conventional pretreatment and paint applications. Therefore, the CO₂ emissions are also respectively higher.

Operational data: Some manufacturers apply dip coats (and topcoats) on workpieces before assembly takes place. In addition to other advantages, more automated processes can be used.

Applicability: At present, electrocoating is widely used for the application of electrocoatings.

Economics: Electrocoating implies high investment and material costs. Wage savings can possibly be made by the implementation of automated processes.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

10.4.3.3 High volume low pressure spraying (HVLP)

Description: See Section 20.7.3.9. The substitution of dip coating by spray application for topcoatings shows that cycle times can be reduced, which will also reduce the costs.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: The use of HVLP spray guns is still very limited. Application efficiencies of over 50 % are to be expected.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

10.4.4 Training

Description: New coating systems (such as waterborne, high solids) need adaptation of application attitudes, as otherwise filmbuilds are applied too thickly. In general, new coating materials often show restricted application windows; thus technical installations and operator skills have to be improved.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [87, ISACOAT, 2004]

10.4.5 Batch painting/colour grouping

This technique is commonly applied as the number of colours applied is usually limited, see Section 20.6.3.6.

10.4.6 Waste gas treatment

The following techniques are commonly applied:

- the solvents in the waste gas from the driers are extracted, reduced or destroyed (see Section 20.11.2.5), depending on the throughput of the installation and the emission levels
- dry filter systems, see Section 20.11.3.6. 'Dry removal' of paint particles is applied
- electrostatic filter, see Section 20.11.3.7. 'Dry removal' of paint particles is applied.

10.4.7 Waste water treatment

The following techniques are commonly applied:

- ultra and nanofiltration is commonly applied to the electrocoating dip baths, see Section 20.12.6
- cascade rinsing, see Section 20.7.5.1
- use of ion exchanger, see Section 20.7.5.2.

11 COATING OF SHIPS AND YACHTS

[13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

11.1 General information on the coating of ships and yachts

Ships are largely constructed from shipbuilding steel, and yachts are constructed from ship building steel and aluminium, as well as FRP (fibre reinforced plastics). These materials corrode or deteriorate if unprotected and must, therefore, be preserved by means of corrosion protection systems. The required costs in the case of ship construction amount to about 3 to 7 % of the total construction costs. Corrosion protection enhances ship safety during passage, maintains the ship's value and reduces maintenance costs. Different parts of a ship, e.g. the hull (above and below water), outside decks, hold and tanks, are exposed to a varying degree of corrosion so that different corrosion protection systems are applied. Fouling prevention by the application of anti-foulings is also important. Resistance to mechanical action on surface areas and decks, and visual quality in various areas are also key factors in the specification of coatings.

The requirements for the coating of ships and yachts are different. For the painting of merchant ships, adhesion, corrosion protection and prevention of fouling are the key issues. For the coating of yachts, appearance also play a crucial role, therefore, the coating of merchant ships and yachts are described separately. Due to different construction, coating and pretreatment processes, the painting of new ships and the repair and maintenance are also considered separately. No information on the painting of warships has been submitted.

In 2004, European shipyards completed 360 ships, representing more than 4 million CGT (compensated gross tonnes), 17 % of the world market share in volume, with a value of more than EUR 10000 million – about 30 % of world turnover. Of the total volume in CGT, 26 % was container ships, 24 % passenger ships and 12 % product and chemical carriers. The European ship repair activities amounted to a total turnover of EUR 1900 million in 2004.

The EU's recreational boating industry comprises 37200 businesses with at least 272000 direct employees generating in the region of EUR 23400 million in revenue. Yacht building and repair ranges in scale from craftsman to large manufacturers, i.e. in production volumes or size of yachts, and approximately 98 % of these businesses are SMEs. This figure also includes marine engine manufacturers, marine and yacht paint manufacturers, high technology electronics companies and equipment manufacturers.

11.2 Applied processes and techniques in the coating of ships and yachts

Coating systems consist of one or more layers of solvent-based, low solvent or non-solvent coatings. The bonding agent bases are predominantly epoxy resin (usually 2-component), polyurethane, acrylates, alkyd resin and chlorinated rubber. The total layer thickness is between 200 and 1000 µm. A thicker layer of special top coatings are usually applied to ramps and working areas. Coating materials are usually applied by means of airless spraying processes, which enable the processing of low solvent and non-solvent products. Application by rollers and brushes is widely used in coating yachts, and rollers are used for pre-delivery coating of passenger ships. They are not widely used in other parts of the industry (with the exception of small areas).

For new construction of ships and yachts, and yacht repair and maintenance, both the preparation and coatings are generally agreed between the shipyard and the customer. The specification will consider the required corrosion and physical protection, appearance and antifouling, and also the warranty requirements. In repair and maintenance yards, the customer has more influence on coating choice and may purchase the coatings directly.

11.2.1 New construction

The coating of ships is mainly carried out by contractors that specialise in corrosion protection for shipbuilding. In modern shipbuilding, sheet metal is made into sections or block stages. These are large sub-assemblies which are then joined together in a building dock or slipway (ships were previously built in the dock from the keel up). These are then coated after surface pretreatment with a coating system according to the specification. Multiple coating of the sections takes place in the open air, in large shipbuilding halls (usually a covered dry dock or covered slipway) or in specially equipped blasting and coating shops. Areas left free of coating for welding are finished on the completed hull on the stocks or in the dock. In smaller shipyards, the hull is completely coated once it is assembled on the stocks or in the dock.

Corrosion protection begins with primary surface pretreatment according to standard specifications on degrees of preparation. All steel plates and sections used to construct the ship are completely cleaned of mill scale, rust and other impurities through blasting in automated plants. This gives the steel surface a specific roughness to ensure good coating adhesion. Subsequently, a shop primer (solvent- or water-based) is sprayed on which protects the steel until further coating is applied. Steel plates and sections are often treated with a shop primer by the supplier. Surface treatment of the assembled steel plate sections, or of the complete hull, is carried out by partial blasting with a dry or wet agent or by angle grinding. This removes corrosion on welding seams as well as all impurities, and roughens the surface. At large shipyards, sections are treated in dedicated blasting and coating shops.

In enclosed areas, ventilation systems are used and may include dust and VOC abatement. Blasting grits can be collected and treated for re-use and/or recycling.

The coating of yachts is carried out either by a specialist team within the yard or by specialist contractors who can achieve the quality of finish required for the yachts. Increasingly, water-based shop primers are being used for both steel and aluminium yachts.

11.2.2 Ship repair and ship maintenance

Repair and maintenance (including painting) of the hull is carried out during dry docking in graving (concrete) or floating (steel) docks. Depending on the condition of the surface, the damaged areas are cleaned and recoated, or the paint is completely removed from the hull for repainting. Cleaning of the areas to be treated can be by dry or wet blasting or high pressure fresh water jetting.

The paints are specified by the ship owners. Large repair yards may treat four or more ships simultaneously, with paints specified from different suppliers.

11.2.3 Coating of ships

The preparation for, and application of, coatings for new build construction and for maintenance is usually in areas open to the outside air.

Corrosion protection of the hull

Coating is carried out according to the lifetime of the antifouling, the corrosion protection required and the colour required. The area to be coated is degreased, and the coats of alkyd resin, polyurethane or acrylic resin are applied. In critical areas, such as the whole external area, in holds and water tanks, single and multilayered epoxy resin (2-component) coatings are generally used. Chlorinated rubber coatings are rarely used, as the chlorinated solvents used are controlled by EU regulations. The coatings meet visual requirements, such as colour and gloss, as well as resistance to mechanical and corrosion action. Coating materials are generally supplied in 20 litre pails, although for large scale applications, 1000 litre re-usable (IBC) containers can be used.

Tie coat (hull)

As a tie coat (coupling agent) between the corrosion protection paint and the final coat of antifouling paint, a solvent-based, 1- or 2-component vinyl resin or epoxy tie coat is applied. For some paint systems, a coupling agent is not necessary if the application of the antifouling paint is undertaken within 36 hours after the application of the corrosion protection material, although this technique (wet on wet) is rarely used. The coupling agent is also applied via the airless spraying technique. The layer thickness amounts to approximately 75 - 100 µm.

Antifouling (hull)

[128, TWG, 2005] [175, Kiil, et al., 2006/07]

Antifouling paints are applied to ship hulls to prevent settlement and growth of fouling organisms (bacteria, algae and animals). Settlement of such fouling increases the surface roughness leading to increased frictional resistance, which in turn leads to increased fuel consumption to keep the same speed or decreased speed at the same fuel consumption. Up to 150 kg of organisms can settle on one m² surface area within six months. The increased frictional resistance can raise the fuel consumption by up to 40 %. This will result in either increased bunker costs or expenses due to lost earnings or time delays. Fouling of the ship hull also decreases the manoeuvrability of the vessel and increases the possibility of premature corrosion. Further, by applying antifouling paint the potential for transmigration of fouling organisms is also decreased.

The antifouling coatings predominantly used today contain organic and inorganic biocides incorporated into a binder system. The biocides are released from the paint in a controlled manner creating a microlayer of sufficient concentration over the hull surface to prevent the organisms from settling onto it. Up until 2003, most of the antifouling paints used organotin compounds as biocides incorporated into the self-polishing binder system. Due to increased concern about the reported adverse effects in the marine environment (e.g. on certain snails and oysters), the International Maritime Organisation (IMO), a UN body, placed TBT on the work programme during the 90s. In October 2001, IMO adopted the International Convention on the Control of Harmful Anti-Fouling Systems on Ships banning the application of TBT-based paint on ships from January 2003. From January 1, 2008 the use of active TBT-based paint is prohibited which means that any TBT-based paint on the ships hull must either be sealed off or removed by that date. In the EU, this ban was enforced by an amendment to the Marketing and Use Directive whereby application of tin-based paint was banned in EU shipyards by 1 January 2003. Further, an EU Regulation was implemented which in principle implements the IMO Convention in all EU countries from 1 July 2003. Today the major antifouling paint manufacturers have phased out TBT-based antifouling paints from their product ranges.

The organic biocides used in current IMO compliant antifouling paints (1 - 10 % w/w) are rapidly degraded once they are released from the paint surface. Almost all antifouling paints contain copper of up to 50 % w/w as the main biocide. Copper is a metal and not biodegradable, but most of the dissolved copper is complexed with organic and particulate matter in the water and the availability to organisms is thereby reduced or completely removed. Sedimentation removes the complexed copper into the sediment compartment where it is tightly bound to organic matter and inorganic compounds.

Every two to five years, the antifouling coating on the ship's hull is renewed in dry dock depending upon the type of coating and the service time of the vessel. The remains of the exhausted paint are usually removed by blasting (grinding or brushing may be used in some cases) and the anticorrosion paint is repaired. Subsequently, the complete hull is coated with a solvent-based antifouling paint applied by airless spraying in a dry film thickness of 150 - 500 micron per coat, depending upon the specification. The overspray is partly emitted into the environment via wind, in the runoff from rainfall or via flooding of the dry dock, or collected, depending upon the control measures in force.

The dry film thickness of the complete paint system on the hull including the anticorrosive coatings, the tie coat and the antifouling paint is approximately 500 - 1000 micron (0.5 - 1 mm).

Coating of the superstructure and freeboard

A solvent-based, 2-component, polyurethane ground coat can be sprayed onto the primer layer; however, many other systems are also available. Generally, two layers each of 60 µm are applied. On top of the ground coat a 2-component, solvent-based polyurethane material is then applied in two layers. Each layer has a thickness of 40 µm. The layer thickness of the complete paint amounts to approximately 250 - 300 µm for the superstructure. Alternatively, a two-layer system consisting of epoxy resin, 170 micron, and a flexible, high solids polyurethane topcoat, 80 micron, is also used.

11.2.4 Coating repair and maintenance of yachts

Yachts are leisure vessels with a length of up to 180 m, although there have been recent developments of up to 190 and 200 metres. Yachts are already partly painted before assembly. Depending upon customers' requests, the applied coating system varies and for this reason only one option is described in the following paragraphs.

Yachts are made of shipbuilding steel and aluminium, although the majority of yachts (the smaller vessels) are made from FRP (fibre reinforced plastic). Parts of the whole yacht or only the superstructure may be made of aluminium. Sanding takes place between the application of painting layers. Depending on the material, pretreatment and application of the primer are different. The use of water-based materials for coating yachts is increasing.

Although airless spraying is widely used, rollers and brushes are still used, depending on the quality required.

Pretreatment and primer application on shipbuilding steel

Firstly the hull and the superstructure are treated via grit blasting and then either a filler based on zinc phosphate or a chrome- and zinc-free shop primer is applied as a primer in order to obtain the correct profile and a smooth finish (e.g. covering welding roughness). Both materials are solvent-based epoxy resins. The layer thickness varies from 40 - 60 µm.

Pretreatment and primer application onto aluminium

For the degreasing and removal of oxidised layers, aluminium surfaces are treated with cleaning agents. Afterwards, a 2-component epoxy primer or a 1-component PVC primer is applied. Similarly to the coating of ships, corrosion protection paint is sprayed onto the primer layer. This solvent-based epoxy material is applied by the airless technique in two to four layers with a thickness of approximately 120 µm each. The antifouling is usually applied directly to the epoxy coat. If a tie coat is used, it is a solvent-based, 1-component vinyl paint, which is applied via airless-spraying. The layer thickness amounts to about 40 µm.

Afterwards, two layers of a solvent-based antifouling material are applied by airless spraying or by roller. The layer thickness of the antifouling coating amounts to approximately 100 µm for each layer. Usually copper-based, self-polishing antifouling coatings are used. However, they may also contain other biocides.

Coating of the superstructure

Like the hull, the superstructure is made of shipbuilding steel or aluminium is also coated with two layers of a solvent-based (1- or 2-component epoxy or polyurethane paint) corrosion protection material. It is applied using the airless-spraying technique. The applied layer thickness amounts to about 120 µm.

After the corrosion protection paint has dried, filling materials are applied onto aluminium and shipbuilding steel of the superstructure in order to obtain the correct profile and a smooth finish (e.g. covering welding roughness). The materials are applied using trowels, long boards and bations, spatulas. They may be solvent-free or contain approximately 80 g/l benzyl alcohol. Sanding takes place in between these processes.

After the filling, a solvent-based 2-component polyurethane filler or a solvent-based epoxide filler is applied by using airless spraying techniques. The layer thickness applied is in the range of 50 - 100 µm. A primer/undercoat is applied over the filler.

The yacht is taken for sea trials when the appropriate coat has dried; this may or may not be the primer coat. After the trials, the yacht is cleaned with fresh water and sanded and then the final topcoat is applied.

The topcoat is applied by using a wet-on-wet spraying technique, and two or three layers are applied. The materials used are generally solvent-based, 2-component, polyurethane combination lacquers. The complete layer thickness amounts to approximately 100 µm.

In several Member States where yachts are repaired or maintained, the removal of antifouling from yachts is carried out using techniques to collect and treat the removed antifouling to prevent water pollution.

11.3 Current consumption and emission levels in the coating of ships and yachts

11.3.1 Mass balances

No data submitted.

11.3.2 Consumptions

11.3.2.1 Materials

[128, TWG, 2005]

For the coating of ships, solvent-based paints are applied. Depending on the material used, the solvent content is in the range 20 - 40 wt-%. Due to the processing conditions (humidity, temperature, air draught, etc.) and surface conditions, water-based paints have only a limited area of application (only partly used for interior areas and prefabricated parts). Consumption of materials will depend on the size of the vessel, specification to be met, etc.

The material consumption in repair yards for medium sized ships (>15000 GT) is approx. 20 tonnes per coated merchant ship (based on data from Portugal, Greece, Malta and Italy). The corresponding VOC usage is approx 6 tonnes. A large repair yard can repair from 60 up to 150 ships with an average size of 40000 GT per year.

In a new-build shipyard, the material consumption for complete coating of one 40000 GT size ship is approx. 68 tonnes. HDW Kiel in Germany processes up to 59 t solvent/yr for a maximum of five ships a year. Blohm + Voss Repair GmbH in Hamburg, Germany processes about 60 t/yr of organic solvents.

11.3.2.2 Water

In repair yards, the consumption of fresh water for high pressure cleaning (at 200 bar) of the complete hull is approx. 500 tonnes for medium sized ships (>15000 tonnes GRT (gross registered tonnes)).

11.3.2.3 Energy

No data submitted.

11.3.3 Emissions

11.3.3.1 Emissions to air

[128, TWG, 2005]

Processes in shipyards are generally carried out outdoors, in dry docks, in open workshops or on the quay. Therefore, pollutants that are generated by grinding and blasting or painting operations are emitted directly into the environment. Generally, all VOC emissions from painting processes are emitted as fugitive emissions. Beside VOCs, dust from blasting agents (e.g. silicates, or steel or copper sinter), metal particles and overspray have an environmental significance. Where spraying is used and depending on the application conditions, the overspray can amount up to approx. 30 % of the material input. Depending upon weather conditions, the particles from blasting and the overspray can be carried for several kilometres.

Emissions of environmentally hazardous materials from coating processes in the new construction of ships can be reduced effectively by the utilisation of closed workshops for painting and blasting operations. These may also be used for the construction of block stages – sections of a new or significantly upgraded ship that are prefabricated and then lifted into place. Closed workshops may have air extraction with filters for dust and/or waste gas abatement units for VOCs.

Another option to reduce the dust emitted is the use of water or slurry blasting.

The amount of overspray has been reduced in open air to 5 % by using mobile application devices with integrated extraction of overspray in one yard. Additionally, further emissions from overspray can be reduced by closing the dockends with nets (to achieve wind reduction).

In repair yards for medium sized ships (>15000 GRT, with an average 70000 GRT), the paints used contain on average about 30 – 40 % organic solvents. About 150 g VOC are emitted per square metre painted, as the antifouling coats form the largest amount of paint applied. In Germany, it was reported that the paints used contain an average of 20 - 25 wt-% organic solvents. About 100 g VOC are emitted per painted m².

New yacht construction is usually carried out in closed facilities, and also using rollers and brushes, which have a high application efficiency with no overspray. For large (super and mega) yachts, this will be according to the client's specification. Repair and maintenance of the large mega yachts may be done in docks, but for most of them, maintenance and repair are also carried out in closed facilities.

11.3.3.2 Emissions to water

Maintenance operations generate contaminated blasting agents, paint residues, used containers, and overspray. There may be other residues from maintenance, such as oil residues (containing hydrocarbons), mud, scrapped materials, etc. After maintenance operations, the dock is cleaned to reduce emissions to the environment.

Where water blasting or slurry blasting is used to avoid dust emissions from blasting, the process water is commonly treated either in integrated equipment or at a waste water treatment plant. The water may be re-used.

Where the waste water is contaminated, several techniques can be applied to reduce emissions. The treated water is either disposed of as waste water or re-used. These are both described in Section 11.4.9.

11.3.3.3 Waste

Waste from the maintenance operations of ships include for example:

- organic cleaning solvents
- paint sludges/residues
- contaminated paint containers, brushes and rollers
- used/contaminated blasting materials
- filters
- oil residues (containing hydrocarbons)
- mud
- scrapped materials
- residual water from the cleaning of a dry dock before flooding.

The implementation of large re-usable containers (IBC, 1000 litres), instead of 10 or 20 litres single use containers, leads to a reduction of waste containers and the amount of waste paints that remain in old containers. However, this is only applicable for large ships and/or for large amounts of one type or colour of paint. When 2-component paints are supplied in IBCs, the mixing of paints takes place by means of a precise dosage system with permanent monitoring of the mixture ratio. In cases where several ships are being maintained at any one time, with differing specifications and quantities, or in the case of yachts, these containers are too large for the quantities consumed. In addition, there are problems with settlement of the paints in such large containers.

During the painting of ships, especially in maintenance operations, large amounts of contaminated blasting agents are generated. Heavy metals and TBT from blasting and grinding dusts are of special environmental significance. Water blasting generates only 1.5 % of the amount of waste arising from conventional grit blasting.

11.4 Techniques to consider in the determination of BAT for the coating of ships and yachts

In Chapter 20, techniques are discussed which might also be applicable to the coating of ships and yachts. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to the coating of ships and yachts. In Table 11.1, the general techniques relevant for the coating of ships and yachts that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 11.1: Reference to techniques generally applicable to the sector

11.4.1 Management systems – dock discipline

Description: This is a specific management system defining the different entities responsible for performing works in dry docks and slipways, including the preparation for docking, careening and undocking vessels. It also includes the maintenance, repair or building activities carried out in dry docks and slipways, such as surface treatment operations (cleaning, removal of old paint and antifouling, etc.). It controls the collection of wastes, and the forwarding of wastes to licensed receivers for their further appropriate management and/or disposal.

Dock discipline also covers other issues that assist in reducing pollution, such as when and where to carry out polluting activities. For example, describing in what wind conditions grit blasting and spraying in the open air can be carried out, requiring these activities to be carried out at the bottom of the dock or slipway and portable equipment to be used (such as nets, water curtains, etc.).

It may contain part of, or all, the requirements of an EMS (see Section 20.1).

Achieved environmental benefits: Describes procedures for minimising environmental impacts from the installation.

Cross-media effects: None.

Operational data: See Description, above.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: Meeting legislation for health and safety and the environment for air pollution, water pollution and waste management, particularly as they apply to ports, harbours and enclosed waters, etc.

Example plants: Widely applied in the industry.

Reference literature: [128, TWG, 2005] [173, Portugal, 2006]

11.4.2 Enclosure techniques

11.4.2.1 Open areas

Description: Processes in shipyards are generally carried out outdoors, in dry docks, in open workshops or on the quay. Repair and maintenance (including painting) of the hull is carried out during dry docking in graving (concrete) or floating (steel) docks.

Achieved environmental benefits: None.

Cross-media effects: Pollutants that are generated by grinding and blasting or painting operations are emitted directly into the environment. Generally, all VOC emissions from painting processes are emitted as fugitive emissions. Beside VOCs, dust from blasting agents (e.g. silicates, or steel or copper sinter), metals and overspray have an environmental significance. Depending upon weather conditions, these particles can be carried for several kilometres.

Operational data: No data submitted.

Applicability: Normal working practice.

Economics: No data submitted.

Driving forces for implementation: Cost.

Example plants: Widely used.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005] [174, CEPE, 2006]

11.4.2.2 Partially enclosed areas, windbreaks, spray curtains, etc.

Description: Techniques can be used to act as windbreaks, as such as nets or tenting (described in Section 11.4.2.3) and water spray curtains can be used around areas used for grit blasting, etc. These may be permanent or temporary.

Achieved environmental benefits: Reduction in drifting particles from grit blasting and spray painting, either by reducing wind strength or by trapping particles.

Cross-media effects: Power for pumping water sprays or curtains, and possible treatment of the waste water.

Operational data: There are reports of practical difficulties using nets and the larger the ship in comparison with the dry dock, the more difficult they are to use. They cannot be used in repair yards for medium sized ships (>15000 GRT) in large dry docks and the following are typical examples of problems encountered:

- variations in the size and type of ship, the ships may overhang the dock ends, etc.
- interference with cranes and other equipment and
- problems with access for other maintenance operations.

Poor practical results are obtained compared with the cost of encircling the dock. Where used, the nets are therefore usually placed at one or both ends of a dock, around smaller docks or between the ship and the dockside.

Applicability: See Operational data, above.

Economics: No data submitted.

Driving forces for implementation: Cost.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005] [174, CEPE, 2006]

11.4.2.3 Fully enclosed areas

Description: Enclosed areas are used to control the local working environment, enabling temperature and humidity control for working and surface preparation, protection from rain, etc. Enclosed areas usually have air extraction for occupational health reasons, and this can be used in conjunction with waste gas treatments to control the emissions of environmentally harmful materials. The equipment may be abatement for dust and/or with a waste gas abatement unit for VOCs.

Some areas, such as slipways and small docks can be temporarily (or semi-permanently, i.e. portable structures or tenting kept on site for long periods of time) enclosed or 'tented in'. This assists control of dust from blasting and overspray, but unless the enclosure is sufficiently enclosed, adding waste gas treatment for dust and VOC reduction is likely to require the treatment of large volumes of air with high energy usage.

Tenting may also be applied between a ship and the dockside, to help prevent the drift of dust and overspray and keep rain off prepared and freshly coated areas.

Achieved environmental benefits: Retention of particles from blasting and spraying. Removal of dust and/or VOCs from the extracted air streams by waste gas treatment becomes possible.

Cross-media effects: Energy used for air extraction.

Operational data: Provides improved quality control of processes and working environment. Can increase available working time during the day and/or year.

Applicability: Permanent workshops can be used for preparing steel plates, sections and block stages in new construction. In some cases, whole docks may be enclosed. The docks used for the repair and maintenance of ships are not enclosed (and possibly not those used for some mega yachts).

For yachts, the preparation and coatings areas are usually enclosed, either permanently or semi-permanently, both for new build and repair and maintenance.

Economics: Capital cost of construction of workshops. Capital costs and running costs of abatement equipment.

Driving forces for implementation: Improved quality control of coating processes and internal climate control (i.e. weather protection) allowing for all day/all year working. SED. Legislation for health and safety and dust.

Example plants: HDW Kiel, Germany.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005] [174, CEPE, 2006]

11.4.3 Surface preparation

In new build and for new materials, the surface requires pretreating to provide adhesion. For repair and maintenance, old paint layers and antifouling are removed, particularly in loosely-adhered and damage areas. The preparation and technique is to an agreed specification, depending on the coating system and warranty given with the work and/or coating. For example, the surface roughness using shot blast can be up to 20 μm , and for grit blasting it can be in the range 75 - 100 μm . Also, not all techniques can be used for all vessel areas, e.g. slurry blasting in a double bottom tank, hydroblasting in a cargo tank refurbishment, etc.

The removal of old paint and antifouling will generate wastes containing these materials, with their associated hazards, for example, antifouling contains biocides and older antifouling contains TBT, old paint layers may contain lead and chromates, etc.

Large amounts of dust are created with some techniques. Some techniques use an abrasive medium to remove the coating layers, and these are either recovered and re-used or disposed of as wastes, depending on the technique used. With all techniques, it is good practice to remove the residues from dry docks before flooding.

11.4.3.1 Dry blasting – open system

Description: Blasting using compressed air and a dry abrasive medium such as steel grit, silica, shot, etc.

Achieved environmental benefits: No data submitted.

Cross-media effects: Creates dust from the removed paint and the abrasive medium.

For repair and maintenance, the grit consumption per ship is approximately 200 tonnes for a medium sized ship (>15000 tonnes GRT).

Operational data: This is usually the quickest and cheapest technique per square metre (m^2).

Applicability: This is the most commonly used technique in repair yards for medium sized ships (>15000 tonnes GRT). It can be used for the removal of rust and old layers of paint from floors and external sides, for removal of hull fouling and for the removal of loose paint.

Economics: No data submitted.

Driving forces for implementation: Cost.

Example plants: Widely used.

Reference literature: [76, TWG, 2004] [128, TWG, 2005]

11.4.3.2 Dry blasting – closed system, vacuum or shroud blasting

Description: This is dry blasting in closed blasting systems, such as with a suction head and centrifugal blasting using steel grit in closed loop systems with low emissions.

Achieved environmental benefits: Low dust emissions. The blasting medium is recovered for re-use, therefore there is less waste. Removed antifouling and paint are recovered with the blasting medium and separated for disposal.

Cross-media effects: No data submitted.

Operational data: Mechanical blasting equipment is operated by hand or fixed to the arms of tool carriers and passed along the area to be treated by remote control.

A typical system for new build preparation may be cast-steel blasting granules applied in a closed loop and at a pressure of about 5 bar.

Applicability: It can be used for the removal of rust and old layers of paint from floors and external sides, for removal of hull fouling and for the removal of loose paint.

Economics: No data submitted.

Driving forces for implementation: Control of dust emissions and health and safety at work. Reduced waste management costs.

Example plants: Widely used in shipyards and other industries.

Reference literature: [76, TWG, 2004] [128, TWG, 2005] [174, CEPE, 2006]

11.4.3.3 High pressure fresh water jetting or blasting

Description: There are several techniques categorised according to the water pressure used. Hydroblasting is carried out at pressures above 700 bar, and UHP (ultra high pressure) hydrojetting up to 20000 bar. By varying the water pressure, single layers of paint or the entire paintwork can be removed.

Achieved environmental benefits: This technique avoids the creation of dust emissions and contaminated blasting agents that require disposal. The water used can be retained and recycled, with treatment if necessary.

Cross-media effects: Paint waste which may contain removed antifouling or lead or chromium pigments from older coatings require collection and managed disposal.

In repair yards, the consumption of fresh water for the high pressure cleaning (200 bar) of the complete hull is approx. 500 tonnes for medium sized ships (>15000 tonnes GRT).

Operational data: With water blasting techniques, the waste water can be collected in the dock, pumped into tanks and treated (e.g. by settlement) prior to emission.

Applicability: Can be used for the removal of rust and old layers of paint from floors and external sides. For hull fouling and the removal of loose paint, pressurised water blasting can be used.

Water blasting cannot be used on new surfaces, as it does not create a surface roughness in the material to be coated.

The use of ultra high pressure water blasting is not common practice in repair and maintenance, because there are some technical problems: it is reported that it is difficult to achieve spot blasting and more than 50 % of the areas to be blasted are 'spots'.

This technique is also used in the preparation of yachts. When carried out in conjunction with recovery and separation of the wastes, it prevents the release of heavy metals and of TBT from old antifouling (note that the application of TBT on smaller yachts has been banned for more than 13 years).

Economics: No data submitted.

Driving forces for implementation: Legislation controlling dust emissions in the environment and health and safety in the workplace.

Example plants: Widely used.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005] [174, CEPE, 2006]

11.4.3.4 Wet or slurry blasting

Description: This is blasting with water containing a fine abrasive, such as a fine cinder (e.g. copper cinder) or silica.

Achieved environmental benefits: This technique avoids the creation of dust emissions.

Cross-media effects: Increased waste from the abrasive.

Operational data: With water blasting techniques, the waste water can be collected in the dock, pumped into tanks and treated (e.g. by settlement) prior to emission. This may be integrated into the slurry blasting equipment. The water and the abrasive can be re-used.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Widely used in shipyards and many other industries.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005] [174, CEPE, 2006]

11.4.3.5 Other surface treatments

Description: Grinding is used on welded joints and other specific areas. Brushing may also be used, e.g. with wire brushes. Sanding is used between coats on yachts.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: Technical requirements.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005] [174, CEPE, 2006]

11.4.4 Coating materials

In general, the client usually specifies the paint systems to be used, especially in ship repair and maintenance and yacht building, repair and maintenance. The specification is also influenced by the warranty conditions of the paint.

11.4.4.1 Conventional solvent-based coating materials

Description: For the general description, see Section 20.7.2.1. On average, the conventional solvent-based paints applied onto ships contain 20 - 40 wt-% organic solvent. The application is usually manually using airless spraying.

In repair yards for medium sized ships (>15000 GRT, with an average of 70000 GRT), the paints used contain on average about 30 - 40% organic solvents. About 150 g VOC are emitted per square metre painted, as the antifouling coats form the largest amount of paint applied. In Germany, it was reported that the paints used contain, on average, about 20 - 25 wt-% organic solvents and about 100 g VOC are emitted per painted m².

When applying solvent-based systems, a VOC emission factor of about 100 to 150 g VOC/m² painted surface (without emission abatement) is reported.

Typically, processes in shipyards are carried out outdoors in dry docks, in open workshops or on the quay. Under these circumstances, VOCs from paints are emitted completely untreated.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: Curing times are shorter than those required for water-based systems. It is common practice to treat the waste gases containing solvents.

Applicability: Solvent-based paints can be used in all phases of the painting operations. For several applications, alternatives are available. However, the tie-coat is always solvent-based, and a solvent content of at least 270 g VOC/l is needed.

Economics: No data submitted.

Driving forces for implementation: Cost. Solvent-based paints have been used for a long time and a lot of experience has built up.

Example plants: Widely used.

Reference literature: [13, DFIU and IFARE, 2002] [27, InfoMil, 2003] [76, TWG, 2004] [128, TWG, 2005]

11.4.4.2 Replacement of solvent-based materials (substitution)

11.4.4.2.1 Water-based paints

Description: For a general description, see Section 20.7.2.3.

Achieved environmental benefits: Reduced VOC emissions.

Cross-media effects: Extra energy if forced ventilation or heating is applied.

Operational data: Longer drying times are required, although this can be shortened with good ventilation and, in some cases, heating. There are problems in freezing and thawing conditions. Generally, the dry film thicknesses are lower on application.

Applicability: Currently, water-based paints are the only viable alternatives to reduce VOCs in internal areas and for shop primers.

A water-based universal primer is widely used in Finnish yards. Water-based paints are available for several applications, but are used only in limited numbers. Solvent-based primer is only used in winter for outdoor application.

Not applicable on surfaces exposed to severe marine atmospheric conditions, e.g. heat, sun, rain and salt. The availability of water-based paints for ship and yacht manufacturing is as follows:

- shop primers: water-based zinc silicate is available, but it is only sporadically applied. Water-based epoxy and modified alkyds are also available but not usually applied
- exterior of ships: water-based alkyd, epoxy and acrylate paints are available and occasionally applied. Water-based acrylate/alkyd and water-based zinc silicate are occasionally applied
- interior of ships: water-based systems are available, however, this poses difficulties in drying when applied in small and closed areas and are only occasionally applied. They are not applied in storage areas because they are not sufficiently wear-resistant
- for yachts, water-based paints are available, they are now increasingly applied as primers and internal primers. The finish quality has limited their application in top coats.

Water-based antifoulings are available, but only on the retail market.

Economics: The costs involved for the paint system for newly built ships are low. In the repair and maintenance of ships, incompatibility with old paint layers might require their removal by blasting, resulting in considerable costs.

Driving forces for implementation: SED.

Example plants: Widely used in Finnish yards. Increasingly used for yachts.

Reference literature: [27, InfoMil, 2003] [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

11.4.4.2.2 High solid paints

Description: For the general description, see Section 20.7.2.2. The high solid-based paints currently applied contain 250 g VOC/l or more, e.g. 450 g/l epoxies for underwater areas.

Achieved environmental benefits: Reduced VOC emissions.

Cross-media effects: No data submitted.

Operational data: No data. submitted.

Applicability: The availability for ship and yacht manufacturing is as follows:

- shop primers: high solids are not applied as the film thickness is too high (only 20 µ required)
- outside of ships for the parts below water: high solid epoxy coatings are widely applied. The VOC content of the paint applied on parts below the waterline is generally 450 g/l
- outside of ships for the parts above the waterline: high solid epoxy coatings are applied; high solids flexible polyurethane coating is also applied. High solid alkyd coatings are not applied
- inside of ships: high solid epoxy and alkyd coatings are available
- yachts: high solids paint may be used but generally they are not. They can be applied below the waterline. High solids are sometimes also applied on interiors.

Flexible, surface-tolerant high solids polyurethane coatings are partly replacing epoxy mastic/acrylic topcoat systems for new build and for maintenance purposes. They can be applied on almost any type of old paint.

Single and multilayered 2-component epoxy resin coatings are widely used. For example, in high wear areas of merchant ships, such as the whole external area, in holds and water tanks. These paints are also used for coating yachts.

Economics: The costs involved for the paint system for newly built ships are low. In the repair and maintenance of ships, incompatibility with old paint layers might require their removal by blasting, resulting in considerable costs.

Driving forces for implementation: SED.

Example plants: Widely used.

Reference literature: [27, InfoMil, 2003] [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

11.4.5 Additional corrosion protection – cathodic protection

Description: The immersed surface of ships can be protected against corrosion by applying cathodic protection. It is also used to protect the surfaces of tanks within ships. It is not used as an alternative for antifouling.

Achieved environmental benefits: Cathodic protection is an additional corrosion mechanism and does not replace coatings systems. It may assist in increasing the periods between repair of the coatings and therefore to a reduction of the spraying activities and VOC emissions. Sacrificial anodes are not applied, so there is no emission of heavy metals.

Cross-media effects: No data submitted.

Operational data: Neighbouring ships in the harbour that are slightly damaged may experience accelerated corrosion.

Applicability: Used worldwide on all kind of ships, both for professional and (less commonly) recreational use.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Widely used.

Reference literature: [27, InfoMil, 2003] [76, TWG, 2004] [128, TWG, 2005].

11.4.6 Paint application techniques and equipment

11.4.6.1 Airless spraying

For a general description, see Section 20.7.3.11. For the construction and maintainance of all new ships, almost all paint layers are commonly applied with airless spraying. The amount of overspray is about 30 % maximum of the material input.

[13, DFIU and IFARE, 2002] [27, InfoMil, 2003] [128, TWG, 2005]

11.4.6.2 Hot spraying

Description: For a general description, see Section 20.7.3.10. On ships, solvent-free 2-component coatings can be applied by using hot airless spraying. Layers of 300 - 1000 microns are achieved.

Achieved environmental benefits: VOC emissions are omitted and, compared to conventional airless spraying (see Section 11.4.6.1), the number of layers can be reduced.

Cross-media effects: Energy is used for heating.

Operational data: Computerised online mixing is required to achieve the proper mixing ratio. Working time is short with a pot-life of only 10 minutes. These types of coatings form a very hard, pore-free and very smooth surface and are therefore very corrosion-resistant to seawater, oil products and chemicals. They are also resistant to abrasion, such as floating ice encountered during navigation. However, the finish may poor, and the product range that can be used is very limited. The equipment used for hot spraying is difficult to repair.

Applicability: This technique can be applicable for the coating of large surfaces on the interior and exterior of the ship.

Economics: The costs for these coatings are higher compared to conventional coatings, however, labour time is shorter and so is the drying time. Savings are there because less energy is used for spraying activities and costs for maintenance are reduced. The equipment costs for hot spraying are higher.

Driving forces for implementation: SED.

Example plants: No data submitted.

Reference literature: [27, InfoMil, 2003] [128, TWG, 2005]

11.4.6.3 Integrated air extraction at the point of application

Description: A mobile paint application head with an integrated overspray extraction system has been developed which extracts air at the point of spraying. This is analogous to robot spraying (see Section 20.2.3).

The technique is reported to be no longer used.

Achieved environmental benefits: Due to the increased efficiency, the material consumption, the VOC emissions and also the overspray emissions are significantly reduced. Overspray can be reduced to 5 % of the material input.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: These paint application units can only be used for even, perpendicular surfaces, and not, for example, on curved bow and stern sections or flat bottoms.

Economics: No data submitted.

Driving forces for implementation: Health and safety.

Example plant: Blohm + Voss Repair GmbH, Hamburg, Germany. HDW Kiel, Germany

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

11.4.7 Alternatives to antifouling paints based on biocides

For information on the environmental impacts of using antifouling paints based on biocides, see Section 11.2.3.

11.4.7.1 Fouling release coatings based on silicones

Description: Silicone paints have a low surface tension (non-stick) with the effect that the fouling organism cannot establish a firm attachment to the coating surface. Fouling may attach to the surface during idle periods, but currents created over the paint surface during sailing faster than a certain minimum speed will clean the surface. Silicone paints are applied by airless spraying.

Achieved environmental effects: Foul-release coatings do not contain any biocides. They provide very smooth surfaces resulting in a potential for lower frictional resistance. This may decrease fuel consumption or increase speed compared to self-polishing biocide containing paints.

Foul-release coatings do not erode or polish during service time and as such the paint is kept intact during the service period.

Cross-media effects: No data submitted.

Operational data: During application of silicone coatings, overspray to surfaces to be coated with other types of paint must be prevented due to later adherence problems. Application and repair of silicone paints need to be done strictly according to a specified procedure.

Applicability: Fouling organisms will be able to settle on the silicone paints during idle periods. In order for the release effect to work during the sailing period, a certain speed has to be achieved. Today, the technology can be used on ships with short idle periods and a minimum speed of 15 - 17 knots. Silicone paints are not suited to vessels exposed to a lot of mechanical damage. Therefore foul-release coatings are still considered to be niche products for special vessel types.

Economics: Costs of silicone paints are considerably higher compared to antifouling paints containing biocide.

Driving forces for implementation: SED. Water pollution legislation and policies.

Example plants: Used worldwide.

Reference literature: [128, TWG, 2005]

11.4.7.2 Mechanical methods

Description: Brushing and scraping off fouling in short intervals and the use of hard, resistant coating materials is an alternative to antifouling coats. There is a variety of devices with rotary brushes which can remove the fouling during short downtimes.

Achieved environmental benefits: This antifouling method does not use heavy metals or biocides.

Cross-media effects: This method does not reduce the risk of the introduction of new species from the world seas.

Underwater brushing creates an uncontrolled risk of water pollution during such diving operations.

Operational data: The disadvantages of the procedure are short cleaning intervals.

Applicability: This process is suitable for ships operating in brackish or fresh water at lower temperatures.

Economics: No data submitted.

Driving forces for implementation: SED. Water pollution legislation and policies.

Example Plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [69, Watermann, et al., 2003] [128, TWG, 2005]

11.4.7.3 Electrochemical processes

Description: The surface is protected by voltage, which causes electrolysis. Toxic chlorine compounds are produced (in salt water) and/or the pH value at the surface is shifted which inhibits the settling of fouling. This technique abates corrosion.

Achieved environmental benefits: This antifouling system does not contain biocides.

Cross-media effects: The electrodes can be made of copper, resulting in the emissions of copper ions which are toxic to the fouling organisms. Toxic chlorine compounds are produced.

Operational data: The amounts of copper released are comparable to copper-based antifoulings. This method proved to be very effective against fouling.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: SED. Water pollution legislation and policies.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [69, Watermann, et al., 2003] [128, TWG, 2005]

11.4.8 Waste gas treatment

Description: For a general description, see Section 20.11.

Emissions from painting and blasting activities can be reduced effectively by using closed workshops (see Sections 11.4.2.3 and 20.11.2.1). These can be equipped with waste gas treatment techniques as described in Section 20.11.

For example, VOC containing waste gases from spraying can be adsorbed via activated carbon (see Section 20.11.6.1). Alternatively, the organic solvents can be treated in a thermal oxidiser (see Section 20.11.4.4). Where concentrations of VOC allow, the solvent can be regenerated from absorption, or the thermal oxidiser used can be regenerative and recover the heat from the oxidation process.

Dust and overspray particles may be treated by techniques described in Section 20.11.3.

Achieved environmental benefits: Significant reduction in VOCs and/or dust emissions.

At the example plant, a waste gas treatment installation of 300000 m³/hr capacity is used. VOC emissions are reduced by 75 % and an average clean gas concentration of 23 mg/m³ is achieved. Efficient ventilation and dust abatement systems enable a five-fold change of air each hour and in the cleaned air, dust concentrations of less than 5 mg/m³ can be achieved.

Cross-media effects: Energy consumption for waste gas treatment.

Operational data: Dust levels may have to be reduced prior to VOC abatement.

Applicability: Applicable to the refurbishment of shipyards.

Economics: High costs are involved.

The investment for the example plant was about EUR 21 million. The annual operation costs are about EUR 1 million, which is slightly lower than the operational costs for the conventional process. This also included filter systems for grit blasting operations.

Driving forces for implementation: SED.

Example plant: HDW Kiel, Germany.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

11.4.9 Waste water treatment

Description: Waste water can be treated prior to discharge, either at the source (e.g. when slurry blasting) or collected and sent to a waste water treatment plant, either on or off-site. The treatment required will depend on the substances present and the discharge point (to surface waters such as the harbour, or to the municipal foul sewer). Section 20.12 discusses several waste water treatment techniques and provides other sources of information.

Achieved environmental benefits: Reduction in water pollution, particularly in enclosed harbours or estuarial areas.

Cross-media effects: Any energy and chemicals used in treatment.

Operational data: For example:

(i) When using water blasting techniques, the waste water can be collected in the dock, put into tanks and fed into waste water treatment plants (see Section 11.3.2.2).

(ii) At one installation, the waste water treatment is in several steps consisting of precipitation and flocculation (such as by using iron (III) chloride), followed by separation and filtration. To reduce the volume and weight of waste produced, the separated sludge is pressed prior to disposal. The cleaned waste water is re-used or, in the case of surplus water, discharged as waste water. With this system, emission levels for filterable substances of 10 mg/l can be achieved after treatment.

Applicability: Readily applied.

Economics: Costs are dependent on the size of the installation. In example (ii) given above, the cost in Germany for the complete plant including installation was about EUR 100000 (in 2000).

Costs for water treatment installations in ship repair yards dealing with medium sized ships (>15000 GT) are quoted as exceeding EUR 2 million.

Driving forces for implementation: Water, port and harbour pollution legislation.

Example plants: Flender-Werfft, Lückbeck, Germany.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005]

11.4.10 Waste management

Description: The following residues are collected and their disposal is managed according to the relevant legislation and procedures. This is particularly important prior to flooding a dry dock:

- paint residues that have been removed
- paint leftovers, and used paint recipients
- coating overspray
- used and contaminated blasting abrasives
- cleaning materials
- mud, oily residues and other materials that have been scraped off or removed.

Some materials, such as used abrasives and scrap materials, may be collected separately to assist their recycling and re-use.

Achieved environmental benefits: Prevents contamination of the water environment.

Cross-media effects: None.

Operational data: See dry dock discipline, Section 11.4.1.

Applicability: Applicable in all cases.

Economics: No data submitted.

Driving forces for implementation: Meeting water pollution, port waste and harbour waste management regulations.

Example plants: Widely practised.

Reference literature: [128, TWG, 2005] [173, Portugal, 2006].

12 COATING OF AIRCRAFT

[13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

12.1 General information on the coating of aircraft

In this section, the painting of civil aircraft with more than 50 seats is described. Due to different processes, this section is divided into construction and maintenance.

For maintenance, the paintwork is repaired or applied completely new, and the entire paint application is carried out manually. The selection of the coating system depends on manufacturer defaults, international regulations and requests of the customer. Data reported in this section on aircraft maintenance were gathered at the Lufthansa Technik AG, located in Hamburg, Germany.

Applied processes and techniques for new constructions were investigated at AIRBUS Deutschland GmbH in Hamburg, Germany.

AIRBUS is the only large civil aircraft constructor in the EU-25, but other companies build smaller aircraft, military aircraft or fabricate sections (such as wing sections). The main carriers also have maintenance facilities which may carry out coating. There are also other commercial maintenance facilities in some countries as well as military facilities which may carry out coating. As the coating for whole aircraft, fuselages and large sections is carried out by hand on a batch basis, the rate of consumption of solvent per hour may be more pertinent than the annual quantity consumed [190, Humberstone. S].

12.2 Applied processes and techniques in the coating of aircraft

12.2.1 Construction

Since the manufacturers' corrosion protection guarantee lasts for 25 years, only specific paint systems can be utilised, as with the maintenance of aircraft, customers' requests also have to be considered.

12.2.1.1 Painting of components

Components are partly painted before assembly takes place. These component parts are coated with a primer and subsequently with a topcoat. A wash primer is only applied in exceptional cases. Increasingly surface spraying is automated. Convection driers and also infrared driers are used for the painting of components. The surface area of the components is about four times greater than that of the aircraft's exterior surfaces. Parts that are delivered by external manufacturers are already coated with ground coats containing chromate.

12.2.1.2 Painting of exterior surfaces

Outside surfaces of the completed aircraft are coated manually. As the final lacquer finish takes place after the first flight, only coatings that cure at an ambient temperature can be used. At present, predominantly solvent-based paints (with solvent contents of about 55 – 65 %) are used. However, high solid paints (with a solvent portion of between 30 and 40 %) are increasingly used. As with maintenance, the coating of new planes is carried out in closed workshops. The applied coatings cure at ambient temperatures. First, the hull is coated and completely dried. Then, the hull is masked with packaging paper and the wings are subsequently painted. The paint layers are applied by the wet-on-wet technique. The painting process is subdivided in pretreatment, application of the wash primer, application of the primer and application of the topcoat.

Pretreatment

Before the exterior surfaces are coated, impurities, e.g. kerosene, oils and grease, are removed. The hull is cleaned with cleaning agents and the total consumption per aircraft amounts to about 200 litres. Afterwards, anodisation with chromic acid takes place. The purpose is to generate a thicker oxide layer for increased corrosion protection. The primer containing chromate is sanded dry and the hull is again cleaned with organic solvents.

Application of the wash primer

After pretreatment, the wash primer is applied manually by using electrostatic spraying techniques. The wash primer is a solvent and chromate containing material based on polyurethane or epoxy resins or polyvinyl butyrate (PVB). The solvent content amounts to about 70 - 90 %. For increased corrosion protection, strontium or zinc chromate is necessary. The layer thickness varies from 8 - 10 µm. After application, evaporation of solvents takes place at ambient temperature.

Application of the primer

After the wash primer, a solvent containing primer based on epoxy resin or polyurethane is applied. This is done manually via an electrostatic spray application. The solvent content of these materials varies from 50 - 65 %. The content of strontium or zinc chromate amounts 10 - 20 %. The applied layer thickness averages 15 - 25 µm. The material cures at ambient temperature.

Application of the topcoat

The topcoat can be very different according to customers' requests. Solvent-based 2-component paints with a solvent content of 55 - 65 % are exclusively used. The topcoat is applied in several layers (two to four according to the colour) via electrostatic spraying. According to the applied colour, the layer thickness amounts to 60 - 100 µm. After the first layer is applied, a short flashing-off takes place and, before a second layer is applied, another evaporation of about one hour takes place. Subsequently, the three layers are dried. Afterwards, the decoration is applied via a spray application or by pressure sensitive foils. For the painting of exterior surfaces, conventional paints and high solid paints with a solid content of about 70 % can be used. At the request of a customer, a clear coat can be applied on the topcoat.

12.2.1.3 Temporary corrosion protection

The so-called 'temporary corrosion protection' is obtained by application of water-rejecting layers in the internal area of the aircraft. The material remains in the plane permanently. The main areas are, e.g. doors, gates, wheel wells and cargo storage areas. The temporary corrosion protection materials are solvent-based, wax-like substances. The application takes place with a brush or via spraying. The solvent content of the products amounts to about 40 - 60 %. About 60 – 80 litres are processed per aircraft.

12.2.2 Maintenance

The paint application is carried out in closed workshops where temperature and air humidity can be regulated. For the deposition of overspray from exhaust air streams, wet dust collectors are installed. The applied paints dry at ambient temperature.

12.2.2.1 Paint removal

In the context of maintenance, the primary coat and the topcoats are removed every six to eight years. If an airline company changeover takes place, paint removal is undertaken sooner. This is most common for leasing companies. The paint removal (and new paint application) is done for optical reasons and for examining the structure for wear and corrosion. Paint removal is usually done chemically. Water blasting, which was favoured for environmental reasons, is no longer applied due to the causation of excessive mechanical stress. The aircraft is cleaned with a water-based, alkaline cleaning agent. After drying the windows, running gear and parts consisting of fibre-reinforced plastic, composite materials are masked. The following paint removal process is done via acid cleaning or by mechanical sanding. For acid cleaning, a water-based benzyl alcohol formic-acid is applied with airless spraying techniques. The sealants in the seams are manually removed. For composite materials and partly for metal surfaces, pretreatment is done by sanding.

12.2.2.2 Cleaning

Macerated paint layers are removed by water. Subsequently aqueous-alkaline neutralisation and cleaning takes place. Before paint application, the surfaces are cleaned manually with organic solvents and cleaning wipes. In general, a mix of butyl acetate and butyl alcohol is used as solvent.

12.2.2.3 Pretreatment

Before the primer is applied, a solvent-based wash primer is applied onto metal surfaces. This material contains 76 % organic solvents and about 14 % zinc chromate (in the solid content). Up until now, no zinc-free materials have been used. The material is applied via an electrostatic spray application. The wash primer is not applied onto composite materials.

12.2.2.4 Primer

Two different materials are used as primers:

- primer based on polyurethane or epoxy with a solvents content of 70 % without chromate, and
- primer with strontium chromate (about 20 % in the solids content) and about 67 % organic solvents.

Primers containing chromate are used for increased corrosion protection for climate conditions with a high humidity and high salinity of the atmosphere or upon the request of a customer. Application is carried out manually via electrostatically assisted spray applications.

12.2.2.5 Topcoat

As topcoats, conventional 2-component paints with a solvent content of about 61 % and 3-component high solids with a solvent content of about 43 % are used. Both paints are free of chromate and lead. The application is carried out manually by electrostatically assisted spraying.

12.2.2.6 Clear coat

Conventional topcoats are generally coated with a clear coat layer. If high solid topcoats are applied, an additional clear coat layer is not necessary. It is only used at the request of a customer. The same application method as for topcoats is used.

12.3 Current consumption and emission levels in the coating of aircraft

12.3.1 Construction

12.3.1.1 Material consumption

For the determination of the material consumption, the aircraft's surface has to be measured. In addition to the exterior surface, the surface of coated component parts also has to be taken into account. Coating the exterior surface takes up to eight days. Most of the time is needed for masking and finishing. The largest amount of paint is consumed by the coating of component parts. The surface area of component parts is about four times greater than that of the exterior surface of the completed aircraft. Table 12.1 shows material consumption for an A 320 (150 passenger seats).

Coating surface	Surface (m ²)	Layers
Component parts	3600	1 – 2
Outside surfaces	1200	2 – 4
Inside area	500	2
Conservation of rivet heads	10000 (running meters)	1 – 2

Table 12.1: Coated surfaces for an A 320
[13, DFIU and IFARE, 2002]

For the coating of an A 321 (about 180 passengers), the total surface area of components and interior areas is about 3600 m² and the total exterior surface area of the completed aircraft is about 945 m². The applied dry material has a total weight of 380 kg. For an average paint system (consisting of wash primer, primer and topcoat), about 0.9 kg/m² material is applied. For the painting of component parts or single paint layers, no data could be obtained. Data of the paint consumption are given in Table 12.2.

Paint layer or process step	Material consumption
Pretreatment	200 l solvents (30 % isobutanol and 70 % butyl acetate) for 600 m ²
Wash primer	75 kg wet lacquer (for the hull); overspray about 20 %
Primer	100 kg wet lacquer (for the hull); overspray about 20 %
Topcoat	200 kg wet lacquer (for the hull)

Table 12.2: Consumption of materials for the painting of exterior surfaces of planes
[13, DFIU and IFARE, 2002]

12.3.1.2 Water consumption

No data submitted.

12.3.1.3 Energy consumption

No data submitted.

12.3.1.4 Emissions to air

[128, TWG, 2005]

About 600 g VOC/m² are emitted for an average material consumption of about 0.9 kg/m². The emitted overspray is far below 1 mg/m³. The total VOC emissions per aircraft amount to 450 kg for the painting of exterior surfaces. For a plant with a production capacity of 60 aircraft per year, approximately 27 t of VOC are emitted from the coating of exterior surfaces.

Since the interior surface area is about four times greater than that of the exterior surface area, the entire emission for the plant can be estimated up to about 100 t per year. The painting of component parts is generally carried out in different plant locations. In the Airbus Deutschland GmbH Company in Nordenhamm, Germany, the total solvent input was about 131 t in the year 2000. In the Airbus plant in Hamburg, Germany, 69 t VOC/yr may be processed, according to their permit. In 2001, 70 aircraft were produced there.

Due to the difficulty of enclosing the large items being coated (whole planes, fuselages, wings and other large sections) and the high air volumes subsequently extracted. Therefore, a key technique to reduce VOC emissions is to reduce the amount of VOC in the coatings used, for example, by using high solids and/or 2-component coatings.

12.3.1.5 Emissions to water

Along with the paint sludge, waste water is generated from the wet deposition of overspray. The treatment of waste water is similar to the processes used in the serial painting of passenger cars.

12.3.1.6 Waste

Painting of aircraft generates the following wastes:

- paint sludge (hazardous waste)
- filters
- cleaning wipes
- organic solvents (recycled)
- packaging paper (recycled)
- foils
- grinding dust
- empty paint containers.

12.3.2 Maintenance

Due to different geometries of aircraft, the consumption and emission values are given for a B 747 – 400 (see Table 12.3). For this type of aircraft, about 2780 m² has to be painted. The data comes from Lufthansa Technik, Germany from 2001

Process	Material	Material consumption (kg)	Solvent content (%)	VOC emissions (kg per B 747)
Paint removal	Chemical stripping agent	3000		No VOC ¹
Pretreatment	Wash primer based on polyvinyl butyrate containing chromate	240	76	182
	Primer containing chromate	450	67	301
	Primer chromate-free	450	71	319
Cleaning	Butyl acetate, butyl alcohol	200	100	200
Topcoat	High solid	1200	43	516
	Solvent-based	1300	61	793
Clear coat	Solvent-based	1200	65	780
Note: ¹ No VOC according to the definition of the Solvent Emissions Directive 1999/13/EC				

Table 12.3: Material consumption exemplified for a B 747 – 400 by Lufthansa Technik [13, DFIU and IFARE, 2002]

According to the utilised paint system, the VOC emissions amount to 1.2 – 2.3 t per coated B 747 – 400. If high solid topcoats are utilised, the VOC emissions amount to about one tonne less, compared to conventional topcoatings and an additional clear coat layer. Waste gas treatment equipment, e.g. oxidisers, are not installed due to large volume flows (approx. 450000 m³/h) and low VOC concentrations.

Different types of aircraft are completely or partly coated in the plant, the coating of 150 A 300 aircraft per year is considered as a benchmark for calculating the level of VOCs being emitted in one year. For 2000, it was calculated that 67 t VOC was emitted. The emission value of 150 kg/h is exceeded temporarily for some coating processes due to the simultaneous paint application from several employees (up to 12 painters).

12.4 Techniques to consider in the determination of BAT for the coating of aircraft

In Chapter 20, techniques are discussed which might also be applicable to the coating of aircraft. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to the coating of aircraft. In Table 12.4, the general techniques relevant for the coating of aircraft that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 12.4: Reference to techniques generally applicable to the sector

12.4.1 Conventional solvent-based materials

Description: Conventional solvent-based paints contain the following solvent contents by weight:

- wash primer: 70 - 90 % solvent containing chromate, based on polyvinyl butyrate, or epoxy or polyurethane resin
- primer: 50 - 67 % solvent containing 10 - 12 % chromate, based on epoxy or polyurethane resin
- primer: 71 % solvent, chromate-free
- topcoat: 55 - 65 % solvent
- clear coat: 65 % solvent.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: The selection of the lacquer system depends on manufacturer defaults, international regulations and customer requests. It is common practice to treat the waste gases containing solvent.

A reported VOC emission range when applying conventional solvent-based systems for painting the outside of a Boeing 747 – 400 (without emission controls) is 430 – 830 g/m², depending on the utilised paint system. For coating the outside of a new Airbus 321, about 480 g VOC/m² are emitted. The surface of the components is about four times greater than that of the outside of an aircraft, e.g. the total surface of the component parts for an Airbus 320 to be coated is about 3600 m².

For internal coating, including the components of an Airbus 321, an estimated emission factor of 300 g VOC/m² is reported.

Applicability: Solvent-based paints can be used in all phases of the painting operation (wash primer, primer, topcoat, clear coat and repair), and can be used on metals and plastics. Since the manufacturer's corrosion protection guarantee lasts for 25 years, only specific paint systems can be utilised.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Lufthansa Technik AG, Hamburg, Germany. AIRBUS Deutschland GmbH, Hamburg, Germany.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004]

12.4.2 Replacement of solvent-based materials (substitution)

12.4.2.1 High solid paints

Description: For the general description, see Section 20.7.2.2. Instead of a conventional three layer system (wash primer, primer and topcoat), a high solid system consisting of a high solid epoxy primer and a high solid topcoat can be utilised. 2-component paints are applied in topcoat and have a solvent content of 30 - 43 %.

Achieved environmental benefits: Compared to the conventional paint systems, the VOC emissions can be reduced by up to 30 %, giving estimated VOC emissions of 200 - 320 gVOC/m² compared to conventional systems, see Section 12.4.1.

Cross-media effects: No data submitted.

Operational data: The optical surface qualities and technical properties of high solids are equal or even better compared to those of conventional paints.

Applicability: Applicable for the construction and maintenance of new aircraft.

Economics: Material costs and the costs of paint removal for maintenance operations are higher.

Driving forces for implementation: SED.

Example plants: Widely used. Lufthansa Technik AG, Hamburg, Germany. AIRBUS Deutschland GmbH, Hamburg, Germany

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005]

12.4.3 Replacement of hexavalent chromating (substitution)

The application and treatment of hexavalent chromating and its replacement by other options is covered in the STM BREF [59, EIPPCB, 2006].

Wash primers and primers containing chromate are used for increased corrosion protection for climate conditions with a high humidity and high salinity of the atmosphere or upon customer's requests. Primers are applied by using electrostatically assisted spraying.

A chromate-free primer can be applied if the aircraft is utilised under regular climatic conditions. However, the wash primer containing chromate cannot be substituted for safety reasons [13, DFIU and IFARE, 2002].

A chromate-free primer is reported to be available which may replace the separate wash primer and primer for corrosion resistance [128, TWG, 2005].

12.4.4 Paint application techniques and equipment

12.4.4.1 Electrostatically assisted spraying

For a general description, see Sections 20.7.3.15 and 20.7.3.17. These techniques are commonly applied.

12.4.4.2 Wet separation spray booths

For a general description, see Section 20.7.4.1. This technique is increasingly applied in the automated coating of aircraft components.

12.4.4.3 Components painting – enclosure and automated application

Description: Component parts are increasingly painted by applying automated painting processes in enclosed spray booths equipped with waste gas treatment (see Sections 20.2.3 and 20.11.2.1).

Achieved environmental benefits: This reduces the overall VOC emissions for an aircraft as the surface of the components is about four times greater than that of the outside of an aircraft, e.g. the total surface of the component parts for an Airbus 320 to be coated is about 3600 m² compared with the 1200 m² of the fuselage.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: AIRBUS France, Nantes, France.

Reference literature: [13, DFIU and IFARE, 2002] [162, Eurocar, 2005]

12.4.5 Waste gas treatment

12.4.5.1 Venturi particle separation

Venturi systems are used to improve the efficiency of wet dust collectors (see Section 12.4.5.2). For a general description, see Section 20.11.3.5 [13, DFIU and IFARE, 2002]

12.4.5.2 Scrubber

For a general description, see Section 20.11.3.8. For the deposition of overspray, wet dust collectors are installed. An achieved emission level of $<1 \text{ mg/m}^3$ of dust from spraying is reported.

[13, DFIU and IFARE, 2002]

12.4.5.3 Treatment of waste gases from body painting

The application onto aircraft is done in closed workshops (see Section 20.11.2.1) and completely by hand with an application gun. Waste gas treatment is not typically applied due to substantial volume flows (about $450000 \text{ m}^3/\text{h}$), low VOC concentrations and the discontinuous operation of installations.

[13, DFIU and IFARE, 2002]

13 COATING OF OTHER METAL SURFACES

13.1 General information on the coating of other metal surfaces

A wide range of metal surfaces are coated for corrosion prevention and/or decoration. They may be for finished products (such as cleaning machines) or in sub-assemblies that are a part of other products, such as engine blocks for vehicles. They are not dealt with individually in detail, but example data are given. Some examples are:

- steel furniture, e.g.
 - furniture and fittings for commercial use, hospitals, etc.
- household appliances, e.g:
 - white goods: fridges, washing machines, etc.
- mechanical engineering, components, cabinets
 - e.g. for high voltage switch gear
- automotive sub-assemblies, eg:
 - engine blocks
 - windscreen wiper assemblies
 - radiators
 - brake discs
 - aluminium rims
- construction, e.g:
 - facade panels
 - door and window frames
 - heating panels, radiators.

This is a group of activities classed among ‘other coatings’ in the SED [123, EC, 1999]. The EGTEI data sheet for the industrial application of paints considers three sub-groups [142, EGTEI, 2005]:

- general industry: trade coaters, general engineering, industrial equipment, original equipment, heavy engineering and ACE (see Chapter 10), aerospace (see Chapter 12)
- continuous processes: furniture, rigid metal packaging and drums (see parts of Chapter 15),
- plastic coating: plastic and automotive OEM components (see Chapter 16).

13.2 Applied processes and techniques

Any of the techniques in Chapter 20 may be applied.

13.3 Current consumption and emissions levels

This group of activity emits NMVOC originating from the use of paints containing solvents, thinners and cleaning solvents. NMVOC emissions from this sector may vary significantly from country to country. At EU-25 level for 2000 (according to the RAINS model), NMVOC emissions were 543.8 kt representing 5.9% of total NMVOC emissions. Total activity was 1601 kt of paints used, giving an average emission factor of about 339.6 g NMVOC/kg paint consumed meaning that emissions from this sector are already partly treated in the EU-25 (unabated emission factors range between 690 and 750 g/kg of paint according to the sub-sector). [142, EGTEI, 2005]

Due to the wide range of this industry group, it is not possible to give details of consumptions and emissions. They will depend on:

- the type of processes applied
- end-of-pipe treatments applied
- products
- volume of production.

General information can be found with the appropriate techniques in Chapter 20.

13.4 Techniques to consider in the determination of BAT for serial painting of other metal surfaces

In Chapter 20, techniques are discussed which might also be applicable to the serial painting of other metal surfaces. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to serial painting of other metal surfaces. In Table 13.1, the general techniques relevant for the serial painting of other metal surfaces that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

The EGTEI synopsis sheet for the industrial application of paints (see Annex 24.1.1) gives some data on the cost-benefit at a European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations or products [142, EGTEI, 2005].

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 13.1: Reference to techniques generally applicable to the sector

13.4.1 New multiple coating systems for the painting of aluminium rims/wheels

Description: A new production site for aluminium wheels achieves the following:

- replacement of chromium (VI) by a heavy metal free system in the pretreatment
- replacement of the solvent-based paint by powder coating (acrylic resin)
- replacement of the solvent-based metallic paint by water-based metallic paint to reduce VOC emissions.

Simultaneously, the selected process meets high technical standards as well as quality standards of the customers and it should be economically optimised.

Achieved environmental benefits: The technique has the following benefits (see Figure 13.1):

- the use of chromium (VI) has ceased
- the application of water-based paint for the metallic basis layer through a combination of high rotation bells and HVLP application lead to an efficiency degree of 80 %
- the powder coating for the base layer reached an application efficiency of 98 %
- for the final layer with acrylic-based powder coating, an application efficiency of 98 % has been reached
- the VOC emissions have been reduced by approx. 94 %.

Cross-media effects: No data submitted.

Operational data: See Table 13.2 and Table 13.3.

		Conventional process		New process	
		Paint consumption	Solid application	Paint consumption	Solid application
Coating/basic layer	Basic powder	80 – 100 g		80 – 100 g	
	Application efficiency	98 %		98 %	
Metallic basis layer	Solvent-based wet paint	<60 g	12.5 g (approx.)	--	--
	Water-based wet paint	--	--	35 gram	<10 gram
	Application efficiency	50 – 60 %		80 %	
Coating clear coat	Solvent-based clear coat	<60 g	15 g	--	--
	Powder	--	--	45 g	
	Application efficiency	50 – 60 %		98 %	

Table 13.2: Input/consumption of resources per coated aluminium wheel

	Conventional process	New process	Remarks
Coating/basic layer			
Waste powder	<2.5 t/yr	<2.5 t/yr	No production chain, because the same process step is used
Metallic-basis layer			
VOC	37 t/yr (approx.)	4 t/yr (approx.)	Reduction by water-based coat about 90 %
Solid output in waste water	8 t/yr (approx.)	2 t/yr (approx.)	Reduction and replacement of hazardous substances, Cr (VI)
Coating clear coat			
VOC	29 t/yr (approx.)	0 t/yr	Reduction about 100 %
Solid output in waste water	20 t/yr (approx.)	--	Reduction about 100 %
Waste powder		1 t/yr (approx.)	New waste

Table 13.3: Emissions related to 1 million wheels/year

Applicability: Applicable in new installations.

Economics: Capital investment for the new installation: EUR 3.975 million. The process works economically, in particular because of the high level of automation and the controlled, minimised layer thickness.

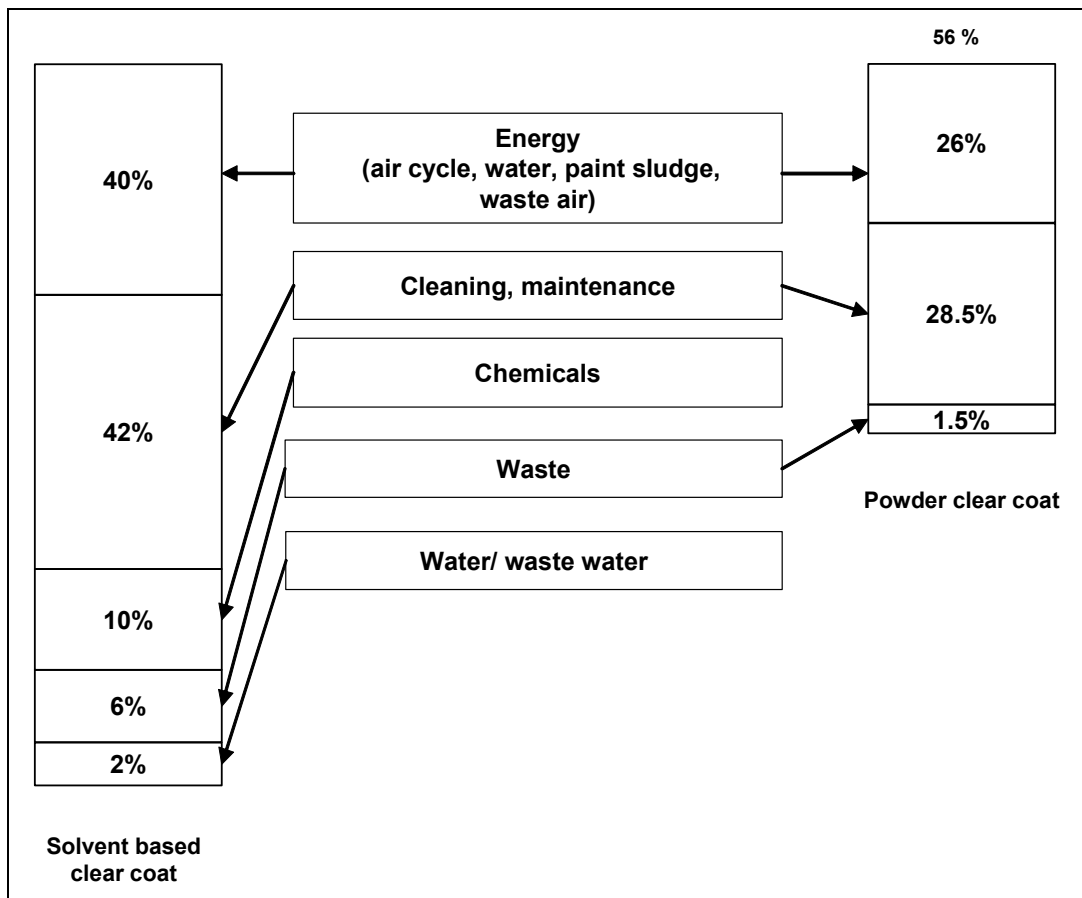


Figure 13.1: Comparison of the use of solvent-based clear coat and the use of powder clear coat

Driving forces for implementation: Solvent Emissions Directive 1999/13/EG.

Example plants: BBS Kraftfahrzeugtechnik AG, Germany.

Reference literature: [105, UBA - DE, 2002]

14 COIL COATING INDUSTRIES

[58, ECCA, 2004, 76, TWG, 2004, 128, TWG, 2005]

14.1 General information on coil coating

The definition of a coil coating process according to EN-10169-1:1996 is as follows: *'A method in which an organic coating is applied on a metal strip in a continuous process. This process includes cleaning and chemical pretreatment of the metal surface and either one-side or two-side, one or multiple application(s) of (liquid) paints or coating powders which are subsequently cured, or laminating with plastic films'*.

The substrate is normally either cold rolled zinc or zinc alloy coated steel (75 %) or aluminium (25 %) expressed as surface area. 95 % of the coatings consist of paints and 5 % of plastic laminates. The latter coating type is experiencing rapid growth at present, particularly as a combination of prepainting and laminating.

The coated coil process gives the option of a wide range of colours, gloss levels and surface textures. The coil can be delivered in coil form, slit or as cut lengths; it can be subsequently bent, profiled, deep drawn, fastened, etc., without detriment to the surface coating. All stages of the process are under continuous control, e.g. the chemical bath concentration and temperature, coating thicknesses, colour, gloss, adhesion and mechanical qualities of the coating.

14.1.1 The size of the coil coating industry

Most of the coil coaters in Europe are integrated companies in large, steel or aluminium groups, normally supplying big quantities of pre-coated metal. Some coil coaters such as coil coaters of narrow strips, and specialised service centres (increasingly becoming more common), for example, deliver smaller and more customised quantities to the user.

Currently there are around 390 lines worldwide (outside North and South America) installed in 50 countries, with new capacities still emerging, showing the growing demand.

Table 14.1 gives the number of production lines by country in Europe and the yearly production volumes of pre-coated steel and aluminium. It is not known if all of these fall within the scope of the IPPCD.

	Number of production lines	Yearly volumes of prepainting coil lines	
		Steel (kt/yr)	Aluminium (kt/yr)
Austria	2	375	
Belgium	7	670	8
Denmark	3	20	10
Finland	2	270	*
France	17	1415	45
Germany	24	1469	382
Greece	4	60	50
Ireland	0	0	0
Italy	34	1225	197
Luxembourg	0	0	0
Netherlands	15	170	55
Portugal	2	40	*
Spain	18	428	68
Sweden	13	350	*
United Kingdom	9	510	10
Czech Republic	1	40	
Hungary	1	90	*
Poland	4	200	10
Slovak Republic	2	80	5
Total	158	7412	840
		8252	
Note:			
*Steel and aluminium data are not split so the total has been considered in the steel figures			

Table 14.1: Number of production lines and yearly production of pre-coated steel and aluminium in some European countries
[58, ECCA, 2004]

Pre-coated sheet metal products are widely used in industries as varied as building and construction, consumer products, the automotive industry, furniture, lighting, technical packaging, etc. The scale of the uptake of pre-coated products can be seen in Table 14.2 where 2002 figures for pre-painted steel and aluminium are listed.

	Steel		Aluminium	
	(kt)	(%)	(kt)	(%)
ECCA (1)	4674	31.3	344	36
NCCA (2)	4179	28	558	58.4
Rest of World	6064	40.7	53	5.6
Total	14917	100	955	100
Notes:				
- ECCA – European Coil Coating Association				
- NCCA – National Coil Coating Association (from the United States)				

Table 14.2: Coil coating statistics for 2002
[58, ECCA, 2004]

14.2 Applied processes and techniques in coil coating

[58, ECCA, 2004], [71, BSTSA], [76, TWG, 2004, 128, TWG, 2005]

A coil coating line coats metallic substrates of coiled strip products with paint or a laminate. These are typically applied onto cold rolled, hot dip or electro-galvanised steel or aluminium; copper alloys, stainless steel and other metal substrates can also be coated.

14.2.1 Typical coil coating line process description

A typical organic coil coating line comprises decoilers, an entry strip accumulator, cleaning, conversion coating, prime coating, finish coating, an exit accumulator and recoilers. This configuration allows the line to operate continuously at high speeds for seven days a week, twenty-four hours a day, for maximum efficiency. All process parameters are controlled to assure effective operation.

Table 14.3 shows the typical operating parameters of an organic coil coating line, and Figure 14.1 the basic layout of the line.

Parameter	Value
Operating speeds (m/min)	30 – 180
Gauge (mm)	0.1 – 2
Width (mm)	150 – >1600
Coating thickness (μm each side)	1 – 200

Table 14.3: Typical operating parameters of an organic coil coating line
[58, ECCA, 2004], [76, TWG, 2004]

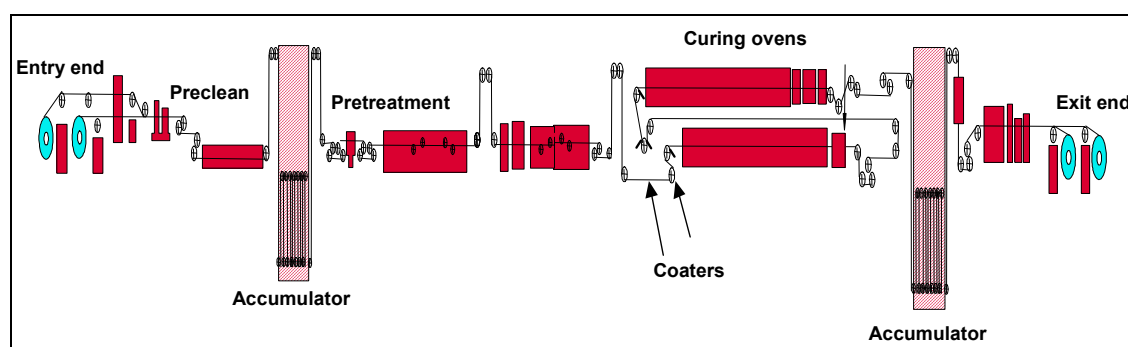


Figure 14.1: Typical layout of a coil coating line
[58, ECCA, 2004], [76, TWG, 2004]

The next sections explain the different parts of the coil coating line in more detail.

14.2.1.1 Entry

The coiled strip is fed into the line by a coil car and pay off reel. The coil is measured to ensure compliance with quality standards, and then passed through a shearing process to remove any damaged material from the leading edge. A stitch or weld is created between the leading edge of the new coil and the end of the coil already being processed in the line, to allow a continuous flow of material through the processing section. The strip then goes through a notcher, which allows the stitch to be tracked through the line.

14.2.1.2 Leveller

Tension levelling may then be used to ensure that a good standard of flatness is achieved. This is required to facilitate passage of the material through the roller coaters and ovens, and to meet customer requirements. Poor strip shape can result in an uneven paint layer and scratches.

14.2.1.3 Accumulator

After the leveller, the strip enters an entry accumulator, this normally operates to full capacity but will release stored strip to allow sufficient time for the entry section to stop and stitch or weld coils together.

14.2.1.4 Cleaning section

The strip is chemically cleaned and degreased in an aqueous cleaning solution, via either a dip and/or spray system. It is essential that the surface of the strip is free from impurities, such as grease, oil or abraded metallic fines, so that it can be fully coated with the conversion coating, thus ensuring optimal performance of the final product. Cleaning is followed with hot and cold water rinses to remove all residual chemicals. A 'squeegee' roll set-up is generally used to ensure that low carryover from the degrease section occurs. A 'pre-cleaning' section may be installed before the entry accumulator in case of heavily soiled substrates.

14.2.1.5 Conversion coating (pretreatment)

The strip is dried prior to being treated with a conversion coating. This coating usually contains chromic or chromium-free salts and provides an activated surface that enables the organic paint layer to adhere to the metallic surface of the strip. For metals such as cold and hot rolled steel and various forms of galvanised steel, a coating of iron or zinc phosphate may be applied instead. Special additives will also typically be used to promote the coating deposition on different metals and to increase process efficiency. The presence of this conversion coating improves the paint adhesion and humidity resistance, and hence improves the longer-term corrosion resistance of the final product. The coating can be applied via a chemical roller coater ('chemcoater', which does not require rinsing) or by a spray/dip and squeegee roll arrangement. Some coatings require a final rinse to remove any residues left on the strip component, the component is oven dried before entering the coating section.

14.2.1.6 Prime coat application

The painting process comprises two stages, namely 1) primer application, and 2) finish application. In the first stage, the strip passes through a roller coater machine that applies a primer to both sides of the strip. The roller coater can be adjusted in order to regulate the amount of paint applied onto the strip surfaces. Coating operations are carried out in an enclosed, no smoking area that is adequately ventilated to ensure safe working conditions for personnel under local and European regulations.

After application of the primer, the strip passes through an oven, the temperature and residence time of which is controlled to ensure that all the volatiles are removed and that the paint is properly cured. This will be dependent on the paint system applied and the cross-sectional area of the strip. After oven curing, the strip is cooled by either an air or water cooling system, and in some instances both.

14.2.1.7 Finish coat application

Once dried, the strip passes through a second roller coater machine, which applies the finish paint coat to either one or both surfaces. A similar or different coating may be applied to the reverse side of the coil. Again the thickness of paint applied to each side of the strip can be controlled. The strip then passes through an oven set at an appropriate temperature to ensure that all the volatiles are removed and that the paint is fully cured. After oven curing, the strip is cooled by either an air or water cooling system, and in some instances both.

For the production of plastisol products, an embossing roller may be used to imprint a pattern into the hot paint surface prior to quenching.

The adhesive required for the production of laminated materials can be applied with either of the roller coater heads. It is subsequently cured in an oven and then processed through the laminator.

All coating operations are normally carried out in an enclosed, no smoking area that is adequately ventilated to ensure safe working conditions for personnel.

14.2.1.8 Embosser/laminator

Embossing rolls are used to imprint patterns or textures into the thicker coatings. Embossing is followed by quenching and drying.

For the production of laminated materials, rolls of thin polymer film are bonded to the strip with or without a separately applied adhesive. The film is laid on to the hot coating by roll pressure, followed by quenching and drying as for paint coating.

14.2.1.9 Cooling systems

In order to minimise water usage, consistent with the product quality, an evaporative or other cooling tower may be used to provide a closed system for strip cooling.

14.2.1.10 Exit

After being cooled, the strip passes through an exit accumulator and guillotine/shears. This accumulator allows the line to run continuously while the exit section slows or stops in order to remove a finished coil. The strip is inspected and tested to ensure that it complies with quality standards, and is then coiled onto a tension reel. The completed coil is removed and strapping is applied. It is then identified and moved to the packing area, where it is packed as per customer requirements.

14.2.2 Coating types

As the coil coating line has the ability to apply paint or laminate to a substrate, a large variety of products can be manufactured. The coatings, which include polyesters, PVF₂, polyurethanes, plastisols, epoxy and epoxy phenolic coatings, primers, backing coats and laminates, are typically applied in thicknesses of between 1 and 200 microns.

A flexible anticorrosive primer or a base coat is applied onto the pretreated metallic sheet to give good adhesion and durability to the subsequently applied topcoat. For each product, the coating is built up in a number of layers, a typical example for steel coated material can be seen in Figure 14.2.

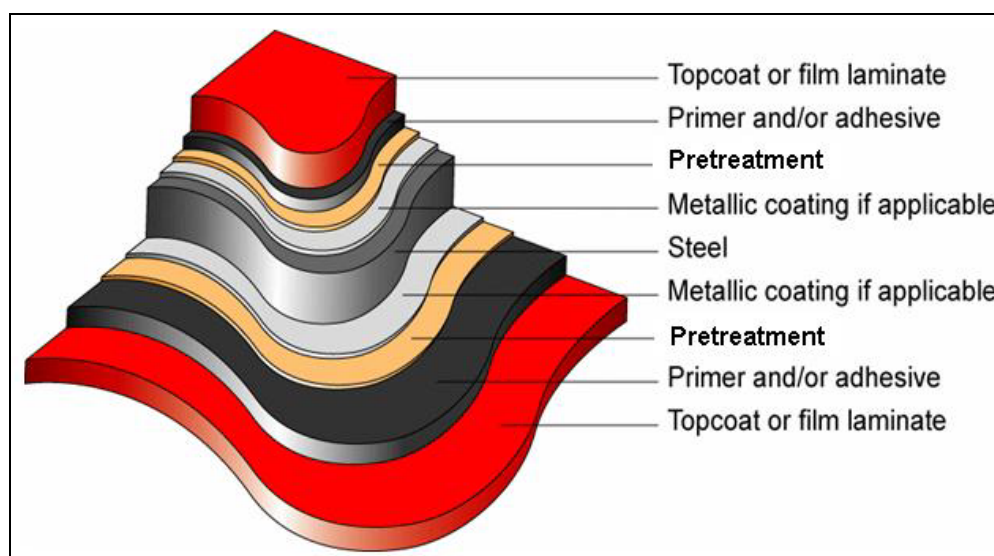


Figure 14.2: Typical layers of a steel coated product
[58, ECCA, 2004]

Table 14.4 lists some typical organic coating types used in the coil coating industry.

Coating	Dry film thickness (µm)	Resin types	Solvent content (%)	Solvent types	Cure temperature (°C)
Primers Conventional	4 – 9	Epoxy/urea Epoxy/melamine Polyester/melamine Polyurethane Acrylic	50 – 70	High boiling aromatics; alcohols; glycol ethers/esters; high boiling esters	210 – 230
Primers High build	12 – 25	Polyester/melamine Polyurethane	40 – 50	High boiling aromatics; alcohols; glycol ethers/esters; high boiling esters	210 – 230
Back coats	4 – 15	Polyester/melamine Epoxy/melamine Epoxy/phenolic Alkyd/melamine	50 – 70	High boiling aromatics; alcohols; glycol ethers/esters	180 – 250
Topcoats					
Polyester	18 – 25	Saturated polyesters cross linked with melamine-formaldehyde resins	35 – 55	High boiling aromatics; glycol ethers/esters; high boiling esters/alcohols	210 – 230
SMP (silicone modified polyester)	As above	As above except for silicone modification in the polyester resin	45 – 55	High boiling aromatics; glycol ethers/esters; high boiling esters	210 – 230
Polyurethane	20 – 30	Saturated polyesters with urethane cross-linking	30 – 50	High boiling aromatics; glycol ether/esters; high boiling esters	220 – 240
PVDF PVF₂	20 – 25	Polyvinylidene difluoride + acrylic polymer	40 – 65	High boiling aromatics; glycol ethers/esters; high boiling ketones	240 – 260
PVC plastisol	100 – 200	Polyvinyl chloride + plasticisers	<10	High boiling esters; high boiling aliphatics	190 – 210

Coating	Dry film thickness (µm)	Resin types	Solvent content (%)	Solvent types	Cure temperature (°C)
Topcoats					
Water-based products (includes some primers and back coats)	10 – 25	Acrylic/melamine	5 – 15	High boiling esters; glycol ethers/esters	220 – 230
Non-stick bakeware coatings	12 – 15 (2-coat 7+7)	Polyether-sulphone PTFE	65 – 80	N-methyl pyrrolidone; butyrolactone; high boiling aromatics	350 – 370
Laminate film coatings	15 – 120	Polyvinyl chloride, PVC; polyvinyl fluoride, PVF; polyethylene terephthalate, PET; acrylic; polypropylene	0	None in film, but used in primer/adhesive	Lamination at 180 – 230
Powder coatings	35 – 100	Polyester/epoxy polyurethane	0		200 – 250

Table 14.4: Organic coating types used in the coil coating industry
[58, ECCA, 2004], [76, TWG, 2004]

14.3 Current consumption and emission levels in coil coating

[13, DFIU and IFARE, 2002], [58, ECCA, 2004], [76, TWG, 2004, 128, TWG, 2005]

14.3.1 Mass balances

General consumption and emission data from the coil coating processes are reported in the following sections. However, several consumption and emission data from some individual plants have also been gathered and reported in the relevant sections below.

14.3.2 Consumptions

[13, DFIU and IFARE, 2002] [58, ECCA, 2004], [76, TWG, 2004] [128, TWG, 2005]

14.3.2.1 Materials

[128, TWG, 2005]

Table 14.5 lists the usage of organic coatings in 1993 and 2002.

Coatings type	Relative usage (%)	
	1993	2002
Primers	16.5	20
Backing coats	13.2	16.6
Top coats		
Polyester	36.1	39
SMP (silicone modified polyester)	3.4	0.2
Polyurethane	Unknown	6.2
PVdF (polyvinylidene difluoride)	2.7	2.2
PVC plastisol	19.9	14.1
Water-based	0.4	0.2
Laminate films	6	6
Powder	Unknown	~0.5
Acrylic (solvent-based) – largely historical	0.3	0.002
Other	7.5	1
European total usage	95000 t/yr	158000 t/yr

Table 14.5: Usage of organic coatings 1993 and 2002
[58, ECCA, 2004]

The following materials are used in organic coil coating processes:

- metallic substrates
- paint
- solvents
- cleaning and pretreatment chemicals paint stripper
- engineering oils
- (demineralised) water (about 0.3 l/m² coil)
- others: biocides, grease, cleaning materials.

Table 14.6 shows the inputs to the coil coating process, their uses and typical end-of-life destination.

Substance	Use	Typical end-of-life destination
Inputs in solid form		
Metal strip (as coil)	Substrate	Product or scrap
Cleaning wipes (fabric)	Cleaning	Can be laundered for re-use
Inputs in liquid form		
Paint	Strip coating	Product/licensed removal
Solvent	Cleaning and thinning paint	Licensed removal
Cleaning chemicals	Cleaning strip	Treatment plant/licensed removal
Pretreatment chemicals	Pretreatment of strip	Product/treatment plant/licensed removal
Paint stripper	Cleaning paint heads	Licensed removal
Water	Cooling/treatment	Waste stream/effluent
Engineering oils	Lubricant	Licensed removal
Coating oils	Anti-corrosion	Product/licensed removal
Biocides	Water treatment chemicals	Waste stream effluent
Inputs in gaseous form		
Steam or hot water (1)	Strip drying/solution heating	Condensate – drain system
Natural gas (1)	Fuel	Combustion products to air
Hydrogen	Oven monitoring	Combustion products to air
Ethylene in air	Oven monitoring	Combustion products to air
Note: 1) An alternative option is to use electricity		

Table 14.6: Inputs to the coil coating process, their uses and typical end-of-life destination [58, ECCA, 2004], [76, TWG, 2004]

Organic coating

For the coil coating sector, solvent-based coating systems are used almost exclusively; see Table 14.5. Organic coating systems are based on polyester and polyurethane (or a combination of both), epoxy or epoxy-phenolic, and polyvinylidene difluoride (PVdF or PVF₂). For special surfaces, coatings with thermoplastic foils based on polyvinyl chloride (PVC), or polyethylene terephthalate (PET) are applied, but may also include polyvinyl fluoride (PVF) and other polymers.

The resin base for primers may be epoxy, polyester, polyurethane or acrylic, depending on the particular specification. Traditionally, anti-corrosive primers rely on the chemical activity of zinc or strontium chromates to provide corrosion protection. While internal and lower specification systems have performed adequately without chromate pigments, the use of chromate-free primers in long life coatings in aggressive environments is not currently established (see the STM BREF [59, EIPPCB, 2006]).

The solvents used most frequently have been included in Table 14.8.

Type of solvent	Some examples
Alcohols	Diacetone alcohol
Glycol acetates	Propylene glycol methyl ether acetate, ethyl diglycol acetate
Glycols	Butyl diglycol, butylglycol, propylene glycol monomethyl ether
High boiling esters	Dibasic esters, mixtures of refined dimethyl esters of adipic, glutaric and succinic acids
Ketones	Isophorone
Petroleum hydrocarbons	Commercial aromatic fractions, xylol

Table 14.7: Solvents used most frequently in organic coating
[76, TWG, 2004] [128, TWG, 2005]

Another source reports that, in the United States, the solvents used most frequently include xylene, toluene, methyl ethyl ketone (MEK), butanol, diacetone alcohol, isophorone, butyl carbinol, mineral spirits, ethanol, nitropropane, tetrahydrofuran, methyl isobutyl ketone, isopropanol and di-isoamyl ketone and many mixtures of other special solvents [57, Rentz, et al., 1999].

There is an increasing application of thin film coatings (around 3 μm) especially in the vehicle industry as well as a decrease in the use of polyvinyl chloride plastisols.

The solvent-based paints currently applied have a solid content in the range of 30 – 70 wt-%. The applied layer thickness for systems based on acrylate, epoxy, polyurethane or polyester varies from less than 1 up to 50 μm , however this is most commonly around 25 μm .

For plastisols with a solvent content of 5 - 10 %, a layer thickness of up to 200 μm is typical.

For powder coating systems, a common layer thickness is in the range of 60 – 100 μm .

Typical consumption figures in relation to one square metre coated coil applying a layer thickness of 50 – 60 μm of powder or liquid coating is shown in Table 14.9.

Paint system	Paint consumption (g/m^2 coil)
Solvent-based (50 wt-%)	32 – 53
Powder paint	60 – 80
Note: Due to the various coatings systems and layer constructions, these figures represent only an approximation.	

Table 14.8: Typical paint consumptions in coil coating
[13, DFIU and IFARE, 2002], [76, TWG, 2004] [128, TWG, 2005]

In Germany, about 22000 tonnes of solvent-based paint was applied in 2000. In large installations, solvents are used at the rate of hundreds of kilograms an hour.

Consumables containing non-solvents listed in Table 14.10 include cleaning and pretreatment chemicals.

Process	Product	Application method	Substrate	Main components	Consumption rate (kg/1000 m ²)
Cleaning	Alkali liquid	Spray	Cold rolled steel Zinc coated steel	Potassium hydroxide Sodium hydroxide Phosphates Sugar-based complexing agent Surfactants	1.6
Cleaning	Alkali liquid	Spray	Aluminium	Potassium hydroxide Sodium hydroxide Phosphates Sugar-based complexing agent Surfactants	2.5
Cleaning	Acid liquid	Spray	Aluminium	Sulphuric acid Phosphoric acid Hydrofluoric acid Surfactants	1.3
Pretreatment	Alkaline oxide (stage 1)	Spray and immersion	Zinc coated steel	Sodium hydroxide Sugar-based complexing agent Ferric nitrate Cobalt nitrate	4.8
Pretreatment	Alkaline oxide (final rinse)	Spray	Zinc coated steel	Cr ⁶⁺ , Cr ³⁺ , Zn, HF	0.94
Pretreatment	Chrome (no rinse)	Chemcoater	Cold rolled steel Zinc coated steel	Cr ⁶⁺ , Cr ³⁺ , phosphoric acid	0.52
Pretreatment	Zinc phosphate	Spray	Zinc coated steel	Zinc phosphate	6.6
Pretreatment	Chrome (rinsed)	Spray	Zinc coated steel	Cr ⁶⁺ , Cr ³⁺	11
Pretreatment	Chrome-free (no rinse)	Chemcoater	Zinc coated steel	Titanium, manganese, zirconium, phosphoric acid, organic polymer	0.4
Pretreatment	Chrome (no rinse)	Chemcoater	Aluminium	Cr ⁶⁺ , Cr ³⁺ , phosphoric acid	0.52
Pretreatment	Chrome (rinsed)	Spray	Aluminium	Cr ⁶⁺ , Cr ³⁺ , phosphoric acid, hydrofluoric acid	2.00
Pretreatment	Chrome-free (no rinse)	Chemcoater	Aluminium	Titanium, manganese, zirconium, phosphoric acid, organic polymer	0.40
Pretreatment	Chrome-free (rinsed)	Spray	Aluminium	Titanium, zirconium,	2.00
Pretreatment	Chrome-free (no rinse)	Spray and immersion		Zirconium	

Table 14.9: Chemicals containing non-solvents
[58, ECCA, 2004], [76, TWG, 2004] [128, TWG, 2005]

14.3.2.2 Water

The main water usage is for the cleaning and pretreatment stations, although some is used in quenching after coating and embossing. Techniques and BAT for controlling and reducing water usage are in the STM BREF. Key techniques are benchmarking consumptions, see Section 20.1.3, and the techniques discussed in Section 20.4 (re-use and recycling, regeneration, cascade rinsing, and controls) [128, TWG, 2005].

14.3.2.3 Energy

Natural gas is normally used as the fuel source for the paint curing ovens and for the oxidiser (combustion process). Commonly, a regenerative or recuperative oxidiser is applied. The heat generated can eventually be used in the process or can be used for steam generation or hot water. Natural gas can also be used to heat the no-rinse coating system oven, which dries the chromate solution that has been applied to the strip. Dampers and temperature gauges are used to ensure that control of oven settings is achieved. In an integrated steel plant, recovery of energy can be connected to the overall energy system of the site.

Electricity is used to power the line, and is sourced from the national grid. The main use of electricity is for process operations and coil movements with the overhead cranes and line drives, which are all electrically powered. Typical consumption levels are shown in Table 14.11 and Table 14.12 below.

Electricity (kWh/1000 m ²) Aluminium			Electricity (kWh/1000 m ²) Steel		
Minimum	Average	Maximum	Minimum	Average	Maximum
270	360	375	250	350	440

Table 14.10: Electricity use for aluminium and steel substrates
[58, ECCA, 2004]

Fossil fuels (MJ/1000 m ²) Aluminium			Fossil fuels (MJ/1000 m ²) Steel		
Minimum	Average	Maximum	Minimum	Average	Maximum
4000	7000	9800	3000	6500	10200

Table 14.11: Fossil fuels consumption for aluminium and steel substrates
[58, ECCA, 2004]

14.3.3 Emissions

14.3.3.1 Emissions to air

[13, DFIU and IFARE, 2002] [58, ECCA, 2004], [76, TWG, 2004] [57, Rentz, et al., 1999].

Solvents are released as VOC emissions, especially during the process steps of coating (about 8 %), drying (about 90 %) and cooling with water and/or air (about 2 %)

In general, there are four main sources of air emissions in a typical coil coating line. These are:

- fumes (mist) from the conversion coating section if a dry in place or dipping application is not used
- paint/solvent fumes from the coaters and ovens
- fumes from the paint kitchen and mixing bays
- emissions from the cooling system. These can be point source emissions or fugitive.

Typical emissions to air are given in Table 14.12 below:

Emission source	Species emitted
Oxidiser	VOC, CO, NO _x
Finish oven air quench	VOC
Laboratory fume cabinet	Low level assorted fume
Occupational health vent from coating rooms	VOC
Pretreatment scrubber exhaust	Chromic acid Potassium hydroxide Sodium hydroxide
Pre-clean scrubber	Potassium hydroxide Sodium hydroxide
HCl bulk tank scrubber	HCl fume
Flocculation tank fume	SO ₂

Table 14.12: Typical air emissions from coil coating processes (all are point sources)
[58, ECCA, 2004], [76, TWG, 2004] [128, TWG, 2005]

Typical air emissions from point sources with abatement equipment are VOCs, and oxides of carbon and nitrogen.

The VOC and CO emissions for lines with abatement can vary depending on the product being produced. Those with high solvent loads can give rise to higher emission values than those with low solvent loadings. Thicker coatings (e.g. plastisols and laminates) can lead to lower emissions than thin coating layers.

The VOC levels from unabated release points can vary intermittently and at times may be >50 mg/m³ due to intermittent localised activities within the coater house such as clean downs and tray cleaning. However, their volume in comparison with abated emissions is still very low, although the emissions will need to be reviewed on a site-by-site basis.

Industry wide, clean gas concentrations of <20 – 50 mgC/m³ are achieved. Fluorides are not emitted from the organic paint systems, and blocked isocyanates are used in some coatings as this eliminates isocyanates emissions. Any emissions >50 mg/m³ VOC are likely to breach the SED limits and therefore abatement would be required.

Table 14.13 shows some specific VOC emission values for different coating systems with an average coating thickness of 55 µm. The VOC content of the plant ovens is in the range 8.75 - 9.3 g/m³, which is about 22 % of the 40 g/m³ LEL.

A capture efficiency of 97 % of all VOC emissions that occur throughout the coil coating process can be achieved; resulting in 3 % fugitive VOC emissions. In the situation using a coating system with 50 % solvent content in combination with a removal efficiency of 99 % in the incinerator, about 0.04 kg solvents per kg of used coating solids are emitted.

Coating system	Specific VOC emission (g/m ² coated coil)	Abatement technique
Solvent-based	0.73 – 0.84	Incinerator connected to oven
Solvent-based (50 wt-%)	28 – 29 ¹	None
Powder coating	0 – 0.8 ²	None
Notes:		
¹ Concentration values achieved with no further abatement of the air stream		
² VOC emissions relate to curing reactions rather than solvents		

Table 14.13: Specific VOC emissions for several coating systems
[13, DFIU and IFARE, 2002], [76, TWG, 2004] [128, TWG, 2005]

Other possible emissions may include isocyanates from polyurethane products and fluorides from coatings containing fluoride where emission levels are typically $<0.1 \text{ mg/m}^3$.

14.3.3.2 Emissions to water

[13, DFIU and IFARE, 2002] [58, ECCA, 2004], [76, TWG, 2004] [59, EIPPCB, 2006]

The main source of waste water from a coil coating line is from the entry cleaning section and some pretreatment processes that require subsequent rinsing (e.g. passivation, chromatisation), and these are discussed in the STM BREF. Pretreatment processes, whether they contain chrome or not, may also be applied using the so-called 'no rinse method' (application by a roller technique). This method does not generate significant amounts of waste water. Pretreatment and cleaning solutions and their associated rinse-waters can either be treated at an on-site effluent treatment plant or taken off-site for treatment or disposal.

There are some emissions to the quench water used after curing in the primer and topcoat application, and after embossing but these are not particularly significant. As all paint systems require quenching, there are no differences in the quantities of waste water generated for the different paint systems, but there may be slight differences in the actual level/types of contaminants. The type of emissions from the cleaning and pretreatment sections for a steel coating line depends upon the metallic substrate and the chemical nature of the cleaning and pretreatment sections. Emissions may include zinc, aluminium, chromium, cobalt, iron, suspended solids, and acid or alkali causing pH variations. A source reported that copper and nickel may be also present. The organic coating used in the steel coating line may also have an influence on the components appearing in the waste waters.

14.3.3.3 Waste

[13, DFIU and IFARE, 2002], [76, TWG, 2004]

The cleaning agents containing solvents are used for the cleaning of the coating devices. They are normally collected and treated for re-use. The amount of used solvents in a plant is about 7000 kg/yr. Paint residues are generated in small amounts and are disposed of or re-used for coating the coil's reverse side.

The amount of crystalline iron sulphate from the galvanising process in a plant is about 4000 kg/yr and is externally re-used in smelting processes. The amount of zinc hydroxide is about 7000 kg/yr and this is also re-used in smelting processes.

General (non-hazardous waste) is normally collected in waste containers of varying sizes and design located throughout the plant, and, depending on the contents of the container, is taken to a variety of locations for disposal. General waste includes, for instance, waste packaging material and general rubbish.

Hazardous waste materials are usually tankered off site for disposal or recovery. These can include solvents, paints, contaminated wipes, oils and any other hazardous materials. A suitable recycle/disposal route is normally identified for the material and the necessary checks are made to ensure that the material is passed to a licensed facility. A registered waste carrier is used to transport the material. The necessary transfer note or special waste consignment note is completed and accompanies the waste.

Table 14.14 indicates some characteristics of the main wastes arising from a coil coating process and the recycling or disposal route.

Process plant source	Waste or by-product	Recycling or disposal route	Physical state
Scrap metal	Scrap metal	Recycled	Solid
Coating	Waste paint	Licensed removal	Liquid
	Used solvent	Licensed removal	Liquid
	Waste pretreatment	Treatment plant/licensed removal	Liquid
	Alkali cleaners, acid cleaners	Treatment plant/licensed removal	Liquid
	Rinse-waters	Treatment plant/licensed removal	Liquid
	Quench waters	Surface water/sewer	Liquid
General	Oil contaminated materials	Licensed removal	Solid
	General waste (including packaging)	General waste to landfill	Solid
	Waste paper (office)	Recycled by licensed contractor	Solid
	Waste engineering oil	Licensed removal	Liquid

Table 14.14: Typical wastes from a coil coating line process [58, ECCA, 2004]

Scrap metal

Generally process scrap metal can be recycled or re-used. The amount of scrap metal produced during the process will largely depend on the width and gauge of the substrate being used, and hence is not normally directly correlated to the paint system being manufactured. Aluminium is recovered by remelting in special ovens, where recovery is achieved using energy equivalent to just 5 % of the energy used in its original manufacture. Steel scrap is generally recovered by charging scrap metal, including painted products, into the basic oxygen steelmaking vessel as a raw material. Studies have shown that plastisol coated steel can also be recycled in this way, with no adverse effect on the emissions from the process. The coating generates energy in return when the steel/aluminium strip is remelted.

14.4 Techniques to consider in the determination of BAT for coil coating

In Chapter 20, techniques are discussed which might also be applicable to coil coating. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to coil coating. In Table 14.15, the general techniques relevant for coil coating that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

The EGTEI synopsis sheet for coil coating (see Annex 24.1.1) gives some data on the cost-benefit of some techniques to reduce VOC emissions at a European level. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 14.15: Reference to techniques generally applicable to the sector

14.4.1 Water management

14.4.1.1.1 Re-use of water within the plant

For a general description, see Section 20.4.1.2. This technique is widely used in the coil coating industry.

[58, ECCA, 2004]

14.4.1.1.2 Monitoring rinsing water before discharge by conductivity measurements

For a general description, see Section 20.4.1.4. This technique is widely used in the coil coating industry.

[58, ECCA, 2004]

14.4.1.2 Reverse cascade rinsing

For a general description, see Section 20.4.1.3. This technique is widely used in the coil coating industry.

[58, ECCA, 2004]

14.4.2 Conventional solvent-based coatings

Description: The majority of coil coating paints are solvent-based, with solvent contents from less than 10 % up to more than 70 % for some specific purposes. The emitted VOCs are captured and abated. For more details, see Section 20.7.2.1, Table 14.4 and Table 14.5.

Achieved environmental benefits: Reduced VOC emissions.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002], [76, TWG, 2004]

14.4.3 Replacement of solvent-based coatings (substitution)

14.4.3.1 High solid coatings

Description: See Section 20.7.2.2. High solid coating systems with a solid content of 70 – 95 % are applied in coil coating processes.

Achieved environmental benefits: Reductions in extracted VOCs place a lower demand on the abatement equipment. Reduced solvent loadings within the ovens may allow reductions in extracted airflows or increased line speeds for a certain concentration in the air. This reduces the use of gas in the oxidiser, reduces the use of solvents and lowers the volumes to transport.

Cross-media effects: The reduction of solvent vapours in the waste stream may increase the demand for gas/fossil fuel in the oxidiser, and/or reduce the energy recovered for preheating the oven air.

Operational data: PVC plastisol coatings generally contain less than 10 % solvent. These make up around 15 % coil coating topcoats, but they are applied at a much higher film thickness. There is a trend to reduce solvent contents in other coating chemistries consistent with the application properties and performance demands of the finished product.

Applicability: These are not suitable for all applications. High solids alternatives are not yet available to meet the performance specifications for many coil coating end uses. Utilisation of high solid technology is limited by its ability to meet the application properties and performance demands.

Economics: Higher solids content coatings require application at a reduced wet film thickness to achieve the same final dry coating thickness – this places greater stresses on the application rolls and may incur higher maintenance costs and increased electrical energy to drive the coater.

Driving forces for implementation: Reduced solvent loads within the ovens may allow higher line speeds – increased efficiency, reduced energy demand. SED.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002], [58, ECCA, 2004]

14.4.3.2 Water-based coatings

Description: See Section 20.7.2.3. Water-based paints contain water dilutable or water-dispersible resins usually based on polyester, acrylic, melamine and epoxy resins. Most water dilutable paints currently available also contain up to 20 % of organic solvents as coalescents.

Achieved environmental benefits: Elimination or important reduction in solvent emissions from coating systems. The application of water-based coating systems represents a possibility for abatement of VOC emissions on principle.

Cross-media effects: Due to the solvent content, around 20 %, and the high yearly load, a waste gas treatment is needed with the related high energy consumption.

Water has a higher energy of vaporisation than organic solvents, so water-based coatings may require greater energy inputs in the curing ovens, and, unless they are totally solvent-free, will still require exhaust abatement where again a high gas consumption could result. Water-based systems can present difficulties in cleaning operations on the coater equipment, demanding more powerful cleaning agents than solvent-based coatings.

Operational data: Water-based systems usually use amines for pH stabilisation. Experiments with these amines in a company have encountered major problems concerning employee protection.

Applicability: Water-based paint systems are not applicable for a wide range use. Currently, processed water-based paints do not exceed 0.2 % of the total paint consumption in coil coating processes in Western Europe. If water-based coatings are used, the application is mostly limited to primers and backing or ground coating. Water-based coating systems have been used on some coil coating lines for many years, but they are not applicable for a wide range of end use specifications. They may be used on lines dedicated to a limited product range where specific formulation development satisfies the performance demands.

Economics: Water-based coating systems do not cause major cost increases, but there may be problems with corrosion in storage, pumping and application equipment, and in the ovens and exhaust ducting. Replacement of equipment with stainless steel alternatives is typically more expensive.

Driving forces for implementation: No data submitted.

Example plants: A plant in Austria.

Reference literature: [13, DFIU and IFARE, 2002] [58, ECCA, 2004] [76, TWG, 2004]

14.4.3.3 Powder coatings

Description: See Section 20.7.2.6. These coating systems are finely divided powder coatings, generally based on polyester resins. The powder particles are normally applied by electrostatic charging in spray guns or a cloud chamber and are then attracted to the earthed metal strip as it passes. The chemical pretreatment of the surface is similar to the application of solvent-based products. Drying or curing is typically carried out by a combination of infrared and circulating hot air. Object temperatures of 180 - 250 °C are achieved. The curing process is typically completed within 1.5 – 2 minutes. Application is generally carried out at one side of the strip with one layer with a typical layer thickness of 50 to 60 µm.

Achieved environmental benefits: A complete elimination of solvent emissions from the coating system. There is a potential for reduced gas consumption, as exhaust incineration may no longer be needed.

Cross-media effects: Film thickness limitations will increase the quantities of coating materials used. The development in the curing oven of reaction products emitting odour, during the fusion and reaction of the powder could make the application of an abatement technique necessary anyway.

Operational data: No data submitted.

Applicability: There is a severe reduction in line speed for powder application, melting, fusion, flow and cure (limited to 15 m/min). There is also a very limited range of powder coating qualities that can be applied and cured in these short times. Current technology cannot yet achieve uniformity in powder coatings at less than 30 microns film thickness. Together, these limitations mean that a changeover to powder coatings is not feasible for conventional installations at present. This technique is especially used by the construction sector, e.g. for flat panels, window frames, sanitary cabins and by the sheet metal processing industry (computer enclosures and others). It is also used in small volume niche products. Two-sided powder coating on a coil coating line is still problematic.

Economics: Production costs are higher compared to liquid coating processes due to the severe speed restrictions and the difficulty in controlling the applied film thickness.

Driving forces for implementation: Elimination of solvents.

Example plants: There are a few full width powder coating installations in Europe for aluminium and steel coils.

Reference literature: [13, DFIU and IFARE, 2002] [58, ECCA, 2004] [128, TWG, 2005]

14.4.3.4 Laminate film coatings

Description: For some specific end uses, solvent-free and solid polymer films are applied to coil coating plants. These films may be based on a number of polymers including:

- PVC (polyvinyl chloride)
- PVF (polyvinyl fluoride)
- PET (polyethylene terephthalate)
- acrylics
- polypropylene.

In some cases, the films are coloured or opaque and may be decorated with printed patterns. In others, they are clear films offering specific properties of hardness, stain resistance, etc. In almost every case, the film is applied over a liquid paint base coat or adhesive layer.

Achieved environmental benefits: Elimination of solvent from one layer in the coating system preventing the emissions of solvent to the air.

Cross-media effects: The polymer films are produced off-site by an extrusion or calendering process.

Operational data: Films are applied by a pressure roll onto a preheated coating of appropriate base coat/adhesive usually immediately on exit from the curing oven.

Applicability: Generally used for very specific end use properties.

Economics: More expensive than conventional liquid coatings.

Driving forces for implementation: Product specifications and innovation.

Example plants: No data submitted.

Reference Literature: [58, ECCA, 2004]

14.4.4 Coating application techniques and equipment

14.4.4.1 Roller coating

Description: The roller coating process dominates the application of liquid coatings on modern coating lines.

A train of two or three rollers serves to 'pick up', 'meter' and 'apply' the coating at high speed onto the moving strip. Roller directions, rotation speeds, spacings and pressures are controlled to set the film thickness and to optimise the transfer properties and flow out of the wet coating.

Transfer efficiency is very high with the only loss being associated with material remaining in containers and pipework at the end of a product 'run'. This is normally drained back into the original container for use on later occasions. After draining, final traces of the coating are cleaned up from the rollers and the pick-up tray with appropriate solvent-impregnated wipes.

The coaters are normally housed in enclosures to minimise the release of organic solvent vapours to the factory area. The coating houses are vented to the outside of the building with flowrates designed to maintain satisfactory working conditions at all times for the operators within the coating house.

The application rollers generally have a thick elastomeric, polyurethane coating which may become damaged, requiring refacing on a lathe. Ultimately, the coating must be renewed by a specialist contractor. The pick up and metering rolls are normally steel and less prone to damage.

Achieved environmental benefits: Very high transfer efficiency, approaching 100 % thus achieving a minimal waste of materials.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Used in virtually all European coil coating lines.

Economics: High initial costs, but established as industry standard.

Driving forces for implementation: Very high transfer efficiency and, therefore, minimal waste of materials.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004]

14.4.4.2 Cleaning of application equipment

Description: In coil coating plants, there are two recognised methods for the cleaning of machine parts and equipment:

- all cleaning takes place in situ, i.e. within the coating house/room
- in situ cleaning for fixed equipment, with moveable items such as paint trays pumps and stirrers removed to an ancillary cleaning station as detailed above.

Wipes impregnated with solvents are used when manual cleaning of the plant and equipment takes place. Disposable dirty wipes are retained in sealed containers and disposed of usually by incineration. Re-usable dirty wipes are also retained in sealed containers and are usually laundered.

Achieved environmental benefits: Localised extraction to ovens/abatement reduces fugitive solvent emissions.

Cross-media effects: No data submitted.

Operational data: Some, but not all, coating houses are equipped with localised extraction, which is directed into the oven/waste gas treatment system, with the balance vented to the air. Where an ancillary cleaning unit is used, extraction is generally abated. In other instances, all coating room air is vented directly to the air, as it is widely considered that the installation of abatement equipment is not a practical option, as air volumes for occupational health reasons, are high with low emission concentrations. Compared with emissions from driers/ovens, emissions from coating houses are considered to be insignificant.

Applicability: The practicality of the retrofitting of localised extraction in coating rooms will be dependent upon the age, design and capacity of the combined curing (drying) and abatement equipment.

Economics: Costs will depend on the existing extraction system and on the capacity of the waste gas treatment technique. Retrofit might, therefore, be very expensive.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004]

14.4.5 Conversion coatings

Conversion coatings including hexavalent chromium conversion and substitution and control techniques are discussed in the STM BREF [59, EIPPCB, 2006].

14.4.5.1 Conversion coating containing chrome

See Section 20.7.1.2.3.

14.4.5.2 Chrome-free conversion coatings

See Section.20.7.1.2.4

14.4.6 Application of conversion coatings

Hexavalent chromium conversion coatings and associated techniques are also discussed in the STM BREF [59, EIPPCB, 2006].

14.4.6.1 'Spray, squeegee and rinse' application

Description: Conventional pretreatment refers to products that are applied by spray and dip processes for all substrates. Spray application is carried out in closed cabinets. In all cases, the use of a further water rinsing step is absolutely necessary.

Iron phosphating products for cold rolled steel strips are used together with a post rinse containing chromate. The alkaline conversion coatings (cobalt-based), in combination with post rinses containing chromate, provide excellent paint adhesion and corrosion protection on zinc or zinc-alloy coated substrates. Both technologies have been used for many years in coil coating lines all over the world.

Moreover, chromating of zinc coated and aluminium strips is a common process for conventional surface treatment.

Achieved environmental benefits: High durability is achieved.

Cross-media effects: This technique causes a high consumption of surface treatment chemicals. There is a high drag-out causing polluted rinsing water for subsequent waste water treatment and additional waste.

Operational data: The process temperature is between room temperature and about 70 °C. The spray pressure applied is between 0.5 and 2 bar.

Applicability: This is a well known and common application technology, however it requires a high demand for chemical process control.

Economics: No data submitted.

Driving forces for implementation: It is a well known and safe technology.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004]

14.4.6.2 'No rinse' or 'dry in place' application

Description: The 'no rinse' or 'dry in place' technology for applying conversion coatings does not require a further water rinsing. It applies the pretreatment products by rollcoater or squeegee rollers to the strip surface. Because it avoids aerosol formation, no chromate can be measured in the air. Without any rinsing, the wet film is dried in place, using IR radiation or convection heat and painted directly afterwards. This kind of process does not limit the line speed in the pretreatment section (no reaction time), needs no rinse stages after the pretreatment section, and generates extremely little waste water. Another advantage compared to the conventional rinse process products, is their suitability for multi-metal pretreatment.

Achieved environmental benefits: This technique generally produces waste in very small volumes, whereas the technique above (see Section 14.4.6.1) produces larger volumes of waste. Also, the chemical consumption is much lower in comparison to the technique because application efficiency and material usage approaches 100 %. This makes overflow to waste water superfluous as also any waste gas abatement technique.

Cross-media effects: No data submitted.

Operational data: Generally, the conversion coating contains chrome from which the treatment involves reducing the oxidation state of the chromium from (VI) to (III), thus making it less hazardous prior to disposal.

Water quality in the last rinse prior to the no-rinse conversion coating application must be strongly monitored by conductivity measurements.

Applicability: Widely used in some parts of Europe. This application technology is currently well known and approved.

Economics: There are investment costs involved for the application unit. Savings are made because of the low consumption of surface treatment chemicals and much less waste water has to be treated.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004]

14.4.7 Drying

14.4.7.1 Convection drying or curing

For a general description see Section 20.8.1.1. Gas fired forced air recirculation ovens are commonly applied at temperatures of around 350 °C; the waste gas is extracted and routed to the abatement plant. Use of heat exchangers allows preheating of the air for the oven input to a maximum temperature of about 400 °C.

[58, ECCA, 2004] [76, TWG, 2004]

14.4.7.2 Radiation curing processes

For a general description, see Section 20.8.2. No commercial application is known for coil coating applications, but see Emerging techniques, Section 22.14.2.

[58, ECCA, 2004]

14.4.8 Waste gas treatment

14.4.8.1 Air extraction from conversion coatings station

When conversion coatings containing chromium are applied (see Sections 14.4.5.1 and 14.4.6), the mist arising from the spray application and drying of the conversion coating are extracted and routed to a waste gas treatment system, such as a wet scrubber (see Section 20.11.3.8). See the STM BREF for details of the techniques and BAT.

[128, TWG, 2005]

14.4.8.2 Air seals on the entrance and the exit of the ovens/driers

For a general description, see Section 20.11.2.2. This technique is commonly applied in the coil coating industry.

[58, ECCA, 2004], [76, TWG, 2004]

14.4.8.3 Negative pressure in drying

For a general description, see Section 20.11.2.3. This technique is commonly applied in the coil coating industry.

[13, DFIU and IFARE, 2002] [58, ECCA, 2004], [76, TWG, 2004]

14.4.8.4 Air extraction from coating preparation

For a general description, see Section 20.11.2.4.

Description: Coatings are prepared by stirring to ensure that any settled pigments are thoroughly mixed and that the coating is at the correct viscosity for application. Solvent-based raw materials are mixed, e.g. for achieving a certain viscosity or colour. In coil coating plants, the mixing and stirring of paint takes place either in the coating house/room or in a separate room often referred to as a paint kitchen. Commonly, coating houses are equipped with localised extraction. The extracted air is directed into the oven/waste gas treatment system, with the balance vented to the air.

Achieved environmental benefits: Reduction of VOC emissions from the coating house/paint kitchen.

Cross-media effects: To achieve safe working conditions and a low VOC content of the airstream, large quantities of energy (e.g. gas) are needed for treatment.

Operational data: As for occupational health reasons, air volumes are high with low emission concentrations, in some installations all the coating room air is vented directly to the air. It is widely considered that installing abatement equipment is not a practical option in these cases.

Compared with emissions from ovens/driers, emissions from coating houses are considered to be insignificant.

Applicability: The practicality of the retrofitting of localised extraction in coating rooms will be dependent on the age, design and capacity of the combined curing (drying) and abatement equipment.

Economics: On existing coil coating lines where additional abatement equipment capacity is required, cost may be high.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004], [76, TWG, 2004]

14.4.8.5 Air extraction from the paint application station

For a general description, see Section 20.11.2.4.

Description: The paint application station is enclosed (see Section 20.11.2.1), and part or all of the extracted air is drawn into the ovens, and hence to an exhaust abatement system.

Achieved environmental benefits: About 8 % of the processed solvents are released as VOC emissions in the paint application booths and, by applying this technique, are extracted and treated.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: This technique is commonly applied.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [58, ECCA, 2004]

14.4.8.6 Air extraction from the oven/drier

For a general description, see Section 20.11.2.5.

Description: Drying/curing of the coil coating is done in ovens/driers which are connected to abatement equipment, e.g. thermal oxidiser (see Section 20.11.4.2).

Achieved environmental benefits: Up to 2 % of the processed solvents are released as VOC emissions into the ovens/driers. These are collected and transferred to an abatement plant.

Cross-media effects: No data submitted.

Operational data: The VOC content in the ovens of an example plant is in the range of 8.75 - 9.3 g/m³, which is around 22 % of the LEL (40 g/m³).

The flow of fumes is continuously measured. The concentration of VOC in the oven/drier can be measured. The quality control of the product ensures that all solvents are released out of the paint.

Applicability: This is commonly applied.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [58, ECCA, 2004] [76, TWG, 2004]

14.4.8.7 Air extraction from the cooling zone

For a general description, see Section 20.11.2

Description: After curing, the strip is typically cooled by water sprays. The area where the strip is cooled is enclosed and fitted with a local exhaust ventilator. The waste gas containing solvent is subsequently routed to abatement equipment, e.g. thermal oxidiser. The water is cooled and recycled.

Achieved environmental benefits: Approximately 2 % or less of the processed solvents are released as VOC emissions in the cooling zone. Due to ovens operating under negative pressure solvent emissions are minimised.

Cross-media effects: The energy consumption to treat air containing low solvent concentrations will be significant.

Operational data: In some instances, the first step strip cooling is achieved using high volumes of blown air.

Applicability: Extraction of air containing solvent from this activity is commonly applied. However, it is usually not treated in an abatement system as it implies high gas consumption. This energy is required to treat large volumes of very low concentration and low temperature extracted air.

Water cooling is commonly applied in the coil coating industry. Air cooling is applied in some special cases depending on the market and the quality of the products (but commonly in the aluminium coil coating industry).

Economics: High costs are involved.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [58, ECCA, 2004], [76, TWG, 2004]

14.4.8.8 Recuperative thermal oxidation

For a general description, see Section 20.11.4.3. Recuperative thermal oxidation has been commonly applied in the coil coating industry in Europe since the 1970s. [58, ECCA, 2004]

14.4.8.9 Regenerative thermal oxidation – dual bed

For a general description, see Section 20.11.4.4. This technique has been commonly applied in the coil coating industry in Europe since the end of the 1990s. [58, ECCA, 2004]

14.4.9 Waste water treatment

14.4.9.1 Treatment of rinse-water before discharge

Description: Process waters are usually treated in a waste water treatment plant with a sequence of process steps. Dissolved metals in rinse-water are precipitated, e.g. by using lime or sodium hydroxide (see Section 14.4.9.3). The liquor is subsequently processed through a filter press to separate the solids from the liquids. Some chemicals are most effectively managed by treating them separately before mixing them with other effluents.

Achieved environmental benefits: For some substances, contaminant treatment and removal is only possible after separate treatment. Use of waste alkali solutions (such as degreasers) to neutralise waste acid solutions saving chemicals.

Cross-media effects: Will be case dependent.

Operational data: No data submitted.

Applicability: Consideration should be given at every process discharge point as to whether treatment is better carried out on the separated stream, before mixing flows for subsequent treatment.

When using waste alkali flows to neutralise waste acids, additional chemicals may be required to achieve a suitable pH for discharge through a flocculation system.

Economics: Capital and treatment costs may be significantly reduced by treating individual waste water streams separately.

Driving forces for implementation: The specific process chemistry will dictate which chemicals may require separation. Separate treatment streams may be more efficient and cost effective.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004] [59, EIPPCB, 2006]

14.4.9.2 Treatment of waste water containing chromate

Description: Hexavalent chromium compounds (chromates or dichromate) are difficult to precipitate and are normally reduced to trivalent chromium, which is subsequently precipitated as chromium (III) hydroxide on neutralisation. The reduction is made at pH values under 2.5. The most common reducing agent is sodium hydrogen sulphite (bisulphite).

Achieved environmental benefits: Reduction and removal of chromium (VI). Commonly, values of <0.1 mg Cr(VI)/litre are achieved.

Cross-media effects: Care should be taken with sodium hydrogen sulphite (bisulphite), as SO_x fumes are formed. Workspace ventilation may be required.

Operational data: If only a small amount of chromium (VI) is present at high pH values, the reaction can also be carried out in the alkaline area with sodium dithionite or iron (II) compounds, whereby the formation of salt by acidifying is not necessary if using iron (II) compounds.

Applicability: This technique is widely used. Flows containing chromate must be pretreated separately before being mixed together or mixed with other waste waters. The chromate reduction takes place at pH values <2.5. In order to limit the use of additional chemicals, acid waste water can be neutralised with alkaline waste water.

Economics: No data submitted.

Driving forces for implementation: Water pollution protection legislation.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004] [59, EIPPCB, 2006]

14.4.9.3 Hydroxide precipitation

Description: The removal of the transition metals is made via neutralisation then precipitation at pH values of 9 - 11. A water-solid mixture results from the precipitation. Lower emission values can be achieved if fine filtration is also used.

Achieved environmental benefits: Removal of transition metals from effluent.

Cross-media effects: No data submitted.

Operational data: Settlement tanks need space and may be costly to install. Caustic solution usually precipitates the heavy metals as hydroxides or phosphates. If several metals exist in the effluent at the same time, the precipitation of any metal that is more difficult to precipitate is facilitated.

The solubility of the metals increases with increased neutral salt concentrations. The metals partly precipitate in very fine particles, therefore the addition of flocculating agents (iron (III) chloride, lime) and/or flocculants (polyelectrolyte) are necessary for better separation and filtration.

Applicability: This technique is widely used.

Economics: Investment costs might be significant.

Driving forces for implementation: Water pollution protection legislation.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004] [59, EIPPCB, 2006]

15 COATING AND PRINTING OF METAL PACKAGING

[13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

15.1 General information

At a European level, the metal packaging sector comprises more than 260 sites employing more than 40000 people with annual sales of EUR 7000 million. The metal packaging industry converts raw materials into metal containers and components which are supplied to the packer/filler who in turn supplies the retailers.

Metal packaging is manufactured from steel and aluminium, and is commonly referred to as cans, pails and drums used for storage of products, protection and to facilitate transport. Metal packaging includes domestic containers of less than 25 litres capacity and industrial containers (drums) with more than 20 litres capacity. This packaging is used for a wide range of different products, for example:

- food, e.g. preserves, soups and drinks
- paint
- cosmetics
- pharmaceuticals
- chemicals
- oils
- tobacco
- lids for jars and bottles
- aerosols.

There are four key manufacturing processes that are carried out within this sector and one or more of these, together with associated sub processes, may be carried out within a specific installation. These are reflected in Table 15.1.

Metal packaging manufacturing processes	Information
Two piece canmaking	<ul style="list-style-type: none"> • draw and wall iron (DWI) can manufacture. Coating and printing is mainly carried out by the dry offset process • easy open end manufacturing. Spray coating is applied to steel ends
Metal packaging manufactured from flat sheet	<ul style="list-style-type: none"> • flat sheet coating and printing. Primarily roller coating and lithographic printing (wet offset) • three piece can manufacture. Protective coating applied to the side seam • end manufacture (non easy open ends and easy open ends). Sealant is applied to the curl of the end in preparation for assembly to the can
Impact extruded aluminium tube manufacture	<ul style="list-style-type: none"> • monobloc aerosols and collapsibles
Drums	<ul style="list-style-type: none"> • drum manufacture • external and internal protective coating applied mainly by spraying but also roller coating and lithographic printing (wet offset)

Table 15.1: Overview of the metal packaging manufacturing techniques
[76, TWG, 2004]

Table 15.2 gives an overview of the techniques used for coating and printing in the different sectors of the metal packaging industry.

Surface to be treated	DWI	Sheet for ends, cans, components	Three piece cans	Components			Extruded aluminium tubes	Drums
				NEOE	EOE	Caps/closures		
1) Coating (protection)								
Roller								
- All-over coating	X	X	X*				X	
- Spot coating		X						
Spray	X		X*		X			X
2) Printing (decoration)								
- Dry offset	X						X	
- Lithography (wet offset)		X						
3) Compound lining (Sealing)				X	X	X		X
Typical applications	Drinks, food, aerosol	Intermediate product for fabrication of ends, cans, caps and closures	General line food, drinks, aerosol	Three piece cans	Two and three piece cans	Drinks food in conjunction with jars and bottles	Aerosol collapsible tubes for pharmaceuticals and cosmetics	Products from industry
Notes: *side stripe NEOE: non easy open ends; EOE: easy open ends; DWI: 2 piece cans								

Table 15.2: Techniques used for coating and printing of metal packaging
[76, TWG, 2004] [128, TWG, 2005]

15.2 Applied processes and techniques in the coating and printing of metal packaging

15.2.1 Two piece can manufacture (DWI)

Figure 15.1 shows the schematic production process for beverage cans.

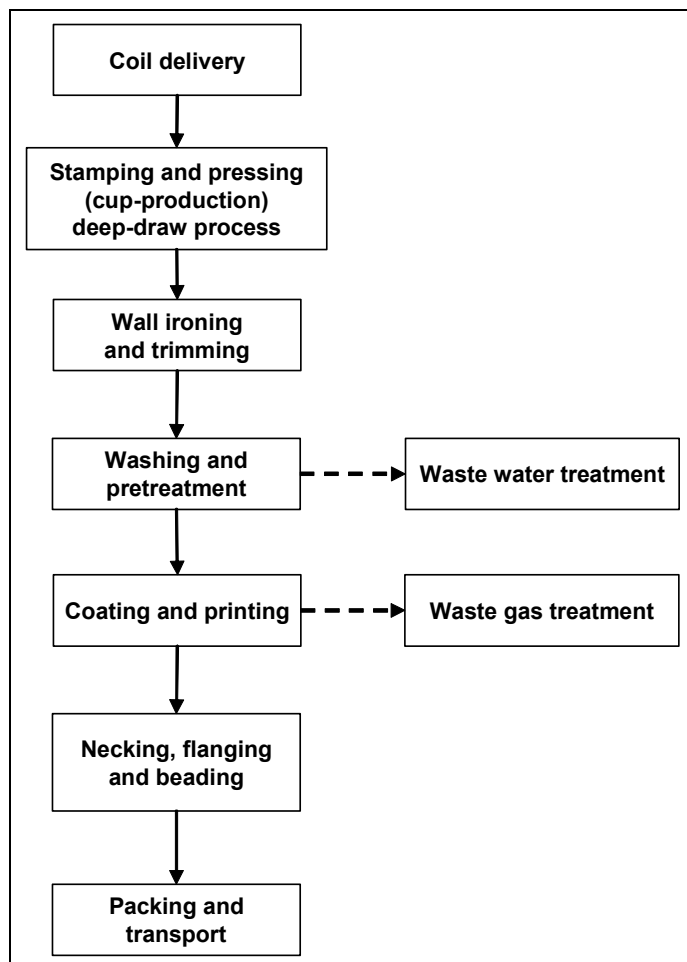


Figure 15.1: Production process for beverage cans
[13, DFIU and IFARE, 2002]

The following generic description covers the manufacture of beverage cans, which normally carry an external printed design, and food cans, which are normally finished with a colourless clear external coating and not printed. The entire process including conveying between the process stages is fully automated.

Aluminium or packaging steel is supplied in continuous coil strips and fed automatically through a cupper, a mechanical press where blanks are stamped and deep drawn into cups. The cups are conveyed to the body makers, long stroke presses where the cup walls are elongated by wall ironing and the bottom profile is formed. Immediately after wall ironing, the excess metal of the can brim is trimmed off.

The metal forming operations use a waterborne synthetic lubricant plus a small amount of biocide, both subsequently removed in the cleaner. There is also the possibility of tramp hydraulic oil from the presses mixing with the lubricant. Excess lubricant is treated and re-used in a closed loop system. Scrap arising from the blanking and trimming operation is recovered.

Cans exiting the trimmer, which are loaded with lubricant and debris, are then cleaned. This process is different for aluminium and steel substrates. Steel cans are cleaned with mains water by passing spray stations in reverse cascade arrangement, then rinsed with demineralised water and finally dried in a natural gas fired oven. Aluminium cans are cleaned in a similar way. Additionally, to provide an etched surface needed for inking operations, aluminium cans are then pretreated using acid or alkaline aqueous solutions before rinsing with demineralised water. A mobility enhancer may be applied before the aluminium cans are finally dried in the oven.

Waste gas from the can cleaning and drying is emitted directly to the air via an exhaust stack. Excess water from the cleaning process can be recycled to substitute town water. There is a natural carryout of water via the wet cans entering the oven. Waste water from the aluminium cleaner is treated before discharge

Where cans should not be decorated, which is the normal case for food cans, a clear external protective coat is applied to the upturned can via a curtain coater, between the can cleaner and drying oven. The coated cans then have a period of drainage, before entering the oven to dry them and cure the external coating. The external wash coat system is a recirculating system with the process designed to collect as much of the excess coating as possible. Waste water from the can cleaner, deioniser unit and the wash coat is treated prior to discharge.

After cleaning, the cans are passed automatically for external decoration. This consists of either base coat and ink on top or ink and over-varnish on top. In the base coater, the can walls are coated with either a coloured or clear layer. The lacquer is applied via a roller offset process onto the rotating can. The cans are then fed through a thermal convection oven.

After the curing of the base coat, the cans are transferred to the decorator (printing machine) where the decoration is applied by using printing inks (typically containing 25 - 40 % organic solvents) in a dry offset process. If an over-varnish (typically containing 15 - 50 % organic solvents) is required, it is applied as a wet-on-wet organic solvent, directly after printing on the same machine by a roller offset process. Aluminium cans are usually coated on the external bottom rim by application rollers. This operation is carried out before entering the decorator oven where the rim varnish is cured together with the inks and the optional over-varnish.

The cans are then conveyed to the necker, which finishes the necks of the cans to accept the ends. The neck forming operation is supported by compressed air and small amounts of synthetic lubricants are used.

For rust protection, steel cans are usually spray coated on the external bottom prior to the inside spray application. This bottom coat dries at room temperature. The inside of the can is then coated with an airless spray technique with materials containing 15 - 20 % organic solvents. A set of nozzles sprays the lacquer into the rotating can such that the desired film weight distribution is achieved (typically a thickness layer of 5 - 15 μm). The cans are then passed through a thermal oven where both the inside lacquer and the bottom spray receive the final cure.

After each lacquering operation, the cans immediately pass gas fired multiple zone ovens at typical drying temperatures of 180 - 200 °C. The emissions of the curing process are collected in a duct and exhausted by fans to the air or to abatement equipment. In general, the volatile gases created in the lacquer application machines are captured as well.

Finally, prior to palletising, all cans must pass through a light tester and camera for inspection. Any with potential damage are rejected.

Drying of the applied coating layers takes place in convectional driers at temperatures of 180 - 200 °C. The waste gases containing VOC from driers and also coating application units are generally treated via regenerative, thermal combustion. The process heat can be used via heat exchangers, e.g. for the cleaning process.

15.2.2 Flat sheet coating and priming

Flat sheet coating and printing operations follow four key processes:

- internal coating (exceptions are: aerosols, food containers for non-aggressive products, promotional packaging)
- external base coat or size, however, conventional print can be directly applied to tinplate
- printing
- varnish or top coating.

Curing of solvent-based coatings and inks takes place in thermal ovens at rates of up to 8000 sheets per hour at temperatures of between 150 and 220 °C. Speeds and temperatures are dependent on sheet sizes, thickness and the coating specification.

Flat sheet coating and printing is the first separate and distinct operation necessary for the subsequent operations for the manufacture of three piece and drawn cans, ends or caps and closures. Figure 15.2 shows the production process of flat metallic sheet.

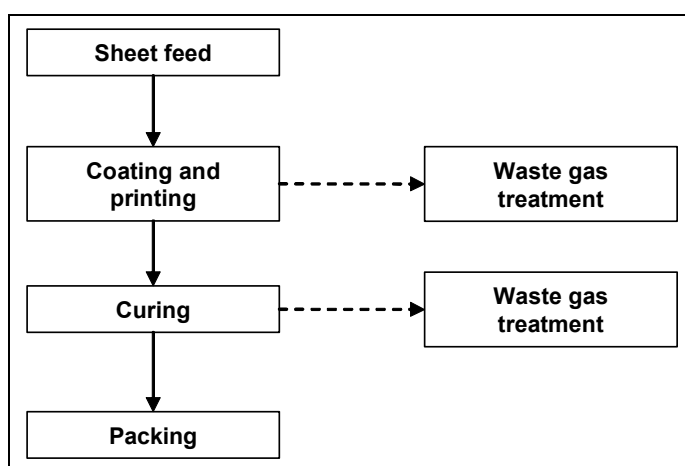


Figure 15.2: Production process for flat metallic sheet
[76, TWG, 2004]

The substrate materials used in the flat sheet printing and coating process are mainly tinplate, tin-free steel, blackplate or aluminium. The material is received either as stillages of pre-cut sheets or as coils which have to be processed on-site into the cut sheets.

Metal sheets may pass through the printing and coating lines several times as several coating and decorative applications and curing passes are sometimes required. Internal can coatings, as required by the product being packed, are generally applied first. This can be followed by application of an external base coat, a printed design and an external varnish in various combinations as required by the finished product.

On the coating lines, the material required for the design is pumped from a reservoir at the machine up to the application rollers. The subsequent excess material is collected and returned to the reservoir. The film weight is accurately set on the coating machine as required by quality standards and measurements.

On the printing lines, ink is spooned onto the application rollers by hand. Any subsequent excess material is collected and returned to the container on completion of the production run. The application of the ink to the sheet is measured to ensure the minimal required application rate is applied to achieve the desired depth of colour. The printing techniques commonly used are offset lithographic, dry offset and, in some cases, a waterless lithographic process may be employed.

Periodic cleaning of the coating and print rollers is required to remove the build up of coating and ink constituents. Excess coating is removed from the bottom roller whilst the machine is running by a scraper, to prevent contamination of the underside of the sheet.

At changeovers, more thorough cleaning of the coating and printing machines is carried out using various organic solvents, including reclaimed solvents, either manually or automatically. The waste organic solvent is often distilled and rebled either on-site or off-site.

The coated or printed sheet is then transferred to the thermal curing oven where it is heated to the required curing temperature. VOCs from the organic solvent used in the materials applied are collected from the oven exhaust and machine hoods with ducts and exhausted by fans to the air or sent to abatement equipment.

Following this, the cured sheet is cooled by drawing outside ambient air through fans and ducts and blowing it over the sheets. This reduces the materials sticking together and the stack of sheets is rebuilt on stillages for subsequent transfer to the next stage of the process.

Where UV curing inks and coatings are used, UV lamps are used. This does not release VOCs but creates a low level of ozone which is exhausted to the air.

15.2.3 Three piece can manufacture

The production process for three piece cans is shown in Figure 15.3.

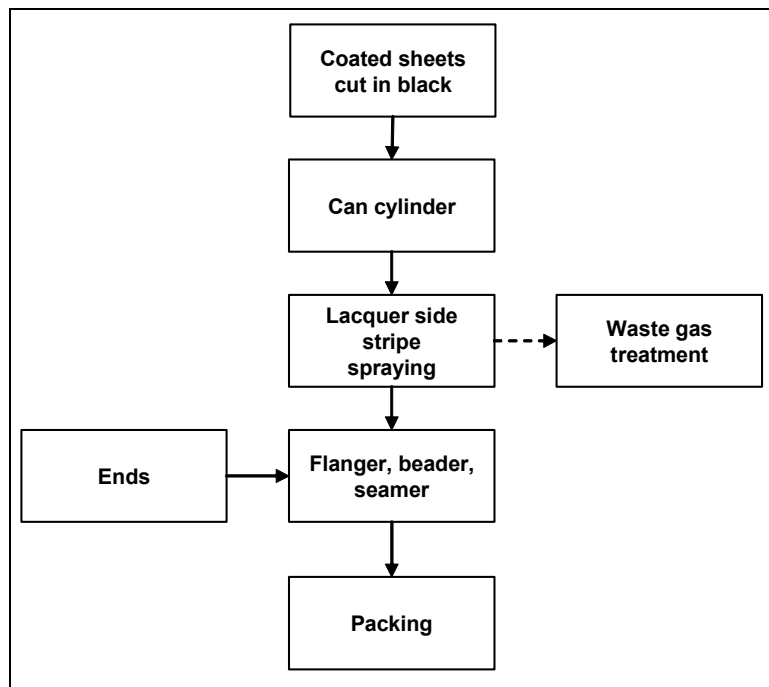


Figure 15.3: Production process for three piece cans [76, TWG, 2004]

Three piece can manufacture covers diverse products such as food cans, paint cans, oblongs, and aerosols. Tinplate sheets coated and/or decorated, as described earlier in Section 15.2.2 under flat sheet coating and priming, are slit into individual body blanks. These body blanks are automatically fed into a welding machine that rolls the body blank into a tube and then welds it along its length to produce a straight-sided welded cylinder. During slitting, the excess tinplate is trimmed off and subsequently recycled. The welding rolls and welding head are water-cooled using chilled recirculating water. To ensure a quality weld, copper wire is fed over the internal and external weld rolls such that the entire length of each weld is produced using fresh copper wire as the electrodes. The used copper wire is chopped-up, collected and returned to the manufacturers for recasting. An alternative means of joining the side seam is by mechanical clinching. In some cases, the circular cylinders can be reformed into other shapes, e.g. rectangular.

Immediately after welding, and while still on the welding machine, the internal surface and external surface of the weld may have a protective coating applied depending on the specification of the three piece can being manufactured. This protective coating is called a side stripe and may either be an organic solvent-based, a water-based or a powder coating, depending on the intended end use of the container. In the case of side stripe lacquers, these are applied using rollers or airless spray guns and any overspray is collected and ducted to the air. In the case of powder coatings, these are applied electrostatically and any overspray is collected and recycled.

Following welding/side stripe application, the cylinders pass through an oven to cure the applied side stripe. These ovens are generally either hot air or induction and apply a localised heat to the weld area of the cylinder. Emissions from the side striping oven are emitted directly to the air via exhaust stacks.

Following side stripe curing, some specifications of three piece cans (typically food cans) are then automatically fed into a beading machine so that strengthening beads can be fabricated into the body wall of the cylinder. This process is purely mechanical and requires no additional process materials. After beading or side stripe curing, depending on the can specification, the welded cylinders are automatically fed into either necking and flanging machines or just flanging machines so that both ends of the cylinder can be profiled ready to accept an end component. Again, necking and flanging are purely mechanical processes requiring no additional process materials.

The fabricated body is then automatically passed to an end seamer where an end component, previously manufactured, is fed and seamed onto one end of the fabricated cylinder. The seaming operation is also purely mechanical and does not require any additional process materials.

For some specifications, such as food cans, the three piece can is supplied to the user with only one end seamed and in this case, the end seaming is followed by palletisation. However, other three piece cans such as paint cans, oblong cans and aerosols pass through a second seaming machine and a second end component is seamed prior to palletisation.

15.2.4 End, cap and closure manufacture

The production process for ends, caps and closures is shown in Figure 15.4.

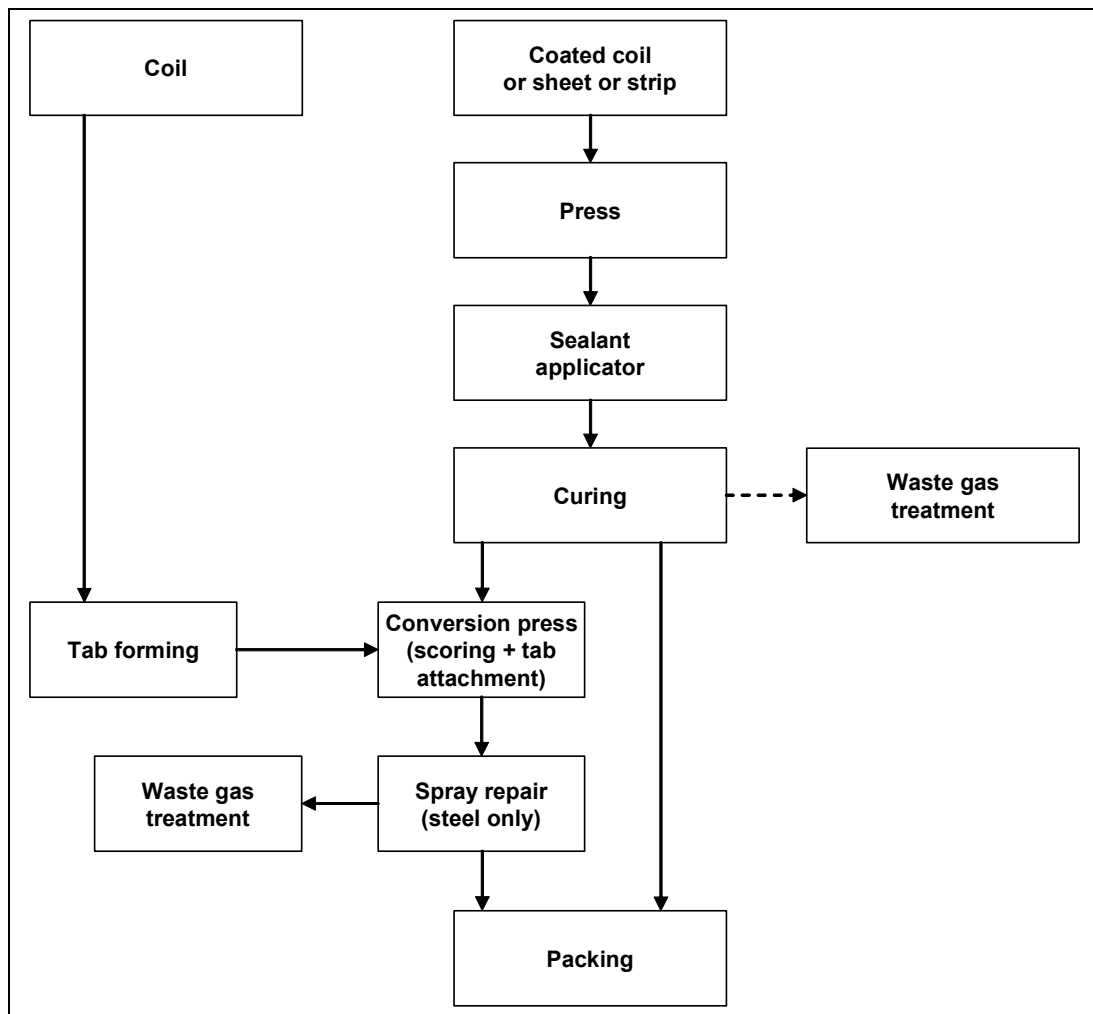


Figure 15.4: Production process for ends, caps and closures
[76, TWG, 2004]

The manufacture is either from a plain or pre-coated/decorated sheet or coil in aluminium or packaging steel. The metal may be pre-lubricated prior to fabrication. The metal is fed to a stamping press where the initial forming is carried out. Additional forming operations are carried out to complete the profile. The completed shell then proceeds to a lining machine where a sealant (sometimes referred to as lining compound) or gasket (sometimes referred to as compound) is applied. Organic solvents may be contained in the sealant.

Additionally, for easy opening ends, once the shell has had the compound applied, it proceeds on to a conversion press where the tab is fabricated and fitted and a final pressing is carried out to complete the end. For easy open ends made from tinplate, the end score will be repaired with a spray lacquer. Some sealants and gaskets require passage through an oven for forced drying or curing. Once completed, the ends, caps or closures are packed and palletised for despatch to customers.

15.2.5 Extruded aluminium tubes manufacture

The production process of extruded aluminium tubes is shown in Figure 15.5.

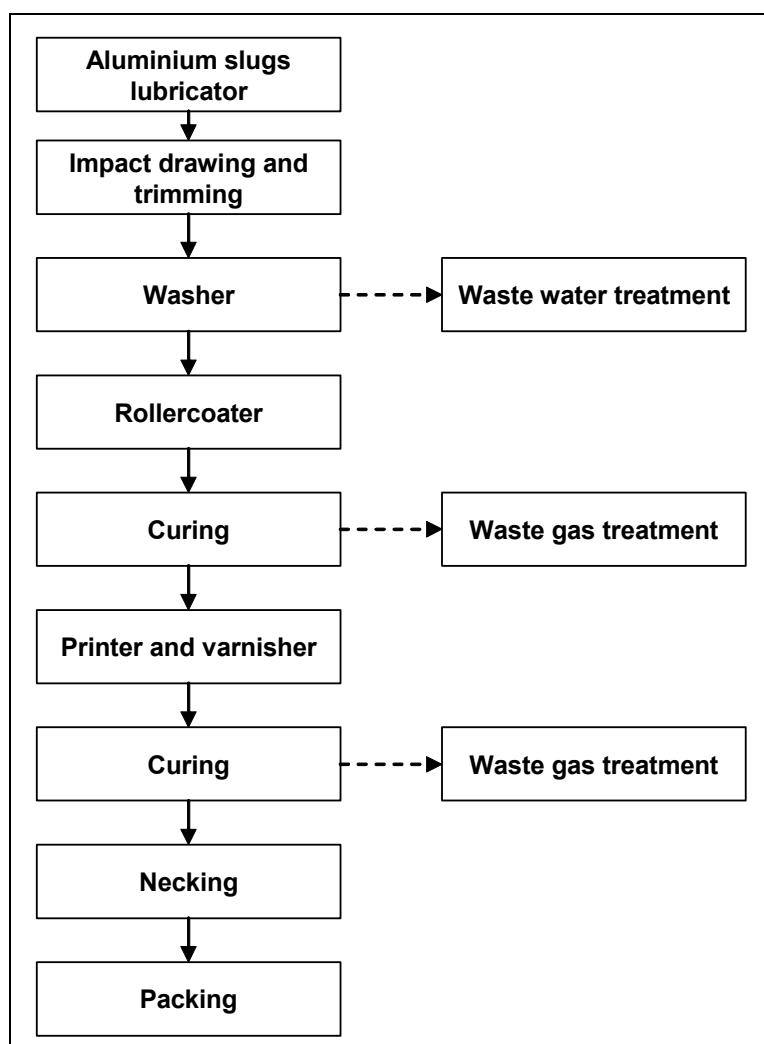


Figure 15.5: Production process of extruded aluminium tubes
[76, TWG, 2004]

Aluminium slug, which is 99.5 % pure aluminium, is lubricated and then converted in a series of high impact drawing operations into a tube with a single open end. The open end is trimmed to produce an even cylinder and the trim collected for recycling. Further separate metal from forming operations may inwardly dome the closed end for pressure resistance (aerosol), perforate it for later addition of a plastic screw thread and cap or further form it into a screw thread (the latter two for collapsible tubes).

The formed article is then cleaned in a continuous cleaner to remove residual lubricant and to prepare the surface for application of organic coatings. The chemicals used in the cleaning and etch process comprise caustic-based anionic detergents. The contaminated waste water may be discharged partly or totally to a sewer with local consent and/or re-used to feed the caustic scrubber system described below as a means of fume abatement.

The cleaned cylinders are then transferred to a base coater whereby a metered coating of clear or pigmented base coat is applied by a roller with the cylinder rotating. The coating material is contained in a reservoir in which the pick-up roller runs and excess material removed by the metering system is fed back into the reservoir. Typical base coats are organic solvent-based but waterborne coatings may also be used. The coating station is extracted by fan and generally ducted to the air via high stacks. From the base coater, the coated cans pass automatically into a drying/curing oven, the extract from which is collected and sent directly to the air via high stacks or to abatement equipment.

The cured base coat provides the key for the subsequent printed design, which is applied via a multicolour decorator using the dry offset process. Inks are hand-spooned to the reservoir rolls and a precision system of rolls accurately meters each colour separately onto the applicator roll, which picks up the colours in register and transfers the complete image to the workpiece. A protective over-varnish is applied as the final operation before the cylinder passes automatically into an oven for drying and curing. There is fume extraction at the decorator, which is ducted to the air having passed through a caustic scrubber and separate ducting of the oven exhaust to the air or abatement equipment.

For aerosol cans, the cylinder undergoes further reforming, with controlled application of a mineral lubricant, to ‘neck-in’ and curl the open end to accept the valve assembly which will be fitted subsequently to filling.

15.2.6 Drum manufacture

Steel drums are manufactured primarily for industrial use. The principle of manufacturing drums is similar to the three piece can manufacturing process. This is shown in Figure 15.6.

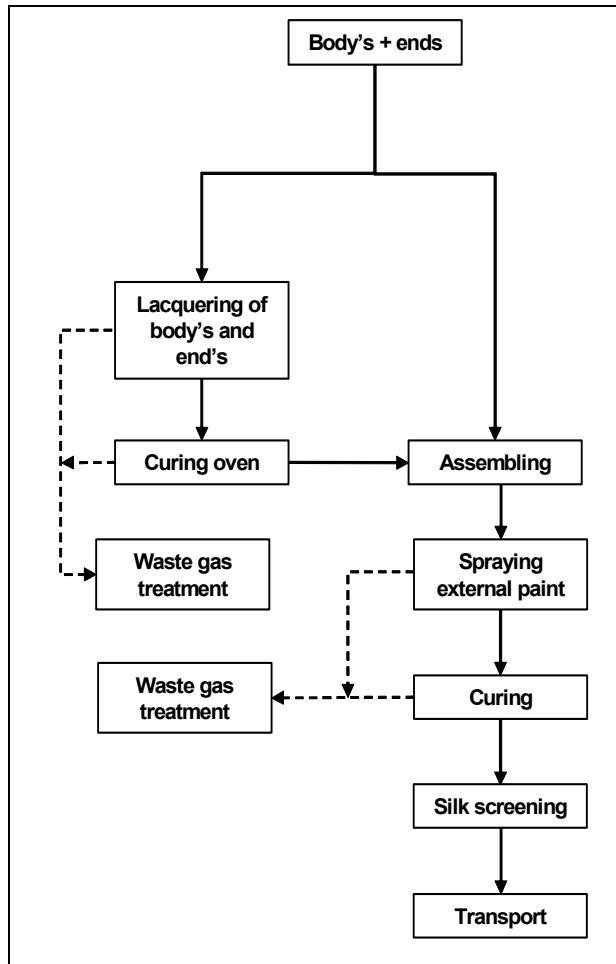


Figure 15.6: Production process of drums [76, TWG, 2004]

Generally the body, top and bottom are produced separately on cutting and forming lines, using plain steel. If required, the formed drum bodies and ends are separately coated with internal lacquer and cured. On the seaming machine, just before assembling of these components, the seaming compound is applied. As a last step, the drum is coated on the outside with external drum paint and the coating cured and dried simultaneously. Internal drum coatings are generally applied via rotation discs (for the body) or by hot airless spraying. The majority of internal coatings are solvent-based because of the required chemical resistance against the filling goods and subsequently contain 45 to 65 % organic solvents. External drum paints are generally applied by hot airless spraying. External drum paints are mainly solvent-based and contain around 50 - 55 % organic solvents. In specific cases, water-based external drum paints are used, containing less than 10 % organic solvents. VOC process emissions are directed to the air via exhaust stacks or treated by abatement techniques first.

15.3 Current consumption and emission levels in the coating and printing of metal packaging

15.3.1 Mass balances

No mass balances were submitted, but see data below.

15.3.2 Consumption and emissions data

[13, DFIU and IFARE, 2002], [76, TWG, 2004]

Consumptions and emissions data for the various products and pre-products are given in the tables below:

Plant reference	Plant A ¹	Plant B	Plant C
Substrate	Tinplate	Tinplate	Aluminium
Size and geometry of workpieces	33/50 cl	33/50 cl	15, 20, 25, 29.6, 33 and 35 cl
Frequency of colour changes	Approx. 500 decoration changes per year for the production of 33 cl cans and 1100 for 50 cl cans	Approx. 400 decoration changes per year per production line	2200 decoration changes in 1999
Annual capacity million of m ² (base year 2000)	~ 120 tinplate	~ 100 tinplate	72.09 ² aluminium
Solvent consumption (g of solvents/m ²) yearly amount (tonnes)	maximum 7.2 maximum 864	maximum 6.7 maximum 670	3.2 ² about 250 – 300
Annual operation time (h)	6500 – 8400	6500 – 8400	8300
Year of commissioning	1978	1984	1968
Notes:			
Food law requirements are applied to all three plants.			
¹ Plant A is a plant with a coating store house, applying dust filters, an adsorption installation and a regenerative thermal combustion unit for the treatment of waste gases.			
² Data from year 1999.			

Table 15.3: Data for the coating and printing of beverage cans
[13, DFIU and IFARE, 2002]

Activities performed	Sheet coating and printing	Sheet coating and printing and three piece can
Production of lacquered sheets (million)	22	10
Production of printed sheets (million)	68	21
Tonnage of sheets used (tonnes)	23000	7410
Energy (electricity) used (MWh)	3600	2000
Energy (gas) used (MWh)	6600	1600
Solvent consumption (tonnes)	210	105
Solvent emission (tonnes)	44	100
Water usage (tonnes)	2030	2610

Table 15.4: Data for the coating and printing of flat sheet
[76, TWG, 2004]

Activities performed	Three piece cans
Production of cans (million)	434
Tonnage of tinplate used (tonnes)	25300
Energy (electricity) used (MWh)	2300
Energy (gas) used (MWh)	3260
Solvent consumption (tonnes)	33
Solvent emission (tonnes)	30
Water usage (tonnes)	2898

Table 15.5: Data for three piece can coating and printing
[76, TWG, 2004]

Activities performed	Caps
Sheets lacquered (million)	36
Sheets printed (million)	12
Production of caps (million)	920
Tonnage of tinplate used (tonnes)	9126
Energy (electricity) used (MWh)	3840
Energy (gas) used (MWh)	1890
Solvent Consumption (tonnes)	300
Solvent emission (tonnes)	45
Water usage (tonnes)	1053

Table 15.6: Data for cap coating and printing
[76, TWG, 2004]

Activities performed	Metal drums
External paint/drum	250 grams
Tonnage external paint/year	250 tonnes
Lacquer (internal coating)/drum	300 grams
Calculation internal lacquer based on	50 % of all drums
VOC % in internal drum lacquer	65 %
% made with solvent-based (external paint)	90 %
% made with water-based (external paint)	10 %
VOC % in solvent-based	55 %
VOC % in water-based	10 %
Solvent consumption/year (external coating)	126 tonnes
Solvent consumption/year (internal coating)	98 tonnes
Total solvent consumption/year	224 tonnes
Note: Values refer to estimated mass balance per one million large drums	

Table 15.7: Mass balances for drum coating and printing
[76, TWG, 2004]

15.3.3 Consumptions

[13, DFIU and IFARE, 2002], [76, TWG, 2004]

15.3.3.1 Materials

Consumption of raw materials in the coating and printing of two piece cans

The solvent consumption of two installations (plant A and B) depends on the design and the filling (beverage) and is about 7.2 g per coated m² of tinplate. The capacities of these two plants were about 100 – 120 million m², in the year 2000. 670 and 864 tonnes respectively of organic solvents from coatings and printing inks were processed.

The coating materials applied in the plants mentioned above are water-based. However, for an improved workability they contain 15 - 45 % organic solvents. Typically 10 – 12 g coating per m² tinplate is consumed. The varnish applied for coating the interior of the can normally contains 10 - 15 % organic solvents, and typically 19 – 22 g/m² varnish is consumed.

The can may be coated with a base coat to serve as a support for the ink layer. The base coat contains approximately 20 to 50 % organic solvents. The can is then printed. In other cases, this base is not used because the can is printed directly. The printing ink may contain between 18 to 38 % of organic solvents and typically 0.5 to 0.7 g ink per m² tinplate is consumed. The can may optionally then be coated with a thin layer of overvarnish for the protection of the print. The overvarnish contains approximately 25 to 35 % organic solvents.

The consumption data for the processing of aluminium in one plant are shown in Table 15.8.

Process step	Material	Consumption (t/yr)	Comments
Base coating	Lacquer	127	12.5 wt-% solvents
Printing	Printing inks	58	15 wt-% solvents
Overvarnish	Overvarnish	257	16 wt-% solvents
Bottom varnish (roller application)	Bottom rimcoat	19	33.5 wt-% solvents
Inside coating	Lacquer	1050	15 wt-% solvents
Complete painting process	Cleaning agents, solvents	26	
Total process	Water	135000	
Cleaning process		172	Sulphuric acid, tensides
Cleaning process		55.4	Nitric acid, phosphoric acid, hydrofluoric acid
Surface pretreatment		53	Hydrofluoric acid
Surface pretreatment		24	Improvement of mobility
Adsorption wheel	Activated charcoal	2	
Waste water treatment	Lime	82.3	
	Anti-foaming agent	2.1	
	Flocculant	2.54	
	Breakdown agent	12.1	Ferroline
	Breakdown agent	14.4	
	Caustic soda	35.1	
	Hydrochloric acid	34.5	
	Sulphuric acid	5.78	

Table 15.8: Consumption of materials in one plant
[13, DFIU and IFARE, 2002], [76, TWG, 2004]

Consumption of raw materials in the coating of drums

On average for 217 litres drums, one drum line produces around 400 drums per hour (the maximum output is 600 drums per hour). All drums are externally painted. The amount of external paint used is around 250 grams per drum and the solvent consumption will be around 50 - 55 kg/hr if solvent-based coatings are used. Some installations have several drum lines. The internal coating (50 % of the drums) could be done simultaneously on a separate coating line (spray booth + oven) dedicated either for bodies or for ends and the additional consumption of solvent is 80 kg/h. For reasons of chemical durability, phenolic coatings might be used, which have some phenol content.

[128, TWG, 2005]

Consumption of raw materials in the coating and printing of flat sheet

For the coating operation, the solvent consumption varies to a large extent depending on the end use of the can and the substrate metal used. The applied solids may range from 4 to 6 g/m² exterior gold coating for a standard can, and up to 25 g/m² for the interior gold coating for a can designed for aggressive products. The typical range of solvent content in the coatings used ranges from 45 to 70 %. For certain specific applications, water-based coatings are being used which range from 10 to 25 % solvent content. The printing usage of solvents is about 10 % of the solvent consumption for the coating operation. Table 15.9 shows data on consumption of raw materials in the coating and printing of flat sheet.

Application		Typical film weight (g/m ²)	Typical solids content (%)
Three piece bodies	Interior	5 – 40	30 – 35
	Exterior gold	4 – 6	30 – 40
	Exterior size	2 – 3	25 – 35
	Exterior white	12 – 16	50 – 60
	Exterior varnish	5 – 7	35 – 45
	Exterior varnish (UV)	5 – 7	100
End components	Interior	4 – 14	30 – 55
	Exterior gold	4 – 7	30 – 40
	Exterior size	2 – 3	25 – 35
	Exterior white	12 – 16	50 – 60
	Exterior varnish	5 – 7	35 – 45
	Exterior varnish (UV)	5 – 7	100
Caps and closure	Interior system	10 – 20	40 – 50
	Exterior size	2 – 3	30 – 40
	Exterior white	10 – 15	50 – 60
	Exterior varnish	2 – 4	35 – 45

Table 15.9: Consumption of raw materials in the coating and printing of flat sheet
[76, TWG, 2004]

Consumption of raw materials in the coating and printing of three piece cans

The can's protective side stripe coating can be either a water-based material, solvent-based or powder. The selection of the side stripe coating is dependent upon the type of can, its end use and the film weight necessary for product resistance. A critical feature of the cured side stripe coating is the ability to withstand metal deformation at the beading and flanging stages.

The range of the film weight is 5 to 25 g/m² for liquid side stripes. This equates to potential VOC levels of between 5 and 100 g/m² of side stripe (that is 8 – 160 mg VOC per typical 0.5 kg can).

For powder side stripes, the range of the film weight is 70 to 140 g/m². There are no VOC emissions associated with powder side stripe application.

Currently there is no one side stripe standard technology or material capable of meeting all canmaking specifications. Table 15.10 shows data on consumption of raw materials in the coating and printing of three piece cans.

Application		Typical film weight (g/m ²)	Typical solids content (%)
Side stripe	Liquid	5 – 20	15 – 25
	Powder	70 – 140	100

Table 15.10: Consumption of raw materials in the coating and printing of three piece cans [76, TWG, 2004]

Consumption of raw materials in the coating and printing of ends, caps and closures

In addition to preventing leakages, sealants and gaskets must also provide essential biological safety, especially in the case of food and beverage cans, ends and closures.

Sealant and gasket compound consumption is measured in volume as opposed to weight per area unit. When a repair spray is required, a typical number would be 95 g per 1000 ends (EOE) for a diameter of 73 mm. All repair sprays are solvent-based only. Typical sealant volumes are shown in Table 15.11 below.

Diameter (mm)	Food can ends	Drink can ends	General line can ends	Aerosol can tops	Aerosol can bases
48				35 – 55	
50		22 – 33			28 – 48
52	30 – 45	25 – 35		40 – 60	
54					30 – 50
57		30 – 40			
60				40 – 70	
63					35 – 60
65				45 – 75	35 – 60
70			40 – 65		
73	30 – 50				
83	40 – 60				
99			70 – 100		
153	80 – 110		150 – 225		
165			165 – 245		

Compound volume (mm³) for different can/end diameters and applications

Table 15.11: Consumption of raw materials in the coating and printing of ends, caps and closures [76, TWG, 2004]

15.3.3.2 Water

No data submitted.

15.3.3.3 Energy

Consumption of energy in the coating and printing of two piece cans

The energy consumption of example plants A and B in the year 1999 – 2000 is shown in Table 15.12.

	Plant A (MWh)	Plant B (MWh)
Natural gas	67000	60000
Electricity	43000	55000
Regenerated energy	4000	
Note: Plant A and B are described in Section 15.3.3.1		

Table 15.12: Energy use and recovery in two installations
[13, DFIU and IFARE, 2002], [76, TWG, 2004]

15.3.4 Emissions

15.3.4.1 Emissions to air

[13, DFIU and IFARE, 2002], [76, TWG, 2004]

Table 15.13 shows a summary of the VOC emissions reported.

	¹ Emission level at application (g/m ²)	
	Solvent -based	Water-based
Food contact		
• DWI drinks	6.7 – 10.5	3.2 – 4.5
• sheet for ends, cans and components	4 – 93	1 – 30
• drums	90 – 100	
Non-food contact		
• sheet for ends, cans and components	4 – 93	1 – 30
• drums	60 – 70	11 – 20
Print varnish		
• sheet for ends, cans and components ²	2.5 – 13	1 – 6
Notes:		
¹ Values also include fugitive emissions		
² UV ink and varnish applications are limited to non-food and special applications and can achieve lower levels than 1		
No data have been reported for aluminium tubes		

Table 15.13: VOC emissions levels reported in different coating and printing of metal packaging
[76, TWG, 2004] [124, SEFEL, 2005]

Emissions to air from the coating and printing of two piece cans

Due to extraction and treatment via regenerative, thermal combustion of waste gases from printing machines, coating applications and drier units, the amount of VOC emissions is relatively low. The efficiency of the waste gas treatment is more than 99 %; however this depends on inlet concentration. The mass flow of total C in the clean gas after the regenerative incineration process is in the range of 0.6 – 1.2 kg/h. Clean gas concentrations of <20 mg C_{total}/Nm³ are achieved.

Table 15.14 shows emission data from plant A applying a regenerative incinerator with a capacity of treating a gas volume flow of 76000 Nm³/h for two production lines, and applying an adsorption wheel treating a gas volume flow of 90000 Nm³/h also for two production lines:

Parameter	Mass flow (kg/h)	Mass flow (kg/yr)	Comments
VOC	No data	No data	
Total C	0.61	5075	After incineration
	1.2	10080	After adsorption wheel
Dust	0.00015	1.27	After incineration
CO	1.37	11400	After incineration
NO _x	1.52	12600	After incineration

Table 15.14: Emission values of clean gas after waste gas treatment from plant A [13, DFIU and IFARE, 2002]

Table 15.15 shows emission data from plant B applying a regenerative incinerator with a capacity of treating a gas volume flow of 71240 Nm³/h for three production lines, and applying a bioscrubber treating a gas volume flow of 31820 Nm³/h for two production lines.

Parameter	Mass flow (kg/h)	Mass flow (kg/yr)	Comments
VOC	No data	No data	
Total-C	1.19	6764	After incineration
	0.3	252	After bioscrubber
Dust	0.03	202	After incineration
CO	0.69	3929	After incineration
NO _x	1.71	9721	After incineration

Table 15.15: Emission values of clean gas after waste gas treatment from plant B [13, DFIU and IFARE, 2002]

Table 15.16 shows emission data from plant C applying a regenerative incinerator with a capacity of treating a gas volume flow of 35000 Nm³/h, and applying an adsorption wheel treating a gas volume flow of also 35000 Nm³/h. The solvent-laden air from the ground coat and topcoat applications is led through the adsorption wheel, achieving an efficiency of 54.4 % for butoxyethanol and 16.7 % for dibutylaminoethanol. The outlet gas from the adsorber is subsequently routed to the incinerator. Air extracted from the driers is only routed to the combustion unit, achieving a removal efficiency of 99.9 %.

Parameter	Mass flow (kg/h)	Mass flow (kg/yr)	Concentration (mg/m ³)	Comments
Total C	1.75	14525	50	After adsorption
	<0.07	581	<2	After incineration
Dust				
CO	2.55	21206	73	After incineration
CO ₂		8290		Incinerator and driers
NO _x	2.80	23240	80	After incineration

Table 15.16: Emission values of clean gas after waste gas treatment from plant C [13, DFIU and IFARE, 2002]

VOCs are mainly emitted as fugitive emissions from, e.g. transport processes, conveyor systems or at the withdrawal of driers. From plants A, B and C, about 31 – 47 t VOC per year were emitted as fugitive emissions. The estimated fugitive emissions from plant C are 34 t/yr, which is 15 % of the solvent input.

The emission of VOC from varnishes and from cleaning (before treatment) is reported to be in the range of 10 – 12 g/m² tinplate [23, Spain, 2000].

Emissions to air from drum coating and printing

Table 15.17 shows emissions data from the coating and printing of drums.

Waste gas abatement (WGT)	30 %
VOC eliminated by WGT	67 tonnes
VOC emissions to air	143 tonnes/year
Note: Typical estimated emissions per million large drums	

Table 15.17: Emissions to air from the coating and printing of drums
[76, TWG, 2004]

15.3.4.2 Emissions to water

[13, DFIU and IFARE, 2002]

Waste water in the coating and printing of two piece cans

Waste water is generated from the pretreatment processes. The concentrations of tin result from the cleaning of the deep-drawn cans made of tinned tinplate. After precipitation and flocculation the concentrations of tin are 4 and <2 mg/l for plant A and B respectively.

AOX values after treatment are 0.5 and <1 mg/l for plant A and B respectively. Concentration of hydrocarbons after treatment were, for both plants, <20 mg/l. The treated waste water of plant C has a COD concentration of 350 mg/l and for AOX 0.5 mg/l.

15.3.4.3 Waste

[13, DFIU and IFARE, 2002]

Waste from coating and printing of two piece cans

Significant wastes from the production process are shown in Table 15.18. The amount of waste is expressed in tonnes per year and as a relative value to each square metre of tin or aluminium processed.

Waste	Plant A		Plant B		Plant C	
	(t/yr)	(g/m ²)	(t/yr)	(g/m ²)	(t/yr)	(g/m ²)
Coating sludge from the cleaning of installations	2.95	0.025				
Solvents and solvent mixtures	42.15	0.351			8	0.11
Organic solvents, cleaning agent and alkaline solutions	56.79	0.473				
Oil-contaminated filters, cleaning wipes and protective clothing	61.66	0.514	43	0.43	5.2	0.02
Coating sludge			87.00	0.87	32	0.40
Varnish filters			6	0.06		
Packaging with hazardous contaminations			8	0.08		
Sludge from cleaning tanks					11	0.15
Oil residues					12.4	0.17
Lime sludge					316	4.0
Mixed industrial waste					53	
Aluminium scrap					3.63	

Table 15.18: Wastes arising from coating and printing of metal packaging
[13, DFIU and IFARE, 2002], [76, TWG, 2004]

Other reported data show that per square metre of tinsplate 1 – 2 g/m² used solvents arise, which are normally cleaned and recycled on or off site [23, Spain, 2000].

Wastes arising from drum coating and printing

Table 15.19 shows emissions data from the coating and printing of drums.

Waste	6.25 %
Waste	14 tonnes
Note: Typical estimated emissions per million large drums	

Table 15.19: Emissions from the coating and printing of drums
[76, TWG, 2004]

15.4 Techniques to consider in the determination of BAT for the coating and printing of metal packaging

In Chapter 20, techniques are discussed which might also be applicable to the coating and printing of metal packaging. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to coating and printing of metal packaging. In Table 15.20, the general techniques relevant for the coating and printing of metal packaging that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 15.20: Reference to techniques generally applicable to the sector

15.4.1 Conventional solvent-based coating and ink systems

Description: For the general description, see Section 20.7.2.1. Coating and ink materials are typically organic solvent-based in the following metal packaging manufacturing processes:

- external coating applied to DWI cans
- decorative inks applied to DWI cans
- sheetfed special applications
- base coat and ink applied to aluminium extruded tubes
- internal and external coating of drums.

Achieved environment benefits: Reduced cleaning (wash-up) frequency and consumption of materials. Waste materials are cost effectively recycled for solvent recovery.

Cross-media effects: No data submitted.

Operational data: Waste gases from sheetfed processes are usually treated as follows:

- coating processes are usually treated
- printing processes are usually dispersed directly to air.

Waste gases from DWI and drum processes in sheetfed technologies are, depending on local conditions, either treated or dispersed directly to air.

Waste gases from aluminium extruded aluminium tubes manufacturing processes are usually treated as follows:

- base coat activity is usually dispersed directly to air
- driers are sometimes treated
- decorator ink applicators and clear coat waste gases are typically routed through a caustic scrubber and subsequent drier gases are commonly treated by thermal oxidation.

Applicability: Suitable for coating and printing of metal packaging processes that are subject to specification requirements as follows:

- superior wetting features
- resistance to water permeability
- wet-on-wet varnish
- improved chemical resistance
- resistance to oil and lubrication contamination.

Economics: No data submitted.

Driving forces for implementation: Product quality and safety.

Example plants: No data submitted.

Reference literature: [125, SEFEL, 2005]

15.4.1.1 Solvent-based inks in two piece DWI can manufacture

Description: The applied printing inks contain 18 - 38 % organic solvent.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: DWI printing machines are capable of speeds >2000 cans/minute having 4/6/8 independent sections that are able to apply sequentially up to eight colours and one top coat. Thermal ovens cure the inks at temperatures ranging from 180 to 450 °C for 7 to 60 seconds.

The inks are cured in a thermal oven and the waste gas can be treated by thermal oxidation. The decorators are designed to allow waste gas extraction. The presses are usually enclosed to enhance waste gas extraction and subsequent treatment.

Applicability: Dry offset processes are commonly applied, however, on newer installations engraving rollers also are utilised. The decorating machines are designed to allow waste gas extraction.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [65, UKDEFRA, 2003] [76, TWG, 2004]

15.4.2 Replacement of coatings and inks containing solvents (substitution)

15.4.2.1 Water/solvent-based coating and ink systems

Description: For the general description, see Section 20.7.2.3. The following are applied to DWI cans:

- exterior coat (bottom not included): 15 – 45 wt-% organic solvent content
- interior coat: 10 – 15 wt-% organic solvent content
- base coat for the bottom of the can: 80 wt-% organic solvent content.

On aluminium DWI cans, this is:

- interior and exterior coat: 12 – 16 % organic solvent content
- coat for the bottom of the can: about 33 % organic solvent content.

On steel drums, this is:

- exterior coat: 5 - 15 % organic solvent content.

Achieved environmental benefits: No data submitted.

Cross-media effects: Changing to water-based means increased energy use (and therefore CO₂ emissions) for driers and thermal oxidisers. However, if the VOC emission reduction is sufficient and the oxidisers can be shut off, the energy usage may be the same or less (see the ECM REF, Annex 14 on water-based printing).

Operational data: The exhaust air from the spray application and the driers is usually treated. Substitute coatings are mainly available for drawn and ironed cans (DWI) coating processes.

Applicability: Aluminium cans are mainly coated with water-based coatings (e.g. lacquers).

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plant: Rexam, Berlin, Germany (tin cans).

Reference literature: [13, DFIU and IFARE, 2002] [65, UKDEFRA, 2003] [70, UBA Germany, 2003] [76, TWG, 2004] [128, TWG, 2005]

15.4.2.2 Water-based coating systems and compounds in metal packaging manufacture based on sheeffed technology

This section gives information on three piece cans as well as the other metal packaging which is not DWI.

Description: For the general description, see Section 20.7.2.3. The following water/solvent-based coating systems are applicable to metal packaging as follows:

- three piece cans for food, drinks, aerosols and speciality products
- three piece cans welded side stripe protection. Water-based coatings may be applied onto the side stripe of weldings
- ends, caps, lids and closures for three piece cans, jars and bottles
- two piece non-DWI cans.

Achieved environmental benefits: Reduction in organic solvent emissions because no organic solvents are used.

Cross-media effects: Increased machine cleaning frequency and downtime. Increased sludge in the extract system (condensate and resin). Reduced health and safety risks for operators of coating machines because of a reduced exposure to solvents. Reduced fire and explosion risks. Requires thermal drying ovens.

Operational data: Exhaust air from the coating process and the driers is usually treated. Water-based coating systems have to be stored in a frost-free environment. Reduced health and safety risks for operators of coating machines because of a reduced exposure to solvents. Reduced fire and explosion risks.

Applicability: Water-based compounds are often available and applied. Wet-on-dry applications only subject to quality parameters. Applied to metal packaging components, caps and closures.

Economics: Process pumps and pipework need to be of high quality steel. Increased maintenance costs for wear to scraper blades, increased extract system cleaning costs. Investment necessary for drying ovens and high quality supply of distribution pipework systems.

Driving forces for implementation: Legal environmental compliance.

Example plants: Impress Hoogeveen and Impress Deventer both in the Netherlands.

Reference literature: [65, UKDEFRA, 2003], [76, TWG, 2004]

15.4.2.3 Sheetfed coating

This section gives information on three piece cans as well as the other metal packaging which is not DWI.

Description: Waterborne materials are suitable for certain metal packaging products but are limited to polyesters, acrylic and epoxyphenolic (excludes organosol), however, all waterborne coatings contain some organic solvents, mainly to aid wetting.

Achieved environmental benefits: Reduced emissions of organic solvents. Reduced health and safety risks for operators of coating machines because of a reduced exposure to solvents. Reduced fire and explosion risks.

Cross-media effects: Increased scraper blade wear and condensate production.

Operational data: Downtime for cleaning is typically 30 minutes longer than for solvent-based materials.

Applicability: Suitable for wet-on-dry applications only. Applied to metal packaging manufacture based on sheetfed technology.

Economics: Approximately the cost is neutral between waterborne and solvent-based.

Driving forces for implementation: Compliance to the reduction scheme of solvents.

Example plants: Impress Hoogeveen, the Netherlands.

Reference literature: [76, TWG, 2004]

15.4.2.4 Liquid side stripe

This section gives information on three piece cans only.

Description: A lacquer side stripe is applied to the external and internal areas of the welded region of the can cylinder. Film weight per typical can is approximately 0.02 g/can and the type of lacquer is selected according to the aggressive nature of the products that must be filled into the can. Waterborne materials are available for selective can products after having undergone extended qualifying pack tests.

Achieved environmental benefits: Reduced organic solvent emissions.

Cross-media effects: No data submitted.

Operational data: Waterborne lacquers may be used with standard side striping equipment. Reduced health and safety risks for operators of coating machines because of a reduced exposure to solvents. Reduced fire and explosion risks.

Applicability: Waterborne materials are not suitable for inside side striping of cans for aggressive products.

Economics: Approximately the cost is neutral between waterborne and solvent-based.

Driving forces for implementation: Compliance to the reduction scheme of solvents.

Example plants: No data submitted.

Reference literature: [65, UKDEFRA, 2003] [76, TWG, 2004] [128, TWG, 2005]

15.4.2.5 Repair spray

This section gives information on cans with easy open ends only.

Description: Steel easy open end ‘scoring’ takes place after the primary coating and press operation and this scoring must be repair sprayed to prevent corrosion of the steel. Suitable lacquers are currently available in organic solvent-based lacquers only.

Achieved environmental benefits: No data submitted.

Cross-media effects: Organic solvents are normally dispersed direct to the air.

Operational data: Good wetting properties and resistance to surface oils.

Applicability: Steel easy open ends. Applied to metal packaging manufacture based on sheetfed technology.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004] [128, TWG, 2005]

15.4.2.6 Powder spray side strip coating

Description: See Section 20.7.2.6.

Achieved environmental benefits: No organic solvent emissions.

Cross-media effects: The film weight is typically 10 times that needed for a liquid side stripe.

Operational data: Electrostatic control of spray is necessary.

Applicability: Applied to metal packaging manufacture based on sheetfed technology. Inside side stripe protection of cans for aggressive filling goods. Powder coatings may be applied onto the welding and are called ‘side stripes’. Powder coatings are used for three piece welded can side stripe protection.

Economics: Applied costs of powder are higher than for liquid lacquers.

Driving forces for implementation: Environmental legislation.

Example plants: Impress Deventer, the Netherlands.

Reference literature: [65, UKDEFRA, 2003] [76, TWG, 2004]

15.4.2.7 Coil coated materials

This section gives information on three piece cans as well as the other metal packaging which is not DWI.

Description: See Section 20.7.2.8. Coil coated materials can be applied.

Achieved environmental benefits: Significant reduction of VOC emissions dependent on the coating activities that are replaced by applying coil coated materials.

Cross-media effects: Loss of materials as skeletal waste at an average of 20 % which includes coated material.

Operational data: No data submitted.

Applicability: Applied only to some ends and domes for aerosol cans.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005]

15.4.2.8 Pre-coated coil

Description: This technique can be used for the production of three piece cans as well as for other metal packaging which is not DWI.

Achieved environmental benefits: No organic solvent emissions at the metal packaging manufacturing facility.

Cross-media effects: Process metal scrap (shred) contains coating.

Operational data: No data submitted.

Applicability: Applied to metal packaging manufacture based on sheetfed technology and to coil fed processes. Pre-coated coil is available from a limited number of metal suppliers and is suitable for selected ends, closures and deep drawn closures only. Not suitable for DWI cans.

Economics: No data submitted.

Driving forces for implementation: Environmental licensing or there is a need to sub-contract out the coating activity.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004]

15.4.2.9 UV compounds (varnish and inks)

Description: See Section 2.4.2.2.1. UV inks are applied to a wide range of products: aerosols, food, general line, closures, and caps. UV varnishes are also used for aerosols, food and some general line.

Achieved environmental benefits: No organic solvent emissions. No thermal curing ovens and associated energy and emissions implications.

Cross-media effects: Ozone is emitted.

Operational data: Caution must be exercised with the use of UV materials and its suitability for any fill product.

Applicability: This technique applies to three piece cans as well as the other metal packaging which is not DWI.

Use of UV inks for metal packaging has increased in non-food applications and are commonly applied. Applied to metal packaging manufacture based on sheetfed technology. UV lamp curing replaces conventional thermal drying ovens. Applications of UV varnish are highly limited by standards in tooling flexibility and resistance to abrasion.

Economics: No data submitted.

Driving forces for implementation: Environmental compliance.

Example plants: No data submitted.

Reference literature: [65, UKDEFRA, 2003] [76, TWG, 2004]

15.4.3 Application of coatings and ink

15.4.3.1 Rollers for two piece DWI can manufacture

Description: See Section 20.7.3.1. Roller coating and dry offset is commonly used for the application of the external coating and inks.

Achieved environmental benefits: Optimum material utilisation.

Cross-media effects: Sometimes the exhaust air from the coating and printing processes are dispersed directly to air.

Operational data: The applicator rollers are enclosed and excess coating material is collected and returned to the reservoir.

Applicability: Roller coaters are commonly used for the application of the external coating and dry offset printing for the application of inks.

Economics: No data submitted.

Driving forces for implementation: Optimum material utilisation.

Example plants: Rexam, Berlin, Germany (steel cans).

Reference literature: [13, DFIU and IFARE, 2002] [65, UKDEFRA, 2003] [70, UBA Germany, 2003] [76, TWG, 2004]

15.4.3.2 Rollers for sheetfed technology

This section gives information on three piece cans as well as the other metal packaging which is not DWI.

Description: See Section 20.7.3.1. Layers of coatings are accurately controlled to typically 3 to 10 microns.

Achieved environmental benefits: Optimised lacquer application and reduction of organic solvent emissions.

Cross-media effects: No data submitted.

Operational data: The applicator rollers for coating sheets are enclosed and excess coating material is collected and returned to the reservoir.

Applicability: Roller coaters are used exclusively for coating the sheets. Side stripes can also be applied by using rollers. The metal packaging industry in selected operations uses continuous and spot coating rollers for applying lacquers.

Economics: Coating material savings.

Driving forces for implementation: Cost and quality control of coating application.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [65, UKDEFRA, 2003], [76, TWG, 2004]

15.4.3.3 Rollers for aluminium extruded tube manufacture

Description: See Section 20.7.3.1. Roller coaters are used for applying the base coat; the cylinder rotates and the roller is static. The pick-up roller runs through a reservoir containing the coating material, excess material is then removed by the metering system and is fed back into the reservoir. After the printing process, an overvarnish (clear coat) is applied using the rollers. The coating station is usually enclosed and waste air is extracted, and treated by a scrubber unit. The subsequent drying process is then abated with a thermal oxidiser.

Achieved environmental benefits: Reduction of solvent emissions to air.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [65, UKDEFRA, 2003] [76, TWG, 2004]

15.4.3.4 Compressed air spraying

Description: For a general description, see Section 20.7.3.8.

Achieved environmental benefits: The application efficiency of the interior spraying ranges from 93 – 97 % for two piece DWI can manufacture.

Cross-media effects: No data submitted.

Operational data: The overspray is commonly separated by applying dry filter systems. The overspray coating is not re-used or recycled.

Applicability: Compressed air spraying is commonly applied for the application of internal coating for two piece DWI can manufacture and in manufacture of metal packaging based on sheetfed technology.

Economics: Minimises the use of lacquer through targeted profile application.

Driving forces for implementation: Environmental benefits and economical reasons.

Example plants: Rexam, Berlin Germany (steel cans).

Reference literature: [13, DFIU and IFARE, 2002] [65, UKDEFRA, 2003] [70, UBA Germany, 2003] [76, TWG, 2004]

15.4.3.5 Airless spraying

Description: See Section 20.7.3.1. Side stripes can be applied by using airless spray guns. Airless spraying (electric) is commonly used for the application of the internal coating.

Achieved environmental benefits: The application efficiency of the interior spraying is 90 % in the manufacture of two piece DWI cans. Minimises the use of lacquer through targeted profile application.

Cross-media effects: None.

Operational data: The overspray is commonly collected by dry filter systems. The overspray coating is not re-used or recycled.

Applicability: Airless spray is commonly applied for the internal coating of two piece DWI can manufacture and in metal packaging manufacture based on sheetfed technology.

Economics: High application efficiency and lower raw material use, see Driving forces for implementation below.

Driving forces for implementation: Reduces air emissions and is cost-effective.

Example plants: Rexam, Berlin, Germany (steel cans).

Reference literature: [13, DFIU and IFARE, 2002] [65, UKDEFRA, 2003] [70, UBA Germany, 2003], [76, TWG, 2004]

15.4.3.6 Electrostatic spraying

Description: Side stripes coated with powder coating are applied by using electrostatic spray guns.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: The excess coating material is collected and returned to the reservoir.

Applicability: Metal packaging manufacture based on sheetfed technology.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [65, UKDEFRA, 2003]

15.4.3.7 Powder spraying

Description: The metal packaging industry uses electrostatic spray equipment for three piece welded can side stripe applications.

Achieved environmental benefits: Closed loop recirculation of powder prevents dust emissions.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: Used for three piece cans with lacquered side striping. Applied in metal packaging manufacture based on sheetfed technology.

Economics: Applied material costs are higher than for liquid side stripe lacquers.

Driving forces for implementation: Environmental compliance.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004]

15.4.3.8 Curtain coater

Description: This is a coating technique used for the external anti-corrosion protection of DWI cans for food products where a plain (non-decorative) protective finish is required. The coating normally also contains a lubricant to aid can mobility during subsequent manufacture and filling. The coating is applied by the passage of previously cleaned and rinsed upturned (base uppermost) cans, en masse on a wide conveyer belt, under single or multiple waterfalls or curtains of a dilute waterborne 'washcoat'. The excess wet coating runs off the cans into a capture and recirculating system, then the can immediately enters an oven to evaporate the liquid carrier and cure the remaining solids into a protective film. The curtain coater is normally constructed as an integral part of the overall can cleaning, rinsing and drying facility. The continuous ingress of deionised water on the can from the prior can rinsing process dilutes the washcoat in the system which is reconcentrated by ultrafiltration and/or periodic additions of concentrated washcoat. The washcoat is primarily waterborne but with a small VOC content to aid wettability of the can surface.

Achieved environmental benefits: Use of waterborne coating materials minimises solvent content.

Cross-media effects: No data submitted.

Operational data: When cans are not to be decorated as is the normal case for food cans, then a clear external protective coat is applied to the upturned can via a curtain coater. Curtain coating systems incorporate a closed loop capture and recirculating facility.

Applicability: Food cans external protection. Applied in two piece draw and wall iron (DWI) can manufacture.

Economics: Optimisation of materials.

Driving forces for implementation: Cost and environmental benefit.

Example plants: No data submitted.

Reference literature: [65, UKDEFRA, 2003] [76, TWG, 2004]

15.4.3.9 Radiation curing

For a general description, see Section 20.7.2.5.

15.4.4 Printing

15.4.4.1 Lithographic (wet offset) for sheetfed technology

This section gives information on three piece cans as well as the other metal packaging which is not DWI.

Description: See Section 2.4.1. For a general description, see Section 15.2. Modern lithographic printing presses are capable of speeds in excess of 6000 sheets per hour. The number of printing colours employed is design specific, e.g.

- milk powder containers can have 10/11 colours
- promotional metal containers can have 13/14 colours.

Achieved environmental benefits: Printing inks used for lithographic processes contain typically less than 10 % organic solvent resulting in low VOC emissions.

Cross-media effects: The organic solvents are typically dispersed directly to the air from the drying ovens.

Operational data: Printing lines are comprised from between one and six printing decks and can apply from one and six colours in sequence. Some designs are achieved with a four colour process set; whilst others are achieved with the six colour hexachrome printing set. However, a large proportion of designs is still achieved using spot colours (i.e. inks colour matched to a specific shade to meet the needs of the design).

Applicability: Common technology used in the flat sheet metal packaging printing industry.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: This technique is commonly applied.

Reference literature: [65, UKDEFRA, 2003], [76, TWG, 2004]

15.4.4.2 Waterless lithographic

Description: See Section 2.4.1.6.

Achieved environmental benefits: Savings of resources, raw materials and emissions from dampening solutions are eliminated. Reduced set-up times for decoration changes. To reduce the material consumption for the exterior varnish, the can can be directly printed via the offset process and then coated with a thin layer of varnish (clear coat) for protection of the print.

Cross-media effects: Chilling of the plant is required.

Operational data: No data submitted.

Applicability: This process is normally used when print registration to the product is not possible such as on circular surfaces; examples are drink cans, caps and extruded aluminium tubes. This technique can be applied for selected metal packaging products. In new installations, engraving rollers are utilised for the application of the printing ink.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: This technique is commonly applied.

Reference literature: [13, DFIU and IFARE, 2002] [65, UKDEFRA, 2003] [76, TWG, 2004]

15.4.4.3 Waterless offset lithography for aluminium extruded tube manufacture

Description: See Section 2.4.1.6. The cured base coat provides the key for the subsequently printed design, which is applied via a multicolour decorator using the waterless offset process.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: Inks are spooned by hand to the reservoir rolls and a precise system of rolls accurately measures each colour separately onto the application roll. Usually, there is a fume extractor at the decorator, which is ducted to the air once it has passed through a caustic scrubber.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [65, UKDEFRA, 2003]

15.4.5 Waste gas treatment

15.4.5.1 Dry filter systems

For a general description, see Section 20.11.3.6. This technique is commonly applied in two piece DWI can manufacture and metal packaging manufacture based on sheetfed technology for the removal of coating particles.

[13, DFIU and IFARE, 2002], [76, TWG, 2004]

15.4.5.2 Electrostatic filter

For a general description, see Section 20.11.3.7. This technique is commonly applied for the removal of coating particles. Electrostatic filters are not in use in the canmaking industry. [76, TWG, 2004]

15.4.5.3 Thermal oxidation

For a general description, see Section 20.11.4.2. VOC emissions can be reduced effectively by the post-combustion of waste gases from driers used on coating and printing presses and other printing activities. Heat recovery can be applied for heating of pretreatment rinsing water and it is state-of-the-art in some industries.

This technique is applied to driers. However, it is less common for coating and printing applicators. It is not typically applied when the solvent reduction scheme has led to the use of waterborne materials. This technique is applied to the following sectors:

- two piece draw and wall iron (DWI) can manufacture
- metal packaging manufacture based on sheetfed technology
- aluminium extruded tube manufacture
- drums.

[65, UKDEFRA, 2003] [76, TWG, 2004] [128, TWG, 2005]

15.4.5.4 Catalytic oxidation

For a general description, see Section 20.11.4.6. The use of catalytic oxidation is under development. [65, UKDEFRA, 2003]

15.4.5.5 Adsorption to activated carbon

For a general description, see Section 20.11.6. Adsorption wheels can be applied as a pretreatment to thermal oxidation. Applied in the two piece DWI can manufacture sector. [13, DFUI and IFARE, 2002], [76, TWG, 2004]

15.4.5.6 Biological treatment

For a general description, see Section 20.11.8. The use of biological treatment is under development. [65, UKDEFRA, 2003]

15.4.6 Waste water treatment

15.4.6.1 Flocculation/sedimentation

For a general description, see Sections 20.12.1 and 20.12.2. This is commonly applied to the waste water generated from a can cleaner. It is used in the case of DWI cans. For the production of steel cans, a discharge tin concentration of <2 to a maximum of 4 mg/l has been reported. [13, DFUI and IFARE, 2002], [76, TWG, 2004]

15.4.6.2 Ultra and nanofiltration

For a general description, see Section 20.12.6. This technique can be applied to waste waters generated from the pretreatment processes of the following industries:

- two piece draw and wall iron (DWI) can manufacture
- metal packaging manufacture based on sheetfed technology
- aluminium extruded tube manufacture.

It is not used currently for treating waste waters from canmaking plants.
[76, TWG, 2004]

16 COATING OF PLASTIC WORKPIECES

[13, DFIU and IFARE, 2002] [76, TWG, 2004, 171, May, 2006]

16.1 General information on the coating of plastic workpieces

A wide variety of modern products incorporate plastic parts, although many are used with the appropriate finish achieved in the moulding process, and do not require coating. In general, around 75 % of the paints supplied to this industry are applied to plastic parts of vehicles. This is predominantly for bumpers, wheel covers and steering wheels. The remaining 25 % of the paints are for coating TVs, hi-fis and computer housings.

The plastic parts coated for the vehicle industry include parts that are coated by the vehicle producer (in-line vehicle production or in separate coating lines), as well as parts that are coated by component suppliers. Plastic parts integrated in the car body often have to achieve a matching colour. Nowadays colour design is increasingly in the automotive sector, including the interior decoration, for example, colour matching the steering wheel to the instrument board or to the interior. In many cases, the car bodies and the components may be coated in different installations using different application devices and/or coating materials and good colour matching is of major importance.

Due to the increase in the use of recyclable plastics in the vehicle component supplier industry in recent years, the use of polyolefins has also greatly increased. These materials are non-polar and need a surface preparation to guarantee the necessary adhesion for the coating.

Plastics typically display certain basic characteristics, and these affect the type of surface preparation which can be applied, the type of coating which can be used, and the process used to apply it. Some basic characteristics of plastics are:

- resistant to mechanical or thermal stress
- chemically resistant
- electrically non-conducting
- additional wetting and adhesion properties compared to metal surface
- possibility of leakage or migration of the plastic ingredients.

Coating systems need to be chosen carefully with respect to the solvent they contain, as some aggressive solvents may cause swellings and embrittlements, may create cracks in the plastic or reduce the adhesive strength of the coating system. Also the coating needs to be more elastic than the substrate in order to resist deformations.

16.2 Applied processes and techniques in the coating of plastic workpieces

Generally in the serial coating of plastic parts, three issues need to be addressed:

- surface preparation
- structure of the coating
- coating system and application technique applied.

Surface preparation

Surface pretreatment may be applied to prepare the surface for the coating, e.g. to increase the adhesive properties of the surface (especially for applications of water-based coating systems), to activate the surface, to increase the electrical conductivity of the surface (e.g. for use with electrostatically supported application devices) or to reduce faults in the surface, e.g. created by the leakage of ingredients. Typical pretreatments include chemical pretreatments in baths; flame treatment; plasma processes; the corona technique; and fluoridation, which offers the advantages of one layer coating and enabling the parts to be stored for longer periods before being supplied for a following coating process.

Structure of the coating system

Depending on specific requirements two, three or four layers of paint may be necessary. A ground coat may also first be applied depending on the composite. On the surface of especially difficult surfaces such as polypropylene, an additional primer may be necessary. For soft PVC or PUR soft foam, an isolating or inhibiting ground coat is needed to avoid migration of the softener. In order to smooth surface roughness, an elastic filling is applied. The topcoating may be either one or two layers, and is also elastic.

Coating system and application technique applied

The choice of coating system and application technique depends on the end-product needs. In Germany, predominantly solvent-based 1- and 2-component systems based on PUR and 1-component paints based on acryl melamine are used, although water-based systems, UV cross-linking systems and powder coatings are also used.

Typically high pressure air spraying is used for wet paints. Depending on the workpiece's geometry, the application efficiency is between 20 and 40 %. The high volume low pressure (HVLP) paint application method is also common for some applications, with achievable application efficiency factors varying between 25 and 50 %. There is an increasing use of robots, as they allow a more homogenous layer thickness to be achieved compared to manual painting.

Electrostatic application techniques are also available but up to now have only been used for multilayer superstructures. Here, an electrically conducting ground coat is first applied with conventional spray guns, often followed by a base coat, also applied with conventional guns. The application of the clear coat layer can then be carried out electrostatically (e.g. by high rotating bells). Application efficiency factors can be greatly increased by using electrostatic techniques, e.g. if high rotating bells are used, application efficiency factors of up to 85 % can be achieved. In some cases, a maximum level of only 50 – 65 % transfer efficiency can be obtained (e.g. in the case of the complex parts of some processes in the automotive industry, for example the low conductivity of substrates in the case of plastic parts). However, the electrostatic coating technique cannot be used for single layer coatings, as it needs an electrically conducting pre-coat.

In general, drying and curing are carried out at a maximum temperature of 80 °C, due to the heat sensitiveness of the substrate. However, in certain cases, heat-up zones of up to 135 °C and hold zones of up to 110 °C can be reached. For some plastics, UV and electron beam curing may cause a yellowing of pale colourings.

The following spray booths and techniques are applied:

- simple spray booth
- spray booth and drier
- wet separation spray booth
- dry-separation spray booth
- water emulsion techniques in a spray booth
- paint-in-paint spray booth.

16.2.1 Coating of bumpers

An example of a simplified water-based bumper coating process is shown in Figure 16.1. The workpieces being coated consist of polyurethane moulded pulps and thermoplastic plastics.

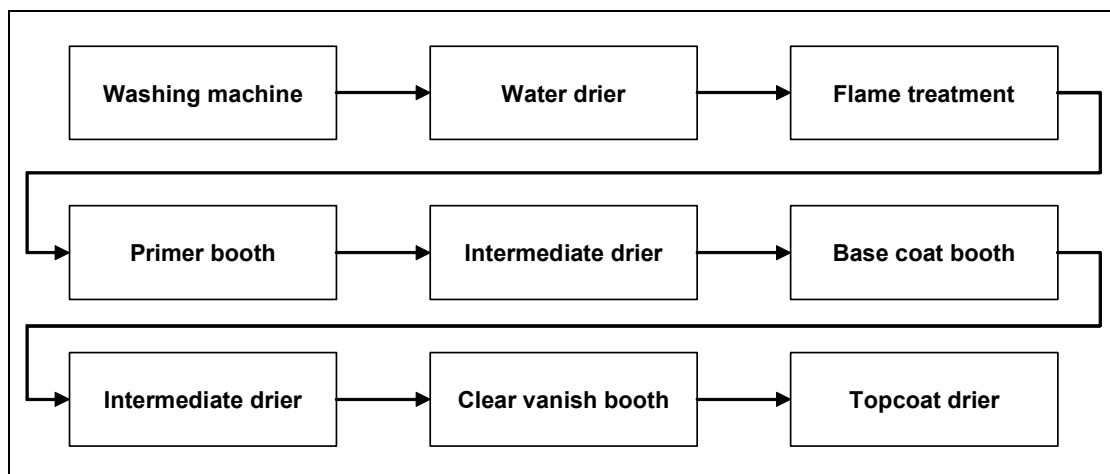


Figure 16.1: Water-based bumper coating process

Surface preparation

Different techniques can be used for the surface preparation. Often spray cleaning with water is carried out by automation, with the parts progressively passing through different zones, e.g:

- first degreasing with an aqueous-alkaline cleaning agent
- rinsing with water
- second degreasing with a watery, alkaline cleaning agent
- rinsing with water
- final rinsing with deionised water.

Spray cleaning with water and chemicals can be avoided for polypropylene bumpers by manually wiping the bumper with solvent impregnated wipes. In one example installation, the bumpers are cleaned manually with a water-isopropanol mixture (the proportion of isopropanol is 5 wt-%) and afterwards dried in convection driers.

Cascade rinsing is usually used, in order to reduce water consumption. The water discharging from the parts can be used for substitution of evaporation losses of the degreasing step. Also the deionised water can be recycled. These measures allow an almost waste water free surface preparation (with the exception of the waste water produced by the periodic emptying of tanks for cleaning). After the cleaning process, the parts are transported through a blowing, drying and cooling unit. If a condensation drier is used, the cooling unit is not necessary.

After drying, the workpiece's surfaces are typically activated by flame treatment or plasma ionisation. Polyurethane parts do not need any further preparation.

Application of the coating

In general, bumpers are coated with a three layer coating consisting of a ground coat, a base coat and a clear coat. The paint is applied by robots or manually by using electrostatically assisted spraying or by spraying with HVLP guns. First, a primer is applied to the plastic parts. Primer can be either solvent-based (e.g. solvent-based 2-component ground coating) or water-based. The primer may need to be dried (e.g. within a circulating airflow at 80 °C) prior to the application of subsequent layers. Application of the base coat is carried out with the same technique as the ground coat. Where the base coat uses medium solids paint, the solvent proportion can be up to 70 %. Base coats are 1-component paint systems, either water-based or solvent-based. After the paint application, a conventional solvent-based 2-component clear coat is applied and evaporated. Additionally, wet-on-wet application can also be used eliminating the need for intermediary drying zones.

After evaporation, the paint layers are dried in the drier. Solvent-loaded exhaust air originating from the flashing-off areas and driers are captured and passed to a thermal treatment unit. The achieved efficiency factor may be 95 – 99 % (depending on the load to the combustion unit). For example, a concentration of 277 mg C/m³ in the raw exhaust gas is reduced to 25 mg C/m³ in the cleaned gas. Cleaning of the overspray is carried out via wet deposition. Table 16.1 below shows the proportions of solvents in different coating systems.

Coating structure and systems	Solvent proportion (wt-%)
Ground coat	
• solvent-based	40 – 55
• water-based	15
Base coat	
• solvent-based	50
• water-based	15
Clear coat	
• solvent-based	50
• water-based	30

Table 16.1: Proportions of solvents in different coating systems used for the coating of bumpers

16.2.2 Coating of wheel covers

The coating system for wheel covers is characterised by two layers. First a conventional or water-based metallic base coat and subsequently a conventional solvent-based 2-component clear coat or a UV clear coat are applied. The requirements for the coating include scratch resistance, water resistance and resistance against stone-chips, as well as a high surface quality. The coating is carried out by automation.

Figure 16.2 below illustrates the production procedure of wheel covers with solvent-based paints.

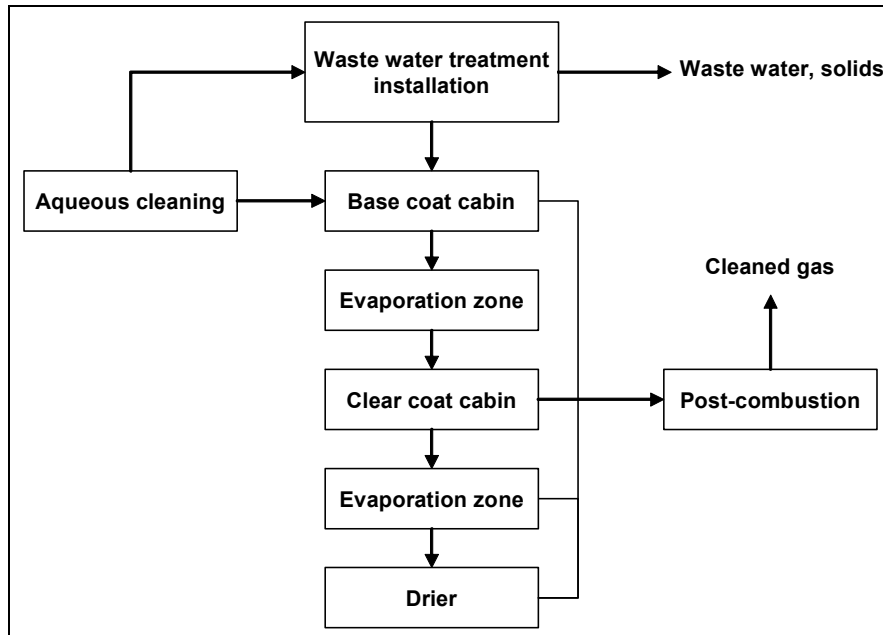


Figure 16.2: Process flow for the coating of wheel covers with a conventional coating system

Table 16.2 below compares some different systems in use.

Coating structure and systems	Solvent proportion (% by weight)
Base coat	
• solvent-based	75
• water-dilutable	10
Clear coat	
• solvent-based	50
• UV curing	10
• water-dilutable	16

Table 16.2: Comparison of the proportions of solvent in coating systems applied for the coating of wheel covers

16.2.3 Coating of steering wheels

For steering wheels, properties such as resistance against sun radiation, cleaning agents or sweat from hands have to be guaranteed by the coating. At present, steering wheels are typically coated by the in-mould technique. For this technique, a release agent is applied onto the heated mould and the in-mould coating is sprayed onto the release agent. In this way, the proportion of overspray and therefore the material loss is comparably low, approx. 20 %. After a short evaporation time, the mixed PUR components are poured in. During the foaming process within the closed mould, the material creates a strong connection with the coating. The applied coating has to be compatible with the mould release agent and to the polyurethane system used. Up to now, solvent-based 1 and 2-component coating systems have been in use.

16.2.4 Coating of reflectors

Reflectors require an extremely smooth and homogenous surface. The coating structure is a one layer type.

16.2.5 Coating in the production of TVs, hi-fis and computer housings

Nowadays, there is a trend in the audio and video sector for more colourful products and even individual customer requests regarding the colour design. The quality requirements for the coating of the housings include resistance against alcohols, skin fat, etc., scratch and abrasion resistance, and good optical surface properties. State-of-the-art is the serial use of water-based coatings, although solvent-based coating systems are still widely used. An application efficiency of 45 % can be achieved in the coating of TV housings, with the coating being carried out by automation.

16.3 Current consumption and emission levels in the coating of plastic workpieces

Due to the wide range of this chapter, it is not possible to give details of consumptions and emissions. They will depend on:

- the type of processes applied
- end-of-pipe treatments applied
- products
- volume of production.

This industry is classed as ‘other coatings’ in the SED [123, EC, 1999] (see Annex 24.6).

General information can be found with the appropriate techniques in Chapter 20.

16.3.1 Mass balances

No data submitted.

16.3.2 Consumptions

16.3.2.1 Materials

Data for paint consumption in g/m² are difficult to obtain due to (i) the different geometries of the workpieces and (ii) this is not the usual way of expressing paint and solvent application in this industry. (It would have to be expressed as g/m² painted surface and not e-coat surface as for vehicles, see Annex 24.5). It is more usual to express this as kg VOC/kg solids input (see Annex 24.2).

Coating of bumpers

For one example site in Germany (Volkswagen, Wolfsburg), in 2002 [171, May, 2006]:

- about 1 million bumpers were painted
- surface area (external side only): between 0.9 and 1.5 m²
- substrate: polypropylene with EPDM modification
- three layer coating system with primer, base coat and clear coat
- pneumatic atomisation of coating materials by spray-guns mounted on robots
- drying oven after primer and clear coat, wet-on-wet process for base coat and clear coat.

Solvent consumption figures in Table 16.3 refer to a mixed coating system with solvent-based primer, water-based base coat and solvent-based clear coat. The solvent used may increase by 20 % when medium solid paint is used. If a complete solventborne system was applied, the solvent consumption would amount to 550 t/yr. Consumption of paint solids would be 207 t/yr. VOC emissions according to EVABAT range between 51.75 and 72.45 t/yr. Emissions are 0.25 to 0.35 kg VOC/kg paint solids.

Coating system	Solvent used*(t)	Totals solvents used
Ground coat (solvent-based)	125	
Base coat (water-based)	31	
Clear coat (solvent-based)	84	
Total solvent in paint		240
Rinsing diluent ground coat	61	
Rinsing diluent base coat	9	
Rinsing diluent clear coat	41	
Total rinsing diluent		111
Total solvent used		351
Note:		
* It has been reported that the solvent used may increase by 20 % when medium solid paint is used If a complete solventborne system was applied, the solvent consumption would amount to 550 t/yr		

Table 16.3: VOC use in 2000
[76, TWG, 2004]

Coating of truck cab roof tops and other plastic parts for commercial vehicles

A jobbing coating shop in Germany reports the following data [171, May, 2006]:

- coating of about 30000 truck cab roof tops and complete plastic part sets per year
- surface area (external side only) between 6 and 11 m² per roof top
- substrate mostly fibre-reinforced SMC polyester.

The combination of techniques used is:

- predominantly two layer coating systems with primer surfacer and solid colour topcoat
- atomisation of coating materials by high-rotation bells mounted on robots, assisted by shaping air, but without electrostatic charging
- drying oven after topcoat, wet-on-wet process for solvent borne primer surfacer and topcoat.

In the case of the conventional medium solids system, solvent consumption was about 400 t/yr, and consumption of paint solids was (in 2005) 253 t/yr.

Due to specific technological requirements (i.e. covering of substrate defects, customer specification, wet-on-wet process), the jobcoater for plastic workpieces prefers to continue the use of solventborne coating materials. In the area of trucks and commercial vehicles, more than 95 % of objects are coated with single-layer topcoats instead of base coat/clear coat. The colour range is typically above 600, due to matching fleet colour schemes. This leads to a very high number of colour changes, including the purging of 5 to 7 m supply hoses for robots. As a consequence, large quantities of purging liquids are used (and recovered).

Paint	Consumption kg/yr	VOC %	VOC kg/yr	Non-volatile %	Non-volatile kg/yr
Putty	1000	8.5	85	91.5	915
Sanding primer	3900	29.5	1150	70.5	2750
Primer surfacer	88000	32.4	28512	67.6	59488
Topcoat	133000	42.2	56126	57.8	76874
Elastic additive	4100	22.3	914	77.7	3186
Base coat	5050	77.3	3904	22.7	1146
Clear coat	10400	54.0	5616	46.0	4784
Hardener	66300	54.5	36134	45.5	30166
Diluant	28600	100	28600	0	0
Special products	275	46.3	127	53.7	148
Purge solvent	137000	100	137000	0	0
Structure topcoat	22000	42.0	9240	58.0	12760
Powder	2000	0	0	100	2000
Total	501625		307408		194217

Table 16.4: Breakdown of conventional VOC materials

The option to achieve low VOC emissions would be the introduction of high solids and very high solids coating material and adapted purging liquid (see Table 16.5). This would give an emission value of 0.29 kg VOC/kg paint solids.

Low emission materials include:

- very high solids wet-on-wet primer surfacer
- high solids topcoats
- low VOC purging liquid (70 % organic materials not classified as VOC)
- additional low emission products (see Table 16.5).

Coating material	Consumption kg	Solvent content %	Solvent content kg	Solid content %	Solid content kg
Putty	600	8.5	51	91.5	549
Wet-on-wet primer	98985	15	15343	84.5	83642
Sanding primer	4260	29.5	1257	70.5	3003
Primer surfacer	140	56.7	79	43.3	61
Topcoat	150955	28.4	42871	71.6	108084
Hardener	49507	25	12376	75	37130
Additive	624	22.3	139	77.7	485
Clear coat	11027	37	4080	63	6947
Base coat	5226	9.5	496	23.7	1239
Diluant	27618	100	27618	0	0
Structured coat	17022	8	27618	54	9192
Hardener	2635	5	133	95	2505
Special products	255	46.3	118	53.7	137
Purging liquid	106311	30	31893	0	0
Total	475165		137815		252974
Recovery	197185	33	65071		
Total VOC emission			72744		

Table 16.5: Breakdown of low VOC materials to achieve low VOC emissions

16.3.2.2 Water

No data submitted.

16.3.2.3 Energy

No data submitted.

16.3.3 Emissions

The coating of plastics is one of the activities grouped in the industrial application of paints (see Chapter 13). This group of activities emits NMVOC originating from the use of paints containing solvents, thinners and cleaning solvents. NMVOC emissions from this sector may vary significantly from country to country. At an EU-25 level for 2000 (according to the RAINS model) NMVOC emissions were 543.8 kt representing 5.9% of total NMVOC emissions. Total activity is 1601 kt of paints used, average emission factor is about 339.6 g NMVOC/kg paint consumed meaning that emissions from this sector are already partly treated in EU-25 (unabated emission factors range between 690 and 750 g/kg of paint according to the sub-sector) [142, EGTEI, 2005].

16.3.3.1 Emissions to air

Coating of bumpers

Bumper paintshops are smaller than car paintshops, with correspondingly lower paint use.

Figure 16.3 shows the fate of the solvents in air emissions.

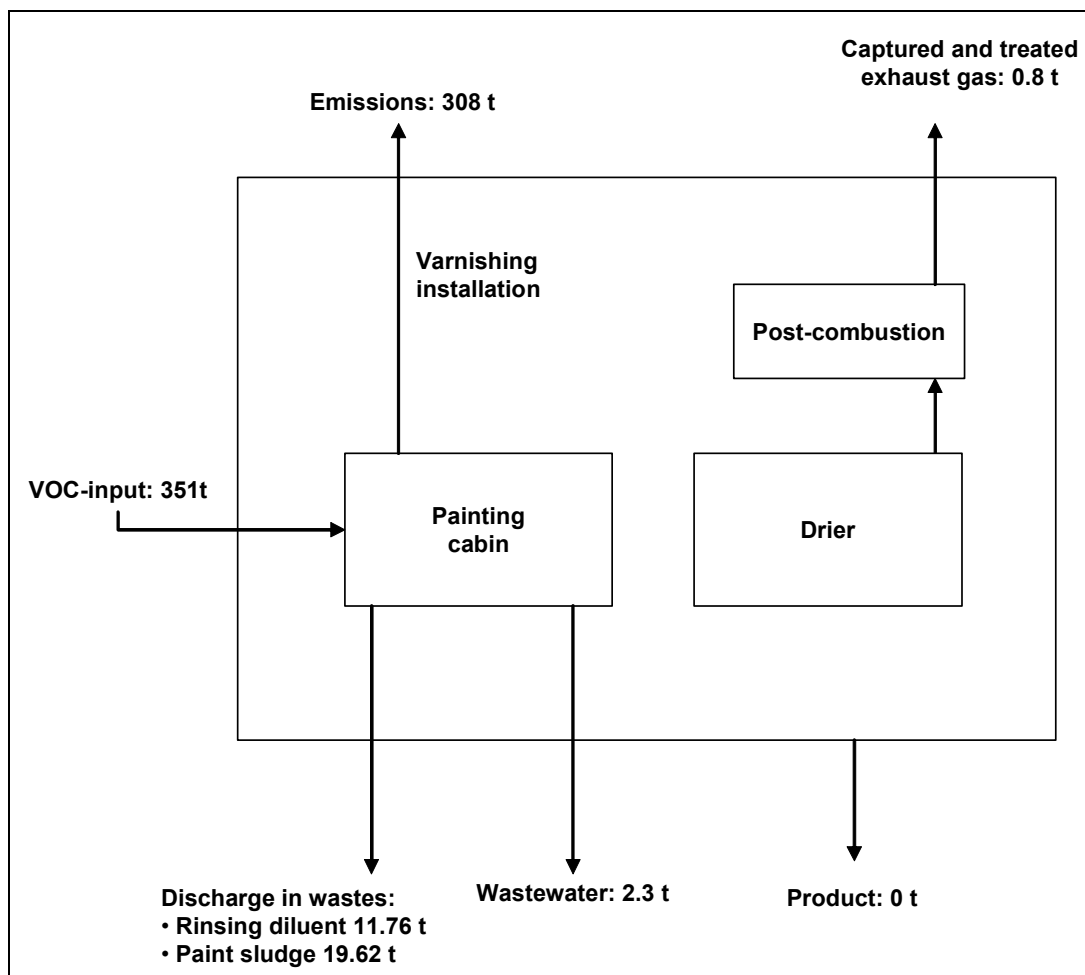


Figure 16.3: Fate of the VOC input in the car bumper plant (2000, Volkswagen, Wolfsburg, Germany)

Coating of wheel covers

The exhaust air from the spraying cabins, driers and evaporation zones is led to a post-combustion unit, and a cleaned gas concentration of 20 mg C/m³ can be achieved. The cleaning process is carried out with aqueous-alkaline cleaners.

16.3.3.2 Emissions to water

Paint particles are removed through wet scrubber systems. These systems are working in a closed loop, once to twice a year they are emptied and filled with fresh water. The waste water produced from the coating of bumpers is shown in Figure 16.3.

16.3.3.3 Waste

The wastes produced from the coating of bumpers are shown in Figure 16.3.

16.4 Techniques to consider in the determination of BAT for the serial painting of plastic workpieces

In Chapter 20, techniques are discussed which might also be applicable to the serial painting of plastic workpieces. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to serial painting of plastic workpieces. In Table 16.6, the general techniques relevant for the serial painting of plastic workpieces that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 16.6: Reference to techniques generally applicable to the sector

The EGTEI synopsis sheet for the industrial application of paints (see Annex 24.1.1) gives some data on the cost-benefit at a European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations or products [142, EGTEI, 2005].

16.4.1 Minimisation of raw material consumption

Description: Some techniques to reduce the amount of waste in the painting process are:

- the optimisation of the painting process, including automation (see Section 20.2.5)
- dewatering of paint sludge
- recycling paint sludge or the water emulsion.

Achieved environmental benefits: Reduce the amount of waste (e.g. paint overspray) produced by the process.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Coating of bumpers.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Volkswagon, Wolfsburg, Germany.

Reference literature: [106, ACEA, 2005]

16.4.1.1 Batch painting/colour grouping

For a general description, see Section 20.6.3.6. This technique is commonly applied in the coating of bumpers.

Colour block building can reduce the consumption of coating material and rinsing diluents. Furthermore, the rinsing thinner can be captured and re-used. About 66 tonnes of rinsing diluent can thus be saved per year, for a recapture proportion of 90 %.
[13, DFIU and IFARE, 2002]

16.4.1.2 Pig-clearing systems

For a general description, see Section 20.6.3.7. This technique is commonly applied in automated systems.
[13, DFIU and IFARE, 2002]

16.4.1.3 Increase of the number of high rotation bells

Description: For a further increase of the application efficiency for water-dilutable primers and base coats, an increasing number of high rotation bells are in use for automated application techniques. Scrapper-cleanable ring circuits are used in installations with automated application techniques in order to minimise paint leftovers and rinsing losses.

Achieved environmental benefit: Decrease the amount of waste generated.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: For base coats, water-based coatings are already applied. Applied to the coating of bumpers.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.2 Water management

Description: See Section 20.7.5. Some techniques to consider are the minimisation of dumping of the tanks from the spray booths to reduce water consumption and effluent discharges by minimising the building up of the paint sludge. Optimising the paint transfer efficiency also reduces the need to change the water. The waste water can be treated in a waste water treatment plant.

Achieved environmental benefits: The above techniques can achieve the emission levels shown in Table 16.7.

Waste water parameter	Concentration (mg/l)
Suspended solids	<1000
BOD	<100
COD	<2500

Table 16.7: Waste water emission levels from the coating of plastic workpieces

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Coating of bumpers.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [106, ACEA, 2005]

16.4.3 Conventional solvent-based materials

Description: See Section 20.7.2.1. Solvent-based coating systems are applied to ground coat, and base coat, although it is usually applied for the clear coat.

Achieved environmental benefits: Compared to water-based systems, less energy is required for drying.

Cross-media effects: Solvent-based materials generate VOC during drying that, in many cases, needs to be abated.

Operational data: Solvent-based paints have a shorter drying time and, thus, a higher production capacity can be achieved.

Applicability: Steering wheels are currently coated exclusively with solvent-based 1- and 2-component coating systems with the so-called 'in-mould' technique.

Economics: No data submitted.

Driving forces for implementation: Short drying times are an important issue in the use of solvent technology. VOC abatement is typically required to satisfy national legislative requirements.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002], [76, TWG, 2004]

16.4.4 Replacement of solvent-based materials (substitution)

16.4.4.1 Water-based paints

Description: For the general description, see Section 20.7.2.3. Water-based coating systems can be applied in ground coat, base coat and sometimes to the clear coat. The following water-based paint systems are commonly applied:

- 1-component acrylate dispersion: 5 wt-% organic solvent
- 2-component PUR system: 10 – 15 wt-% organic solvent
- 2-component epoxy resin: 5 wt-% organic solvent.

Achieved environmental benefit: The amount of used solvents can be reduced by up to 48 % by the use of water-based ground coats, and consequently solvent emissions can also be reduced accordingly in the case of coating of bumpers.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: In the vehicle component supplier industry, water-based paints are already in use as fillers and base coats on, for example, bumpers and wheel covers. Waterborne paints can lead to mechanical constraints on the physical characteristics of the plastic. In the painting of TV, hi-fi and computer housings, the serial use of water-based coatings is commonly applied. For steering wheels, water-based in-mould coating systems are currently in the testing phase. First results indicate that slightly longer drying times will be necessary in comparison to conventional systems and therefore integration into existing processes should be possible.

The remaining issue is the introduction of a waterborne clear coat (50 % solid content, 13 % organic solvent content). Products are formulated and tested, but not yet approved and commercialised. This might lead to, for example, in the reference plant in Section 16.3.3.1, another 50 t/yr reduction of VOC emissions. First approvals may be expected in 2007.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002], [76, TWG, 2004, 171, May, 2006]

16.4.4.2 Powder coating – conventionally dried

Description: See Section 20.7.2.6. Powder coatings with conventional convection drying are currently not broadly applied due to the lack of electrical conductivity and the temperature sensitivity of plastics. Only small batches in the coating of small parts, such as composite parts of metal and plastics for car radiators.

Achieved environmental benefit: No data submitted.

Cross-media effects: No data submitted.

Operational data: Developments of thermal curing low temperature powder coatings look promising.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.4.3 Radiation curing paints

Description: See Section 20.7.2.5. UV curing coatings are applied to clear coats, e.g. on wheel covers, and contain 10 wt-% organic solvent. A progressive technique is the automated application of UV during coating on reflectors; the coating system contains about 5 - 10 wt-% organic solvent. Another relatively new industrial application of UV curing powder is for the coating of PVC floor tiles.

Achieved environmental benefits: Water-based and solvent-free radiation curing paints do not generate VOC emissions.

Cross-media effects: None.

Operational data: UV curing paints can be applied by several different techniques, such as brushing, rolling, casting, spraying and vacuum coating.

Applicability: These paints can be applied for all paint layers.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.4.4 One layer coating after fluoridation

Description: If pretreatment of the plastic surface is done by using the fluor preparation, the filling layer is partially not necessary because this technique already creates a homogenous surface independent of the geometry of the workpiece.

Another advantage of fluoridation is that the fluoridated parts can be stored for a long time before being supplied subsequently for a following painting process.

Achieved environmental benefits: Reduction in VOC emissions and in coating materials.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.5 Paint application techniques and equipment

16.4.5.1 In-mould painting

Description: This technique is applied to steering wheels which are made from 2-component PUR materials that are poured into a mould. The production and painting of the wheel is done at the same time. For the coating of the wheel, a release agent is applied onto the heated mould and the coating material is sprayed onto the release agent. After a short evaporation time, the PUR material for the wheel is poured into the mould and the mould is closed. The foaming process of the PUR starts and at the same time that the coating material adheres to the PUR.

Until now only solvent-based coating materials have been applied; water-based in-mould coating systems are currently in a testing phase.

Achieved environmental benefits: The proportion of overspray and, therefore the material loss is about 20 % of the input.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.5.2 Conventional high and low pressure spraying

Description: See Section 20.7.3.8. Typically, pressure air spraying with the high pressure method is used for the processing of wet paints.

Achieved environmental benefits: Depending on the geometry of the workpiece, the paint application efficiency factor can vary between 20 and 40 %.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.5.3 High volume low pressure spraying (HVLP)

Description: See Section 20.7.3.9.

Achieved environmental benefits: Depending on the geometry of the workpiece, the paint application efficiency factor can vary between 25 and 50 %.

Operational data: There is an increasing use of painting robots, because with this technique especially, a more homogenous layer thickness can actually be achieved compared to manual painting.

Applicability: This technique is common for some applications.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.5.4 Electrostatically assisted high rotation bells

Description: See Section 20.7.3.15.

Achieved environmental benefits: Application efficiencies of up to 85 % can be achieved.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Until now, electrostatic coating techniques cannot be used for one layer coatings, because it is only possible to use this method for electrically conducting pre-coats. Clear coats are commonly applied by using high rotation bells.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.5.5 Electrostatically assisted compressed air, airless and air assisted spraying

Description: See Section 20.7.3.17. Generally, an electrically conducting ground coat is first applied with a conventional spray gun. Following this, the base coat is also often applied with conventional guns, e.g. the coating of bumpers is carried out automatically and manually by electrostatically assisted spraying or with HVLP guns.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Until now, this technique has been exclusively used for multilayer superstructures. Current investigations regarding this application have shown that the electrostatic painting of plastic parts is partly possible under production conditions without additional working steps and without the application of electrically conducting paint materials. This investigation showed a potential reduction in paint consumption and solvent use of 40 - 55 %.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002], [76, TWG, 2004]

16.4.5.6 Processing of powder coatings – electrostatically assisted spraying

Description: See Section 20.7.3.18. Powder coatings can be applied by all common spray application techniques. However, the best results are achieved via electrostatically assisted spraying.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.6 Drying

16.4.6.1 Convection drying

Description: See Section 20.8.1.1. After the cleaning process, the parts are transported through a blowing, drying and cooling unit. Convection driers are partially used for the removal of retained water. If a convection drier is used, the cooling unit is not necessary.

Achieved environmental benefits: About 25 % of the supplied energy can be saved compared to the use of conventional driers, as an energy intensive subsequent cooling zone is not necessary.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Convection driers are commonly applied in the coating of plastic bumpers.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.6.2 Ultraviolet (UV) curing

Description: See Section 20.8.2.3. In general, drying and curing are carried out at a maximum temperature of 80 °C due to the heat sensitivity of the substrate. One technique used is the automated application of UV curing coating systems (with a solvent proportion of about 5 to 10 wt-%).

Achieved environmental benefits: With this technique, solvent emissions are reduced significantly compared to conventional coating systems with solvent proportions of up to 70 wt-%. The coating process is accelerated and the quality is increased (scratch resistance, high opacity). Due to the fast curing process and the temperature stress during the coating process, there are savings of space and energy is reduced.

Cross-media effects: No data submitted.

Operational data: For some plastics, a yellowing of pale colourings may be caused by UV curing.

Applicability: This is commonly applied. For example, the technique is applied to the coating of reflectors.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.6.3 Electron beam curing

Description: See Section 20.8.2.4. In general, drying and curing are carried out at a maximum temperature of 80 °C due to the heat sensitivity of the substrate.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: For some plastics, a yellowing of pale colourings may be caused by electron beam curing.

Applicability: No data submitted.

Economics: This technique is currently only used for large surface throughputs because of high investment costs.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.6.4 Use of condensation driers

Description: Condensation driers can be used for drying layers of water-based coating systems.

Achieved environmental benefits: About 25 % of the supplied energy can be saved, compared to the use of conventional driers as a subsequent cooling zone is not necessary. If the deionised water flows in a closed loop, the generation of waste water can be avoided in the cleaning section. Also, the consumption of fresh water can be reduced by using cascade flow.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

16.4.7 Waste gas treatment

16.4.7.1 Electrostatic filter

For a general description, see Section 20.11.3.7. Spray booths are used. However, no information was made available on how the waste gas is treated.
[13, DFIU and IFARE, 2002]

16.4.7.2 Venturi particle separation

For a general description, see Section 20.11.3.5. Wet separation spray booths are used. However, no information was made available on how the waste water and waste gas is treated.
[13, DFIU and IFARE, 2002]

16.4.7.3 Scrubber

For a general description, see Section 20.11.3.8. Dry separation spray booths are used. However, no information was made available on how the waste gas is treated.
[13, DFIU and IFARE, 2002].

16.4.7.4 Treatment of waste gases from the painting booths

Description: The painting booth's waste gases can be captured and treated. An effective reduction of VOC emissions can be achieved by the capture and treatment of the painting booth's waste gas flows (see Section 20.11.2.1).

Achieved environmental benefits: Reduction of VOC emissions.

Cross-media effects: The system is relatively inefficient due to the high air volumes that need to be treated and the relatively low VOC concentration, especially for manual applications where high air volumes are required for workplace safety.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: Reported to be expensive due to the need for waste gas collection and the use of energy in extraction and possibly in supporting combustion.

Driving forces for implementation: SED and other legislation. Emission limits in some Member States can be achieved without the need for waste gas treatment.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002], [76, TWG, 2004]

16.4.7.5 Concentration and recirculation of waste gases from the painting booths

Description: Some manufacturers of plastic workpieces prefer to continue the use of solvent-based coating materials. This is because of the specific technical requirements (i.e. characteristics of plastic substrates, customer specifications, flexibility in use, ability to use wet-on-wet processes).

To assist in achieving low solvent emissions, the plastic coating industry concentrates the waste gas streams externally by means of rotating adsorbers (see Section 20.11.3.2). They also use internal recirculation in spray booths with automatic application of the paint.

The exhaust air of a spray booth (typically 40000 to 80000 m³/h) is recirculated after intense filtration (typically a venturi wet scrubber plus an additional filtering step) which achieves particle concentrations below 0.1 mg/m³ in order to avoid optical surface defects on the workpieces. By reheating the exhaust behind the wet scrubber, stable climatic conditions (about 70 % relative humidity) can be achieved. By achieving 90 to 95 % recirculation of air volumes, the solvent concentration in spray booths is increased by 10 or 20 (typically from 250 mg/m³ to 2.5 g/m³). The solvent concentration then has to be controlled for safety reasons (to remain sufficiently below lower explosion limits) and for technical reasons (the influence on the evaporation of solvents from workpieces). Between 5 and 10 % of air volumes is sent to abatement. The low air volume and high solvent concentration are good preconditions for thermal oxidation.

Achieved environmental benefits: Reduction of VOC emissions.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Recirculation of air streams with increased solvent concentration is only suitable for installations which allow effective enclosure of spray booths (small inlet and outlet openings), where application is performed by automatic devices, and for workpieces without internal space volumes. It is therefore not applicable for car bodies, truck cabs and similar objects. Where appropriate, about 90 % reduction of VOC emissions can be achieved.

Economics: Reduced cost of thermal treatment, due to lower volumes, and higher VOC concentration achieve autothermal conditions.

Driving forces for implementation: SED. See Economics, above.

Example plants: Volkswagen, Wolfsburg, Germany.

Reference literature: [171, May, 2006]

16.4.7.6 Thermal oxidation

For a general description, see Section 20.11.4.2. If solvent-based coatings are used, usually the waste gas from the driers is treated in a combustion unit. The waste gas from painting booths is commonly not treated in a combustion unit. However, in the coating of wheel covers with conventional solvent-based paint, waste gas from the spraying cabins, driers and evaporation zones is routed to a post-combustion unit. A cleaned gas concentration of 20 mg C/m³ is reached. The capture of waste gases from driers only affects 10 - 30 % of the total VOC emissions.

[13, DFIU and IFARE, 2002], [76, TWG, 2004]

16.4.7.7 Biological treatment

For a general description, see Section 20.11.8.

[13, DFIU and IFARE, 2002]

16.4.8 Waste water treatment

16.4.8.1 Ultra and nanofiltration

For a general description, see Section 20.12.6. Wet separation spray booths are used and equipped with an ultrafiltration unit to separate the paint material, which is then recovered.

[13, DFIU and IFARE, 2002]

17 COATING OF FURNITURE AND WOOD MATERIALS

[13, DFIU and IFARE, 2002] [76, TWG, 2004] [107, VDI, 2005] [128, TWG, 2005]

17.1 General information on the coating of furniture and wood materials

Wood is a natural raw material characterised by its inhomogeneity and anisotropy, and which displays irregular properties in terms of surface structures, the varying contents of different substances (e.g. waxes, water, resins), and variable electrical resistance. Wood fibres often have the characteristic that they swell-up and become erect under the influence of liquids (in particular, with water). Wooden surfaces are coated, in order to conserve or strengthen the colour, surface structure and/or porosity. The coating is applied to provide, for example, resistance against:

- chemical impacts
- mechanical stress
- climatic impacts
- staining.

Currently, the wood and furniture industry is facing new market requirements, as complicated product geometry and higher qualities (e.g. colour variety, new surface effects) are demanded. To meet these expanding requirements, spray application techniques are increasingly being utilised.

This industry is characterised by a strong predominance of medium-sized companies, with 75 % of enterprises having less than 100 employees. In Germany, the following enterprises exist:

- 45000 joineries (with an average of 4.5 employees)
- 1500 wood and wooden furniture paintshops (with an average of 75 employees)
- approx. 8 very large enterprises with more than 1000 employees.

In the German wood and furniture industry, more than 80000 tonnes of paints were processed in 1999, with approx. 60 % being used in industrial applications and the remaining 40 % being consumed by handicraft enterprises. Over the past few years, the processed amounts of paints have slightly decreased, and it is expected that this trend will continue in the future. This is due to a number of reasons, including the shifting of production capacities to Eastern Europe, the increasing utilisation of plastic films for the surface design, a continuing reduction of the coating layer thickness and the increasing use of paints with high solids content.

Over the last few years, the level of automation of paint application in the furniture industry has increased significantly, mainly due to increasing quality, efficiency and environmental requirements.

A variety of materials are processed and coated in the wood and furniture industry. These can be distinguished in a number of fields of applications:

- exterior construction, fittings and furniture
- interior construction, fittings and furniture
- commercial and public applications, e.g. schools
- domestic applications
- wet applications, e.g. for swimming pools, saunas, kitchen and bathrooms.

17.2 Applied processes and techniques in the coating of furniture and wood materials

The application of coating materials for wood and wood materials involves:

- pretreatment of the wood surface
- application of a base coat
- application of a topcoat
- application of the paint
- flashing-off and drying/curing.

Depending on the desired surface structure (i.e. open or closed cell pore structure), different paint systems may be used. If the wooden grains need to be visible, e.g. for solid wood or veneer, uncoloured paints (i.e. clear coats), oils and waxes are used. For example, medium dense fibre (MDF) panels are coated with pigment paints of the desired colour. If pigment paint systems are used, a barrier layer is applied before the base coat, which restricts permeation of paint to the wooden sub-surface and allows a more uniform paint layer to be applied.

17.2.1 Pretreatment of the wood surface

Due to irregular growth and the varying surface structure, and because of the differing content of certain substances such as resin or wax, proper pretreatment of the surface to be coated is essential. This pretreatment can address different aspects of the wood, such as the existing surface flatness, removal of working marks, treatment of colour differences, unevenness, fibre erections, cracks, boughs, as well as wood moisture. Typical pretreatment techniques include:

- mechanical pretreatment, e.g. sanding
- colouring methods, such as:
 - staining
 - glazing
 - bleaching.

For some special kinds of wood, it is necessary to use chemical cleaning processes which utilise soap solutions, ammonia or organic solvents, together with a sanding technique for the disposal of paint incompatible wood substances such as resin and wax.

Sanding

Usually for ideal paint results, wood and wooden base materials need an intermediate sanding to be applied after the application of a base coat or after staining or the application of other paint layers, since an erection of wood fibres is caused by the interaction with fluids. This kind of napping of the wooden surface is especially significant when water-based paint systems are used.

Staining

The aim of staining is to change the colour of the wood to a darker colouring. The wooden structure and the pore structure respectively remain the same. Depending on the applied type of staining, the drying time varies considerably. Stains are suspensions of pigments or solutions of dyes in water or organic solvents. The most commonly applied stain is solvent-based. If chemical stains such as, for example, 1-component positive stains are used; longer residence times have to be taken into account. If water-based stains are processed, the swelling and roughening of the wood (napping) has to be allowed for. Also combinations of water-dilutable organic solvents and water can be used (combi-stains). The traditionally applied stain is a water-based material. The compositions of some different types of stains are listed in Table 17.1 below:

	Water content (%)	Content of organic solvents (%)	Proportion of pigments (%)
Water-based stain	up to 95	0	up to 15
Solvent-based stain	0	85 – 95	5 – 15*
Combi-stain	65 – 70	25 – 30	5
Note: * In some roller applications, the proportion of pigments may be up to 15 %			

Table 17.1: Composition of different types of wood stains [76, TWG, 2004]

Application is either carried out manually (with sponge, brush, rolls, spraying) or is automated (automated spray applications, rolling, foam rubber rolls). Subsequent drying takes place at ambient temperatures or in convection driers, flat driers or jet driers.

Glazing

Modern glazes are high liquid wood covers based on lacquer resins. The materials achieve a good penetration of the wood and often contain water repellents and fungicide ingredients to improve the wood. They may be colourless or may be pigmented with different colourings. Different materials are used for outdoor and indoor usage. Glazes without fungicides, as well as colourless wood glazes, are only suitable for indoor usage.

Bleaching

In general, bleaching brightens the wood colour. Sometimes it is necessary to bleach several times, for example if maple is used. For bleaching, hydrogen peroxide (30 – 35 %) and several additives or radiation are used. The impact time has to be adjusted to the desired effects. As bleaching splits off oxygen, a sufficient drying is necessary in order to avoid blistering. Bleaching is also used for wood with non light-resistant colourings such as cherry or rosewood. After bleaching, staining with highly light resistant pigments is used to reproduce the original wood colouring. If PUR coating systems are used, the curing agent has to be peroxide-resistant.

17.2.2 Application of a base coat

Base coat material needs to be suitable for sanding down. Application techniques include:

- spraying (manually or automatically; conventional, airless, air assisted airless (so-called 'airmix') and electrostatically assisted)
- casting
- rolling (e.g. using a UV curing lacquer suitable for rolling)
- dipping (only for special workpieces).

After drying of the pretreatment stage, sanding (with material of an appropriate grain size) takes place before a colourless base coat is applied. Afterwards the surface is sanded again before a topcoat is applied. In some cases, a wooden structure is printed directly onto the base coat. As the substrate, mainly simple veneers are used or alternatively, the surface to be coated may already incorporate a coloured base coat/stopper.

17.2.3 Application of a topcoat

For the coating of wood and wood materials, paints, foils or other panel-like coating materials, as well as textiles or leathers are used. Some specific coatings are:

- nitro cellulose paint (NC) sometimes called cellulose nitrate paint (CN)
- acid curing paints
- polyurethane paints (PUR)
- unsaturated polyester paints (UP):
 - open-cell UP materials
 - thick-film layer systems
- water-based paints
- powder coatings
- alkyd paints/glazes
- combined/mixed paint systems
- waterborne UV lacquers
- 100 % UV lacquers.

The same application techniques are used as described in Section 17.2.2.

Table 17.2 itemises the main properties of the most commonly used wood stains and paints.

Wood stain or paint type	Proportion of solvent (%)	Proportion of water (%)	Components	Type of reaction	Catalyst	Remarks
Wood stain						Organic solvents; water-dilutable solvents; combi-wood stain; water-dilutable solvents; napping of wood
• solvent-based						
– type a)	95	0				
– type b)	70	25 – 30				
– type c)	25 – 30	70 – 80				
• water-based	0	85 – 95				
NC paint (CN paint)						Surface resistance with limited usability
• uncoloured	approx. 75	0	Collodium wool (cellulose nitrate)	Physical drying		
• pigmented	approx. 60	0				
Acid curing paint			Alkyde-melamine urea resins polyoles	Forced drying	Acid	Older paint systems emitted formaldehyde; high resistance
• 2-component; uncoloured	40 – 50					
• 2 component, pigmented	20 – 30					
• 1-component; uncoloured	20 – 30					
PUR paint			Isocyanates; acrylates; polyesters	Addition reaction (physico-chemical)		Generally 2-component materials; high resistance
• uncoloured	65 – 70	0				
• pigmented	36 – 60	0				
• medium solid; uncoloured	40 – 50	0				
UP paint			Polyester, unsaturated (organo-metallic materials)	Polymerisation		Component systems; for infrared curing UP coatings, pre-drying and curing times have to be allowed for
• conventional	approx. 35 (15)	0		• heat	Organic peroxides	
• containing paraffin	approx. 35 (15)	0		• radiation		
• free of paraffin	approx. 35 (15)	0				
• UV curing	approx. 35 (15)	0				
– rolling lacquer	approx. 20 (20)	0				
– stopper	approx. 20 (10)	0			UV radiation; photo initiator	
• UP-spraying paint						
– uncoloured	65 – 70	0				
– UV curing	65 – 70	0				
Acrylate paint			Polyacrylate, unsaturated	Electron beam	Photo initiator	
• UV curing	2 – 40					
– rolling lacquer	2 – 10					
– spraying paint open cell structure	65 – 70					
• electron beam curing	2 – 5					

Wood stain or paint type	Proportion of solvent (%)	Proportion of water (%)	Components	Type of reaction	Catalyst	Remarks
Water-based paint <ul style="list-style-type: none"> • conventional drying • UV curing • PUR, 2-component 	5 – 7 approx. 2 approx. 9	60 – 65 58 – 60 60 – 65		Physically drying; polymerisation; addition reaction	UV radiation	Napping of the wood; longer drying times; possibly application of UV base coat followed by a water-based paint application; UV curing water-based paint is becoming more and more significant. UV coating can only be applied where flat pieces can be coated separately and coating is done before the piece of furniture is assembled
Powder coating <ul style="list-style-type: none"> • conventional drying • UV curing 	0	0	Epoxy resins Polyester-acrylate resins	Addition and condensation	UV radiation	Powder coatings with conventional convection drying are not suitable for the coating of wood at present. Application systems exist only for the coating of MDF
Alkyde resin paints	10 – 80	0	Alkyde resins	Oxidation in air physico-chemical drying	Organo-metallic compounds	Organic solvents

Note (1) data in brackets means the solvent content emitted as % of the coating

Table 17.2: Overview of the properties of wood stains and paints
 [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

17.2.4 Application of the paint

The following application techniques are used for wood and wood materials:

- painting, rolling
- manual spraying (partly also using electrostatically assisted processes)
- automated spraying (partly also using electrostatically assisted processes)
- automated spraying with or without the recycling of overspray (partly also using electrostatically assisted processes)
- rolling
- vacumat technique
- filling with stoppers
- curtain coating
- dipping/flooding
- printing.

Besides manual spray applications, spraying installations or spraying machines equipped with 2-component dispensing units are in use in the furniture industry. Table 17.3 lists the achievable application efficiency factors.

Application technique	Efficiency factor ⁽¹⁾	Remarks
Painting, rolling	95 – 100	Reduced uniformity of surface
Spraying, conventional	30 – 60	High amount of overspray
Spraying, HVLP	40 – 75	Application of low viscous wood stains, increasing use also for other paint systems
Hot spraying	40 – 60	Application of paints with a high solids content, also applicable for hot wax spraying
Airless spray application	40 – 75	Bundling of sprayed material
Air assisted airless technique	35 – 50	Bundling of sprayed material
Spraying, electrostatically assisted wet lacquer	50 – 70	Electrical conductivity has to be considered
Spraying, electrostatically assisted powder	80 – 95	Electrical conductivity has to be considered. Currently, only applicable for the coating of MDF (only a few applications)
Curtain coating	95	Limited by workpiece's geometry
Rolling	95	Limited by workpiece's geometry
Vacumat technique	95	Only applicable for narrow parts and edges, water-based paints and UV curing materials with a high solids content, also the workpiece's geometry has to be considered

⁽¹⁾ Depending on the occupancy rate and geometry of the workpieces, etc.

Table 17.3: Achievable application efficiency factors
[13, DFIU and IFARE, 2002]

17.2.5 Flashing off and drying/curing

Drying/curing of the paint layer requires an intense flashing-off. The flashing-off takes place in special installations that are generally located upstream of the driers. For water-based paints, the humidity of the evaporating air needs to be taken into account to enable a sufficient drying.

Some specific drying processes applied (some more commonly applied than others) are:

- through-circulation drier with dehumidification
- convection driers
- infrared systems:
 - thermal reactors
 - near infrared drying (NIR drying)
- UV radiation drying
- microwave
- high frequency driers (HF driers)
- X-ray curing.

17.2.6 Examples of some coating processes

Coating of chairs

In most of the cases, the first layer used for coating chairs is solvent-based to minimise raising the grain. Chairs made of beech wood are generally coated with a colouring wood stain or a glaze first. After pre-sanding, a first layer of a water-based coat (120 g/m²) is applied. The material dries at ambient temperature or via forced drying. After a second sanding, a second layer of water-based paint (120 g/m²) is applied and subsequently dried. The electrostatically assisted spray application of water-based paints is usually used for the coating of chairs due to their geometry. Thus the overspray and, therefore, the amount of paint and the VOC emissions are reduced.

Coating of window frames

Compared with other sectors of the wood industry, the coating of wooden windows is often still carried out manually. As the wood surfaces of windows have to resist weather influences and blue stain infestation, up to four coating layers are partly necessary to achieve sufficient resistance. Both the grinding and the drying processes are very demanding with respect to time and work. The use of water-based paints (e.g. acrylate paints) for the coating of windows is state-of-the-art in Germany, although solvent-based coating systems (e.g. alkyd paints) are also used. Water-based paints show a lower wet adhesion compared to conventional solvent-based paints.

Flooding is a widely used application technique for the coating of pressed frameworks for wood preservation and base coating. Here, the topcoat is applied via spray application in one or two layers in the form of a water-based paint system. Due to the workpiece's geometry, a high amount of overspray is generated even if an electrostatically assisted spraying process is used. To reduce costs and environmental impacts, lacquer recovery installations are utilised. Furthermore, the spraying booths are equipped with a dry separation of overspray in order to avoid coagulation or disposal of paint sludge.

Coating of high quality furniture

[128, TWG, 2005]

The following process steps are carried out for the coating of high quality furniture:

1. sanding and removal of dust
2. adaptation of colour, e.g. by staining
3. sanding and removal of dust
4. base layer
5. sanding and removal of dust
6. top layer.

The second step is mostly by (manual) spraying, steps 4 and 6 also mostly by spraying. UV curing paints are rarely used in the coating of high quality furniture. The main reason is because it can only be applied where flat panels can be coated separately and coating is done before the piece of furniture is assembled. However, if the pieces of the furniture are not yet assembled, it is possible to use UV-based coatings, and hence another type of application than spraying (mostly by rolling).

At least one German company (Rippert GmbH) and one Finnish company (Tikkurila Coatings Oy) have separately developed a UV curing method, which utilises UV curing under inert atmosphere. With this method it is possible to cure UV lacquers and UV paints on 3D components and on assembled chairs. Equipment and coatings are commercially available.

For furniture made of solid pieces of wood (whose surfaces are oiled or waxed) destined for kitchens, bedrooms, living rooms and children's rooms, the following processes are generally carried out:

1. the pre-sanded furniture parts are treated with smoothing brushes
2. after dedusting, the oil is applied onto the wood surface with a spraying machine
3. subsequently the oiled workpieces are brushed
4. a hot wax is applied via spraying
5. the waxed surface is brushed
6. the workpieces are turned over and processes 1 – 5 above are repeated.

Powder coating of MDF panels

Powder application onto MDF panels for the production of TV units and office furniture is carried out without previous priming. The entire plant length for preheating, coating, curing and cooling is significantly shorter than for a conventional plant, as coating takes place in a single working cycle.

Due to the very low electrical conductivity of MDF, the plates are preheated up to 60 - 70 °C before the powder is applied via corona spray guns. At this temperature, the powder particles adhere to the MDF surface creating a consolidated coating that is subsequently dried by UV radiation. Grinding processes following the respective drying steps are not required.

Due to the recycling and re-use of powder, significant cost savings can be achieved. However, this application technique is only applicable for certain colourings and surface structures.

Coating of wooden kitchen and bathroom furniture

Kitchen and bathroom furniture is made of solid pieces of wood (e.g. oak, beech, maple, stone pine, and cherry) and wood materials (e.g. MDF) and coated. For painting, wet paint systems are used exclusively with a significant proportion of water-dilutable UV paint as well as water- or solvent-based wood stains. At present, solvent-based polyester and PUR paint is only applied in small amounts, partly for the painting of spare parts. Wood stains are applied via automated roller coating heads. Conversion to water-dilutable UV curing paints for base and topcoats was undertaken for environmental, labour protection and technological reasons and in order to reduce the fire hazard. The applied materials have a solvent proportion of 1 - 2.5 % by weight. The coating is mainly carried out in fully automated installations. The material is applied via compressed air spraying. The overspray is collected (via doctor blades) and re-used.

Paint particles of the exhaust air are separated dry. In general, the paint system consists of two layers. The base coat surface can be sanded before the topcoat is applied. Due to the use of water-dilutable UV curing paints, the amounts of emitted solvents are very low and amount, even in big installations, to less than 10 kg/h. Exhaust gas cleaning with regard to VOC is therefore not in use. The exhaust air is emitted directly via a stack. Cleaning agents are recycled via distillation.

17.2.7 Finishing with solid coating substances

Solid coating substances are materials which are pressed in the solid state onto panel-like or profiled workpieces. They may be veneers, sheets, papers or laminates.

Veneers

Veneers are thin sheets of wood having a thickness of about 0.5 to 2 mm and are applied to the base panels by exposing them to temperature and pressure in presses. Standard adhesives are urea-formaldehyde (UF) resins and polyvinyl acetate (PVAC) glues.

Sheets, papers or laminates

These are applied to the base panels using various adhesives by exposing them to temperatures and pressure using surface presses, membrane presses and roller presses. This process is termed lamination. Standard adhesives are glues composed of ethylene vinyl acetate copolymer (EVA) for decorative papers and sheets, and urea-formaldehyde (UF) adhesive resins and polyvinyl acetate (PVAC) glues for laminates.

Adhesives and glues

PVAC glues contain water, the polyvinylacetate binders and organic solvents (generally up to 3 % by mass of butyl or ethyl acetate) and the amounts applied are approximately 120 g/m². During drying, water and not more than 3.6 g of solvent are emitted per m².

UF resins contain urea-formaldehyde resin, possible extenders, catalysts and water. The so-called 'free formaldehyde' component of the adhesive is between 0.1 and 0.5 % by mass, most of which is incorporated during curing. The amounts applied are approximately 100 g/m². During curing, water and formaldehyde which has not been incorporated are emitted.

EVA glues contain ethylene vinyl acetate copolymer, water and, in some cases, up to 3 % by mass of organic solvents, generally ethanol and toluene. The amounts applied are approximately 90 g/m². During drying, water and, if they are present, up to 2.7 g of organic solvents are emitted per m².

17.3 Current consumption and emission levels in the coating of furniture and wood materials

For the coating of furniture and wood materials the main issue for air pollution control is the emission of VOCs. Wastes and waste water generation, as well as energy consumption are also issues.

17.3.1 Mass balances

No data submitted.

17.3.2 Consumptions

17.3.2.1 Materials

Table 17.4 below itemises the applied quantities of paint materials for different application techniques:

Application technique	Quantity (g/m ²)	Remarks
Rolling	25 – 60	
Curtain coating	60 – 250	In exceptional cases up to 500 g/m ²
Dipping	60 – 200	
Flooding	60 – 200	
Spraying	Up to 250	Material losses due to low efficiency
Printing	1 – 2	

Table 17.4: Quantities of paint materials applied in different application techniques [13, DFIU and IFARE, 2002]

Table 17.5 below gives examples of the amounts of paint and solvent applied on average in each different production sector.

Product	Coating process	Amount of paint (g/m ²)	Amount of solvent (g/m ²)
MDF panels	<ol style="list-style-type: none"> base coat, water-based, roller application water-based, roller application printing ink, water-based AC paint via roller application, UV curing* Drying: convection driers or UV driers	80	3
Stairs	<ol style="list-style-type: none"> parquet seal, water-based grinding parquet seal, water-based or solvent-based, spray application of one or two layers hot spraying Drying: at ambient temperature, convection driers or infrared drying	180	12
Bedroom furniture	<ol style="list-style-type: none"> spray application of two layers of pigmented water-based or solvent-based paints, with intermediate sanding lime paste, spray application grinding colourless, water-based paints, spray application Drying: at ambient temperature, tray system driers	150	9
Doors	<ol style="list-style-type: none"> base coat, water-based, roller application wood stain, roller application AC base coat via roller application, UV curing* grinding two layers of AC paint via roller application, UV curing* Drying: convection driers or UV driers	60	10
Tables	<ol style="list-style-type: none"> combi-stains, spray application AC base coat via roller application, UV curing (3 layers) grinding AC paint via roller application, UV curing Drying: at ambient temperature	100	30
Living room furniture	<ol style="list-style-type: none"> natural oil, hot spraying Drying: at ambient temperature	23	0
	<ol style="list-style-type: none"> grinding solvent-based products (for assembled products), UV-based for flat pieces natural wax with hot spraying (infrequent) Drying: infrared-curing	55	9
Note: * Solvent-based products are still widely used. In many cases in the furniture industry, UV curing coatings are used, especially for flat pieces, which are nearly all UV cured.			

Table 17.5: Applied paints and amounts of organic solvents: examples of different applications in the wood and furniture industry [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

17.3.2.2 Water

No data submitted.

17.3.2.3 Energy

No data submitted.

17.3.3 Emissions**17.3.3.1 Emissions to air**

Table 17.6 summarises some VOC emissions for various painting systems.

Application technique	Solvent content (wt-%)	Emission reduction measures	VOC emission (g/m ²)*
Paint system with high organic solvent proportion and spraying	65	None	80 – 100
Paint system with a high organic solvent proportion	65	Application techniques with an increased efficiency factor (rolling, flooding, dipping, electrostatically assisted spraying, airless spraying) and good housekeeping	40 – 60
Paint system with a medium solvent content	20	Same as above	10 – 20
Paint system with a low organic solvent content	5	Same as above	2 – 5
*Note: these figures depend on the amount of material used and the rate of application. The figures given are for usual rates of application and are a guide only.			

Table 17.6: Specific VOC emissions for various paint systems and, some, with primary emission reduction measures

[13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

17.3.3.2 Emissions to water

The volume of generated waste water in the coating of wood is generally very small, since the process water circulates in a closed loop. When using water-based coatings (some of them tested nowadays), a significant amount of waste water is generated, which, in some cases, overflows the closed loop capacity of the spray installation.

17.3.3.3 Waste

Especially for the coating of profiled, wooden workpieces, the base and topcoat are applied via spray applications. Thereby, losses via overspray are generated within the spraying booths in one of two waste forms:

- if wet separation is applied, the overspray forms paint sludge. The paint sludge then consists of paint particles, small amounts of organic solvents, coagulation agents and water. Paint sludge is generally regarded as a waste that needs monitoring. In general, the material is used as a fuel in special refuse combustors
- if the overspray is separated dry, contaminated glass fibre filter mats have to be disposed of. As soon as a specific minimum velocity of the airflow is reached, the filter mats have to be replaced. The filter mats, now contaminated with dried paint particles, generally do not need monitoring and can be used as a fuel in regular waste incineration plants.

Mixed 2-component paints cannot be recycled and are disposed of. The solvents are recovered from non-cured paints. In addition, contaminated solvents are generated from the cleaning of application devices, conveyer systems, paint pipelines, spray booths and others. In general, cleaning agents used in the wood industry are recycled via distillation and can be used as recycled cleaning agents. The distillation generates paint leftovers in solid, liquid or paste-like forms. Contaminated solvent, solids from distillation, dried 2K paint and other residues and leftovers that are not re-used are disposed of, usually as hazardous waste.

Hazardous properties of paint sludge from paint overspray have been analysed and in many cases, there is a lack of overall background data on wastes. Therefore, co-operation between paint or lacquer producers, waste producers, environmental authorities, and waste researchers and laboratories is very important. For example, in one study in Finland, the formaldehyde concentrations were analysed based on information received from the producers of paints and lacquers. This provided the essential information for overall assessment of the chemical and ecotoxicological hazard of residues studied. The results confirmed the benefit of combining chemical and ecotoxicological assays in assessing the potential environmental hazard of complex organic mixtures found in paint residue wastes. The pretreatment studies showed that the amount of residues could be minimised by reducing the liquid content of water-curtain-booth residues, and the hazard was decreased by changing the raw materials in the spray painting process to paints and lacquers that contain less harmful solvents. The results also proved that landfilling is not a suitable method of disposal for the paint residues produced in the furniture industry. For these types of organic wastes, a better alternative method of treatment could be incineration. The information of the ecotoxicological and leaching properties of excess paint residues produced in different spray painting processes helped paint producers to develop their products and makes it possible for furniture producers to choose environmentally safer products. Furthermore, this hazard-screening approach will help furniture producers to improve the surface paint process of furniture making in order to minimise the amount and hazard of the wastes produced.

17.4 Techniques to consider in the determination of BAT for the painting of furniture and wood materials

In Chapter 20, techniques are discussed which might also be applicable to the painting of furniture and wood materials. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to the painting of furniture and wood materials. In Table 17.7, the general techniques relevant for the painting of furniture and wood materials that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

The EGTEI synopsis sheets for the coating of wood (see Annex 24.1.1) give some data on the cost-benefit at a European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects or of the technical characteristics of individual installations or products [140, EGTEI, 2005].

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 17.7: Reference to techniques generally applicable to the sector

17.4.1 Minimisation of raw material consumption

17.4.1.1 Batch painting/colour grouping

For a general description, see Section 20.6.3.6.
[13, DFIU and IFARE, 2002]

17.4.1.2 Pig clearing systems

For a general description, see Section 20.6.3.7. In the furniture industry, there is an increasing demand for furniture to be painted in individual and special colours and, consequently, the use of pig clearing systems.
[13, DFIU and IFARE, 2002]

17.4.1.3 Online mixing system for 2-component products

For a general description, see Section 20.6.3.1. This technique is commonly applied.
[63, Vito, 2003] [13, DFIU and IFARE, 2002]

17.4.2 Conventional solvent-based materials

Description: See Section 20.7.2.1. Nitrocellulose paint is classical solvent-based furniture paint. However polyester-, alkyd-, and polyurethane-based paints are commonly applied. Alkyd paints are predominantly used as glazes for outdoor applications. Glazes are transparent painting systems being applied to emphasise the appearance of the wood surfaces. However, these glazes can also be water-based.

Conventional solvent-based paints contain the following solvent contents by weight:

- wood stain: 95 % organic solvent
- wood stain: 70 % organic solvent, 30 % water
- base coat and topcoat: up to 80 % organic solvent.

Achieved environmental benefits: Compared to water-based systems, less energy is required for drying.

Cross-media effects: High VOC emissions.

Operational data: Solvent-based paints have a shorter drying time and, thus, a higher production capacity can be achieved.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: Short drying times are an important issue in the use of solvent technology.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005]

17.4.3 Replacement of solvent-based materials (substitution)

17.4.3.1 Water-based coatings

Description: For the general description, see Section 20.7.2.3. The following water-based coating systems are applied:

- wood stain: 0 % organic solvent
- wood stain: 25 - 30 % organic solvent
- base and topcoat: 5 - 7 % organic solvent; conventional drying system.

Water-based UV curing paints (about 2 % organic solvent) and 2-component paints based on polyurethane (about 9 % organic solvent) are also applied.

Achieved environmental benefits: Significant VOC reductions.

Cross-media effects: Extra sanding and polishing is often necessary to get a smooth surface after each painting step. This produces more waste and more raw materials are consumed.

Operational data: No data submitted.

Applicability: 2-component paints are widely applied in painting, e.g. for durable surfaces such as floor coverings and kitchen fronts.

The application of water-based paints depend on the product used, the surface, the base coat layer (primer), the application method, the desired 'end quality', the availability of high quality products and the product segment the company is aiming at. Currently, the availability of high quality coatings is not sufficient.

Economics: The following investments may be necessary:

- forced drying (usually the largest investment)
- additional area needed for the drier as well as the larger intermediate storage for painted workpieces, in between repeated operation cycles
- stainless steel equipment for paints storage, tools manipulation equipment, etc. whereas standard steel grades can be used for solvent-based paints.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [147, Presti, 2005]

17.4.3.2 Powder coating – conventionally dried

Description: See Section 20.7.2.6. Powder coatings with conventional convection drying are applied to MDF and HDF (medium and high density fibres). They are currently not suitable for the painting of wood, because of the high temperatures needed for drying and the low surface quality achieved.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: The powder application onto MDF panels for the production of TV and office furniture is carried out without previous priming. The entire length of plant needed for preheating, coating, curing and cooling is significantly shorter than that needed for a conventional plant: coating takes place in a single working cycle. Sanding processes following the respective drying steps are inapplicable.

Due to the very low electrical conductivity of MDF, the plates are preheated up to 60 - 70 °C before the powder is applied via electrostatically assisted spray guns. At this temperature, the powder particles adhere to the MDF surface creating a paint layer which is consolidated and subsequently dried by UV radiation.

Low temperature powder coatings, suitable for wooden substrates in general, are applied in, e.g. Sweden and the UK. This technique is not commonly applied.

The re-use of overspray is not possible in short production runs and for frequent colour changes, which often occurs in furniture manufacturing.

Applicability: Only used for MDF, and for low quality parts. Not suitable for coating solid wood or veneers.

Economics: Due to the recycling and re-use of powder, significant cost savings can be achieved.

Driving forces for implementation: No data submitted.

Example plant: Stilexo Industrial, UK.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005] [63, Vito, 2003]

17.4.3.3 UV radiation curing paints

Description: See Section 20.7.2.5.

Achieved environmental benefits: Water-based and solvent-free radiation curing paints do not generate VOC emissions.

Cross-media effects: None.

Operational data: UV curing paints can be applied by several different techniques, such as brushing, rolling, casting, spraying and vacuum coating.

Applicability: UV curing water-based coatings are not currently commonly used, but are increasingly applied in furniture and wood painting. UV curing water-based paints are commonly applied in the coating of chairs, boxlike furniture, office and kitchen furniture, room doors, panels, chipboard for living and bedroom furniture, etc. These paints can be applied for all paint layers. UV curing products are possible where flat panels can be coated separately and coating is done before assembling the piece of furniture. There can be some application of UV curing coatings in the section of joinery and finishing panels. The use of infrared curing products is less known.

At least one German company and one Finnish company have separately developed a UV curing method, which utilises UV curing under inert atmosphere. With this method, it is possible to cure UV lacquers and UV paints on 3D components such as assembled chairs. Equipment and coatings are commercially available.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: For 3D coatings: Rippert GmbH, Germany, Tikkurila Coatings Oy, Finland.

Reference literature: [13, DFIU and IFARE, 2002], [76, TWG, 2004] [128, TWG, 2005]
For coating in 3D: RadTech 2005 conference proceedings, www.tikkurila.fi.

17.4.4 Paint application techniques and equipment

17.4.4.1 Rolling and filling by using reverse coaters

Description: See Section 20.7.3.1. Filling is commonly applied.

Achieved environmental benefits: The efficiency of this is very high. Depending on the workpiece and the processing conditions, material efficiencies of about 90 - 100 % can be achieved. Material savings of up to 40 % can also be achieved.

Cross-media effects: No data submitted.

Operational data: In most cases, normal roller coating is used, with good results, including on closed-cell surfaces.

In 2002, an increasing demand was seen for coatings for closed-cell substrates such as beech, maple, pear, birch, and cherry woods. For the best quality veneer, this had previously only been possible with conventional rolling or spray applications. However, the use of heated smoothing rollers for the application of base coat shows significant advantages. It enables the filling and smoothing of porous surfaces without the application of excess material. Furthermore, cracks in the surface of the veneer and joint connections, raw chipboards, MDF panels and other wood material panels can be filled. Thus, a smoother surface is created and the wood gets a filled and smooth appearance.

These advantages are caused by the opposite rotating heated smoothing rollers that process the UV paint applied onto the workpiece surfaces via the application roller. In this way, the paint is worked into the workpiece's surface. Pores, veneer cracks and splices are also filled this way. The heating of the smoothing roller ensures that the cohesion within the paint layer is reduced, so that the material remains in the filled pores. Additionally, the paint material shows better running properties and forms a plain, even surface.

Applicability: In general, rolling techniques are in use for the application of water-dilutable paints and UV radiation curing paints. Mainly applicable to flat workpieces, but also slightly curved products such as wooden panels can be processed. Application weights from 25 – 60 g/m² can be processed, according to the machine type. Reverse coaters are only applicable for flat workpieces and, therefore, mainly used for plates derived from wood products. For more curved surfaces, stoppers are applied by hand operated equipment such as palette knives.

Economics: A lightweight filling machine used in wood and furniture coating, with a working width of 1.3 metres and an installed electrical load of 5.5 kW cost EUR 55000 in 2000. A machine used in wood and furniture coating with, for example, a foam roller, a working width of 1.3 metres and an electrical load of 3 kW costs about EUR 30000. A machine applying two rollers (double system) with the same working width and an electrical load of 6 kW costs EUR 60000. Both examples are from 2005.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

17.4.4.2 Curtain coating (casting)

Description: See Section 20.7.3.2. Curtain coating (casting) is commonly applied for coating doors, wall units and other plates. Mostly solvent-free lacquers based on polyester are applied, but also other types of coating materials can be processed. Curtain coating can achieve a high quality in the equality of layers.

Achieved environmental benefits: Depending on the workpiece and the conditions of processing, material efficiencies of about 90 - 98 % can be achieved.

Cross-media effects: No data submitted.

Operational data: In comparison to rolling, the wooden workpieces do not have to be absolutely plain. Within a curtain coater, the paint material used is pumped into a header tank from where the coating is discharged in the form of a fine lamina film. The workpieces that need to be coated are sent through this film. Excess paint material is collected in a reservoir and pumped back into the header tank. An efficiency of approx. 95 % is achieved. All types of paint materials can be applied by this technique.

Applicability: In the casting process, plain or almost plain workpieces are coated. According to the machine type, application weights from 60 – 250 g/m² can be processed.

Economics: A casting installation applied in wood and furniture coating with a working width of 1.3 metres and an installed electrical load of 3 kW costs EUR 35000 (year 2000).

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [128, TWG, 2005]

17.4.4.3 Conventional dipping

Description: See Section 20.7.3.3. The conventional dipping technique is commonly applied for the coating of windows in serial production.

Achieved environmental benefits: The advantages of dipping is that it produces very high efficiencies of up to 100 %, complete coatings of workpieces (of outer surfaces as well as inner), cost effectiveness, high operational capacity and good possibilities for automation. However, efficiency ranges of 80 - 90 % are also reported.

Cross-media effects: Compared to spraying, thicker coating layers are achieved which might consequently result in a higher consumption of raw material.

Operational data: Workpieces are either dipped manually or transported and dipped via conveyor systems. Dipping into water-based paints might produce foam. Water-based paints are only stable in a small range of pH levels and, therefore, very sensitive to contaminations that might be dragged over from the pretreatment processes. A drying step after pretreatment, such as cleaning processes, is often not necessary when applying water-based paints. The dipping tank must be equipped with a mixer, circulation pump with filter and thermoregulator.

Application weights from 60 – 200 g/m² can be processed.

Applicability: For the serial production of bulk articles that are coated in a single tone without colour changes, dipping is applicable. Only 1-component paint systems are applicable.

This technique is not applicable for open-cell surface structures of coated products. Also mostly, parts of furniture that are treated differently (e.g. fronts, inlays, backsides) and profiles cannot be dip coated (pore formation is not possible) due to the unfavourable overstretching of profiles.

Economics: This is a cost effective technique.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [147, Presti, 2005]

17.4.4.4 Flooding

Description: See Section 20.7.3.5.

Achieved environmental benefits: Depending on the workpiece and the conditions of processing, efficiencies of 95 - 99 % can be achieved. In comparison to the dipping application, the evaporation losses are higher.

Cross-media effects: No data submitted.

Operational data: In flood coating installations, the workpieces are transported via conveyor systems into closed channels. There, the workpieces are flooded with the paint material via injection tubes. The surplus paint material is absorbed at the bottom of the channel and re-used.

Application weights from 60 – 200 g/m² can be processed.

Applicability: The process is especially suitable for wooden workpieces that tend to swim. Applicable for serial production and large workpieces with a large surface area, without a lot of colour changes.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002],

17.4.4.5 Vacuum coating

Description: See Section 20.7.3.6.

Achieved environmental benefits: Depending on the workpiece and the conditions of processing, efficiencies of 80 - 100 % can be achieved.

Cross-media effects: None.

Operational data: Vacuum coating is only applicable to wood that can withstand vacuum. To test this, a piece of wood is put under low pressure (i.e. <10⁻⁶ bar). The wood is not suitable for vacuum coating when the pressure rises with some 10⁻⁶ bar per minute.

Apart from water-based paints, vacuum coating has also been recently applied to UV curing paint on wood or wood-composites.

Applicability: Vacuum coating is commonly applied in the painting of MDF panels, solid wood, veneer, profiles made out of paper composites, window panes, skirting boards, and panels for walls and ceilings.

Economics: In a real case situation, changing from air assisted airless spraying of water-based paints with infrared drying to vacuum coating, applying UV curing paints resulted in a yearly saving of EUR 262000. The machine cost was EUR 140000. Payback time was less than two years. The result was avoidance of VOC emissions (14 tonnes/yr) and waste (which used to be 100 tonnes/yr) and the material of the UV curing paint was 100 % efficient (2003).

Driving forces for implementation: No data submitted.

Example plants: True Temper Hardware Company, Pennsylvania, US, producing wooden stems and handles.

Reference literature: [63, Vito, 2003], [76, TWG, 2004]

17.4.4.6 Conventional high and low pressure spraying

Description: See Section 20.7.3.8. Compressed air spraying is used, for example for the application of water-based UV curing paint (1 – 2.5 wt-% organic solvent) in an automated installation for the coating of kitchen and bathroom furniture.

Achieved environmental benefits: No data submitted.

Cross-media effects: Raw material consumption is very high (see application efficiencies in Operational data, below).

Operational data: All surfaces can be coated by this method and high surface qualities can be achieved.

Applicability: The efficiency varies from about 5 % for lattice-like workpieces to about 30 - 60 % for workpieces with a larger surface area.

Economics: No data submitted.

Driving forces for implementation: Widely used. Represents the status quo.

Example plants: Widely used.

Reference literature: [13, DFIU and IFARE, 2002]

17.4.4.7 High volume low pressure spraying (HVLV)

See Section 20.7.3.9. This is commonly applied for low viscous wood stains and increasingly for other paint systems. [13, DFIU and IFARE, 2002]

17.4.4.8 Electrostatically assisted compressed air, airless and air assisted spraying

Description: In this technique, the paint is atomised in an electric field, see Section 20.7.3.17. Electrostatically assisted spray applications can be utilised if more electrically conductive materials, such as solid wood for the production of windows, chairs and pad racks are processed.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: The Faraday cage effect makes it impossible for the paint particles to reach cavities. The humidity of wood needs to be at least 10 % to achieve sufficient conductivity of the workpiece.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [147, Presti, 2005]

17.4.4.9 Powder coatings – electrostatically assisted spraying

Description: See Section 20.7.3.18. Powder coatings can be applied by all common spray application techniques. However, the best results are achieved via electrostatically assisted spraying.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: Due to the very low electrical conductivity of MDF, the plates are preheated up to 60 - 70 °C before the powder is applied by electrostatically assisted spraying. At this temperature, the powder particles adhere to the MDF surface creating a paint layer which is consolidated and subsequently dried by UV radiation.

Applicability: Commonly applied when powder coating is used for the painting of furniture and wood.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

17.4.5 Spray booths

17.4.5.1 Wet separation booth

Description: See Section 20.7.4.1. This is a spray booth of stainless steel equipped with a water spray at the back and possibly sides, to absorb the overspray. These are commonly applied and equipped with cascades, or the water is circulated with air flotation and with paint recycling.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: Purchasing costs for a wet separation spray booth with a capacity of 13 kW and 7000 m³/h air output is EUR 150000 (reported 2002).

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003]

17.4.5.2 Paint-in-paint spray booth

Description: See Section 20.7.4.2.

Achieved environmental benefits: Typically 33 - 50 % of the overspray can be re-used.

Cross-media effects: None.

Operational data: Different designs are available, also as an integrated part of an automated spraying zone or line. Cleaning the screen after a colour change takes about five minutes.

Applicability: This process is applicable for 1-component, solvent- and water-based paints. It can be applied in automated and manual spraying activities. It is, however, less suitable for small series with many colour changes and for paints with a short shelf life. Mostly dry or wet spray booths are used. The many different colours used makes this application sometimes impossible to apply.

Economics: The price level of these spray booths is between EUR 25000 – 60000 for air output flows of 5000 – 10000 m³/h. Purchasing costs for a spray booth for manual spraying with a capacity of 15 kW and 7200 m³/h air output is EUR 80000.

The investment costs for a ‘water curtain wall’ in a traditional manual spray cabin are between EUR 30000 and 75000 depending on the size of the wall. The investment cost for a rotating system is between EUR 40000 and 180000 for one spray cabin (reported in 2006).

Energy costs for the cooling of the screen are about EUR 1000 per year. Savings include a reduction of raw material because paint is re-used and less waste paint needs to be disposed of.

The system is economically viable for companies applying 15 tonnes of paint or more per year. Reported payback times of six case studies are in the range 1.5 – 5 years.

Driving forces for implementation: No data submitted.

Example plants: Airtech from Denmark.

Reference literature: [13, DFIU and IFARE, 2002], [63, Vito, 2003], [76, TWG, 2004] [146, CEI-BOIS, 2006]

17.4.6 Drying

17.4.6.1 Convection drying

For a general description see Section 20.8.1.1. This is commonly applied in wood and furniture coating. The drying of wood or synthetics is limited.

[13, DFIU and IFARE, 2002] [63, Vito, 2003]

17.4.6.2 Microwave drier

Description: For a general description, see Section 20.8.1.4.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: It has been reported by a national industry association that there are not many examples of water-based coatings in the furniture industry being used.

Applicability: A microwave drier is not suitable for thick workpieces (>20 cm). This technique is not commonly used in Europe.

Economics: The costs for an installation (without the connection, etc.) are between EUR 55000 - 100000 (12 kW).

Driving forces for implementation: No data submitted.

Example plants: One experimental installation in Norway. The energy consumption is estimated to be 10 - 30% higher versus traditional techniques (IR, hot air).

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [146, CEI-BOIS, 2006] [147, Presti, 2005]

17.4.6.3 High frequency driers

For a general description, see Section 20.8.1.4. Due to the fast evaporation of water, the napping of wood fibres and the amount of dust arising is significantly reduced. It has been reported by a national industry association that there are not many examples of water-based products in the furniture industry being used. Finishing panels is done with UV curing products, which requires other types of driers.

[13, DFIU and IFARE, 2002] [76, TWG, 2004]

17.4.6.4 Infrared radiation curing

For a general description, see Section 20.8.2.1. This technique is applied in combination with circulating air driers. Infrared radiation may alter the wood.

[13, DFIU and IFARE, 2002] [76, TWG, 2004]

17.4.6.5 Near-infrared radiation curing

For a general description, see Section 20.8.2.2. This technique is commonly applied because it is very suitable for heat sensitive materials such as wood due to very short (1 - 5 seconds) curing times. Powder coatings are usually cured by applying NIR curing as also water-based paints on wood. Regarding the coating of wood, the NIR technique achieves the shortest drying and cycle times.

[13, DFIU and IFARE, 2002]

17.4.6.6 Ultraviolet (UV) radiation

For a general description, see Section 20.8.2.3. This technique is widely applied for the drying of painted furniture, especially of flat parts. Wooden or plastic substrates can show a yellowing and may become brittle. A technique also commercially exists to cure UV coatings in 3-D, see Section 17.4.3.3.

[13, DFIU and IFARE, 2002] [63, Vito, 2003]

17.4.6.7 Electron beam curing

For a general description, see Section 20.8.2.4. This technique requires a special and solvent-free coating substance. Due to high investment costs, this technique is currently only applied for large surface throughputs.

[13, DFIU and IFARE, 2002] [107, VDI, 2005]

17.4.6.8 Combined convection/radiation drying (thermal reactor)

For a general description, see Section 20.8.3. The technique is applied in the coating of wood. The coated substrate should be heat resistant.
[13, DFIU and IFARE, 2002] [76, TWG, 2004]

17.4.7 Waste gas treatment

17.4.7.1 Dry filter systems

For a general description, see Section 20.11.3.6. Paint stop filters and paper filters are commonly used in the wood and furniture industry. Particulate emission values of 10 mg/m³ or less are achieved using this technique. At this level, filters may require replacement and are discarded as waste at least every other day, with associated costs and cost-media impacts.
[63, Vito, 2003] [189, CEI-BOIS, 2006]

17.4.7.2 Electrostatic filter

For a general description, see Section 20.11.3.7. Spray booths are applied. However, no information was made available on how the waste water and waste gas is treated. This technique is sometimes considered as not economical for the sector.
[13, DFIU and IFARE, 2002] [76, TWG, 2004]

17.4.7.3 Venturi particle separation

For a general description, see Section 20.11.3.5. Wet separation spray booths are applied. However, no information was made available on how the waste water and waste gas is treated. This technique is sometimes considered as not economical for the sector.
[13, DFIU and IFARE, 2002] [76, TWG, 2004]

17.4.7.4 Scrubber

For a general description, see Section 20.11.3.8. Wet separation spray booths are applied. However, no information was made available on how the waste water and waste gas is treated. Particulate emission values of 10 mg/m³ or less are achieved, although this technique is sometimes considered as not economical for the sector.
[63, Vito, 2003] [13, DFIU and IFARE, 2002] [76, TWG, 2004] [189, CEI-BOIS, 2006]

17.4.7.5 Biological treatment

For a general description see Section 20.11.8. In Germany, only one plant is equipped with a biofiltration system for the reduction of odour.
[13, DFIU and IFARE, 2002]

17.4.7.6 Thermal oxidation

For a general description, see Section 20.11.4. Although theoretically applicable, this is currently not applied.

This technique may be considered as not economically viable when VOC concentrations are low and/or the gas flows are high, because of the high investment and operational costs (additional heat input, electricity consumption of fans). Many wood-based companies work discontinuously and in single or double shift operations. This makes steady conditions hard to realise, as the thermal inertia after cooling down reduces thermal efficiency, and some installations have complex process control equipment that needs time to stabilise after start-up or adjustment. Moreover, VOC loads in exhaust gas flows might be quite irregular during a shift.

However, it may be considered where there is no alternative to using high solvent coatings. Simple thermal oxidation is well-suited to intermittent use and flows <2000 m³/h, although varying VOC loads may be a problem (see Annex 24.9).

[13, DFIU and IFARE, 2002] [147, Presti, 2005]

17.4.7.7 UV oxidation

For a general description, see Section 20.11.4.7. Reported data are applicable to wood and furniture painting when applying solvent-based paints. However, the technique is currently not applied in this sector. It is also not applicable when veneer is coated. This technique is sometimes considered as not economical for the sector.

[35, Aminal, et al., 2002] [13, DFIU and IFARE, 2002] [60, ESIG, 2000] [63, Vito, 2003] [76, TWG, 2004]

17.4.8 Waste water treatment

17.4.8.1 Waste water treatment for wet separation paint spray booths

See Section 20.7.4.1; and Section 20.12 describes treatment options.

17.4.8.2 Ultra and nanofiltration

For a general description, see Section 20.12.6. Wet separation spray booths are applied and are equipped with an ultrafiltration unit to separate and recover the paint material. This technique is sometimes considered as not economical for the sector.

[13, DFIU and IFARE, 2002] [76, TWG, 2004]

17.4.9 Waste treatment

17.4.9.1 Recovery of used solvents by applying distillation

For a general description, see Sections 20.13.1 and 20.13.2.2. Recovery of cleaning agents is commonly applied, e.g. in the coating of wooden kitchen and bathroom furniture.

[4, Intergraf and EGF, 1999] [13, DFIU and IFARE, 2002] [62, CITEPA, 2003] [68, ACEA, 2004]

18 WOOD PRESERVATION

[108, DFIU/IFARE, 1999] [109, European Environmental Agency, 2001] [128, TWG, 2005]
[140, EGTEI, 2005]

18.1 General information on wood preservation

This section considers industrial processes for the preservation with, or immersion of wood in organic solvent-based preservatives, creosote or solvent-free preservatives. Wood is preserved to protect it against fungal and insect attack and also against weathering. Wood preservation is a major industry, with 11.5 million m³ of wood treated yearly in the EU alone.

The sector is characterised by a large number of relatively small plants. It has been estimated that 1000 installations are involved in the treatment of wood in the EU-15. It is reported that 68 % of the plants use less than 25 t/yr of solvents.

18.2 Applied processes and techniques on wood preservation

The application of the preservative may be carried out via vacuum processes, pressure processes, dipping, spraying or brushing. The vacuum process may vary slightly, depending on the preservative used, see Figure 18.1 and Section 18.4.3 below.

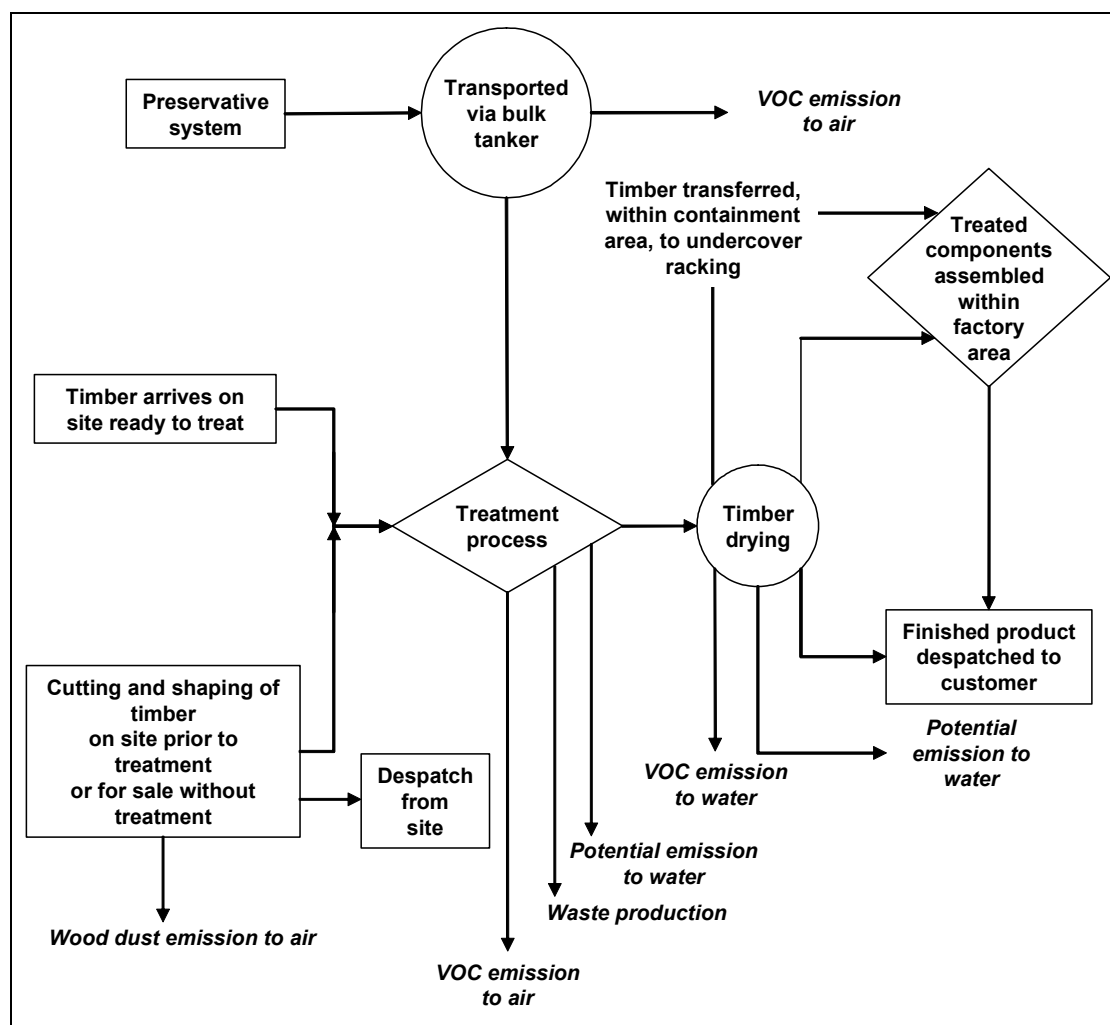


Figure 18.1: Flow diagram of typical wood preservation installation showing consumptions and emissions

[149, UKDEFRA, 2004]

18.3 Current consumption and emission levels on wood preservation

18.3.1 Mass balances

No data submitted.

18.3.2 Consumptions

18.3.2.1 Materials

Each m³ of wood requires 20 kg of organic solvent-based preservatives, usually white spirit or other petroleum-based hydrocarbons. These consist of about 90 wt-% VOC.

For the preservation of 1 m³ of wood, an average of 100 kg of creosote is required. The creosote contains 20 wt-% VOC and a consumption of about 100 – 600 l/m³ redwood splint is reported (depending on the efficiency of the preservation method used).

The average density of commonly treated woods being about 500 - 600 kg/m³ (ranging from 370 to 930 kg/m³), although it often assumed to be 1 kg/m³ for simplicity (www.simetric.co.uk/si_wood.htm).

For pesticides in preservative systems, see Emissions, Section 18.3.3 below. Other references can be found identifying individual pesticides and systems [150, UKHSE, 2006].

18.3.2.2 Water

No data submitted.

18.3.2.3 Energy

No data submitted.

18.3.3 Emissions

18.3.3.1 Emissions to air

The main emission source is from the solvent content of the applied substances. Fugitive and contained emissions can be reduced with the help of abatement equipment. Solvents which remain in the wood after complete drying evaporate over longer periods of time. Fugitive emissions occur during handling, application and drying stages. However, the majority of the emissions occur during the drying process.

At an EU-25 level in 2000 (according to the RAINS model) NMVOC emissions were 54.9 kt representing 0.5 % of total NMVOC emissions (the total estimated EU-15 emission was 47.5 kt/yr in 1990). Total activity in the industry was 11.5 million m³, and the average emission factor is about 4.8 kg NMVOC/m³ meaning that emissions from this sector are already partly abated in the EU-25 (the unabated emission factor being 19.8 kg/m³, see Table 18.1). The contribution to the total EU-15 VOC emissions varies significantly from country to country.

Processes using traditional solvent-based preservatives are likely to need treatment with end-of-pipe techniques in order to be in compliance with the SED requirements. Two secondary measures are possible: thermal oxidation and carbon adsorption [140, EGTEI, 2005].

The options for reducing VOC emissions by primary (in-process) measures and secondary (end-of-pipe) measures have been estimated at a European level. The data have been taken from EGTEI's large reference installation [140, EGTEI, 2005]:

- wood volume to be treated: 5000 m³/yr
- solvent input: 99 t/yr
- full load hours: 6000 h/yr
- flowrate: 22200 m³/h.

Wood preservation is unlikely to be a significant source of emissions of heavy metals to the air.

PMC Primary measure code see Table 18.2	SMC Secondary measure	NMVOE EF (kg/m ³)	Abatement efficiency (%)	Investment (kEUR)	Variable operating costs (kEUR/yr)	Fixed operating costs (kEUR/yr)	Unit cost (EUR/t VOC abated)	Unit cost (EUR/m ³)
00	00	19.80	0.0	0.0	0.0	-	-	0.0
00	01	7.30	63.1	1040.8	75.0	52.2	4114	51.1
00	02	7.30	63.1	494.5	21.4	24.7	1019	21.4
01	00	16.60	16.2	87.0	-11.5	-	-320	-1.0
01	01	6.10	69.2	1055.5	55.4	48.4	3293	45.9
01	02	6.10	69.2	542.9	8.4	22.8	827	18.8
02	00	11.00	44.4	102.0	-22.7	-	-346	-3.0
03	00	0.25	98.7	3.0	28.0	-	289	5.6
04	00	0.15	99.2	90.0	-12.0	-	-55	-1.1

Table 18.1: Wood preservation default emission factors (EF), abatement efficiencies and costs for each combination
[140, EGTEI, 2005]

Primary measure code PMC	Description
00	100 % of solvent-based preservatives conventional application techniques (dipping, brushing, spraying)
01	100 % of solvent-based preservatives improved application technique (vacuum preservation system)
02	Process optimisation 100 % of more concentrated solvent-based preservatives improved application technique (vacuum preservation system)
03	100 % of water-based preservatives conventional application techniques (dipping, brushing, spraying)
04	100 % of water-based preservatives improved application technique (vacuum preservation system)

Table 18.2: Wood preservation: Primary abatement measures
[140, EGTEI, 2005]

Secondary measure code SMC	Description
00	No secondary measure
01	Thermal oxidation (see Section 20.11)
02	Adsorption and solvent recovery (see Section 20.11)

Table 18.3: Wood preservation: Secondary abatement measures
[140, EGTEI, 2005]

18.3.3.2 Emissions to water, soil and groundwater

The preservatives applied in this industry are by nature ecotoxic. The industry has a history of using POPs and/or PBTs. The industry has been a significant source of some POPs, such as PAHs and PCP. PAH emissions from creosote use are important. It was reported in 1999 that wood preservation contributed 30 % of the total EU-15 POP emissions [151, EEA, 1999] [150, UKHSE, 2006].

While the use and emission of these substances has decreased due to increasing legislation and industry changes, substances such as creosote, tributyl tin, sodium trichromate and chromium oxide (hexavalent chromium), arsenic oxide, copper salts, etc. are still in use (some were banned in 2006). More information can be found in the references.

Moves to substances less harmful to human health (in manufacture and application) have led to the use of substances such as permithers. These can have a high aquatic toxicity.

Releases of heavy metals wood preservation to soil and water could be important (arsenic, zinc, copper, tin), see above.

18.3.3.3 Waste

No data submitted.

18.4 Techniques to consider in the determination of BAT on wood preservation

In Chapter 20, techniques are discussed which might also be applicable to wood preservation. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to wood preservation. In Table 18.4, the general techniques relevant for wood preservation that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 18.4: Reference to techniques generally applicable to the sector

The EGTEI synopsis sheet for the preservation of wood (see Section 18.3.3.1 and Annex 24.1.1) gives some data on the cost-benefit of some techniques to reduce VOC emissions at a European level [141, EGTEI, 2005].

18.4.1 Conventional solvent-based preservatives

Description: The traditional preservative systems consist of approximately 10 % active ingredient and 90 % organic solvents, usually white spirit or other petroleum-based hydrocarbons. The active ingredients include insecticides and fungicides, e.g. dinitrophenol, pentachlorophenol, chloronaphthalenes, chlorobenzenes, lindane, dieldrin, organophosphorus and carbamate compounds, and copper/zinc naphthenates.

Achieved environmental benefits: No data submitted.

Cross-media effects: Ecotoxicity of preservatives. Some that have been (or are) used are POPs, others are PBTs.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: See Table 18.1.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [108, DFIU/IFARE, 1999] [109, European Environmental Agency, 2001]

18.4.2 Replacement of conventional solvent-based preservatives (substitution)

18.4.2.1 Creosote

Description: Creosote is an oil prepared from coal tar distillation. Approximately 10 % of the creosote used for wood preservation is made up of VOC. It is gradually being replaced by water-based alternatives.

Achieved environmental benefits: Reduced VOC emissions compared to conventional solvent-based preservatives.

Cross-media effects: Creosote contains significant levels of PAHs and is subject to other controls.

Operational data: In industrial facilities, wood enters a chamber which may be pressurised with air. The chamber is flooded with hot creosote for one to three hours. After draining, a vacuum is applied to draw off the excess creosote. The wood is left to dry in the open air.

Applicability: Creosote is one of the oldest types of wood preservative and is used for external application.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [108, DFIU/IFARE, 1999] [109, European Environmental Agency, 2001]

18.4.2.2 Concentrated pesticide systems

Description: Solvent-based solutions with a higher concentration of pesticides can be used.

Achieved environmental benefits: There is a higher application rate for the same amount of solvent and energy used in process cycles. See Table 18.1.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: See Table 18.1.

Driving forces for implementation: SED

Example plants: No data submitted.

Reference literature: [140, EGTEI, 2005]

18.4.2.3 Water-based preservatives

Description: Water-based preservatives consist of solutions of salts in water. Copper, chromium and arsenic types are the most widely used. They are applied in the same way as creosote. Currently, newer systems use organic pesticides with lower toxicity sometimes in conjunction with one or more metals.

Achieved environmental benefits: Average estimated reduction in VOC emissions of 99.2 %. See Table 18.1.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: See Table 18.1.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [108, DFIU/IFARE, 1999] [109, European Environmental Agency, 2001] [140, EGTEI, 2005] [150, UKHSE, 2006]

18.4.3 Application systems

The application of the preservative may be carried out via vacuum processes, pressure processes, dipping, spraying or brushing. The vacuum process may vary slightly, depending on the preservative used. The application efficiency of the pesticide for dipping and brushing is close to 90 %, and using the vacuum process with full containment is close to 100 %. Spraying has a much lower efficiency, i.e. from 10 - 50 %.

[108, DFIU/IFARE, 1999] [109, European Environmental Agency, 2001]

18.4.3.1 Vacuum application

Description: See Figure 18.1. In industrial installations, the double vacuum (or vacuum low pressure) process is commonly used. A treatment plant consists of three vessels. The treatment vessel incorporates a loading system to enable packs of wood to be moved in and out, either manually or automatically. The treatment vessel door incorporates safety devices to prevent the process starting until the door is fully closed and locked and to prevent it being opened until all preservative is removed. There are normally two storage vessels; one is the working vessel which holds the preservative to flood the treatment vessel, and the other is the bulk vessel which is used to accept delivery of new preservative and to replenish the working vessel.

There are six main stages:

- (1) Initial vacuum – an initial vacuum is used to take air out of the wood. The length of this vacuum period and level used vary according to the specification being followed. The amount of air removed will affect the final uptake and penetration of preservative. To control retentions, some processes run without applying an initial vacuum.
- (2) Flooding – the preservative solution is transferred from the working vessel to the treatment vessel. If applied, the vacuum is maintained during transfer so that its effect is not wasted.
- (3) Pressure period – once the treatment vessel is full, the vacuum is released and returned to atmospheric pressure. The wood is held in the preservative for a period of time or, where the specification requires, a low positive pressure is applied during this time.
- (4) Initial drain – at the end of the pressure period, the preservative is transferred back to the working vessel.
- (5) Final vacuum – a final vacuum is applied to the wood both to remove any excess preservative from the surface layer of the wood and to reduce dripping of the treated wood at the end of the process. As this vacuum is released, air moves back into the vessel and into the surface cells of the wood, carrying with it some of the residual preservative fluid on the wood surface.
- (6) Final drain – during the final vacuum, the preservative collected in the treatment vessel is pumped back into the working vessel. Before the wood is removed from the vessel, fresh air is drawn through the vessel to remove solvent vapour from the working area around the door to minimise operator exposure.

Wood is loaded on a slope on trolleys to assist the wood to emerge as dry as possible from the treatment process and the treatment vessel is filled with wood to capacity whenever practical. About 15 - 25 % of the solvent remains in the wood. A large part of this residual solvent is likely to evaporate over the life of the product.

VOC releases occur when transferring preservative from the road delivery tanker to the bulk vessel, from one vessel to another, from the vacuum pump systems, and from the treated wood itself. When any droplets may be present in air, such as from some vacuum systems, the air is first passed through a coalescing filter system. All plant emissions are vented out of the process building.

Achieved environmental benefits: Nearly a 100 % application efficiency of the preservative system can be achieved.

Cross-media effects: With solvent systems and without additional measures, the emission of VOC is still approx. 19.8 kg/m³.

Operational data: See Description.

Applicability: Widely used.

Economics: See Table 18.1.

Driving forces for implementation: Economic for large scale application. See Table 18.1.

Example plants: No data submitted.

Reference literature: [140, EGTEI, 2005] [149, UKDEFRA, 2004]

18.4.4 Waste gas treatment

Description: Emissions can be reduced by applying a solvent management plan (see Section 20.3.1), enclosing the process wherever possible so that air can be extracted through abatement equipment (see Section 18.3.3 above) and using alternative low solvent coatings (see Section 18.4.2.3). The extracted waste gases can be treated. Section 20.11 describes different waste gas treatment techniques which can be applied.

Achieved environmental benefits: A 70 % reduction of emissions can be achieved with these measures.

Cross-media effects: No data submitted.

Operational data: The EGTEI data discuss the use of two types of waste gas treatment: thermal oxidation, adsorption with solvent recovery. It is not clear if recovery here means on- or off-site. Adsorption on cartridges with off-site recovery or disposal may also be considered.

Applicability: No data submitted.

Economics: In large wood preservation plants, treatment of emissions is carried out. In smaller plants, abatement equipment may not be economically viable. See Table 18.1. Solvent absorption with either off-site recovery or disposal of absorption cartridges may be the most viable option.

Driving forces for implementation: SED.

Example plants: No data submitted.

Reference literature: [108, DFIU/IFARE, 1999] [109, European Environmental Agency, 2001] [140, EGTEI, 2005]

19 MANUFACTURE OF MIRRORS

[61, GEPVP, et al., 2004]

19.1 General information on the manufacture of mirrors

The main production of mirrors is usually carried out by large multinational corporations in plants with capacities of more than 2 million m²/yr. The major facilities are situated in Germany, France, Spain, Italy, Belgium, Poland, the United Kingdom, Luxembourg and the Czech Republic. There are also some small producers.

The total demand for mirrors in Europe is estimated as 40 million m²/yr. This leads to an annual consumption range of solvents of approximately 2000 – 3600 tonnes. The general applications of mirrors in Europe are:

- mirrors for bathrooms
- mirrors for furniture
- architectural uses, e.g. wall covering
- automotive applications.

The specific consumption, i.e. hourly, of each installation is dependent on the surface of the mirrors produced. The largest lines can produce mirrors of 6 by 3.2 m, i.e. 19 m². As mirror production is a continuous process, the speed of the line also affects the hourly consumption rates. Thus, some lines exceed the annual and hourly consumption threshold, whilst others only exceed the annual threshold.

It is estimated that the number of lines that exist in Europe are between 15 and 20. Normally, the number of employees occupied in a mirror line is low, though most lines are part of a large manufacturing company.

19.2 Applied processes and techniques in the manufacture of mirrors

The production line is designed as a continuous process. The glass sheet lies on a large conveyor that leads the mirror through the different steps of manufacturing. Conveyors are up to 3.5 m wide and more than 150 m long to allow the manufacturing of large scale mirrors. Typically, mirrors consist of one glass pane covered by a reflective metallic layer which is protected by one or more paint coatings. After the paint coating, the mirror passes through the drying furnace. Figure 19.1 summarises the different steps in the manufacture of mirrors. These are described in detail in the following sections.

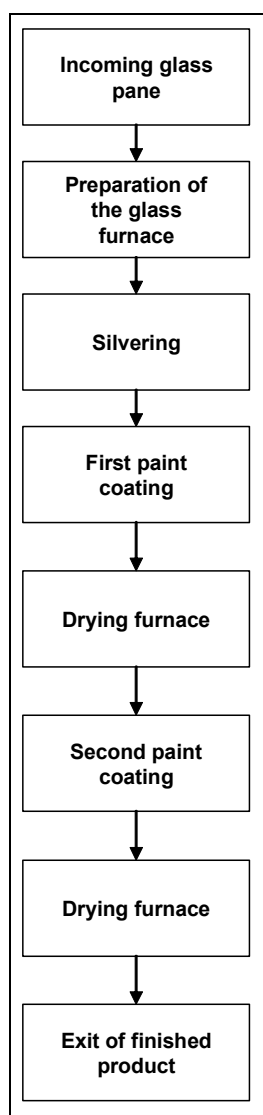


Figure 19.1: Flow chart of the manufacture of mirrors [61, GEPVP, et al., 2004]

19.2.1 Incoming glass pane

Glass is usually fed to the mirror factory by lorries. The glass is then stocked on stillages and unloaded onto the mirror line using vacuum lifting devices. No solvent is used at this stage.

19.2.2 Preparation of the glass surface

The preparation of the glass surface consists of a slight polishing using a water-based abrasive slurry. No solvent is used at this stage. The waste water is treated and the sludge recovered for disposal.

19.2.3 Silvering

The reflective metallic layer is generally made of silver, which is sensitive to corrosion. A description of a silvering process can be found in the STM BREF [59, EIPPCB, 2006]. Currently, most producers use the tin process instead of the copper process for fixing the silver layer. No solvent is used at this stage.

19.2.4 Paint coating

The glass is passed through a laminar curtain of paint, which is continuously falling from a trough-type assembly. The excess coating material is permanently re-used, but extra solvent is added to insure proper application viscosity. The paint used is solvent-based and contains 30 - 40 wt-% solvent. The paint consumption ranges from 150 to 200 g/m². The total thickness of the dried paint coating(s) is in the range of 40 to 70 μ.

19.2.5 Drying

After the paint coating, the mirror is taken to the drying furnace where the solvent is evaporated and the paint dried allowing its polymerisation. Drying is promoted by heating the product by infrared radiation with or without convection heat.

19.2.6 Exit of the finished product

At the end of the line, the mirror is unloaded by using vacuum lifting devices and stacked on stillages. No solvent is used at this stage.

19.3 Current consumption and emission levels in the manufacture of mirrors

19.3.1 Mass balances

No data submitted.

19.3.2 Consumptions

19.3.2.1 Materials

The total solvent consumed amounts to 50 – 90 g/m², depending on the type of product manufactured. Also, some solvent is used for cleaning. The solvent used is xylene.

The greatest proportion of the solvent is used to adjust the paint viscosity and applied onto the product. A small amount is used for cleaning purposes, i.e. <10 %. When this solvent is not contaminated, it is added to the solvent used to adjust the paint viscosity.

Normally, it is expected that 100 % of the glass used as input is transformed into mirror. Only accidental losses of glass may occur (e.g. due to quality problems). In most instances, the rejected glass/mirror is recycled.

19.3.2.2 Water

The water consumption is in the range of 15 to 30 l/m².

19.3.2.3 Energy

No data submitted.

19.3.3 Emissions

19.3.3.1 Emissions to air

The solvent content in the clean gas can be reduced to $<50 \text{ mg C/Nm}^3$ when applying abatement equipment. Lower values can be achieved in new installations. In existing installations, due to the wearing of the mobile parts (e.g. valves), the emission levels increase. The nature of the solvents used can also have an impact on the reduction level that can be achieved. Table 19.1 shows air emission values measured on three different installations.

Line	C (mg/Nm ³)	CO (mg/Nm ³)	NO _x (mg/Nm ³)
1	57 (range 20 – 100)	65	43
2	16	120	<25
3	55	98	41

Table 19.1: Air emission values from three different mirror lines

In a good practice plant, all areas where solvents are used are enclosed and the air containing the solvent is extracted. 97.4 % of the solvent is treated and destroyed. The rest, i.e. 2.6 %, is released to the air because its concentration is too low to be treated.

19.3.3.2 Emissions to water

Because there is no contact between the water and the solvent anywhere in the process, solvent is not present in the waste water.

Water is used for the surface preparation and the application of the tin (or copper) and silver layer (see the STM BREF). Thus, water treatment is needed to remove contaminants and to ensure the recycling of the silver. Conventional techniques are used, for example, when copper is used instead of tin, ion exchange and ammonia stripping can be used to remove the copper from the waste water. Table 19.2 shows water emission values after treatment.

Compound	Value (mg/l)
NH ₃	100
Ag	0.5
Cu	4
Ce	5

Table 19.2: Water emission values after treatment

19.3.3.3 Wastes

The wastes containing solvents consist mainly of wipes from cleaning and spent solvent containing some paint. Its management and disposal is dictated by its composition and specific measures may be needed due to its solvent content. When it does not contain any contaminants that can alter the quality of the final product, the spent solvent is re-used to adjust the paint viscosity. Re-usable or recyclable paint containers are commonly used in mirror production.

19.4 Techniques to consider in the determination of BAT for the manufacture of mirrors

19.4.1 General techniques in the manufacture of mirrors

In Chapter 20, techniques are discussed which might also be applicable to mirror manufacturing. In Section 20.7, techniques relevant to paint application are discussed. These techniques might also be applicable to mirror manufacturing. In Table 19.3, the general techniques relevant for mirror manufacturing that are described in Chapter 20 and/or Section 20.7 are shown. These techniques are normally not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 20.1.

Technique	Section number
Environmental management tools	20.1.1
Ongoing environmental improvement	20.1.2
Benchmarking	20.1.3
Installation design, construction and operation	20.2
Monitoring	20.3
Mass balances for solvents	20.3.1
Water management	20.4
Energy management	20.5
Raw material management	20.6
Coating processes and equipment	20.7
Drying	20.8
Cleaning	20.9
Substitution: using less harmful substances	20.10
Waste gas treatment	20.11
Containment and collection of waste gases	20.11.2
Oxidation	20.11.4
Condensation	20.11.5
Adsorption	20.11.6
Waste water treatment	20.12
Waste minimisation and treatment	20.13
Recovery of used solvents from the process	20.13.1
Dust abatement	20.14
Odour abatement	20.15
Noise abatement	20.16

Table 19.3: Reference to techniques generally applicable to the sector

19.4.2 Replacement of conventional solvent-based paints (substitution)

19.4.2.1 High solids paints

For a general description, see Section 20.7.2.2. The mirror industry is already using this type of paint. The solvent content in the paint is between 30 and 40 wt-%.

19.4.3 Paint application techniques and equipment

19.4.3.1 Curtain coating

Description: For a general description, see Section 20.7.3.2. The glass is passed through a laminar curtain of paint continuously falling from a trough-type assembly. This allows the manufacture of large dimension mirrors while ensuring the required quality in equivalence of the layers. The excess coating material is permanently re-used, but extra solvent is added to ensure proper application viscosity.

The paint used is solvent-based and contains 30 – 40 % solvent. Its consumption ranges from 150 to 200 g/m². In the past, paint contained high quantities of lead (up to 15 %). Today, new developments in mirror manufacturing allow the industry to use a low lead content paint (<0.5 %). No chromate is used in this type of paint.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: This technique is widely used in large mirror plants.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [61, GEPVP, et al., 2004]

19.4.4 Drying

The following techniques are applied:

- infrared radiation curing (see Section 20.8.2.1)
- thermal reactor (see Section 20.8.3)
- ultraviolet (UV) curing (see Section 20.8.2.3).

19.4.5 Waste gas treatment

Description: The areas where the paint is mixed and applied onto the mirror are enclosed and equipped with an air extraction system routing the solvent emissions to the waste gas treatment equipment (see Section 20.11.2). Currently, any oxidation technique described in Section 20.11.4 can be applied.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Given the amount of solvent per cubic metre in the flue-gas, many mirror manufacturers use regenerative thermal oxidisers – multiple bed systems (see Sections 20.11.4.4 and 20.11.4.5). As the solvent is mainly xylene, a low burning temperature (750 - 800 °C) may be applied. Only low levels of NO_x are formed. Regenerative thermal oxidisers are particularly suited to plants working continuously, i.e. 24 hours a day, 7 days a week. For plants working, e.g. only 8 hours per day and 5 days a week, this technique might be not suitable, as the temperature of the installation must be maintained during the non-working hours. In this case, other oxidising techniques might be more suitable.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [61, GEPVP, et al., 2004]

20 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT APPLICABLE IN ALL INDUSTRIES

This chapter sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of this document. Techniques to be considered for each specific industry can be found in Section X.4 (where X is the specific industry chapter).

Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and re-cycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations (from both this chapter and the relevant Sections X.4) to achieve the objectives of IPPC. Annex IV to the Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this chapter will address one or more of these considerations. As far as possible a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the Directive.

The content of the sections in this chapter and in the Sections X.4 are not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of BAT.

Generally a standard structure is used to outline each technique, as shown in Table 20.1:

Type of information considered	Type of information included
Description	Technical description of the technique
Achieved environmental benefits	Main environmental impact(s) to be addressed by the technique (process or abatement), including emission values achieved and efficiency performance. Environmental benefits of the technique in comparison with others
Cross-media effects	Any side-effects and disadvantages caused by implementation of the technique. Details on the environmental problems of the technique in comparison with others
Operational data	Performance data on emissions/wastes and consumption (raw materials, water and energy). Any other useful information on how to operate, maintain and control the technique, including safety aspects, operability constraints of the technique, output quality, etc.
Applicability	Consideration of the factors involved in applying and retrofitting the technique (e.g. space availability, process specific)
Economics	Information on costs (investment and operation) and any possible savings (e.g. reduced raw material consumption, waste charges) also as related to the capacity of the technique
Driving forces for implementation	Reasons for implementation of the technique (e.g. other legislation, improvement in production quality)
Example plants	Reference to a plant where the technique is reported to be used
Reference literature	Literature for more detailed information on the technique

Table 20.1: Information breakdown for each technique described in Chapter 20 and in all the Sections 4 in each of the Chapters 2 to 19

20.1 Environmental management techniques

20.1.1 Environmental management tools

Description: The best environmental performance is usually achieved by the installation of the best technology and its operation in the most effective and efficient manner. This is recognised by the IPPC Directive definition of ‘techniques’ as *‘both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned’*.

For IPPC installations an Environmental Management System (EMS) is a tool that operators can use to address these design, construction, maintenance, operation and decommissioning issues in a systematic, demonstrable way. An EMS includes the organisational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, maintaining, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

Within the European Union, many organisations have decided on a voluntary basis to implement environmental management systems based on EN ISO 14001:1996 or the EU Eco-management and audit scheme EMAS. EMAS includes the management system requirements of EN ISO 14001, but places additional emphasis on legal compliance, environmental performance and employee involvement; it also requires external verification of the management system and validation of a public environmental statement (in EN ISO 14001 self-declaration is an alternative to external verification). There are also many organisations that have decided to put in place non-standardised EMSs.

While both standardised systems (EN ISO 14001:1996 and EMAS) and non-standardised (‘customised’) systems in principle take the *organisation* as the entity, this document takes a more narrow approach, not including all activities of the organisation e.g. with regard to their products and services, due to the fact that the regulated entity under the IPPC Directive is the *installation* (as defined in Article 2).

An environmental management system (EMS) for an IPPC installation can contain the following components:

- (a) definition of an environmental policy
- (b) planning and establishing objectives and targets
- (c) implementation and operation of procedures
- (d) checking and corrective action
- (e) management review
- (f) preparation of a regular environmental statement
- (g) validation by certification body or external EMS verifier
- (h) design considerations for end-of-life plant decommissioning
- (i) development of cleaner technologies
- (j) benchmarking.

These features are explained in somewhat greater detail below. For detailed information on components (a) to (g), which are all included in EMAS, the reader is referred to the reference literature indicated below.

(a) Definition of an environmental policy

Top management are responsible for defining an environmental policy for an installation and ensuring that it:

- is appropriate to the nature, scale and environmental impacts of the activities
- includes a commitment to pollution prevention and control
- includes a commitment to comply with all relevant applicable environmental legislation and regulations, and with other requirements to which the organisation subscribes
- provides the framework for setting and reviewing environmental objectives and targets
- is documented and communicated to all employees
- is available to the public and all interested parties.

(b) Planning, i.e.:

- procedures to identify the environmental aspects of the installation, in order to determine those activities which have or can have significant impacts on the environment, and to keep this information up-to-date
- procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the environmental aspects of its activities
- establishing and reviewing documented environmental objectives and targets, taking into consideration the legal and other requirements and the views of interested parties
- establishing and regularly updating an environmental management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved.

(c) Implementation and operation of procedures

It is important to have systems in place to ensure that procedures are known, understood and complied with, therefore effective environmental management includes:

(i) Structure and responsibility

- defining, documenting and communicating roles, responsibilities and authorities, which includes appointing one specific management representative
- providing resources essential to the implementation and control of the environmental management system, including human resources and specialised skills, technology and financial resources.

(ii) Training, awareness and competence

- identifying training needs to ensure that all personnel whose work may significantly affect the environmental impacts of the activity have received appropriate training.

(iii) Communication

- establishing and maintaining procedures for internal communication between the various levels and functions of the installation, as well as procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties.

(iv) Employee involvement

- involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion-book system or project-based group works or environmental committees.

(v) Documentation

- establishing and maintaining up-to-date information, in paper or electronic form, to describe the core elements of the management system and their interaction and to provide direction to related documentation.

(vi) Efficient process control

- adequate control of processes under all modes of operation, i.e. preparation, start-up, routine operation, shutdown and abnormal conditions
- identifying the key performance indicators and methods for measuring and controlling these parameters (e.g. flow, pressure, temperature, composition and quantity)
- documenting and analysing abnormal operating conditions to identify the root causes and then addressing these to ensure that events do not recur (this can be facilitated by a ‘no-blame’ culture where the identification of causes is more important than apportioning blame to individuals).

(vii) Maintenance programme

- establishing a structured programme for maintenance based on technical descriptions of the equipment, norms etc. as well as any equipment failures and consequences
- supporting the maintenance programme by appropriate record keeping systems and diagnostic testing
- clearly allocating responsibility for the planning and execution of maintenance.

(viii) Emergency preparedness and response

- establishing and maintaining procedures to identify the potential for and response to accidents and emergency situations, and for preventing and mitigating the environmental impacts that may be associated with them.

(d) Checking and corrective action, i.e.:

(i) Monitoring and measurement

- establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on the environment, including the recording of information for tracking performance, relevant operational controls and conformance with the installation's environmental objectives and targets (*see also the Reference document on Monitoring of Emissions*)
- establishing and maintaining a documented procedure for periodically evaluating compliance with relevant environmental legislation and regulations.

(ii) Corrective and preventive action

- establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements as well as objectives and targets, taking action to mitigate any impacts caused and for initiating and completing corrective and preventive action that are appropriate to the magnitude of the problem and commensurate with the environmental impact encountered.

(iii) Records

- establishing and maintaining procedures for the identification, maintenance and disposition of legible, identifiable and traceable environmental records, including training records and the results of audits and reviews.

(iv) Audit

- establishing and maintaining (a) programme(s) and procedures for periodic environmental management system audits that include discussions with personnel, inspection of operating conditions and equipment and reviewing of records and documentation and that results in a written report, to be carried out impartially and objectively by employees (internal audits) or external parties (external audits), covering the audit scope, frequency and methodologies, as well as the responsibilities and requirements for conducting audits and reporting results, in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained
- completing the audit or audit cycle, as appropriate, at intervals of no longer than three years, depending on the nature, scale and complexity of the activities, the significance of associated environmental impacts, the importance and urgency of the problems detected by previous audits and the history of environmental problems – more complex activities with a more significant environmental impact are audited more frequently
- having appropriate mechanisms in place to ensure that the audit results are followed up.

(v) Periodic evaluation of legal compliance

- reviewing compliance with the applicable environmental legislation and the conditions of the environmental permit(s) held by the installation
- documentation of the evaluation.

(e) Management review, i.e.:

- reviewing, by top management, at intervals that it determines, the environmental management system, to ensure its continuing suitability, adequacy and effectiveness
- ensuring that the necessary information is collected to allow management to carry out this evaluation
- documentation of the review.

(f) Preparation of a regular environmental statement:

- preparing an environmental statement that pays particular attention to the results achieved by the installation against its environmental objectives and targets. It is regularly produced – from once a year to less frequently depending on the significance of emissions, waste generation etc. It considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc.).

When producing a statement, the operator may use relevant existing environmental performance indicators, making sure that the indicators chosen:

- i. give an accurate appraisal of the installation's performance
- ii. are understandable and unambiguous
- iii. allow for year on year comparison to assess the development of the environmental performance of the installation
- iv. allow for comparison with sector, national or regional benchmarks as appropriate
- v. allow for comparison with regulatory requirements as appropriate.

(g) Validation by certification body or external EMS verifier:

- having the management system, audit procedure and environmental statement examined and validated by an accredited certification body or an external EMS verifier can, if carried out properly, enhance the credibility of the system.

(h) Design considerations for end-of-life plant decommissioning

- giving consideration to the environmental impact from the eventual decommissioning of the unit at the stage of designing a new plant, as forethought makes decommissioning easier, cleaner and cheaper
- decommissioning poses environmental risks for the contamination of land (and groundwater) and generates large quantities of solid waste. Preventive techniques are process-specific but general considerations may include:
 - i. avoiding underground structures
 - ii. incorporating features that facilitate dismantling
 - iii. choosing surface finishes that are easily decontaminated
 - iv. using an equipment configuration that minimises trapped chemicals and facilitates drain-down or cleaning
 - v. designing flexible, self-contained units that enable phased closure
 - vi. using biodegradable and recyclable materials where possible.

(i) Development of cleaner technologies:

- environmental protection should be an inherent feature of any process design activities carried out by the operator, since techniques incorporated at the earliest possible design stage are both more effective and cheaper. Giving consideration to the development of cleaner technologies can for instance occur through R&D activities or studies. As an alternative to internal activities, arrangements can be made to keep abreast with – and where appropriate – commission work by other operators or research institutes active in the relevant field.

(j) Benchmarking, i.e.:

- carrying out systematic and regular comparisons with sector, national or regional benchmarks, including for energy efficiency and energy conservation activities, choice of input materials, emissions to air and discharges to water (using for example the European Pollutant Emission Register, EPER), consumption of water and generation of waste.

Standardised and non-standardised EMSs

An EMS can take the form of a standardised or non-standardised ('customised') system. Implementation and adherence to an internationally accepted standardised system such as EN ISO 14001:1996 can give higher credibility to the EMS, especially when subject to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

(Regulation (EC) No 761/2001 of the European parliament and of the council allowing voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), OJ L 114, 24/4/2001, http://europa.eu.int/comm/environment/emas/index_en.htm)

(EN ISO 14001:2004, <http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html>; <http://www.tc207.org>)

Achieved environmental benefits: Implementation of and adherence to an EMS focuses the attention of the operator on the environmental performance of the installation. In particular, the maintenance of and compliance with clear operating procedures for both normal and abnormal situations and the associated lines of responsibility should ensure that the installation's permit conditions and other environmental targets and objectives are met at all times.

Environmental management systems typically ensure the continuous improvement of the environmental performance of the installation. The poorer the starting point is, the more significant short-term improvements can be expected. If the installation already has a good overall environmental performance, the system helps the operator to maintain the high performance level.

Cross-media effects: Environmental management techniques are designed to address the overall environmental impact, which is consistent with the integrated approach of the IPPC Directive.

Operational data: No specific information reported.

Applicability: The components described above can typically be applied to all IPPC installations. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

Economics: It is difficult to accurately determine the costs and economic benefits of introducing and maintaining a good EMS. A number of studies are presented below. However, these are just examples and their results are not entirely coherent. They might not be representative for all sectors across the EU and should thus be treated with caution.

A Swedish study carried out in 1999 surveyed all 360 ISO-certified and EMAS-registered companies in Sweden. With a response rate of 50 %, it concluded among other things that:

- the expenses for introducing and operating EMS are high but not unreasonably so, save in the case of very small companies. Expenses are expected to decrease in the future
- a higher degree of co-ordination and integration of EMS with other management systems is seen as a possible way to decrease costs
- half of all the environmental objectives and targets give payback within one year through cost savings and/or increased revenue
- the largest cost savings were made through decreased expenditure on energy, waste treatment and raw materials
- most of the companies think that their position on the market has been strengthened through the EMS. One-third of the companies report increasing revenue due to EMS.

In some Member States reduced supervision fees are charged if the installation has a certification.

A number of studies show that there is an inverse relationship between company size and the cost of implementing an EMS. A similar inverse relationship exists for the payback period of invested capital. Both elements imply a less favourable cost-benefit relationship for implementing an EMS in SMEs compared to larger companies.

According to a Swiss study, the average cost for building and operating ISO 14001 can vary:

- for a company with between 1 and 49 employees: CHF 64000 (EUR 44000) for building the EMS and CHF 16000 (EUR 11000) per year for operating it
- for an industrial site with more than 250 employees: CHF 367000 (EUR 252000) for building the EMS and CHF 155000 (EUR 106000) per year for operating it.

These average figures do not necessarily represent the actual cost for a given industrial site because this cost is also highly dependent on the number of significant items (pollutants, energy consumption,...) and on the complexity of the problems to be studied.

A recent German study (Schaltegger, Stefan and Wagner, Marcus, Umweltmanagement in deutschen Unternehmen - der aktuelle Stand der Praxis, February 2002, p. 106) shows the following costs for EMAS for different branches. It can be noted that these figures are much lower than those of the Swiss study quoted above. This is a confirmation of the difficulty to determine the costs of an EMS.

Costs for building (EUR):

- minimum 18750
- maximum 75000
- average 50000

Costs for validation (EUR):

- minimum 5000
- maximum 12500
- average 6000

A study by the German Institute of Entrepreneurs (Unternehmerinstitut/Arbeitsgemeinschaft Selbständiger Unternehmer UNI/ASU, 1997, Umweltmanagementbefragung - Öko-Audit in der mittelständischen Praxis - Evaluierung und Ansätze für eine Effizienzsteigerung von Umweltmanagementsystemen in der Praxis, Bonn.) gives information about the average savings achieved for EMAS per year and the average payback time. For example, for implementation costs of EUR 80000 they found average savings of EUR 50000 per year, corresponding to a payback time of about one and a half years.

External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum (<http://www.iaf.nu>).

Driving forces for implementation: Environmental management systems can provide a number of advantages, for example:

- improved insight into the environmental aspects of the company
- improved basis for decision-making
- improved motivation of personnel
- additional opportunities for operational cost reduction and product quality improvement
- improved environmental performance
- improved company image
- reduced liability, insurance and non-compliance costs
- increased attractiveness for employees, customers and investors
- increased trust of regulators, which could lead to reduced regulatory oversight
- improved relationship with environmental groups.

Example plants: The features described under (a) to (e) above are elements of EN ISO 14001:1996 (now EN ISO 14001: 2004) and the European Community Eco-Management and Audit Scheme (EMAS), whereas the features (f) and (g) are specific to EMAS. These two standardised systems are applied in a number of IPPC installations. As an example, 357 organisations within the EU chemical and chemical products industry (NACE code 24) were EMAS registered in July 2002, most of which operate IPPC installations.

In the UK, the Environment Agency of England and Wales carried out a survey among IPC (the precursor to IPPC) regulated installations in 2001. It showed that 32 % of respondents were certified to ISO 14001 (corresponding to 21 % of all IPC installations) and 7 % were EMAS registered. All cement works in the UK (around 20) are certified to ISO 14001 and the majority are EMAS registered. In Ireland, where the establishment of an EMS (not necessarily of a standardised nature) is required in IPC licenses, an estimated 100 out of approximately 500 licensed installations have established an EMS according to ISO 14001: 2004, with the other 400 installations having opted for a non-standardised EMS.

In the Netherlands, specific EMS exist for SMEs to reduce the cost and management time required for the introduction of systems.

Reference literature:

- Regulation (EC) No 761/2001 of the European parliament and of the council allowing voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), OJ L 114, 24/4/2001, http://europa.eu.int/comm/environment/emas/index_en.htm)
- EN ISO 14001:2004:
 - <http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html>;
 - <http://www.tc207.org>) [128, TWG, 2005]

20.1.2 Ongoing environmental improvement and cross-media issues

Description: An important component of an EMS is maintaining overall environmental improvement. It is essential that the operator understands what happens to the inputs (understanding the process), e.g. solvents, and how their consumption leads to emissions. It is equally important that when controlling significant inputs and outputs to maintain the correct balance between solvent emissions reduction and cross-media effects, such as energy, water and raw materials consumption. This reduces the environmental footprint of the installation.

Whilst the solvents balance (see Section 20.3.1) is important in these industries, all significant consumptions and emissions should be managed in a co-ordinated manner for the short, medium and long term, in conjunction with financial planning and investment cycles, i.e. adapting short-term end-of-pipe solutions to solvents emissions may tie the operator to long term higher energy consumption, and postpone investment in more environmentally beneficial solutions. This will require some consideration of the cross-media issues, and assistance with these and the costing and cost-benefits issues is given in the ECM REF [97, EIPPCB, 2005] and in Section 20.1.4.

Achieved environmental benefits: Long-term reduction in solvents emissions, with reduced water and energy consumption.

Cross-media effects: A part of the operation's consumptions or emissions, such as solvents emissions, may be higher proportionately for a period until longer term investment is made.

Operational data: No data submitted.

Applicability: The extent of this exercise will depend on the installation size, and the number of the variables. A full cross-media study is carried out infrequently. See Example plants, below.

Economics: Enabling capital investment to be made in an informed manner for reduction of the overall environmental benefit and best value for money.

Driving forces for implementation: No data submitted.

Example plants: An example of considering the cross-media effects is given in the ECM REF [97, EIPPCB, 2005].

Applicability to SMEs: Bovince Ltd, London, UK, are a small printing company with about 48 employees, specialising in screen and digital printing. They have a sustainability policy, and operate an EMS with a continuous improvement programme. The progressive introduction of automatic screen cleaning with solvent recovery, ultraviolet inks for as many jobs as possible and good housekeeping has led to a 50 % reduction in solvent consumption since 1996, with cost savings of about EUR 90000 between 1996 and 2000.

Two theoretical examples are:

1. In a paintshop painting metal components, the need to reduce fugitive solvent emissions is identified as a result of a solvent balance. Key options include the installation of additional extraction equipment and larger end-of-pipe thermal oxidation, or the change to a low solvent process for part of the coating. The former can be installed more quickly, but will significantly increase energy for extraction fans, and support fuel for the thermal oxidation. There will be no reduction in solvent usage, so the management of fugitive emissions from handling, cleaning, etc. remains. A low solvent paint process can be installed, using less energy and 50 % less solvents, but more water. It may cost more in capital, downtime and operator training/familiarisation, however operating costs may be lower. The balance of capital and operating costs is a normal good practice business decision. Data on energy and water consumptions, solvent emission and other emissions may be gained from suppliers, other operators possibly, trade associations, and/or guidance data published internationally and nationally, such as environmental costing models, which may also evaluate cost-benefit (see Section 20.1.4).
2. A vehicle manufacturer is seeking to reduce solvent emissions further. A large step change can be achieved, but this requires replacement of the entire paintshop, which has an operating life of 25 years and a capital cost of about EUR 500000. The energy consumption of the paintshop is about 38 - 52 % of the entire power consumption of the plant and in the order of 160000 - 240000 MWh (of which 60 % is gas). The amount of raw material used, the application efficiency and the amount of solvents lost may also be affected by the degree of automation. The selection of which type of paint and application system, the amount of automation the amount of waste gas treatment and paint system requires a consideration of the operating and capital costs, as well as the consumptions and emissions, over the payback period of the investment. The operating life of the existing paintshop must also be taken into account.

Reference literature: [76, TWG, 2004] [97, EIPPCB, 2005] [157, ACEA, 2005] [128, TWG, 2005] [161, EIPPCB, 2006]

20.1.3 Benchmarking consumptions and emissions and subsequent action

Description: Benchmarking is the systematic recording of inputs (raw materials, water and energy) and outputs (emissions to air and water, and as waste), and the regular comparisons of these with previous data for the installation, with its sector, national or regional benchmarks (see Section 20.1.1 (j)). When data are benchmarked in an installation, it is good practice to maintain a system to identify any actions required from the data gathered and bring these actions to a conclusion (see Section 20.1.1(d)), including:

- identifying a person or persons responsible for evaluating and taking action on the data
- informing those responsible for plant performance, including alerting operators rapidly and effectively to variations from normal performance
- other investigations to ascertain why performance has varied or is out of line with external benchmarks.

Achieved environmental benefits: Assists individual installations to assess their environmental performance with other installations. Assists in identifying techniques used by the best performing installations. Can identify or assist in identifying unplanned or unobserved events, such as pipe or pump seal leakage, losses to soil and groundwater, etc.

Cross-media effects: No data submitted.

Operational data: Provides benchmarks and assessments of operational environmental performance of installations and techniques. Data can be gathered and compared on different levels such as: technique or activity (press, process tank, or process line), site, sector, regional or national. It can be made public while keeping individual site identities confidential. For example:

- solvents consumed and emitted. Fugitive emissions, and therefore total emissions, can only be determined using a solvent balance, Section 20.3.1. Appropriate issues for benchmarking can be identified when carrying out a solvent balance (see Annexes 24.2 and 24.3)
- water consumption – this is important when water-based coatings are used
- energy consumption, e.g. from drying and abatement equipment
- raw materials consumption, e.g. inks, wipes, paper, in press set-up, up to 10 % of the substrate can be wasted
- wastes generated
- significant pollutants emitted to water, air or soil/groundwater.

Applicability: Appropriate benchmarking requires comparable data – a ‘like for like’ comparison, e.g. for surface treatment activities this would be best achieved on a surface area treated basis or other consumption or throughout basis that is meaningfully process-related. The detail of the benchmarking, including the issues to be benchmarked will depend on the consumption.

Economics: Use of the data to optimise the plant environmental performance will usually achieve economic optimisation.

Driving forces for implementation: Benchmarking is also commensurate with good economic performance. Benchmarking and optimising environmental performance (such as raw material, water and power inputs, as well as material losses) will achieve economic optimisation at the same time.

A solvent management plan is the only way to calculate the fugitive and total emissions from an installation and is required under the SED for all the activities covered in this document.

Example plants: No data submitted.

Reference literature: [59, EIPPCB, 2006] [90, Envirowise, 1998] [76, TWG, 2004] [128, TWG, 2005]

20.1.4 Costing environmental benefits and estimating cross-media effects

Description: The concept of BAT under IPPC takes into account the likely costs and benefits of techniques. An objective of the integrated approach is to stop the shifting of pollution from one medium to another by selecting techniques or combinations of techniques that are the most effective in achieving a high level of protection of the environment taken as a whole. This is complementary to seeking ongoing improvements in the installation (see Section 20.1.2).

When selecting techniques, if there is only one environmental objective, with one pollutant and few consumption and emission points to be taken into account, the cost efficiency analysis is a straightforward exercise. It is sufficient to rank possible abatement measures based on their marginal costs and reduction potential, and to select the cheapest measure or combination of measures that realise the environmental objective. Usually, the analysis involves multiple consumption and emission points, pollutants, abatement measures, interactions and trade-offs. The least expensive solution cannot be determined easily.

The ECM REF provides guidance on assessing cost and benefits, as well as guidance on assessing techniques that are most effective in achieving a high level of environmental benefit as a whole (i.e. have the lowest cross-media effects).

Some guidance and models have been developed to assist in assessing costs and environmental benefits. Examples are given in Annex 24.1.

Achieved environmental benefits: Assists with identifying the most cost-effective options.

Cross-media effects: Assists with identifying the techniques or combinations of techniques with the lowest cross-media effects.

Operational data: No data submitted.

Applicability: The extent of this exercise will depend on the installation size, and the number of the variables. A full cross-media study is carried out infrequently. See Section 20.1.2.

When using models to assist with decisions, it is essential to:

- understand the objectives for the model to ensure it will provide the assistance required. For example, is it a tool to inform policy, or for assessing cross-media effects and/or cost-effectiveness at an installation level, or is to inform national policy making
- check for any assumptions made
- ensure that the model results are presented in a form compatible with other data being considered, e.g. costs are annualised, or based on a production or emission measure that is readily comparable (see the ECM REF for advice)
- understand that models are unlikely to contain data on all the BAT options or techniques to be considered (including new ones not listed in this document) so more options may be available
- assess the consumptions as well as the emissions. This is usually most important for energy (and therefore CO₂), and in some cases SO_x and NO_x emissions.

When considering options at an installation level, it is important to consider other factors that will influence choices. Some of these are listed in the introduction to Chapter 21, e.g. factors affecting the speed of implementation, quality and customer specifications, etc.

Economics: Assists with identifying the most cost-effective options.

Driving forces for implementation: Assists with identifying the most cost-effective options. Other legislation such as SED, WFD, etc. Models such as EGTEI and MKM (VITO) are aimed at producing costs of emission reduction techniques and cost benefits for various activities, regional and national scenarios, and provide data for RAINS.

Example plants: Examples are given in the ECM REF. Examples of models are given in Annex 24.1.

Reference literature: [95, Vito, 2005, 97, EIPPCB, 2005, 132, EGTEI, 2005, 133, EGTEI, 2005] [128, TWG, 2005].

20.2 Installation design, construction and operation (including good housekeeping)

This section covers the areas and activities of the installation that are not covered elsewhere, in particular the prevention of emissions to soil, groundwater and surface water, although the techniques are also relevant to the prevention of fugitive emissions to air. However, when considering the integrated operation and the complexity of an IPPC installation, overlaps and repetition with other sections are inevitable: these have been cross-referenced where found.

Design, construction and operation (sometimes referred to as good housekeeping or good practice) to prevent spillages and leakages are described extensively elsewhere, such as generally in the ESB BREF [91, EIPPCB, 2005], in national guidance documents [119, RIZA, 1999], [120, INRS, 1998] as well specifically for this sector [89, Envirowise, 2003]. The following sections are therefore a brief summary of key issues for this sector.

20.2.1 Pollution prevention for unplanned releases

Description: A planned, integrated approach can decrease environmental accidents, or unplanned releases, starting with the identification of those aspects of an installation that may have significant impacts on the environment. The identified risks are then tackled by careful design and construction, as well as by management systems that address the prevention, mitigation and management of accidents and emergencies, and the breaches of permit conditions.

Regulatory and/or good practice systems for pollution prevention are in use in some countries. Many installations in the sector have benefited from the introduction of such techniques. The following activities are key examples where these techniques reduce the frequency and impacts of acute and chronic pollution not only to the air, but also to surface and groundwaters; and soil. They also assist in making the operations more cost effective:

- routine and non-routine maintenance including maintenance of covers and pipe joints for solvent storage and delivery systems
- delivery and storage of raw materials
- process control, process and environmental monitoring.

Some key aspects for preventing pollution are:

- the identification of hazards and pathways
- a simple ranking of hazard potential.

A three step implementation of actions for pollution prevention:

- primary measures (structural):
 - sufficient plant dimensions
 - selection of sealing materials where chemicals are stored or handled, e.g. for flooring, contained areas (see secondary measures, below)
 - stability of the process line and components (including temporary and infrequently used equipment, such as pumps and tanks used for occasional maintenance operations).
- secondary measures (plant or equipment):
 - containment (or secondary containment) refers to additional protection against storage tank releases over and above the inherent protection provided by the tank container itself (in this sector, the tanks may be for storage or production). There are two major types of secondary containment for leakages, namely those that are part of the tank construction, such as double tank bottoms (only for aboveground tanks), double

skinned and double walled tanks and impervious barriers which are placed upon the soil surface below the tanks, and ensuring that routes to sewers or groundwater are isolated or minimised, e.g. by ensuring access hatches (manholes) are effectively sealed against the solvents in use, open drains are closed and sealed, etc.

- correct specification of size and strength of tanks or storage containers to receive pumped-out liquors (see also stability, in primary measures, above), or a self-safe volume control system is installed
- leak identification systems
- tertiary measures (management systems):
 - inspections by external experts and internally including regular maintenance
 - emergency plans for potential accidents
 - test programmes.

The identification of measures and targets for the environmental effects can determine the choice of site, plant and equipment as well as design and construction of the infrastructure and plant.

Achieved environmental benefits: Helps minimise fugitive emissions to air. Particularly useful in minimising contamination of soil and groundwater by routes that are not readily visible and are difficult to identify. Facilitates site decommissioning. Minimisation of unplanned chronic and acute discharges to surface waters as well as municipal waste water treatment systems.

Cross-media effects: No adverse implications.

Operational data: Careful planning and design utilising operational experience can make routine operation, maintenance and monitoring easier, cheaper and environmentally safer.

Applicability: These measures can be considered for all installations; however they are best implemented at the proposal and initial design and build stages. Many changes can be incorporated in major upgrades, while some improvements can be made to existing installations during normal maintenance periods, although retrospective improvement may be more difficult, and may not be as effective. Various standards and guidance can also form part of longer term planning for plant improvements.

Economics: These are part of the investment costs with initial investments or upgrades. Some techniques may be no-cost options at a new build or upgrade stage. Often costs can be recovered by more efficient working, maintenance, and the avoidance of costs for dealing with accidents and breaches of permit.

Driving forces for implementation: Business duty of care and possible liability for any environmental damage arising. The Seveso Directive (as amended), where relevant substances and quantities are stored.

Example plants: Widely used in many countries.

Reference literature:[91, EIPPCB, 2005] [59, EIPPCB, 2005] [119, RIZA, 1999] [111, Eurofer, 2003] [120, INRS, 1998] [187, EC, 1996] [128, TWG, 2005]

20.2.2 Storage and handling of chemicals, hazardous materials and waste

Description: The storage and handling of hazardous materials is described in detail in the ESB BREF [91, EIPPCB, 2005]. Storage and handling of hazardous materials is necessary to maintain the supply of materials to the treatment application systems.

Achieved environmental benefits: Storage areas and handling in purpose built rooms and with appropriate equipment reduces environmental risks.

Cross-media effects: None.

Operational data: The following techniques are important for this sector:

- only small quantities are stored directly in the application areas. For larger quantities, separate rooms are necessary to reduce fire and environmental hazards
- bulk storage tanks for solvents and liquids containing solvent can be back-vented to the delivery tank during filling or vented through carbon absorption. Back-venting may only account for 0.01 to 0.03 % of the amount of solvent passing through the tanks, and is only likely to be considered where it can achieve better benefits
- provide containment for accidental spills (e.g. 'catch pans' for small scale spills), provide adsorbent material at sensitive locations
- underground storage of hazardous materials has a high risk of unplanned leakage which can contaminate soil and groundwater, as well as unobserved emissions to air. This may be avoided by using aboveground storage, or where underground storage is used, by using double-skinned construction and/or leakage detection systems
- all fixed bulk storage tanks should be fitted with audible and/or visual high level alarms or volume indicators to warn of overfilling. Where practicable in relation to the viscosity of the material being handled or pumping system used, the filling systems should be interlocked to the alarm system to prevent overfilling
- unique filling points for each tank to avoid cross-contamination of (especially incompatible) materials.

For large tanks, techniques can be found in the ESB BREF. In particular, techniques to increase reflectivity and reduce heat absorption from solar radiation and therefore reduce losses of solvent by evaporation include:

- paint aboveground tanks white or install a sunscreen or solar shield
- use cone roof tanks with internal floating covers (depending on the frequency of emptying).

Applicability: Special storage for hazardous materials is widely applied as a regulatory requirement or good practice. See back-venting in Operational data, above.

Economics: No data submitted.

Driving forces for implementation: Complying with legal requirements for health and safety and for the prevention of accidents. It must be noted that there are differing national regulations within Europe.

Example plants: Applied in all industries in the scope of this document.

Reference literature: [76, TWG, 2004] [121, UK DEFRA and notes, 2003] [68, ACEA, 2004, 91, EIPPCB, 2005] [128, TWG, 2005]

20.2.2.1 Handling and use of solvents in production areas

Description: Where VOC solvents are used, the following general measures and principles can be applied to ensure they are kept in airtight (or nearly airtight) containers:

- enclosure, e.g. using lids, of the sources of potential emissions
- re-lid partly emptied drums or cans of solvent to prevent vapour losses
- keep solvent containers away from sources of heat and draughts (e.g. movement of fork lift trucks near open containers) to minimise evaporation
- encapsulate vessels, reservoirs and machinery as much as possible, using well-fitting sealed lids and covers
- where vessels and reservoirs do not have proper covers, use plastic wrap or antistatic plastic covers, where necessary attached by elastic bands, tyre inner tubes, or nylon hook and loop fasteners (where these materials are not dissolved by the solvent being covered). Such covers have the added advantage of keeping them free from dust and debris
- store wastes containing solvents, e.g. contaminated wipes and solvent-based residues, in containers (see also Section 20.11.2.8)
- use measuring systems or controlled dosages to avoid excess material containing solvent being used, e.g. the use of pre-impregnated wipes can be effective for cleaning small parts
- avoid manual handling by pumping solvents and solvent-based materials through a piped system (e.g. ring main) to the point of use. The advantages include:
 - reduced risk of spillage during transfer and decanting
 - better containment and lower risk of exposure to contaminants
 - ability to fit flow-meters to allow accurate auditing.

Achieved environmental benefits: Reduced amount of VOCs emitted to the air.

Cross-media effects: No data submitted.

Operational data: Health and safety at work issues may determine whether and how the solvent container is covered.

Applicability: Note that many solvents expand and contract significantly with changing ambient temperatures. Sufficient space should be allowed for this in the storage vessel, according to the solvents used, e.g. containers should allow about 10 % redundant volume.

Economics: No data submitted.

Driving forces for implementation: Workplace health and safety. Legal compliance, e.g. SED.

Example plants: Airbus France use pre-impregnated wipes.

Reference literature:: [76, TWG, 2004] [89, UK and Programme, 1996] [59, EIPPCB, 2005] [128, TWG, 2005]

20.2.3 Automation of equipment

Description: Many operations in an installation may be automated, depending on the activity and the industry. Examples are:

- robot spraying:
 - of cars, see Sections 6.2.4.1 and 6.2.4.2
 - of trucks see Section 7.2.1
 - of ships, see Section 11.4.4
 - of plastics, see Section 16.2
- automatic mixing systems, see Section 20.6.3.1
 - for printing, applicable to flexible packaging only (see Section 2.4.2)
- roller coating, see Section 20.7.3.1
- curtain coating see Section 20.7.3.2
- piped delivery of solvents and solvent-based materials (see Sections 20.2.2.1 20.6.3.4 and 20.6.3.5).

Achieved environmental benefits: Minimises overspray, reduces dust, materials efficiency increased and waste reduced, less waste solvent.

Cross-media effects: See relevant sections.

Operational data: See relevant sections. See example plant below (See Table 20.2 and Table 20.3).

Applicability: See relevant sections. Widely used in car painting. Used in painting aircraft parts.

Economics: See relevant sections. For savings in materials and time in vehicle painting, see Table 20.2 and Table 20.3).

Driving forces for implementation: Increased quality and productivity.

Example plants: See relevant sections.

Aircraft parts: Airbus, Nantes, France

Vehicles: Seat Martorell, Spain; VW Pamplona, Spain, and VW, South Africa; Renault, Flins, France; BMW, powder clear coat with ESTA, Munich, Germany; Mercedes, Germany.

Upper medium class car, 500 units per day. Interior painting: 145 ml front door, 130 ml rear door, 255 ml engine compartment, 150 ml trunk. The paint costs EUR 10/l. Note: No other baseline data are given		
Conversion from manual air spray to:	ESTA	From air automated to ESTA robots
Paint saving:	138000 l/yr 1.2 l/unit	60950 l/yr 0.53 l/unit
Cost saving per year:	EUR 1380000/yr	EUR 609500/yr
CPU (cost per unit) saving:	EUR 12	EUR 5.3
Payback time, paint costs only (ROI)	20 months	13 months
Transfer efficiency: air 30 – 35 %, ESTA 40 – 60 % Path length reduced by up to 60 % Path speed reduced by up to 25 % Painting time reduced by up to 25 % Quality higher due to wrap around Dust reduced due to reduced air Coat thickness: same, possibly thicker		

Table 20.2: Example for the introduction of interior robot spraying on a car assembly line [162, Eurocar, 2005]

Upper medium class car, 500 units per day. Metallic painting: Unit painted surface 9.5m ² . Base coat 2-coat thickness 5 µm, solids content 15 %. The paint costs EUR 10/l Note: No other baseline data are given	
Paint saving per year:	41 641 l/yr
Per unit:	0.45 l/unit
Cost saving per year:	EUR 416410/yr
CPU (cost per unit) saving:	EUR 4.5
Amortisation (ROI)	10 months

Table 20.3: Example for the introduction of exterior robot spraying using metallic paints on a car assembly line
[162, Eurocar, 2005]

Reference literature: See relevant sections indicated in the Description above [162, Eurocar, 2005]

20.2.4 Training

Training is an essential part of an EMS (see Section 20.1.1 (c) ii).

Description: Staff carrying out many of the functions and operating equipment need adequate training. Theoretical and practical training in the handling, use and clean-up of solvents and related equipment is essential. New coating or printing materials, systems and application equipment need changed attitudes. New coating materials often show restricted application windows, thus the technical skills of operators and support staff have to be improved, otherwise problems are caused, such as film build being too thick.

Environmental, economic and health implications can also be emphasised. Written documentation for all operations involving the handling or use of solvents should include:

- process manuals to detail the quantities of chemicals required, provide health and safety data and identify the relevant operating procedures
- operating procedures to explain how to use particular equipment/plants in conjunction with particular solvents or coatings
- dealing with spillages, etc. (see Section 20.2.1).

Achieved environmental benefits: Reduced raw material consumption and waste production. Reduced VOC emissions.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: Widely applied.

Economics: No data submitted.

Driving forces for implementation: Health and safety of employees. Improves and maintains quality.

Example plants: No data submitted.

Reference literature: [89, UK and Programme, 1996]

20.2.5 Optimisation of processes/equipment

Description: Most activities require optimising, i.e. the consumption and/or emissions together with other parameters such as quality, throughput, etc. are monitored while certain process variables are changed. Optimisation can start with the design process, and is often carried out by or with the support of process suppliers. In some cases, software programs can be used.

Examples are:

- optimising the design and operation of waste gas treatment by software, see Section 20.11.1
- optimising the heatset offset printing for low IPA usage, see Sections 2.4.1.3.2, 2.4.1.3.4 and 2.4.1.5, etc.

Achieved environmental benefits: Enables an activity to be optimised for consumption of water, energy and conservation of raw materials, as well as minimising emissions, particularly VOCs.

Cross-media effects: No data submitted.

Operational data: Can use existing data and can be used to benchmark performance as well as plan improvements.

Applicability: All activities.

Economics: See Driving forces for implementation, below.

Driving forces for implementation: Environmental optimisation can also optimise the plant's process and economic performance.

Example plants: Widely applied.

Reference literature: [59, EIPPCB, 2005]

20.2.6 Maintenance

Maintenance of all plants and equipment is essential and forms part of an EMS (see Section 20.1.1 (c) vii).

Description: Keep a maintenance schedule and record of all inspections and maintenance activities:

- visually check for leaking seals, flanges, valves, welds, tanks and bunds
- pressure-test pipelines and tanks
- check the tightness of nuts and bolts
- check for wear and tear on machinery, valves and bunds
- recalibrate metering systems
- ensure that extraction and abatement equipment is fully serviceable, and that:
 - driers or ovens are not leaking
 - ducting is not leaking
 - bypasses are in good working order (i.e. not jammed).

Where possible, the preventive maintenance programme should be organised and supported by computer software. By flagging-up planned maintenance on a daily basis until it is completed, preventive maintenance software can help to ensure that no maintenance jobs are forgotten. Process operators can identify leaks, broken equipment, fractured pipes, etc. and hence help to focus unscheduled maintenance.

Achieved environmental benefits: Reduce solvent losses to air, improve efficiency and product quality, and help to keep the workplace tidy and pleasant.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: Generally applied.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Widley applied in this sector.

Reference literature: [89, UK and Programme, 1996]

20.3 Monitoring

When considering monitoring, the monitoring REF (MON) [113, EIPPCB, 2003] gives guidance and lists appropriate sources of standards procedures to use for issues including:

- direct monitoring, accounting for total emissions including monitoring of fugitive and diffuse emissions, surrogate parameters and mass balances
- timing of sampling
- how to deal with uncertainties.

20.3.1 Mass balances for solvents

Description: As part of understanding the environmental footprint/management plan of an installation (see Section 20.1.2), an operator needs to know:

- how much solvent is used and where
- how much solvent is emitted and where.

The outputs of organic solvents in the waste gas and as fugitive emissions are more difficult to determine than other emissions, such as water. Emissions are determined by a materials balance, referred to as a solvent balance. A solvent management plan is a tool using a mass balance. Annex III to the SED provides guidance on what is required in a solvent management plan [123, EC, 1999]. It includes the principles to be applied and a framework for a mass balance. A solvent management plan (a mass balance) is used to determine particular requirements, such as:

- verification of compliance with a reduction scheme with a total emission limit value expressed, e.g. in solvent emissions per unit production, or other units (see Annex 24.2)
- determination of fugitive emissions.

Figure 20.1 shows all of the usual input and output options for solvents.

The five most common cases (illustrated in Annex 24.4) are:

- no end-of-pipe abatement without internal solvent re-use
- no end-of-pipe abatement with internal solvent re-use
- solvent recovery and re-use (internally or externally)
- when destructive end-of-pipe abatement is used and the fugitive emissions (e.g. cleaning agents) are easily determined directly
- end-of-pipe abatement is used and the fugitive emissions are not easily determined.

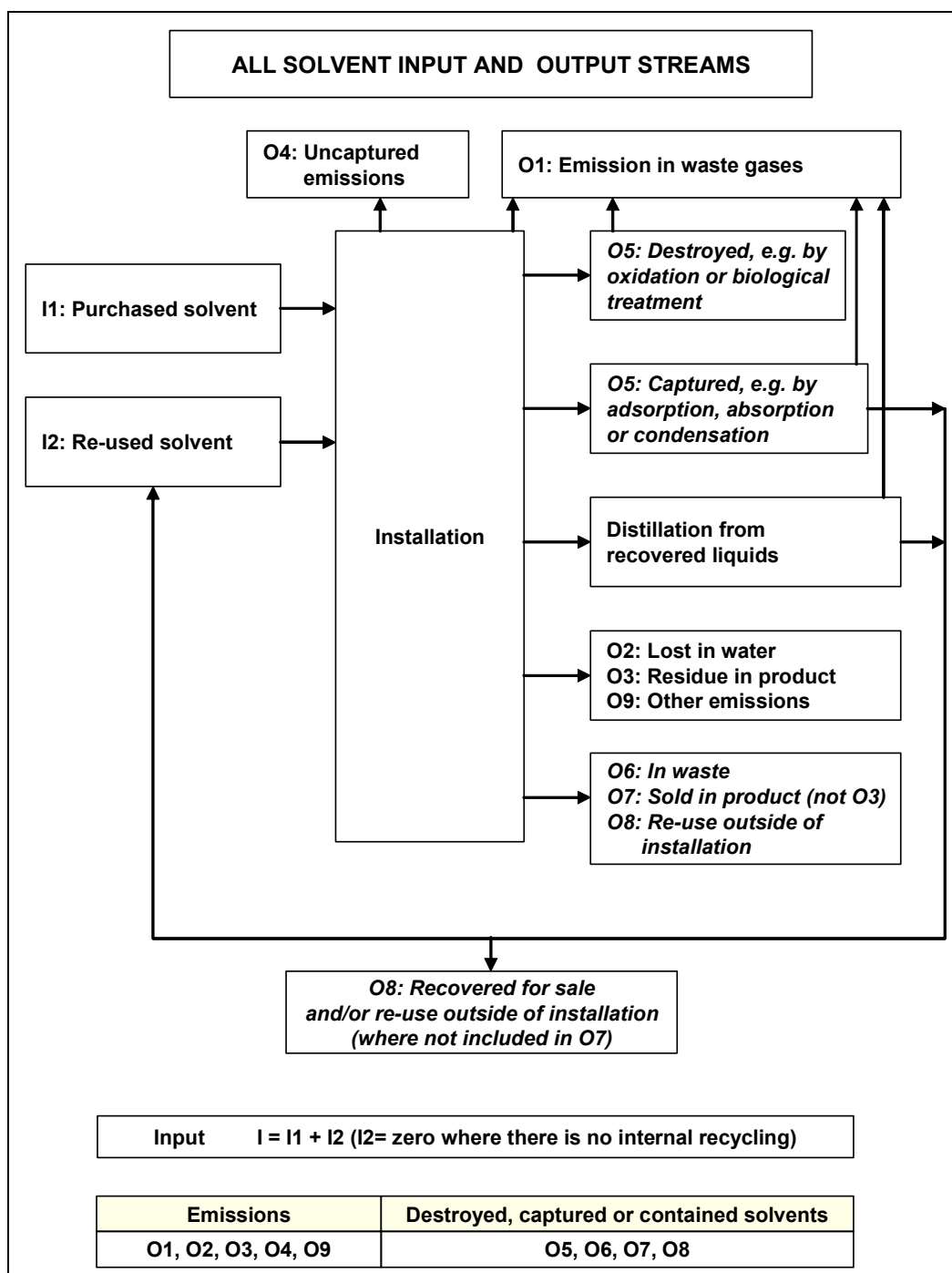


Figure 20.1: All solvent inputs and outputs (using definitions from the SED)

The total emissions $E = O1 + \text{fugitive emissions}$

The fugitive emissions (F) can be calculated as:

$$F = I1 - O1 - O5 - O6 - O7 - O8$$

(O7 is unlikely to apply to industries considered in this document)

or
$$F = O2 + O3 + O4 + O9$$

F can be determined by the direct measurement of the inputs (I) and outputs (O), see Section 20.3.2, below.

Deriving a mass balance usually involves a mix of direct measurement and estimation that will be derived for a specific situation (see Annexes 24.2, 24.3 and 24.5). A technique used in several industries (e.g. for the application in vehicle manufacturing industries, see Annex 24.5) is based on such as using the capture and destruction efficiency of the waste gas system using the following steps:

- measure the amount of solvent input ($I = I1 + I2$)
- measure the amount of emission in water and losses as waste, etc. (Losses = O2, O3, O6, O7, O8, O9)
- measure or calculate the removal efficiency of the abatement technique
- estimate the amount of solvent sent to abatement ($I - \text{Losses}$)
- multiply the amount of solvent by the percentage efficiency of the abatement = waste gas emissions O1
- fugitive emissions (as above): $F = I1 - O1 - O5 - O6 - O7 - O8$ or $F = O2 + O3 + O4 + O9$

Note: it is not necessary to calculate O1 to calculate fugitive emissions: O1 is needed when the total emissions are calculated (such as to comply with a total emission limit value or where a reduction scheme is used, see Annex 24.2).

Solvent balances whose function is to prove compliance to regulations or environmental permits are normally drawn up yearly. However, the balances may be prepared more frequently, e.g. monthly or quarterly, for the following reasons:

- initially, operators will need to apply resources to set up a proper system of data collection and to draw up and check the solvent balances, e.g. one or two man working days per month will be required in large companies. Once a system has been established and key measurements have been identified, they could be easily monitored (see Section 20.1.3)
- frequent solvent balances can be simpler than the annual balances. For instance, they can be put onto a spreadsheet and/or key indicators can be derived for regular checking, such as changes in stock that can be derived from administrative sources rather than by actual physical stocktaking
- making solvent balances is not always easy. The company needs to go along a learning curve. Solvent balances need to be made a number of times before they can be expected to be correct
- frequent balances show trends giving an early warning if problems arise. Balancing will discover where emission limits are likely to be exceeded so that it is possible to correct the situation in time and still be in compliance when the solvent balance for the whole year is made.

In order to have an extra check on the correctness of the frequent balances, the annual balance should not be the mere sum of all these balances but it should, as far as possible, be made separately from original data. This annual balance can then be compared to the sum of the frequent balances to find any discrepancies.

Achieved environmental benefits: Solvent balances are essential to estimate fugitive emissions and therefore control them. Frequent balances indicate any irregular situation, reduce environmental risks and enable the reduction of solvent emissions.

Cross-media effects: None.

Operational data: Emission figures should be comparable and it is important that throughout one industry the same definitions are applied, especially what is classed as 'solvent' for the purposes of the mass balance. It is important to note that the SED not only defines a VOC by vapour pressure at standard conditions, but also includes any compound having a corresponding volatility under the particular conditions of use.

When deriving a mass balance, assumptions will usually be made about the efficient working of any waste gas extraction and treatment system. For example, the space ventilated is the same as the design (i.e. no unrecorded connections), equipment such as fans are operating at design efficiency, etc. Volumes of airflows can be large (e.g. in some cases, orders of magnitude of 10^6 m³/hr), so errors in these figures can cause large errors in calculating emissions emitted (see Annexes 24.2 and 24.3).

In order for the assumptions to be valid, the ventilation system must be inspected and maintained in good working order (see Section 20.2.6 and specifically Section 20.11.1.2). Examples of problems encountered are (see Annex 24.3):

- the extraction system was not constructed as designed or has been altered without the drawings being updated
- automatic pressure controls, valves and dampers not working as designed
- systems working in the wrong way, i.e. blowing instead of extracting, flow being in the wrong direction, etc.
- fan motors, drive belts and/or pulleys may have been changed, giving different flowrates.

For the determination of volumetric flow, see the Reference literature below, and Section 20.3.2.

The accuracy of the calculated source figures for a mass balance needs to be determined (see Annexes 24.2 and 24.3). Where the maximum error in any source has no effect on the objective of the mass balance, no further work is necessary to make the estimate more precise.

Applicability: This technique is applicable to all industries applying solvents and is used to calculate fugitive emissions. It is also to demonstrate compliance with the SED where the reduction scheme is used.

Solvent balances may be inaccurate in complex situations, with large deviations where abatement techniques are used (see Operational data, above).

Many countries and industrial organisations have guidance on how to carry out a mass balance and construct a solvent management plan. One includes a free spreadsheet to assist with the mass balance (in English).

Economics: Cost reduction by optimisation of solvent use.

Driving forces for implementation: Solvents Emissions Directive. All installations are required to determine either the total emissions or the fugitive emissions separately.

Example plants: Widely used.

Reference literature: [4, Intergraf and EGF, 1999] [76, TWG, 2004] [90, ETBPP, et al., 2004] [113, EIPPCB, 2003] [128, TWG, 2006] [135, ADEME, 2004].

20.3.2 Direct measurement of solvents and emissions to air

Description: Section 20.3.1, above, says that some inputs (I) and/or outputs (O), as shown in Figure 20.1 may be measured directly. Examples are given in Annex 24.2.

Direct measurement can simply be the measuring by volume or by weight of solvent or materials containing solvent. In some cases, e.g. some cleaning operations, the solvent issued for use is all evaporated and lost as fugitive emissions. In such cases, the volume or weight issued is the amount emitted to air. In other cases, such as where solvent is retained in waste cleaning materials and residues, the weight of solvent in the residues can be determined and subtracted from the solvent issued.

Direct emissions of waste gases may be measured continuously or discontinuously by various types of detection equipment, for parameters such as TOC, CO, dust (particulates), NO_x. Equally important are the determination of flow and velocity, and understanding and estimating the uncertainties in the measurement. More information on these techniques can be found in the MON BREF [113, EIPPCB, 2003].

Achieved environmental benefits: No data submitted.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: Widely used.

Economics: No data submitted.

Driving forces for implementation: The SED requires all installations to determine fugitive emissions or the fugitive emissions separately.

Example plants: No data submitted.

Reference literature: The Monitoring BREF [113, EIPPCB, 2003] lists relevant CEN, standards (Comitee European de Normalisation), which are considered most robust, followed by the International Standardisation Organisation (ISO) [113, EIPPCB, 2003]. If the substance cannot be monitored using standards covered by the above then other accredited methods can be used, such the following:

- American Society for Testing and Materials (ASTM)
- Association Française de Normalisation (AFNOR)
- British Standards Institution (BSI)
- Deutsches Institute für Normung (DIN)
- United States Environmental Protection Agency (US EPA)
- Verein Deustcher Ingenieure (VDI)
- other accredited national standards.

If the substance cannot be monitored using standards covered by the above then the following occupational methods may be developed, following the requirements of ISO 17025, for stack emission monitoring:

- Method for the Determination of Hazardous Substances (MDHS) series published by the Health and Safety Executive (HSE)
- National Institute of Occupational Safety and Health (NIOSH); and
- Occupational Safety and Health Administration (OSHA).

National guidance also exists on monitoring certain gases and sampling procedures, e.g. [121, UK DEFRA and notes, 2003] [148, TWG, 2006].

The Guidance document for the European Pollutant Release and Transfer Register (E-PRTR, based on Regulation EC 166/2006) lists internationally recognised measuring methods for air and water pollutants: <http://ec.europa.eu/environment/ipcc/eper>.

20.3.3 Water

20.3.3.1 Preventing hazardous atmospheres in sewers

Description: When solvents are used in the production process, solvents may be present in waste waters, either from contact with water or steam in the process, or because of unplanned discharges (leakage, spills, etc.). The presence of solvents in sewers can lead to:

- fire and explosion hazards where the lower explosion limit (LEL) is exceeded
- formation of harmful vapours where the occupational exposure limits (TLV, OEL or MAK value) are exceeded
- damage to the fabric of the sewer
- interference with the waste water treatment.

Note that the substance does not have to be volatile or insoluble, as the temperature of waste waters from the installation and in public sewers may be elevated, and volatilise the solvent. Some substances can be discharged at relatively high concentrations; however, this method does not take into account treatability in a WWTP, either municipal or in the installation, and other reasons for applying other control limits.

Minimising unplanned discharges is discussed in Section 20.2.1.

Where a discharge of solvent is permitted, to ensure that the atmosphere of a sewer does not meet any of the criteria listed above, the first step is to estimate the amount of solvent lost to waste water and its likely concentration and if necessary confirm this by analysis. Where the concentration is sufficiently high enough to consider further investigation, the simplest criterion to use is that the waste water entering the sewer should not cause a harmful concentration of the substance in the air (expressed as the TLV, threshold limit value). This will be the lowest of the factors listed above, and will therefore provide protection for the other factors. This can be calculated by:

$$vp = vp0 * \gamma * mf$$

Where:

- vp = the measured vapour pressure
- vp0 = the vapour pressure of the pure organic liquid
- γ = the activity coefficient
- mf = mol fraction

Achieved environmental benefits: Safe levels of solvents in sewers.

Cross-media effects: No data submitted.

Operational data: Difficult to obtain some data, such as vapour pressure in the waste water.

Applicability: Calculating the concentration of the solvent in the sewer atmosphere is not generally applied, but may be considered where there are higher levels of discharge of solvents, particularly soluble solvents, to waste water.

Economics: Cost of obtaining data if no data are available for a specific solvent.

Driving forces for implementation: Workplace health and safety in the installation and receiving sewers.

Example plants: No data submitted.

Reference literature: [92, WRc_plc, 1980] [128, TWG, 2005] [148, TWG, 2006]

20.3.3.2 Monitoring of BOD and COD and biodegradability

Description: The organic content of waste waters can affect the efficiency of a WWTP (whether municipal or in-house) in two ways: load and biodegradability. The usual parameters measured are BOD (usually as BOD₅) and COD (or alternatively, TOC).

The load is the volume per hour or per day multiplied by the COD or BOD and the receiving WWTP should be capable of receiving and treating the load discharged from the installation.

The ratio of COD to BOD also gives a very approximate indication of the biological treatability of the effluent. The higher the ratio of COD to BOD, the more difficult the waste water may be to treat. More specific tests may be needed if it is necessary to confirm this. Some indicators for comparison are:

- for domestic effluent streams and some easily degradable compounds:
 - BOD₅ = 0.68 x COD (with a reasonable degree of confidence)
- for compounds, a rough indication is (although this is not always reliable):
 - COD:BOD:>100:1 a compound is usually relatively non-biodegradable
 - COD:BOD <10:1 a compound is usually relatively degradable.

Achieved environmental benefits: Ensuring levels of BOD and COD in the waste water have minimal environmental impact.

Cross-media effects: Using water-based coatings to decrease solvent emissions to air may increase the organic load discharged to sewers. This may be as readily treatable BOD and/or refractory COD. This may lead to overloaded waste water treatment facilities (either within or external to the installation) and possibly to refractory COD being discharged to watercourses.

Operational data: No data submitted.

Applicability: See Cross-media effects, above.

Economics: No data submitted.

Driving forces for implementation: Complying with water discharge legislation.

Example plants: No data submitted.

Reference literature: [93, Agences de l'Eau de France, et al., 2002] [128, TWG, 2005] [94, EIPPCB, 2006] [153, CEFIC, 1998] <http://www.cefic.be/activities/hse/rc/guide/11.htm>, [113, EIPPCB, 2003] [148, TWG, 2006]

20.3.3.3 Monitoring and controlling aquatic toxicity

Description: Where water is used, either in cleaning or as the medium for the process (such as electropainting or in water-based inks, etc.), the water may contain materials in suspension or in solution that are toxic in aquatic pathways (including in sewage sludge). Some water-based processes may require the addition of biocides to prevent biological degradation in storage and use. Solutions such as e-coating paints also contain catalysts such as organotin compounds.

Data on the toxicity of raw materials to these pathways can be found in suppliers' information (such as risk phrases relating to the environment, particularly R50 and R53, as well as R51 and R52, see Section 20.10) or directly from suppliers. Other risk phrases may be applicable, depending on the discharge point and the downstream uses of the water (such as fishery, drinking water extraction, etc.).

A key factor is the amount of the material being discharged, and this can be calculated from operational information or determined by analysis. If necessary, suitable toxicity testing may be required.

The options to control the material being discharged are to:

- consider replacement by less hazardous materials (see Section 20.10)
- minimise the use in production, such as by automatic dosing
- minimise the loss from production tanks, such as by multiple (or cascade) rinsing, and membrane filtration (see Sections 20.7.5.1 and 20.7.5.3) with recirculation of the concentrates
- treat the waste waters to remove the problem materials.

Further information on these techniques is given in the STM and CWW BREFs.

Where materials with known aquatic toxicity are discharged at quantities that may have an environmental impact, then the discharge should be monitored according to the type of material and a frequency necessary to enable control of the discharge (see the Monitoring BREF).

Achieved environmental benefits: Protection of aquatic and sludge pathways.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: Widely used. The level to which substances with aquatic toxicity may be discharged may depend on whether the discharge is to surface water or municipal waste water treatment plants. It will also depend on:

- the biodegradability and rate of degradation
- the fate of substances in the treatment (i.e. retained in the water column or separated in sludges)
- the type and fate of the sludges (e.g. sludges from waste water being incinerated or from WWTPs being spread on land).

Economics: Aquatic toxicity testing can be expensive.

Driving forces for implementation: Complying with water discharge legislation.

Example plants: Widely applied across the EU.

Reference literature: [93, Agences de l'Eau de France, et al., 2002, 113, EIPPCB, 2003] [128, TWG, 2005] [67, EIPPCB, 2003, 97, EIPPCB, 2005, 113, EIPPCB, 2003][59, EIPPCB, 2005][148, TWG, 2006]

20.4 Water management

Where most of the surface treatment is solvent-based, water consumption is low, although this increases with water-based cleaning and/or water-based paints and inks. These may also increase the risk of water contamination (e.g. from residual resins, pigments and/or biocides to sewers).

More information on process descriptions meant for water management can be found in the STM BREF [59, EIPPCB, 2005].

20.4.1 Re-use/recycling of rinsing water

20.4.1.1 Regeneration by ion exchange

Spent rinse-water can be regenerated. This can lead to savings in water consumption and will reduce the amount of waste water to be treated, reducing the waste water treatment costs for capital investment, energy usage and chemicals. However, this has to be offset by the cost of the regeneration equipment and the power and chemicals that this may incur. Where incoming water is treated, it is often easier and cheaper (in terms of capital deployed, chemicals and power) to recover the rinse-water than to treat fresh incoming water, as the ionic concentration or TDS in the incoming water may be higher than that of the rinse-water [59, EIPPCB, 2005].

20.4.1.2 Re-use of water within the plant

Description: Recycling of water by use of closed loop systems such as cooling towers (open and closed systems) or heat exchangers reduces the amount of water used on the line.

Achieved environmental benefits: Reduces water consumption and waste water discharge.

Cross-media effects: No data submitted.

Operational data: Quality of water may have a significant impact on final product quality. In such cases, the quality is likely to be carefully controlled, and this may limit the recycling of water within the process. Use of treatment chemicals in water can affect product quality and restrict water recycling.

Applicability: Closed loop (rinsing) water systems are widely used for heat exchangers and cooling processes of the organic coating.

This technique is widely used in the coil coating industry.

Economics: There is a saving because of less water consumption.

Driving forces for implementation: Economic motivation.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004]

20.4.1.3 Cascade rinsing

Description: Reverse cascade rinsing (a multiple rinsing technique) combined with conductivity measurement and related flow-meters in the last water rinse step guarantees minimum water consumption and the lowest generation of waste.

Usually, the cascade consists of three rinsing steps. The more steps that are used, the lower the amount of fresh water that needs to be added to the last step in order to maintain conductivity borders. The overflow from the first rinsing step is usually run into the waste water treatment.

Multiple stage rinsing is particularly suitable to achieve a high rinsing rate with a small amount of rinsing water. For example, in cascade rinsing, the water flows in the opposite direction to the workpiece. This results in a rinsing water requirement of constant rinsing quality (the rinsing criterion), and can be mathematically expressed in the term:

$$Q/t = \{Sk (V/t)\}^{(1/n)}$$

Where:

Q/t	= necessary rinsing water amount (l/h) to reach the rinsing criterion
Sk	= rinsing criterion
n	= number of rinsing stages
V/t	= drag-out (l/h)
l	= litres
h	= hours

The main effect of saving is reached with the transition from the first into the second stage. As Table 20.4 shows, a smaller rinsing quantity of water can be achieved by the selection of the correct rinsing system. With increased numbers of water rinse stages, the volume of water used is reduced and water savings are increased. The achievable recovery rate is, at a given volume of evaporation, directly related to the concentration of process chemicals in the first rinsing step.

Rinsing criterion	10000	5000	1000	200
Number of stages	Necessary rinsing water quantity in l/h			
Single stage	10000	5000	1000	200
Two stages	100	71	32	14
Three stages	22	17	10	6

Table 20.4: Specific rinsing quantity of water (litres of rinsing water per litre drag out) as a function of given rinsing criterion and the number of stages in reverse cascade rinsing

Achieved environmental benefits: Reduction in water use and waste generation. By the introduction of multistage rinsing systems partly combined with a rinsing water recycling system, decreases of waste water of up to 90 % can be obtained. The closer the decrease gets to a zero discharge, the more complete the recovery of process chemicals and the less the requirement for waste water treatment will be.

Cross-media effects: No data submitted.

Operational data: The conductivity in the last water rinsing step is related to the maximum allowed load of contaminants which may influence further surface treatment processes. A lifetime of further chemical treatment baths can be improved by monitoring rinse-water pollution via conductivity.

A build-up of breakdown materials which may reduce process quality is likely unless other solution maintenance measures are taken. Build-up of breakdown materials can be monitored by conductivity measurements.

Applicability: There are options and combinations suitable for all installations where chemical treatment baths are used.

Economics: Generally, the installation of multistage rinsing techniques is associated with greater space requirements and higher investments (costs for additional tanks, workpiece transport equipment and control). The decrease of water consumption, recovery of process chemicals and the smaller effluent discharge, which requires a smaller waste water processing facility and less treatment chemicals, reduces the total costs.

Driving forces for implementation: See Economics, above.

Example plants: This technique is widely used in the coil coating industry.

Reference literature: [58, ECCA, 2004, 59, EIPPCB, 2006].

20.4.1.4 Control of water usage

Description: Water usage can be optimised to meet quality requirements such as by benchmarking, calculation, chemical or physico-chemical analysis (which can be online or manually). The water flow is then controlled by an authorised person using a variety of techniques such as using locking flow valves, or monitoring key parameters. For example, for rinsing, the conductivity in the last water rinsing step is related to the maximum allowed load of contaminants which may influence further surface treatment processes. Monitoring the discharge from the rinses using conductivity measurements can reduce the amount of water used, because it helps to control the amount of make-up water required.

Achieved environmental benefits: Water consumption and waste related to rinsing water will be reduced and the lifetime of further chemical treatment baths will be improved.

Cross-media effects: Reducing water usage could result in higher emission levels, such as BOD and COD emissions and potential stress on WWTP.

Operational data: The conductivity equipment shall be robust in handling and maintenance.

On coil coating, the allowed conductivity for the last water rinsing step depends on the further process, but is generally between 10 and 100 $\mu\text{S}/\text{cm}$ (20 °C). Measurement must be temperature compensated.

Applicability: Applicable where water-based chemical treatment baths are used.

This technique is widely used in the coil coating industry.

Economics: Low investment costs are involved for the conductivity equipment. Savings are achieved because there is a reduction of water consumption and waste generation.

Driving forces for implementation: Economics and overall process stability.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004]

20.5 Energy management

Energy management means a systematic advance to efficient use of energy. It includes technical as well as organisational measures. The aim is the minimisation of energy consumption and energy costs. The following elements must be considered:

- energy-specific data must be known
- efficient energy management (efficient use of energy and cost savings)
- identification of possibilities for energy saving
- influencing the behaviour of the organisation (the culture) and the employees to save energy.

All energy inputs can be recorded on an actual basis, and split according to type and major end-use on a specified basis, such as monthly, daily, hourly, etc. Inputs can also be benchmarked and optimised against other production measures (see Section 20.1.3).

Energy saving measures and techniques are given in Table 20.5, below.

		References
General techniques		
Energy management and maintenance	Design to minimise energy usage	Energy efficiency REF (ENE)
	Energy management systems, including identification of energy saving options	ENE REF, Sections 20.1.1, 20.1.2,
	Gathering and using energy-specific data (benchmarking)	Section 20.1.3
	Installation of energy efficient equipment (see specific references, below)	Section 20.5.3 ENE REF
	Maintenance	Section 20.2.6
Techniques for electricity management		
Adjustment of production and equipment and processes and equipment in associated processes	Examples: <ul style="list-style-type: none"> • adjustable drivers and optimisation (e.g. in printing presses) • optimising energy usage in space heating/cooling • optimising energy usage in lighting • use of energy efficient equipment • timely replacement of worn bearings 	See Sections 20.2.5, 20.2.6
Motors	High efficiency motors	Section 20.5.3
	Variable speed drive	
	Reducing demand on starting, e.g. by: <ul style="list-style-type: none"> • delta to star conversion of motors (with less than 50% loading) • automatic delta star controllers • motor energy savers • soft starters 	Section 20.5.2
	Replace 'v' belts by energy efficient flat belts	
	Switch off when not required	
	Replace over-sized motors by appropriate sized motor	

	Improved maintenance practice, ranging from using clean hands lubrication to ensuring rewinding is carried out in a manner that does not result in efficiency loss	
Drying		Section 20.8
Compressed air (blow or vacuum systems)	Leakage control	
	Compressed air valves at each machine	
	Central system/cascade-connection compressor	
	Reduction in working pressure	
	Efficient compressors	
	Intake of cold external air	
Cooling	Evaporative cooling in tower	CV BREF
	Electronic adjustment of cooling	
	Energy efficient cooling systems	
Techniques for input gas management		
Drying		Section 20.8
Residual heat	Re-use of residual heat from coupled technology	
Steam boilers and systems	Economiser	
	Flue-gas condenser	

		References
Techniques for energy management for waste gases		
Design optimisation and management of extraction and abatement		Section 20.11.1 CWW BREF
System selection design and optimisation	Selection of treatment Energy efficiency below autothermal conditions Cost-benefit of energy consumption to VOC emission reduction	Section 20.11.1.1
Maintenance	Planned maintenance Monitoring key equipment for wear (e.g. bearings, etc.) and that correct settings are maintained	Section 20.11.1.2
Optimising loads to waste gas treatment	By-passing peak loads	Sections 20.11.3
	Utilising over-capacity in waste gas treatment	Section 20.11.1.4
	Maintaining solvent concentration to treatment using variable frequency drives	Section 20.11.1.5
Techniques with energy recovery	Recuperative thermal, regenerative thermal, 2, 3 and multi-bed Catalytic	Section 20.11.4.3 to 20.11.4.6

Table 20.5: Energy saving measures and techniques

More information on energy management in water-based surface treatment, e.g. minimising the energy (current) losses in electrochemical processes such as electrocoating, use of electricity, heating and cooling, can be found in the STM BREF [59, EIPPCB, 2005], [161, EIPPCB, 2006], [4, Intergraf and EGF, 1999] <http://members.rediff.com/seetech/Motors.htm>. [128, TWG, 2005]

20.5.1 Optimisation of electrical power supply

Description: Minimising reactive energy losses – any AC electrical equipment such as transformers, motors etc., absorbs a total energy called the apparent energy. This is made up of active energy (in the form of work or heat) and reactive energy which is unproductive. The reactive energy increases if the current is out of phase in relation to the voltage, and is the difference between the voltage and the current wave peaks. The power factor ($\cos \phi$) of an electrical device is the ratio of the active power P (kW) over the apparent power S (kVA) and is the cosine of the angle between the peaks of the sine curves of voltage and current. The closer $\cos \phi$ is to unity (1), the more efficient the use of power; the lower the $\cos \phi$ value, the less effectively the energy is used. When $\cos \phi$ lies permanently above 0.95, the reactive energy losses at 15 kV and 150 kV levels are limited.

Achieved environmental benefits: Minimises energy losses.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: All installations using a three-phase supply. Power correction, reduction of reactive energy and reduction of instantaneous demand requires skilled review of power demands and correction. All installations using significant three-phase power can ensure reduction of resistance losses in power supplies.

Economics: Energy losses as unwanted heating, reactive energy, etc. increase power consumption and cause higher costs.

Driving force for implementation: Cost saving.

Example plants: Widely used.

Reference literature: [59, EIPPCB, 2006, 111, Eurofer, 2003] [148, TWG, 2006, 191, Senior, 2006]

20.5.2 Optimising electricity demand

Description: High instantaneous demands can cause energy losses by distorting the even pattern of the AC cycles of the phases and loss of useful energy. They can be avoided or controlled on start up by, for example, converting connections from star to delta for low loadings, using automatic delta to star converters, using soft-starters, etc.

Achieved environmental benefits: Minimises energy losses.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: All installations using three-phase motors.

Economics: Unnecessary power consumption and causes higher costs.

Driving force for implementation: Cost saving.

Example plants: Widely used.

Reference literature: [111, Eurofer, 2003, 191, Senior, 2006]
<http://members.rediff/seetech/Motors.htm>

20.5.3 Energy efficient equipment

Description: It is good practice to install energy efficient equipment, such as energy efficient motors. Management techniques such as good preventative maintenance of equipment with high energy high demands can also minimise energy usage.

References to the use of other energy efficient equipment are given in Table 20.5, above.

Achieved environmental benefits: Power saving. Preventative maintenance of fans and motors can minimise noise emissions.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: Depending on the size of the unit and energy consumption, the use of energy efficient motors is good practice for large applications. They can be specified for new installations, for the replacement of defective motors or for cost savings.

Economics: Minimal extra cost when replacing or for new equipment.

Driving force for implementation: Cost saving.

Example plants: Widely used.

Reference literature: [111, Eurofer, 2003]

20.6 Raw material management

20.6.1 Just-in-time management

Description: Applying a just-in-time management system will ensure that the ordered amount of materials, e.g. paint or ink, which are to be used for a specific job, matches the volume that is needed. For example, the ordered amount of paint of a certain colour matches the volume needed for a certain strip to be coated. This applies to external suppliers, and does not include the in-house preparation of batches of inks, paints, etc.

Achieved environmental benefits: Less waste materials will arise and fewer raw materials are used.

Cross-media effects: This type of management system transfers the environmental burden onto the supplier. It involves the manufacture of smaller batch sizes and increased transportation.

Operational data: No data submitted.

Applicability: Paint management systems are commonly applied in coil coating plants, vehicle paintshops and wood coating.

Economics: Cost reduction by optimised logistics.

Driving forces for implementation: Cost reduction.

Example plants: All automotive plants.

Reference literature: [58, ECCA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.6.2 Quality assurance of paints and solvents

Description: Paints and solvents are usually approved by competent experts (in-house or external) before use in paintshops. This approval procedure consists of thorough quality testing and includes verification that no substitute materials with higher toxicological or environmental impacts are used. Quality testing and verification procedures must be designed to specifically take into account environmental, health and safety risks of products.

Achieved environmental benefits: A systematic evaluation and reduction of adverse environmental impacts to air and water.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: In large companies where paint application is a major quality topic.

Economics: In-house material testing and approval is very cost-intensive, and is only installed for accomplishing high paint quality.

Driving forces for implementation: Quality demands.

Example plants: All automotive OEMs.

Reference literature: [76, TWG, 2004] [128, TWG, 2005]

20.6.3 Minimisation of raw material consumption

See also Section 20.13 on waste minimisation and treatment.

20.6.3.1 Advanced mixing systems

Description: When using automated mixing systems, it is not strictly necessary to use standard colours to mix the required colour. Specific colours can be composed from non-standardised colours by computer-controlled equipment. This, however, requires very sophisticated software and exact knowledge of the non-standardised colours which are to be used for the mixing. For this purpose, these non-standardised colours need to be measured with a photo spectrometer and the result is introduced to the colour-computer.

For example, with an online mixing system for 2-component products such as paints or adhesives, the exact amount needed will be dosed and mixed immediately before usage. The mixing unit is not a part of the paint or adhesive application tool. It is a standalone unit.

It is possible to obtain similar proportional benefits from using programmable scales or computerised Pantone colour matching systems.

Achieved environmental benefits: Reduction in waste materials and saving of resources. During manual mixing, losses of 1 or 2 % of solvents can occur. These can account for 15 % of the total VOC emissions. Automated mixing in enclosed machines reduces most of these emissions. Also, less cleaning agent is needed.

In printing, the amount of waste ink may be reduced by 75 % depending on the number of times that inks are mixed and the amounts involved. The automated technique permits a perfect dosage so that no colour correction is necessary, so therefore, only the exact quantity of ink is prepared.

With an online mixing system for 2-component products, reductions of 10 - 30 % of waste can be achieved.

Cross-media effects: Automation requires energy.

Operational data: This working method also makes it possible to use paints or inks that have returned as an ingredient for new paints or inks (see Section 20.6.3.2). The returned paints or inks are mixed according to the approximate colour, i.e. light greens, dark greens, light reds and dark reds. Once a certain quantity is achieved, the resulting colour is measured and the computer is told to use that colour whenever possible.

Applicability: Commonly applied in flexo and packaging gravure for solvent-based inks, where more than 200 tonnes of press-ready ink per year is mixed.

In the coil coating industry, automated colour mixing is routinely carried out in the paint making factories, and the application is offered to the coil coating lines, but it is not always appropriate. It depends on the colour and product mix. There are examples of coil coating lines using in-house computer controlled colour mixing schemes.

Online mixing systems for 2-component products are applicable when produced on equipment dedicated to a single product line. There is no restriction in subsequent application techniques. In the Netherlands, companies are advised to apply this technique when over 2000 litres of 2-components paint needs to be mixed. For adhesives, relatively small amounts are mixed. It is commonly applied in wood and furniture painting. It is also applicable to the coating of trains, e.g. for applying the groundcoat and primer/filler.

Economics: In printing, the investment cost depends on size and exact requirements, starting at approximately EUR 50000. However, a saving will be incurred for the operation because less ink is used and less waste needs to be disposed of. Depending on the size of the operation, the savings may lead to a favourable pay back time for the investment.

For online mixing systems for 2-component products, investment costs are EUR 9000 – 18000 for a mechanically driven installation used for the mixing of base coat. The costs are EUR 27000 – 37000 for an electronically driven installation. The payback time will normally be several years for companies coating small series. However, this depends on the amount of waste prevented, the price of the materials that are mixed and the costs for disposal.

Driving forces for implementation: The driving forces for implementation are the automated mixing rather than avoidance of waste. In adhesive application, automation is the main driving force.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [63, Vito, 2003] [13, DFIU and IFARE, 2002] [76, TWG, 2004]

20.6.3.2 Re-use of returned paints or inks

Description: Solvent- and water-based returned paints or inks can be re-used if they are not diluted too much and are not contaminated with cleaning agents where these differ from the solvent used as thinner. Water-based paints or inks polluted with cleaning agents cannot be re-used at all. To avoid contamination of the rest of the paints or inks, parts of the machines containing the paint or ink have to be emptied as far as possible before being cleaned.

Achieved environmental benefits: Lower consumption of fresh paint or ink and less waste to be disposed of.

Cross-media effects: No data submitted.

Operational data: In general, less water-based compared to solvent-based paints or inks can be re-used. In solvent-based flexo processes, the amount of waste ink that needs to be disposed of can be reduced by 30 - 50 % and less fresh ink is needed.

Applicability: The technique is applied when standardised colours are used. When non-standardised colours are used, computer-based colour matching (colour analysis) is needed to be able to use the mix as a source for a new mix.

Applicable in heatset offset and publication gravure where only four standard colours are used. In these processes, the same ink is used for the next run, and stays in the press. Press-returns are only a problem in cases where specific colours are mixed for specific jobs, as happens in flexible packaging printing.

In coil coating, it is normal practice to re-use the paint returned from the coater heads. The drum will be re-sealed for later use when the same product/colour is required. The only wastage from the coil coating application is the thin film remaining on the rolls and delivery equipment, which requires manual wiping from the surfaces to permit product/colour changes.

Re-use of recovered paints is difficult in the painting of wood and furniture where many different types of colours are used. Applicable when large volumes of the same colours are used.

Economics: Savings due to the lower consumption of fresh paint or ink and less waste needs to be disposed of.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [76, TWG, 2004] [63, Vito, 2003] [147, Presti, 2005]

20.6.3.3 Re-use of recovered coatings or inks

Description: Where water-based coatings paints or inks are applied, it is possible to re-use the recovered paint or ink sludge, e.g. by applying ultrafiltration (see Section 20.12.6). Where mixed waste water is captured, the recovered paint or ink can be re-used as an additive to black paint or ink. When waste water is captured separately from each single unit, the different colours can be re-used in the same colour.

Achieved environmental benefits: Less waste is generated and less fresh materials are consumed.

Cross-media effects: Filtration requires energy.

Operational data: In electro-immersion coating processes (see electrocoating, Section 20.7.3.4), recycling of paint and the completely demineralised water is possible by allowing a closed loop. Ultrafiltration is often applied in this situation.

Applicability: Only applicable to water-based 1-component inks and to water-based or solvent-based 1-component paints and powder coatings. The restrictions on its applicability may be explained by the following:

- black ink is used in small amounts
- each colour ink is a different high quality preparation
- sludge may contain cleaning agents.

In the automotive industry, it is applied by one company in the primer section.

In the printing industry, it is applied in flexible packaging printing. Not applicable for food packaging, as there may be uncontrolled additions to the inks.

Economics: Its high energy consumption makes this technique more cost-effective for dedicated waste water treatment plants.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [13, DFIU and IFARE, 2002] [63, Vito, 2003] [76, TWG, 2004] [54, BMLFUW Austria, 2003]

20.6.3.4 Direct piping of paint or ink from storage

Description: Paint or ink is transported from the storage area directly to the painting or inking units through piping systems.

Achieved environmental benefits: Piped systems have a number of advantages, which are:

- reducing the risk of spillage through transfer and decanting
- removing the need to uncover tanks and reservoirs, allowing better sealing and reducing the risk of exposure to contaminants
- being able to fit with flow meters to allow accurate auditing.

Fewer waste paints or inks, fewer containers and fewer materials to clean. For example, the achievable level of residues for heatset plants is <1 % of the purchased ink.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Direct piping is applied in large plants where large re-usable paint or ink containers are used.

In printing, it is applicable to plants with sufficient ink consumption; commonly applied in large heatset plants. In publication gravure, this is a standard technique. In flexo and packaging gravure, it is not applied because of the many hundreds of different colours that are used.

Widely used in the automotive industry.

Economics: The investment in piping and pumps is considerable. For example, for the printing industry, the minimum investment ranges from EUR 5000 - 24000. Minimal savings are incurred through slightly cheaper ink and less disposal costs.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [76, TWG, 2004] [89, UK and Programme, 1996]

20.6.3.5 Direct piping of solvents from storage

Description: Solvents for viscosity control are piped directly from the storage area to the painting or inking units. For better control, aboveground piping should be carried out as underground pipes for solvents are a known source of serious soil and groundwater pollution.

The system is effective if coupled with regular inspection and maintenance. Otherwise, solvent losses from pumps, valves and flanges may add up and become a significant source of VOC emissions.

Achieved environmental benefits: Piped systems have a number of advantages, which are:

- reducing the risk of spillage through transfer and decanting
- removing the need to uncover tanks and reservoirs, allowing better sealing and reducing the risk of exposure to contaminants
- being able to fit with flow meters to allow accurate auditing.

Cross-media effects: No data submitted.

Operational data: In publication gravure, only toluene is used and, therefore, direct supply is easy to apply. However, in flexible packaging printing, the situation is more complex since the viscosity control needs to be done with different solvents depending on the job in hand. Generally ethanol (for flexo) or ethyl acetate or specific ethanol/ethyl acetate mixtures (for gravure) and sometimes MEK (for adhesives and paints) and sometimes even other solvents are used.

Piping without metering can make the measurement of solvent consumption in some specific parts of the process impossible. This reduces the amount of data available for the solvent management plan and makes identification and quantification of fugitive emissions more difficult.

Applicability: Commonly applied in publication gravure and flexible packaging printing processes. Widely used in the automotive industry. Not applicable in the coil coating industry. Commonly applied in the coating of wood and furniture when larger volumes of paint are used, i.e. in medium-sized or larger companies.

Economics: For new plants this is a low cost item; however, retrofit is very expensive.

Driving forces for implementation: Besides reducing solvent use and emissions, it also decreases the time that the painting or inking units are not running.

Example plants: No data submitted.

Reference literature: [18, UBA Germany, 2003] [76, TWG, 2004] [89, UK and Programme, 1996] [128, TWG, 2005]

20.6.3.6 Batch painting/colour grouping

Description: Batch painting, also called colour grouping or block-to-block painting, means that a series of a specific products is painted in the same colour. This will result in less frequent changes to a different colour.

Achieved environmental benefits: VOC reductions through reduced paint line cleaning/purging. Less paint residues produced.

Cross-media effects: None.

Operational data: Sufficient storage space for the products as well as an appropriate logistical planning system have to be available. It also depends on the number of different colours and their relative abundance in the production programme. For the automotive industry, the average colour group length is between two and six units.

Applicability: This technique is commonly applied in the automotive industry, in the coating of trucks and commercial vehicles and in the coating of metal packaging. Not applicable in printing processes.

Economics: Savings in paint, solvents and cleaning/downtime are offset by higher storage capacity costs.

Driving forces for implementation: No data submitted.

Example plants: Common use in most automotive plants.

Reference literature: [13, DFIU and IFARE, 2002] [68, ACEA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.6.3.7 Pig-clearing systems

Description: This method only fills as much paint into the system as necessary for the coating processes. The paint is pressed back from the (flexible) tube into the paint supply by an elastic separation module (pig-clearing) and is re-used. The purged solvents can be recovered and re-used.

A special type of purging is called ‘soft purging’, where lower VOC paint materials, rather than solvent are used to purge guns and lines.

Achieved environmental benefits: The advantages are the lower use of cleaning agents, the reduction of paint and solvent losses as well as the decrease of the manual processes with the colour change.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Only applicable where:

- paints or inks are delivered to machinery through pipes
- different colours are sent through the same pipe regularly.

Not applicable where low viscosity products are used as they will run past the module. Currently applied in some base coat lines of automotive paintshops.

In the automotive industry, the trend towards more special colours has initiated the development of new lacquer supply systems allowing an economic change in colours. Also soft purging is applied.

In the furniture industry, there is also an increasing demand of furniture painted in individual and special colours and consequently the use of pig-clearing systems.

This technique is not commonly applied in the coating of trains.

Economics: Reduction of costs for paint and solvent consumption.

Driving forces for implementation: No data submitted.

Example plants: Volkswagen AG, Wolfsburg, Germany; and Renault, Flins sur Seine, France.

Reference literature: [13, DFIU and IFARE, 2002] [68, ACEA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.7 Coating processes and equipment

20.7.1 Pretreatments prior to painting

Techniques for cleaning and their selection are also discussed in Section 20.9. More information can also be found in the STM BREF [59, EIPPCB, 2005].

20.7.1.1 Solvent-based degreasing

Description: Oil, grease and dirt are removed from metal or plastic substrates with solvents. This is usually by immersion in a vat of solvent or the solvent vapour above the liquid. The vats can be open or closed, and may be used with ultrasonic systems.

Achieved environmental benefits: No data submitted.

Cross-media effects: Often use highly volatile and/or halogenated VOCs.

Operational data: No data submitted.

Applicability: Widely used where compatible with materials. These processes are not applied in the coating of wood and furniture as they are not necessary and remove oils from the wood.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [59, EIPPCB, 2005]

20.7.1.2 Water-based pretreatments

Water-based pretreatments are applied for three reasons: to remove grease and dirt from previous operations, improve corrosion resistance and to improve adhesion of the subsequent paint layers. The usual pretreatments applied are degreasing, phosphating and chromating. More information can be found in the STM BREF [59, EIPPCB, 2005]. These processes are not applied in the coating of wood and furniture as they are not necessary and they remove oils from the wood.

20.7.1.2.1 Water-based degreasing

Description: Oil, grease and dirt are removed from metal or plastic substrates with water-based detergent solutions. There is a variety of detergents and acid or alkali solutions to suit all situations (see also Section 20.9).

Achieved environmental benefits: Reduction of solvent emissions, particularly halogenated solvents.

Cross-media effects: Usually need heating. These systems contain surfactants which may require waste water treatment.

Operational data: A system needs to be selected to suit the substrate and the oils/greases to be removed.

Applicability: Widely used. See the STM BREF for a discussion of options.

Economics: Cheap to install and run.

Driving forces for implementation: Legal compliance, e.g. the SED encourages the use of water-based systems.

Example plants: Widely used in surface treatment for coil coating, and for automotive bodies.

Reference literature: [59, EIPPCB, 2005] [128, TWG, 2005]

20.7.1.2.2 Phosphating

Description: Phosphate conversion coatings are used to enhance corrosion resistance and the adhesion of subsequent paint coatings to steel substrates. They typically contain iron, zinc, nickel and manganese. They can be applied by spray, but are currently usually applied by dipping to give a more complete and consistent coating. More data is given in the STM BREF.

Achieved environmental benefits: No data submitted.

Cross-media effects: Overall, impacts are low. As well as the metals present, anions may include nitrite and fluoride, although no specific waste water treatment is usually required to remove these. Sludges are formed in the process solutions requiring removal and management as waste. There may be some health and safety issues with components such as nitrites.

Operational data: See the STM BREF.

Applicability: Almost universally used as a pretreatment for large volume painting of steel and easily applied, if the substrate is degreased well. The surface may be activated by speciality solutions containing titanium or magnesium.

Economics: Cheap, depending on the degree of automation of the application system.

Driving forces for implementation: Product finish quality.

Example plants: All car plants, and widely used in other industries.

Reference literature: [128, TWG, 2005] [59, EIPPCB, 2005] [128, TWG, 2005]

20.7.1.2.3 Conversion coating containing chrome

Description: Chromate conversion coatings contain tri- or hexavalent chromium. They are used to enhance corrosion protection on various metal surfaces, including electrocoated zinc, hot dip galvanised zinc, aluminium, stainless steel, cold rolled steel, tin, copper, and magnesium.

The protection mechanism is based on the dissolution of the Cr(VI) present at the surface of the film. The presence of chromate works locally to inhibit any corrosive action on the exposed metal surface. Without such protection, zinc coated steel surfaces have a strong tendency to white rust corrosion.

Hexavalent chromium conversion coatings and associated techniques including alternatives are also discussed in the STM BREF [59, EIPPCB, 2005].

Achieved environmental benefits: Increased product material life. Chromating has no impact on recycling the substrate metals.

Cross-media effects: The concentration of hexavalent chrome in the treatment bath affects, in the case of subsequent rinsing, waste water pollution and waste water treatment.

Hexavalent chromium (CrVI) is toxic due to its carcinogenicity, as well as harmful to the environment. Its use is now virtually banned in the automotive industry, and from electrical and electronic goods. No direct replacements had been identified [59, EIPPCB, 2005] by 2005. However, alternatives have been identified in coil coating for low corrosion exposure applications (see Section 20.7.1.2.3).

Operational data: The layer thickness of the chromating coats is between 0.1 and 2 µm. They are well suited as adhesion mediators for subsequent coating with paint layers or synthetic material coatings. Lubricants can be included in order to decrease the friction values of the treated strip.

This system is applied by spray/dip and squeegee or chemcoater (rollcoater).

Applicability: Widely used for quality reasons. In coil coating, chromating is used to enhance corrosion protection on various metal surfaces, including electrocoated zinc, hot dip galvanised zinc, aluminium, stainless steel, cold rolled steel, tin and copper. Without such protection, zinc coated steel surfaces have a strong tendency to white rust corrosion in hours.

In the automotive industry, passivation of the zinc-phosphating layer used to be by chromium (VI) or zirconium hexafluoride solutions. Nowadays, cathodic immersion prime coating is applied directly over the phosphate layer to achieve high quality corrosion protection.

Chromating is carried out on aircraft for increased corrosion protection for high humidity climate conditions and high salinity of the atmosphere or upon customer requests (about 10 % of aircraft). A chromate-free primer can be applied if the aircraft is utilised under normal climatic conditions. The chromate containing wash primer, is only applied onto metal surfaces and not onto composite materials, and cannot be substituted for safety reasons.

Economics: Cheap to use.

Driving forces for implementation: No data submitted.

Example plants: Widely used but on a decreasing basis.

Reference literature: [13, DFIU and IFARE, 2002] [59, EIPPCB, 2005] [76, TWG, 2004] [102, EC, 2000]

20.7.1.2.4 Chrome-free conversion coatings

Description: Some chrome-free conversion coating systems are available, based on treatments with composite organic-zirconium fluoride solutions, titanium fluoride, tartrate, phosphoric acid, or treatment with organic silicon derivatives (silanes). They may require a subsequent polymer layer to achieve the required corrosion resistance.

Achieved environmental benefits: Eliminates chromium as Cr(VI) from waste and waste water.

Cross-media effects: None.

Operational data: Chrome-free primers in long life coating systems in aggressive environments are still not wholly proven.

Applicability: These are applicable for some specific combinations of metal substrates and paint systems, in particular end use applications, e.g. for internal and lower specification systems.

In the vehicle manufacturing industries, e-coat immersion prime coating is applied directly over the phosphate layer without chromating to achieve high quality corrosion protection.

The chrome-free pretreatment with titanium, phosphoric acid and organic polymer (listed in Table 14.9) has been further developed with a chemical provider for the usual spray and dip processes. Since 1998, a company has used the method successfully in coil coating machines.

Chromium-free conversion coatings are now in use for anodising in the aircraft industry, based on tartrate and phosphoric acid.

Economics: No data submitted.

Driving forces for implementation: Occupational health and safety.

Example plants: Alternatives to CrVI, Airbus, France.

Reference literature: [58, ECCA, 2004], [76, TWG, 2004] [59, EIPPCB, 2005] [128, TWG, 2005]

20.7.1.2.5 Bath maintenance, water and waste reduction and waste water reduction

See Section 20.7.5.

20.7.2 Paint systems

20.7.2.1 Conventional solvent-based paints

Description: Conventional solvent-based paints contain approx. 35 – 80 wt-% of organic solvents for the regulation of viscosity and film formation. The type of the used solvents mainly depends on the resins or binders used. According to the process of film forming, the materials can be subdivided into:

- thermoplastic coatings, drying by solvent evaporation and remaining chemically unchanged in the dry coating film, e.g. acrylics, vinyls
- thermoset coatings, which ‘dry’ by solvent evaporation followed by a chemical cure or reaction to produce an insoluble cross linked polymer network, e.g. polyester/amino, polyurethane, epoxy
- oxidative drying coatings, alkyd resins modified with natural drying oils cure through a reaction with atmospheric oxygen.

The selection of the type of solvent used is based on the following main criteria:

- ability to dissolve the resin
- evaporation rate (drying rate)
- hazard, odour and cost.

Achieved environmental benefits: Compared to water-based systems, less energy is required for drying.

Cross-media effects: The use of conventional solvent-based paints has the highest VOC emissions and is likely to require VOC emission abatement measures as described in Section 20.11.

Operational data: No data submitted.

Applicability: Solvent-based products are used as first layer/sealers, primers and topcoats, depending on the industry and substrate.

Solvent-based paints are commonly applied in:

- the automotive industry: see Section 6.4.1
- coating of trucks and commercial vehicles: see Section 7.4.1
- coating of buses: see Section 8.4.2.2
- coating of trains: see Section 9.4.1
- coating of agricultural and construction equipment: see Section 10.4.1
- coating of ships and yachts: see Section 11.4.1
- coating of aircraft: see Section 12.4.1
- coil coating: see Section 14.4.2
- coating of metal packaging: see Section 15.4.1
- coating of plastic workpieces: see Section 16.4.3
- coating of furniture and wood materials: see Section 17.4.2.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002, 76, TWG, 2004] [128, TWG, 2005].

20.7.2.2 Solvent-based high solid paints

Description: The use of higher solids paints reduces solvent use compared with conventional, solvent-based paints, while still applying the requisite amount of coating. Their solids content amounts to more than 65 vol-% (e.g. yacht use 450 g/l epoxies for under waterline use). The film formers used are mainly based on epoxy, 2-component polyurethane, polysiloxane, oxirane or alkyd resin.

Achieved environmental benefits: Significant reduction in solvent use and emissions.

Cross-media effects: No data submitted.

Operational data: For paints used for the painting of agricultural and construction machines or household devices, high solids based on acrylate and polyester isocyanate are mostly used.

Applicability: Widely applicable.

In the coating of ships and yachts, high solid epoxy coatings are commonly applied onto the underwater parts of ships and yachts.

In the coating of aircraft, high solid coatings are sometimes applied in the topcoat.

In the coating of trains, high solid-based paint is only applied in the 1-coat topcoat.

In the coating of buses, high solids are applied in the 1-coat topcoat system.

In coil coating, high solids are commonly applied.

They are not currently applied metal packaging.

They are not currently applied in the coating of wood and furniture because they are too sticky and result in an undesirable 'plastic-like' aspect of wood-based product surfaces coated.

Economics: Purchasing costs of high solid paints are higher compared to conventional paints, but as they have higher coverage, the cost per m² is usually lower. Savings can be expected on labour costs.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [27, InfoMil, 2003, 76, TWG, 2004] [128, TWG, 2005]

20.7.2.3 Water-based paints

Description: Water-based paints contain water-based or water-dispersible film forming agents. Water-based paint systems can be 1-component paints; however mainly 2-component and UV radiation curing paints are applied. They are mainly based on alkyd, polyester, acrylate, melamine and epoxy resin. Water-based powder and powder slurry coatings are discussed in Section 20.7.2.6 and Section 20.7.2.7 respectively.

Water-based paint systems normally have a water content of 10 – 65 wt-% and often also contain <3 - 18 % organic solvents as a solubiliser and for an improvement of the properties of the wet film layer. Completely organic solvent-free paints are also available. Biocides may be part of the formulation as preservatives for the storage of the paints, in architectural applications and for electrocoat (which is kept in use in tanks).

The main improvements of these materials are their corrosion protection and exterior resistance (against climatic impacts).

2-component water-based paints show an improved resistance, especially mechanically, and also shows a very good isolating function even on woods rich in natural oils.

Achieved environmental benefits: The main advantages of water-based paints are the reduction of VOC emissions and the possibility for recycling of the paint in use in certain applications, e.g. using ultrafiltration. Cleaning of spraying devices and other tools can be carried out with water/solvent mixtures with a solvent proportion of about 5 to 20 %.

Another advantage is that there are no flashpoint hazards associated with this paint, minimising the risks of combustion and explosion.

Cross-media effects: Compared to organic solvents, water has higher evaporation energy. Therefore, the energy demand for the drying of water-based paints may be expected to be higher, if the same drying rate as for solvent-based paints has to be achieved. However, compared to atomisation, acclimatisation of spray booths, heating of substrates, oven losses, etc. the energy demand for evaporation of volatile compounds is only in the range of 1 % for many industrial processes. Water, instead of organic solvents, has a minor impact on total process energy. The additional energy requirement is only significant for drying at ambient conditions and in the case of wet-on-wet processes.

Since water-based paints have lower application efficiencies, paint consumption may be increased. However, in practice, reduced transfer efficiency is valid for high rotation electrostatic bell application if external charging is used (5 % less as the maximum). Reduced transfer efficiency may occur in electrostatically assisted manual application where voltage is limited for safety reasons. Alternative techniques (internal charging) are available and widely used. As waterborne coatings are mostly used in new or redesigned installations, efficiency is usually improved due to better performance of equipment and possibly higher 'right first time' rates. Evidence from automotive applications shows comparable transfer efficiencies with solvent-based systems.

There will be increased BOD and COD in the waste water, and substances such as biocides, organotin catalysts and ammonia which have to be treated accordingly.

Depending on the systems used, the amount and quality of hazardous waste may change significantly.

Operational data: Water-based paints can initiate significant corrosion problems within the spraying systems due to the presence of water and oxygen. A substitution with water-based paint for conventional installations usually requires significant modification of the facility, such as replacement of the paint supply lines by materials made of high grade steel.

Increased blocking of spray equipment is reported in the coating of furniture and wood. It is not known if this is a process problem or can be solved by training and adaptation.

If water-based paints are processed, the following requirements generally have to be met:

- the ambient temperature has to be between 18 - 28 °C
- the surface temperature of the workpieces may not be lower than 15 °C
- an optimum processing is given at air humidity between 55 - 75 %
- water-based paints may not be stored below 0 °C (frost damage)
- good airflow across to the surface.

Applicability: For many years, water-based paints have been available on the market and are widely used. Due to the permanent development of these materials, their range of application is steadily increasing.

They are commonly applied in the automotive industry.

In the coating of ships and yachts, although water-based paints are available for several applications, they are used only in a limited number. Water-based applications use airless spray or roller, and not high rotation electrostatic bell.

In the coating of trains, 2-component chromate-free water-based paints based on epoxy are applied in the groundcoat, primer/filler and sometimes in the topcoats. Water-based paints are also applied for protection of the underbody.

In the coating of buses, water-based paints are used in some cases (cataphoric dip coating and underbody protection). With one exception, water-based paints are not applied as topcoats. In only one installation, city buses are completely coated with water-based paints.

In the coating of agricultural and construction equipment, they are commonly applied in cataphoric dip coating and also in 1-coat topcoats.

In the coating of trucks and commercial vehicles, they are commonly applied in cataphoric dip coating, primer/filler and in base coats on commercial vehicles, truck cabs and chassis and on axles.

In coil coating, if water-based coatings are used, the application is mostly limited to primers and backing coats.

In the coating of metal packaging, water-based paints are used, however, they contain up to 38 % organic solvents. External drum coating uses water-based coatings with <10 % organic solvents.

In the coating of plastic workpieces, water-based coating systems are commonly applied in ground coat, base coat and sometimes in the clear coat.

In furniture and wood, 2-component and UV curing water-based paints are commonly applied in some flat furniture parts before assembly. However, there are technical limitations, such as fibre swelling, depending on substrate. When switching to water-based products the total volume of products to be dried increases, since more painting and drying steps are needed, with additional intermediate sanding and polishing. Both sanding and additional drying result in an increased energy use, raw material use as well as increased labour. As an alternative, other types of drying systems could be introduced. This may need new development work and would increase costs. The finishing of assembled furniture is not possible with UV.

In the coating of aircraft, they are not currently applied because of their low resistance against chemicals such as hydraulic oil. Since the manufacturer's corrosion protection guarantee lasts for 25 years, only specific, approved paint systems can be utilised.

This technique is not widely applied for ships.

Economics: Costs for changing existing automated painting lines may be very high in some cases. Retrofitting is usually done at the end of the technical lifespan of the existing installation. Where painting is applied manually, costs for retrofit are less but still significant, and will depend on the ratio of manual to automatic equipment.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

References: [13, DFIU and IFARE, 2002] [8, IFARE and CITEPA, 2002] [27, InfoMil, 2003] [76, TWG, 2004] [128, TWG, 2005] [168, ESIG, 2005] [63, Vito, 2003] [147, Presti, 2005]

20.7.2.4 Water-based coatings with reduced flash-off requirement

Description: For development from to water-based coatings, see Operational data, below. The base coat systems show similar characteristics to current water-dilutable systems.

Achieved environmental benefits: Energy consumption may be lower than conventional solvent systems, and lower than for the application of conventional water-dilutable base coat systems (no infrared drier is necessary).

Cross-media effects: No data submitted.

Operational data: Standard waterborne base coats need tight control of spray booth operating conditions, good climate-control of spray booths (with a narrow operation window), five to six minutes enforced flash-off, and stainless steel pipelines. The flash-off requirement in particular hinders the application of waterborne coatings used in existing installations. For reduced flash-off base coats, 90 to 150 seconds flash-off time are sufficient (rapidly drying resins, highly volatile and azeotropic co-solvents and high speed blowing zones), so they fit into many existing lines. At the same time, the operating window is enlarged.

Applicability: The use of this concept is restricted by the following paint layer. Tests have shown that good surface quality results are attainable with a 2-component clear coat, whereas with 1-component clear coat systems, some quality imperfections (e.g. cloudiness) may still appear. Successful line trials have been performed. Approvals exist with 2-component as well as with 1-component clear coat.

Economics: The solvent-based base coat can be changed over to a water-dilutable base coat with relatively small technical expenditure (compared with a new plant).

Driving forces for implementation: No data submitted.

Example plants: Products with reduced flash-off time are in commercial use at Hyundai Assam, South Korea and at Alfa Romeo Pomigliano, Italy.

Reference literature: [128, TWG, 2005]

20.7.2.5 Radiation curing paints

Description: Radiation curing coatings rely, for their cure, on the activation of particular chemical groups by UV light or fast electrons (see Section 20.8.2). This property can be found in both resins and liquid diluents, thus it is possible to produce liquid coating systems that cure and harden without heat and without any emission of VOCs. Alternatively, similar chemical functionality can be incorporated into water-based, or even solid (powder) coatings. The base resins include epoxy, polyester, polyurethane but all with acrylic or vinyl functionality. The curing reaction is initiated directly by electron beam radiation (EB) or by ultraviolet (UV) radiation via an added photo-initiator.

For more information on:

- UV (ultraviolet) radiation curing: see Section 20.8.2.3
- EB (electron beam) radiation curing: see Section 20.8.2.4.

Achieved environmental benefits: Neither water-based nor solvent-free radiation curing paints generate waste water or VOC emissions.

Cross-media effects: No data submitted.

Operational data: UV curing paints can be applied by several techniques, such as brushing, rolling, casting, spraying and vacuum coating. Radiation cured powder coatings are being developed, but the majority of the powder coatings are cured in conventional high temperature ovens, see Section 20.7.2.6.

Applicability: Widely applicable.

In the coating of metal packaging, UV cured coatings are widely applied in three piece can manufacturing. However, it is not applied in DWI can and aluminium tube manufacture.

In the coating of plastic workpieces, UV cured coatings are applied in clear coats, e.g. on wheel covers.

In furniture and wood painting, UV cured water-based coatings are commonly applied in some furniture and wood coatings. This is usually where flat panels can be separately coated and the coating is carried out prior to assembling furniture.

They are currently not applied in the automotive industry, in the coating of aircraft, ships, trains, buses, agricultural and construction equipment, trucks and commercial vehicles and in coil coating (see also Section 22.14.2).

Economics: Costs will depend on specification, quantities and supplier. As an example, costs for UV water-based paints (about 50 % solids) are about EUR 6.50 per kilo, which is more than conventional paints (e.g. 2-component PU-paint costs EUR 4.35 per kilo). However, with pure UV cured paints (which are 100 % solids) the overall costs per m² will be lower because with the high solid content a higher efficiency will be achieved and at least 50 % of the overspray can be re-used.

The approximate price per kilo for UV curing powder coating is in the range EUR 3.01 – 5.38.

Investment costs for a new UV curing powder coating unit are about EUR 875000 – comprising about EUR 275000 for the application booth and drying installation and EUR 600000 for automation, material buffers, conveying system, etc. Operational costs are more or less the same as a conventional existing solvent-based application unit.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003, 76, TWG, 2004] [155, CEPE, 2006]

20.7.2.6 Powder coatings – conventionally cured

Description: Powder coatings are solvent-free materials that consist of powder with a particle size in the range 25 – 60 µm. Section 20.7.2.5 discusses the development of radiation curing of powder coatings but the majority of the powder coatings are cured in conventional high temperature ovens.

The main film forming agents are polyester or epoxy resins. To cure, the material is heated in a convection oven where it melts and fuses into a film. Powder coating systems show the following positive properties:

- almost free of solvent emissions
- no water is necessary in order to absorb lacquer particles in the paint booth
- low waste generation if the possibility of paint recycling is used
- paint recycling is technically possible (up to 95 %) and necessary for economical reasons
- high application efficiency, up to 100 %
- the high proportion of circulating air in the paint booth results in a reduction of energy consumption.

However, there are also the following disadvantages:

- the control of the film thickness is difficult (see Operational data, below). For example, in the automotive industry, a higher layer thickness (approx. 65 μm) will be created than is necessary, which results in higher paint consumption; however, increasingly nowadays, thinner layers (approx. 55 – 60 μm) are also achievable
- higher curing temperatures (approx. 140 - 200 °C) are necessary and because of this the technique cannot be applied to all substrates. However, low temperature powder coatings are becoming more readily available which cure at temperatures of around 60 - 100 °C
- application conditions are strictly defined (temperature, humidity)
- manual application is only possible if certain safety regulations (against dust, electrostatic voltages) are met.

Achieved environmental benefits: The application of powder coating generates neither waste water nor significant VOC emissions.

The powder paint technology applied via electrostatically assisted spraying does not require a recapture of overspray paint particles by water. Hence, waste water reprocessing is not necessary and the use of additives (such as coagulation agents) can be avoided.

Application tools and the complete booths can all be cleaned by vacuum cleaning or by blowing with compressed air. In this way, resources are saved and solvent emissions are avoided.

Cross-media effects: High curing temperatures are required. However, curing by combinations of infrared and air circulation techniques has a higher energy efficiency compared to conventional curing techniques.

Some low levels of VOCs may be emitted on curing – due to the reaction chemistry.

There are possible occupational health risks due to, e.g. mutagenic substances such as triglycidyl isocyanurate (TGIC) being used.

There may be potential electrostatic hazards.

Operational data: The subject of film thickness in powder coatings is not a simple one. The possible applied film thickness range is limited by the particle size distribution of the powder as well as by the application speed and cure conditions. Thus, it is technically possible to apply as thin a coat as 5 microns, but the powder needs to be very finely ground and precisely controlled. This is a very expensive operation. In addition, these very fine powders have poor flow and transport properties so they are difficult to apply. Powder coatings capable of application at 30 microns are certainly available for some end uses. At the other extreme, very thick coatings can be applied by powder sintering, but here, the limitation is the time taken for heat transport to melt, flow and fuse the powder. If the formulation is thermoset (heat hardening), the surface may be cured before full melting and fusion has occurred, trapping air bubbles within the film. Unless demanded by a particular end use, film thicknesses of over 90 microns are unusual simply on the basis of economics.

At present, powder coatings are mainly applied via electrostatically assisted spraying onto the workpieces (primarily onto metal but also onto glass surfaces). Powder coatings for the serial coating of wood are only applied in a very limited number of installations because of the high drying temperatures needed. Medium density fibre boards (MDF) are an example where powder coatings are successfully applied. The use of powder coating is also limited for plastic surfaces due to the missing electrical conductivity and temperature sensitiveness.

Applicability: In several sectors, the application of powder coatings is already a well established technique. Regarding environmental advantages, there are possibilities for automation and good profitability due to the possibility of recycling the overspray, and the use of powder coatings is continuously increasing. Powder coatings require electrostatic application techniques and are, therefore, primarily suitable for metal.

In the automotive industry, powder primer and clear coat is used in only one plant in the European industry, see Section 6.4.3.2, although it is more widely used in the US. Currently, as well as the operational problems associated with process change (such as maintaining the correct colours and finish), a powder coat system does not meet most European manufacturers quality specifications.

In the coating of agricultural and construction equipment, one manufacturer is currently building an installation for powder coatings. This production line will replace a conventional, solvent-based, 2-component 1-coat topcoating. This technique is ready for the serial production of agricultural and construction equipment.

In coil coating, powder coating is only used to a limited extent in the coil industry, because of difficulties of speed and control. They are especially used by the construction sector, e.g. for flat panels, window frames, sanitary cabins and by the sheet metal processing industry.

In the coating of metal packaging, powder coating may be applied onto the welding of three piece cans. However, not on the coating of DWI cans.

In the coating of plastic workpieces, it is currently only applied in small batches in the coating of small parts, such as composite parts of metal and plastics for car radiators.

In furniture and wood painting, it is currently only successfully applied onto MDF.

They are currently not applied in the coating of aircraft, ships, trains, buses and trucks and commercial vehicles, only in coating components (as in Chapters 13 on coating other metal surfaces and in Chapter 16 on coating of plastics). The argument concerning aircraft and ships is, that a forced drying step is needed and in these industries can only be applied to components.

Economics: Costs will depend on specification, quantities and supplier. Currently, the price for powder coating systems is still higher than for conventional coating systems. The price per kilo was in the range EUR 3.01 - 5.38 (2006).

Retrofitting a conventional solvent-based application unit with a powder coating unit, only requires replacement of the paint application systems; the ovens may not need to be changed. However, in the automotive industries, powder coatings require completely new spray booths, supply systems and curing ovens.

Driving forces for implementation: Reducing VOC emissions.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [76, TWG, 2004] [128, TWG, 2005] [155, CEPE, 2006] [168, ESIG, 2005] [89, Envirowise, 2003] [90, Envirowise, 1998]

20.7.2.7 Powder slurry

Description: Powder slurries are powders dispersed and stabilised in water and are applied using conventional equipment for liquid paints. They can be used in clear coat application.

Achieved environmental benefits: The application of a powder slurry coating generates neither waste water nor VOC emissions. In the automotive industry, significant energy savings are achieved by substituting the conventional 2-component clear coat by the wet-in-wet applied powder slurry clear coat. With the wet-in-wet application, the intermediate drying step can be missed out.

Cross-media effects: No data submitted.

Operational data: A forced drying step is needed.

Applicability: This technique is currently only applied in the coating of cars, see Section 6.4.3.3.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

20.7.2.8 Pre-coated materials

Description: Pre-coated materials can be used in the assembly of products, reducing the number of paint coatings or eliminating the need to paint. In the case of coating substrates of uniform dimensions, such as coil coated metals, wood or fibre boards, etc. coatings can be applied using techniques which are more difficult to apply to the assembled products or part-products, but are more environmentally beneficial (see Section 20.7.3).

Achieved environmental benefits: Significant reduction of VOC emissions dependent on the spraying activities that are replaced by applying coil coated materials. More efficient use of materials. More efficient drying or curing. More efficient collection and destruction of emissions during coil coating, as the application of the coatings and extraction of waste gases for a continuous flat surface is easier and more efficient than for coating formed components and bodies.

Cross-media effects: None. Although the emissions are transferred to the coil coating producer, they are reduced, see Achieved environmental benefits, above.

Operational data: Pre-coated materials are produced by coil coating, see Chapter 14.

Applicability: Coil coated metal is usually supplied complete with finish coat, but can also be supplied in primer ready for subsequent coat(s). It is used for a growing number of applications including: building and construction products, electrical appliances (white goods), automotive industry, caravans and mobile homes, metal cabinets, etc.

In the coating of trains, coil coated materials are increasingly used for the production of freight wagons.

In agricultural and construction equipment, some manufacturers apply electrocoating and topcoating before assembly takes place; coil coated materials might be an option here.

In the coating of metal packaging, coil coated materials are commonly used in three piece can manufacturing.

Economics: Reduction in production steps and concentration on core business.

Driving forces for implementation: Reduction in emissions to the workplace and environment.

Example plants: Widely used.

Reference literature: [13, DFIU and IFARE, 2002, 76, TWG, 2004] [128, TWG, 2005]

20.7.2.9 Paints containing toxic metals

Description: Paint pigments have contained toxic metals such as cadmium, hexavalent chromium, nickel and lead for the colour of their compounds and for corrosion resistance. However, their use is now strictly limited by regulations to activities which are not in the scope of this document, see Section 1.2.3.

Achieved environmental benefits: No data submitted.

Cross-media effects: Toxic materials in the environment.

Operational data: No data submitted.

Applicability: Specialised applications such as restoration, etc. are not in the scope of this document.

Economics: No data submitted.

Driving forces for implementation: Workplace health and safety. Marketing and use regulations. Product and wastes legislation.

Example plants: No data submitted.

Reference literature: [102, EC, 2000]

20.7.3 Paint application processes and equipment

Processes with a high application efficiency include filling, rolling, casting, dipping, flooding and vacuum coating. These processes generate less overspray than spray applications but are not universally applicable. There are two dipping processes: conventional and electrocoating.

Spraying may be with or without electrostatic assistance. For electrostatically assisted spraying, an electric field is generated between the workpiece and the spray gun. Then the following advantages concerning the environment as well as coat effectiveness are reached:

- lower material consumptions, lower emissions, smaller amounts of paint sludge and a reduced soiling of painting areas (less cleaning)
- improved possibilities for automation of painting processes, faster coating and, therefore, a higher productivity
- less air consumption (less energy demand).

Disadvantages of electrostatically assisted spray applications are the risk of edge runners and layer thicknesses which are too deep into cavities and interior edges due to a concentration of paint materials onto these areas. Several electrostatically assisted spray applications are in use, and they are described in the following sections. Also there may be special requirements concerning quality achieved, geometry, paint materials, electrical conductivity (e.g. affecting the ability to recoat surfaces) and workplace safety relating to the high voltages used.

Despite the increasing use of electrostatic application techniques, spraying without electrostatic charge is still widely used for various applications. In comparison to electrostatic processes, the investments are significantly smaller. Also there are no special requirements concerning geometry, paint materials, electrical conductivity and workplace safety. The disadvantages of these application techniques are low efficiencies. Thus, several techniques were developed for a minimisation of the overspray and their efficiency is comparable to electrostatic processes. These techniques are also described in the following sections [128, TWG, 2005].

20.7.3.1 Roller coating

Description: Application takes place by rotating rubber or foam coated rollers; two side coating is also possible. The application weight can be adjusted by a variation of space between the rollers. If the workpiece and the roll are moving in the same direction, only layers of up to 12 µm can be applied, and only coating materials with a certain viscosity can be used. These problems do not occur in reverse coating processes where the roller rotates in the reverse direction to the movement of the workpiece.

A particular use of reverse coating is the application of fillers to wood. In automated processes, the filling material is applied by rolling in reverse coaters and excess material is wiped off. After hardening, abrasion is necessary to obtain a smooth surface.

Achieved environmental benefits: Depending on the workpiece and the conditions of processing, material efficiencies of about 90 – 100 % can be achieved.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Roller coating is especially applicable for 1- and 2-component materials and polymerisation materials with high viscosity or 100 % solids content.

In the coating of metal packaging, roller coaters are commonly applied for the application of the external coating of cans. In three piece can manufacturing, roller coaters are used exclusively for painting the sheets and also the ‘side stripes’ might also be applied by using rollers. In extruded aluminium tube manufacturing, roller coaters are used exclusively for applying the base coat.

This technique is widely applied in coil coating, see Section 14.4.4.1.

In the coating of wood and furniture, rolling is mainly applicable to flat workpieces, such as panels (plates) made of wood composites, but also slightly curved products such as wooden panels can be processed. For more curved surfaces, fillers are applied by hand equipment such as palette knives.

It is only used in marine industries for the coating of fishnets.

Economics: A lightweight filling machine applied in the wood and furniture coating industry, with a working width of 1.3 metres and an installed electrical load of 5.5 kW cost EUR 55000 in 2000. In another example, a foam roller with a working width of 1.3 metres and an electrical load of 3 kW cost about EUR 26000. A machine applying two rollers (double system) with the same working width and an electrical load of 6 kW cost EUR 52000. Both examples are from the year 2000.

Driving forces for implementation: No data submitted.

Example plants: See Economics.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005]

20.7.3.2 Curtain coating (casting)

Description: The paint or coating is held in a header trough and is discharged in a laminar film through which the workpieces are passed. Excess coating material is caught in a reservoir and pumped back into the sinkhead.

Mostly solvent-free lacquers based on polyester are applied but other types of coating materials can also be processed. Curtain coating can achieve a high quality in the equality of layers.

Achieved environmental benefits: Depending on the workpiece and the conditions of processing, material efficiencies of about 90 - 98 % can be achieved.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: In curtain coating, plain or almost plain workpieces are coated. According to the machine type, application weights from 40 – 500 g/m² can be processed.

Curtain coating is mainly used in the furniture industry for the coating of doors, wall units and other plates.

It is also widely used in coating printed circuit boards (more information can be found in the STM BREF [59, EIPPCB, 2005]).

Economics: A casting installation applied in the wood and furniture coating industry with a working width of 1.3 metres and an installed electrical load of 3 kW cost EUR 35000 in 2000.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [59, EIPPCB, 2005]

20.7.3.3 Conventional dipping

Description: The workpieces are either dipped manually or transported and dipped via automatic systems into a tank filled with the coating material. Dipping can be applied for all 1-component coating systems.

Achieved environmental benefits: The advantages of dipping include the very high efficiency of up to 100 %, complete coating of workpieces (outer surfaces as well as inner), cost effectiveness, high operational capacity and good possibilities for automation. However, an efficiency range of 80 - 90 % is also reported.

There is no spraying action to release solvent, although there will be evaporation from the tank.

Cross-media effects: Compared to spraying, thicker coating layers are achieved which consequently might result in a higher consumption of raw material. In the coating of agricultural and construction equipment, e.g. achieving a layer with a thickness of 50 µm applied via spray coating (HVLP) instead of a thickness of 85 µm when applying dipping, the material consumption is lower (even if the efficiency is lower due to spray application).

Operational data: Vents in the workpieces might be necessary to release trapped air.

Dipping in water-based paints might form foam. Water-based paints are only stable in a small range of pH and therefore very sensitive to contaminations that might be dragged over from the pretreatment processes (more information can be found in the STM BREF [59, EIPPCB, 2005]). A drying step after pretreatment, such as cleaning processes, is often not necessary when applying water-based paints.

Applicability: For the serial production of bulk articles that are coated in a single tone without colour changes, dipping is applicable. Application weights from 60 – 200 g/m² can be processed.

In the coating of agricultural and construction equipment, dipping is used for the application of 1-coat topcoats. Commonly, layers of 85 µm are achieved.

In the coating of wood and furniture, dipping is commonly applied for the coating of wooden window frames in serial production. However, in general this technique is limited in its application for the wood and furniture industry.

This technique is currently not applied in the coating of aircraft and in the coating of ships, and if applicable, only to newly constructed components. It is also not applied to the coating of trains.

In the marine industry, it is used for the coating of fishnets.

Economics: This is a cost effective technique.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [59, EIPPCB, 2005]

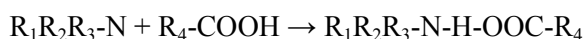
20.7.3.4 Electrocoating

Description: This is also known as electropainting, electrophoretic dipping, e-coat, ELPO, cataphoretic dipping, etc. In the water-based paint tank, a direct electric current is circulated between the workpiece which forms one electrode and the electrodes of the opposite polarity which are located in the tank. A stable protective film is deposited. According to the polarity of the workpiece, anodic (anaphoretic) or cathodic (cataphoretic) electrocoating will take place, with different characteristics. There is the possibility that in anodic coating, the substrate has some metal loss leaving the fresh metal surface in an acidic surface layer which can be readily oxidised (i.e. corroded). This does not happen with anodic systems, which are now the most widely used, contributing to modern high corrosion resistance coating systems (essential as part of quality standards, e.g. for cars).

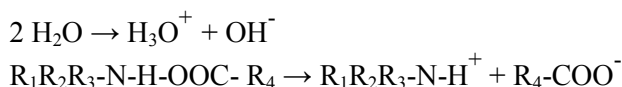
The electrolyte contains the positively charged particles of suspended paint pigments and bases (as a polymer resin) and negatively charged particles of anions of an organic acid R-COOH (usually acetic acid, where R = CH₃).

In the solution (or better, colloidal suspension) the acid anions (in a suitable ratio) are attracted to the soluble resin particles which have a high charge density. Resin particles are formed by high molecular weight tertiary amines (in general R₁R₂R₃-N) which, in the organic acid solution, react to form quaternary ammonium ions with a positive charge.

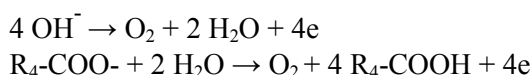
The initial reaction in preparation of paint:



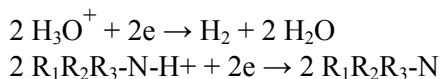
Dissociation processes occurring in solution:



Electrochemical processes occurring at the anode:



The positively charged colloidal particles move in the conducting solution (with its applied potential (voltage)) by electrophoresis to the (negative) cathode. In the first step, the following electrochemical processes occur at the cathode which, in a pH neutral solution, form an alkaline diffusion layer at the anode surface (with a pH of between 12 and 14):



The particles are deposited by electrodeposition as the cations (resin and pigment) react with the hydroxyl ions to become insoluble. Finally, as the paints solids are precipitated at the cathode, the water is driven from the vicinity of the cathode through the semi-porous film by electroendosmosis. The overall effect is to form a physically durable strongly adhered film. Because the film has a relatively high resistance, the process stops itself when the film thickness is nearly equal on all surfaces and edges.

The drag-out contains non-deposited paint which must be readily rinsed off to achieve high quality in the following coatings.

Achieved environmental benefits: All used electrocoatings are water-based and lead-free (lead is replaced by yttrium or bismuth); their content of organic solvents amounts to approx. 2 - 6 %. When combined with reverse cascade rinsing with membrane filtration, a very high proportion of dragged out paint is recovered (nearly 100 %).

Cross-media effects: Possible increase in waste water flows. The paint suspension may contain organotin compounds as catalysts, other ecotoxic compounds, although these are largely retained in the process with the paint solids recycling system. The effluent also contains a substance with COD (1000 to 5000 mg/l were emitted from the rinsing processes) and BOD 200 to 1000 mg/l (1 - 3 g/m² COD and 0.2 - 1 g/m² BOD). 90 % of the COD and 99 % of the BOD can be eliminated by physico-chemical treatment followed by biological treatment.

Operational data: The advantages of electrocoating are:

- the consistent and complete coating with uniform thickness (even in cavities) with no forming of edge runners. This is because, in part, the process inherently limits the film thickness
- the parameters can be controlled by the voltage (potential) applied, coating time and bath solids (within process limitations)
- a high efficiency process with the possibility of full automation.

The disadvantages are:

- the essential high level of maintenance of the paint tanks for quality assurance
- high capital costs of installing a complete system.

Use of cascade techniques and ultrafiltration for the rinsing tanks of electrocoating is common practice (see Section 20.12.6). More information can be found in the STM BREF [59, EIPPCB, 2005].

Applicability: It is commonly applied in the automotive industry, for the coating of buses, coating of agricultural and construction equipment and for the coating of trucks and commercial vehicles.

It can be applied to metal components, even mixed metals such as some alloys and subassemblies with brazing or welding. It is also widely used for coating a variety of small components.

This technique is currently not applied in the coating of aircraft, trains, ships and yachts.

Economics: As electrocoating is usually highly automated and provided complete with countercurrent multiple rinsing systems and membrane filtration to recover the dragged out paint, there are usually high investment and material costs.

Driving forces for implementation: Low workplace safety impacts.

Example plants: Widely used in the vehicle production industry; CROPUSA, Burgos, Spain (for components).

Reference literature: [13, DFIU and IFARE, 2002] [59, EIPPCB, 2005][128, TWG, 2005] [179, France and TWG, 2003 177] [180, CzechRepublic, 2006] [181, ACEA, 2003]

20.7.3.5 Flooding

Description: The workpieces are transported via conveyor systems into a closed channel, which is then flooded with the paint material via injection tubes. The excess material is collected and re-used.

Achieved environmental benefits: Depending on the workpiece and the conditions of processing, efficiencies of 95 - 99 % can be achieved.

Cross-media effects: In comparison to dip applications, the evaporation losses are higher.

Operational data: No data submitted.

Applicability: The process is especially suitable for large workpieces with a large surface area, such as for heating elements, for the painting of parts for truck chassis or agricultural machines and also for the application of cavity sealings in the automotive industry.

Application weights from 60 – 200 g/m² can be processed.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

20.7.3.6 Vacuum coating

Description: The workpieces are transported via conveyor systems into a closed chamber where a vacuum is created. The products that are going to be painted are routed through this chamber at high speed. The paint is applied from four different sides.

Achieved environmental benefits: Depending on the workpiece and the conditions of processing, efficiencies of 80 - 100 % can be achieved.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Vacuum coating can be used in the painting of MDF panels, solid wood, veneer, profiles made out of paper composites, window panes, skirting boards and panels for walls and ceilings.

Apart from water-based paints, vacuum coating has also been recently applied to UV curing paint on wood or wood composites. Vacuum coating is only applicable to wood that can withstand vacuum.

Economics: In a real case scenario, changing from air assisted airless spraying of water-based paints with infrared drying to vacuum coating, applying UV curing paints resulted in a yearly saving of EUR 262000. Payback time was less than two years (reported in 2003). The result was the avoidance of VOC emissions (14 tonnes/yr), waste (which used to be 100 tonnes/yr) and the material efficiency of the UV curing paint was 100 %.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [63, Vito, 2003, 76, TWG, 2004]

20.7.3.7 In-mould painting

Description: The surface coating is applied to a mould and the material to be coated is applied to the coating within or on the mould.

This technique is applied to steering wheels which are made from 2-component PUR materials that are poured and cured in a mould. The production and painting of the wheel is done at the same time. For the coating of the steering wheel, a release agent is applied to the heated mould and the coating material is sprayed onto the release agent. After a short evaporation time, the PUR material for the steering wheel is poured into the mould and the mould is closed. The foaming process of the PUR starts and at the same time the coating material adheres to the PUR.

Achieved environmental benefits: The proportion of overspray produced and, therefore, the material loss is about 20 % of the input.

Cross-media effects: No data submitted.

Operational data: Up to now only solvent-based coating materials have been applied as water-based in-mould coating systems are currently in a testing phase.

Applicability: This technique can be used in the construction of plastic resin components (e.g. boat hulls and for the production of steering wheels).

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

20.7.3.8 Conventional high and low pressure spraying

Description: The atomisation of paint material is carried out mechanically by using compressed air. In a conventional spray gun, paint material and compressed air are introduced to a jet where the paint is atomised. The discharging air transports the paint particles onto the surface. With higher air pressure, more paint will be sprayed, but the overspray losses are also higher. If the air pressure is too low, the result will be a poor surface quality.

Achieved environmental benefits: No data submitted.

Cross-media effects: Highest consumption of resources compared to the other application techniques and this technique is associated with higher VOC emissions.

Operational data: All surfaces can be coated by this method and high surface qualities can be achieved.

Applicability: The efficiency varies from about 5 % for lattice-like workpieces to about 30 - 60 % for workpieces with a larger surface area. Efficiencies in the automotive industry are reported to be in the range of 18 - 35 % where sprayed manually without electrostatic assistance.

Conventional spraying is applicable to all surfaces, and is, for example, applied for the coating of vehicles, furniture and machines. Application weights of up to 250 g/m² can be processed.

In the automotive industry, often an application procedure with a conventional air spray gun is necessary after the electrostatic application of the base coat, in order to achieve the desired optical quality (metallic and pearl effects).

It is commonly applied in the coating of agricultural and construction equipment, coating of trains, coating of metal packaging (for the interior of DWI cans) and for wood and furniture painting.

Conventional spray is the major choice for quality yacht topcoat application as it achieves a high gloss finish.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005]

20.7.3.9 High volume low pressure spraying (HVLP) (high efficiency spray guns)

Description: The atomisation of paint material is carried out mechanically by using compressed air. For atomisation, paint material and compressed air are introduced to a jet where the paint is atomised in a spray gun. The discharging air transports the paint particles onto the surface. With higher air pressure, more paint will be sprayed, but the overspray losses are also higher due to the distracted airflow. If the air pressure is too low, the result will be a poor surface quality. HVLP results in a smaller amount of atomised small paint particles compared to the conventional spraying techniques described in Section 20.7.3.8, because a reduced air pressure is applied.

The HVLP concept was developed in the 1980s with the main idea of achieving a 60 % transfer efficiency by limiting atomising pressure to 0.7 bar. This pressure, however, does not achieve the required quality of finish or the speed of application. New designs of air caps have been developed to give the required transfer efficiency as well as desired quality of finish and speed of application but working under higher atomising air pressure. The atomising pressure in these guns is higher than the pressure related to HVLP but still less than half of the pressure used in conventional air-atomising spray guns. Low pressure guns can be fed from any type of paint container, attached to gun, pressure fed tank or pump. The paint container can be on top of the gun or placed under the gun; the container on top can be used until completely empty.

Achieved environmental benefits: HVLP achieves a material utilisation in the range of 40 – 80 %. In comparison to high pressure compressed air spraying, material savings of up to 20 % are achievable if the paint container is on top of the spray gun.

Cross-media effects: No data submitted.

Operational data: Due to the generation of larger paint particles, the optical appearance can be different compared to conventional spraying. However, modern low pressure guns yield coatings of a quality equal to that achieved with high pressure guns with a similar workload. The work rate using HVLP can be slow and there is little dry film thickness control.

Application weights of up to 250 g/m² can be processed.

Applicability: HVLP can be applied to all surfaces. In wood and furniture painting, HVLP is applied for low viscous wood stains; however, also increasingly for other paint systems. This technique is also widely applied in the general automotive industry and, to a lesser extent, in the coating of trucks and commercial vehicles and the coating of agricultural and construction equipment. Since trains are coated manually, HVLP can be applied for the topcoats. It is also applied for the coating of plastic workpieces.

This technique is not commonly applied in the coating of ships (where HVLP is used in some topcoat applications and possibly for varnish) or aircraft.

Economics: HVLP spray guns cost about EUR 275 - 550, excluding the costs for adapting the compressor and the compressed air tubes to the higher flows. Costs for the training of personnel for about one to two days also need to be taken into account.

Payback time is often less than one year, depending on the amount of paint applied and current efficiencies achieved.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003, 76, TWG, 2004] [128, TWG, 2005]

20.7.3.10 Hot spraying

Description: The atomisation of paint material can be carried out by using compressed air or by using hot airless spraying. The paint material and/or the compressed air are heated, the viscosity of the paint system is therefore lowered and the amount of thinners can be reduced which results in lower VOC emissions. The heating (to 60 - 70 °C) of the paint material is carried out in the spray gun container or via heated pipes for compressed air and the paint material. Flow heaters for the heating of the compressed air are utilised for paint materials that otherwise would already start to react at these temperatures. This can be used with water-based, solvent-based or solvent-free 2-component epoxy systems.

Achieved environmental benefits: The reduced amount of thinners results in lower or even no VOC emissions. Compared to conventional spraying, the number of layers can be reduced.

Material efficiencies of 40 - 60 % can be achieved. An efficiency improvement of up to 10 % can be achieved when compared to conventional spraying.

Cross-media effects: Energy is used for heating.

Operational data: Commonly used for paints with a high solids content, but is also applicable for hot-wax spraying. It can be operated under the following conditions:

- 60 – 200 bar when spraying paints containing high solvent or water
- 200 – 400 bar when spraying paints containing thick, high solids
- 2-component paints if online mixing is applied (see Section 20.6.3.1).

With the increased temperature, higher layer thicknesses can be applied without the formation of edge runners. However, the following restrictions also apply:

- pot life very short
- equipment is expensive
- single integer volume mix ratio needed
- high solids/solvent-free epoxy paint is used
- operator needs training because the equipment is difficult to use.

Applicability: The necessary reheating after colour changes makes this technique unsuitable for processes with frequent colour changes.

Hot spraying is sometimes used in the painting of furniture, e.g. on cupboards. The technique might be applicable for the coating of ships and yachts.

Economics: Because thicker layers are applied, costs for labour are lower compared to conventional coatings and their application methods.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [27, InfoMil, 2003] [76, TWG, 2004, 128, TWG, 2005]

20.7.3.11 Airless spraying

Description: The atomisation of paint material is carried out mechanically by using hydrostatic pressure. Paint material is forced through a small (<2 mm) hard metal nozzle at material pressures of 80 – 250 bar. The paint jet is then broken up by the forces of expansion and interaction of the paint jet with the stationary air outside the nozzle. The airless spraying technique can be fully automated or can be operated manually.

Achieved environmental benefits: The material efficiency of the airless spraying technique is about 5 % for lattice-like workpieces and in the range of 40 - 75 % for workpieces with a larger surface area.

Cross-media effects: No data submitted.

Operational data: To obtain similar surface qualities, processing conditions have to be adjusted when compared to high pressure compressed air spraying. Fast colour changes are not possible due to the essential high pressure pumps.

The use of airless spraying gives a rough profile that needs sanding before further more refined coatings are applied.

Applicability: Airless spraying is used in the automotive industry. It is commonly used in the furniture industry and for the industrial coating of sizeable objects such as aircraft, ships or heavy machines. On trains, ground coat can be applied by airless spraying. On ships, almost all paint layers are commonly applied with airless spraying. It is cheap, fast and well known as it has been in use for many years. Also the dry film thickness can be well controlled. It can be used for both 1-component and 2-component paint.

Economics: Investment costs including a spray gun, a pump and other necessary equipment is in the range EUR 3600 - 7800. Additional costs are necessary for training the operators.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [27, InfoMil, 2003] [76, TWG, 2004]

20.7.3.12 Air assisted airless spraying

Description: The same conditions occur when using the airless technique as described in Section 20.7.3.11.

Achieved environmental benefits: The material efficiency for the air assisted airless technique is about 35 - 70 %.

Cross-media effects: No data submitted.

Operational data: Air assisted airless spraying typically performs better than airless spraying. With a good training of the operator, the same performance can be achieved as with conventional spraying, especially for primers.

Applicability: This technique is mainly applied for coating large pieces or surfaces. It is commonly applied in wood and furniture painting. The use of air assisted airless spraying is becoming more common in yacht finishing.

Economics: Investment costs including a spray gun, a pump and other necessary equipment is in the range EUR 2600 - 5200 (see Reference literature, below). Additional costs are necessary for training the operators.

In one specific case, the initial costs for applying this technique were EUR 2900 while savings of EUR 3100 per month were made on the consumption of paint. In this particular case, the payback time was less than a month.

Driving forces for implementation: No data submitted.

Example plants: See Economics.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [128, TWG, 2005]

20.7.3.13 CO₂ atomisation – the unicarb system

Description: In this process, the organic compounds are replaced by CO₂, which is fed to the high viscous paint material. The paint CO₂ mix is processed at temperatures of 40 - 70 °C and with a pressure of approx. 100 bar. Atomisation is done via an airless spray application. Due to the fast evaporation of the CO₂, a bell shaped spray sheet with a lower velocity of paint particles is used compared to regular airless spraying.

Achieved environmental benefits: The first practical experiences obtained in several sectors, mainly in the US, show significant reductions of material consumption and VOC emissions.

Cross-media effects: Energy is used for heating. Global warming effect of the CO₂ released, although the quantity may not be significant.

Operational data: The first practical experiences were obtained in several sectors, mainly in the US.

Applicability: Applicable in several sectors. CO₂ atomisation does not work with epoxy resins as the CO₂ reacts with the curing agent.

The substrate should be heat resistant as the paint/CO₂ mix is processed at temperatures of 40 – 70 °C. This temperature is sometimes too high for wood (risk of staining).

Economics: No data submitted.

Driving forces for implementation: Workplace health and safety.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [146, CEI-BOIS, 2006]

20.7.3.14 Electrostatic atomising processes

Description: For this process, paint material is atomised via an electric field. Paint material is transported to the workpiece along the same electrical field that causes the atomisation.

There are three different options:

- spraying gap, suitable for flat workpieces without depressions. The maximum material flowrate is 2 – 3 ml/min. The time required for colour changes is high (approx. 30 minutes). Depending on the workpiece and the conditions of processing, the efficiency is up to 99 %
- spraying bell, suitable for small parts and tubular structures with only small depressions. According to the size of the spraying bells, a maximum material flowrate of up to 250 ml/min is possible. Colour changes can be carried out within several minutes. The material efficiency is also very high (up to 95 % depending on the conditions of processing and the geometry of the workpiece)
- spraying disc, also suitable for tubular structures and small parts with depressions. A maximum material flowrate of up to 800 ml/min is possible according to the size of the disc. Times for colour changes as well as the efficiency are comparable to spraying bells.

Achieved environmental benefits: Depending on the workpiece and the conditions of processing, the efficiency is from 95 up to 100 %. Compared to conventional spraying, fewer residues are generated and spray booths are less polluted, so less cleaning agents are needed. Painting time is also reduced.

Cross-media effects: Energy consumption.

Operational data: For wood, the moisture content of the wood needs to be at least 10 %.

Applicability: Generally, in order to apply electrically assisted spray applications, the substrate will have to be conductive so it is not possible to recoat existing coatings (e.g. in ship repair and maintenance). This also limits the coatings and substrates that can use these techniques. A charge transfer additive may have to be added. Water-based materials cannot be processed with this technology, so processes with electrostatic atomisation are only utilised for specific applications. The advantage of such devices is the good reliability and the high effectiveness. The effect of the ‘Faraday cage’ makes it impossible for the paint particles to reach cavities. There may be problems with pinholing and poor appearance.

Automated electrostatic spray application is commonly applied in the coating of cars, trucks and commercial vehicles.

In wood and furniture painting, electrostatic spraying is sometimes used with chairs and window frames. It is usually combined with other spraying applications such as pneumatic, airless or air assisted spraying.

This technique is not applied in the coating of ships and trains.

Economics: An electrostatic system for spraying liquid paint including a spray gun, an eight litre container and associated equipment costs EUR 5100 – 7800.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [62, CITEPA, 2003] [63, Vito, 2003] [76, TWG, 2004]

20.7.3.15 Electrostatically assisted high rotation bells

Description: Electrostatically assisted high rotation bells atomise the paint materials mechanically. Therefore, the electrical properties of the paint material are not relevant. Compared to electrostatic atomisation, these processes show a higher flexibility with regard to paint materials and material flows.

Material flows of up to 1000 ml/min can be achieved. A change of colour can be made within several seconds.

Achieved environmental benefits: Minimisation of material consumption and of waste.

Cross-media effects: None.

Operational data: The charge can be loaded externally or internally; internal charge is more expensive but yields higher transfer efficiencies. If water-based paints are used, the paint must not be loaded electrostatically before leaving the application bell (externally charged). If special lacquers (metallic paints) are applied, a variance in the colour and the surface quality may occur.

Depending on the workpiece and the conditions of processing, application efficiencies of up to 95 % can be achieved. In the automotive industry, efficiencies of up to 70 % can be achieved when internally charged electrostatic systems are used. Compared to conventional spraying, fewer leftovers are generated and spray booths are less polluted, so fewer cleaning agents are needed. Painting time is also reduced.

Applicability: Water-based paints can be processed. This technique can be used with automatic applications or can be operated manually.

Electrostatically assisted high rotation bells are widely used in the automotive industry, and increasingly for automotive parts.

In the coating of aircraft, electrostatically assisted spray application is commonly applied.

In the coating of trucks and commercial vehicles, electrostatically assisted spray application is commonly applied.

This technique is not applied in the coating of ships and trains.

Economics: Internally charged processes typically cost between EUR 250000 – 1600000 depending on the size and amount of automation.

Driving forces for implementation: No data submitted.

Example plants: Renault, France.

Reference literature: [13, DFIU and IFARE, 2002] [68, ACEA, 2004] [128, TWG, 2005]

20.7.3.16 Electrostatically assisted high rotating discs

Description: Electrostatically assisted high rotating discs atomise the paint material mechanically, similar to high rotation bells as described in Section 20.7.3.15.

Achieved environmental benefits: Depending on the workpiece and the conditions of processing, efficiencies of up to 95 % can be achieved. Compared to conventional spraying, less overspray is generated and spray booths are less polluted so fewer cleaning agents are needed.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Typical applications are the painting of profiles and bicycle frames. This process is suitable for almost all paint materials including water-based paints. This technique can be used with automatic or manual applications.

Due to material flows of up to 1500 ml/min and a material efficiency of 95 %, the process is eligible for universal industrial painting operations.

Economics: No data submitted.

Driving forces for implementation: Painting time is also reduced.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

20.7.3.17 Electrostatically assisted compressed air, airless and air assisted spraying

Description: For electrostatically assisted compressed air, airless and, air assisted spraying, the paint material atomisation is similar to regular compressed air spraying except for the airless technique. There, atomisation is realised via the hydrostatic pressure of the material. Additionally, the paint particles are electrostatically charged, however, this does not happen when applying water-based paints. According to the application conditions, the material flows for compressed air amount up to 1000 ml/min. For airless or air assisted airless techniques the material flow can be up to 3000 ml/min.

Electrostatically assisted spraying of powder coatings is addressed in Section 20.7.3.18.

Achieved environmental benefits: The material efficiency is about 85 %. In the painting of furniture and wood, efficiency levels in the range of 50 - 70 % are achievable. Compared to conventional spraying, fewer leftovers are generated and spray booths are less polluted so fewer cleaning agents are needed. Painting time is also reduced.

Cross-media effects: No data submitted.

Operational data: According to the implemented supply equipment (only one pump or one pump for each colour), the time needed for colour changes varies.

Complex geometries with depressions can be painted via compressed air spraying.

Applicability: All the electrostatic techniques can be used for water-based and conventional materials. These techniques can be fully automated or can be operated manually. In the painting of furniture and wood, airless or air assisted airless techniques are mainly used for high material consumptions or high surface throughputs such as, for example, for the automated coating of furniture (workpieces with depressions), automated coating of window frames or manual coating of large workpieces.

In the automotive industry, pneumatic techniques only are used in some applications either manually or by using robots, e.g. for coating the interiors.

In the coating of aircraft, electrostatically assisted spray applications are commonly applied.

In the coating of trains, airless spraying systems can be used for applying ground coats; however, no information was submitted on electrostatically assisted spraying of trains.

In the coating of plastic workpieces, electrostatically assisted spray applications are commonly applied.

This technique is not commonly applied in the coating of ships, because in the open air there is too much air movement and in other poorly ventilated areas there is a potential for explosion. However, it is used in some yards in the Netherlands.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: See Applicability, above.

Reference literature: [13, DFIU and IFARE, 2002] [128, TWG, 2005]

20.7.3.18 Application of powder coatings – electrostatically assisted spraying

Description: The powder particles are electrostatically charged and sprayed onto the ground workpiece using compressed air.

Achieved environmental benefits: Material efficiencies in the range of 80 – 95 % are achieved.

Spray booths and application tools can be cleaned by vacuum cleaning or by blowing with compressed air. In this way, resources are saved and solvent emissions are avoided.

Cross-media effects: Compressed air requires energy use.

Operational data: Electrical conductivity has to be considered.

Applicability: Generally applied.

Used in a small number of coil coating lines, but has serious limitations on speed and film thickness, see Section 14.4.3.3. In the painting of furniture and wood, it is commonly applied when powder coating is used.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

20.7.3.19 Application of powder coatings – powder sintering

Description: For the sintering of powder coatings, the workpieces are heated above the melting temperature of the powder coating before the coating is applied. As soon as the powder comes into contact with the surface, sintering and merging takes place. Several techniques to apply this principle are available such as, for example, fluidised bed coating.

Achieved environmental benefits: High efficiency of the materials used.

Cross-media effects: Increased energy consumption.

Operational data: No data submitted.

Applicability: Generally applied.

A variant of this technique is under development for coil coating, but it uses a solid block of formulated coating material which is ‘wiped’ against a preheated metal strip. This new technique is not generally applicable, see Section 14.4.3.3.

The substrate should be heat resistant as the workpieces must be heated. This temperature is in some cases too high for wood as there is a risk of staining and/or burning.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [146, CEI-BOIS, 2006]

20.7.4 Techniques to manage overspray

20.7.4.1 Wet separation spray booth

Description: Overspray in a spray booth where surfaces are sprayed with paint materials can be intercepted by applying a water curtain. The water-paint mixture is captured and treated in a reservoir below the spray booth. For waste water treatment, see Section 20.12. Figure 20.2 shows a scheme of waste water treatment applied in a wet separation spray booth.

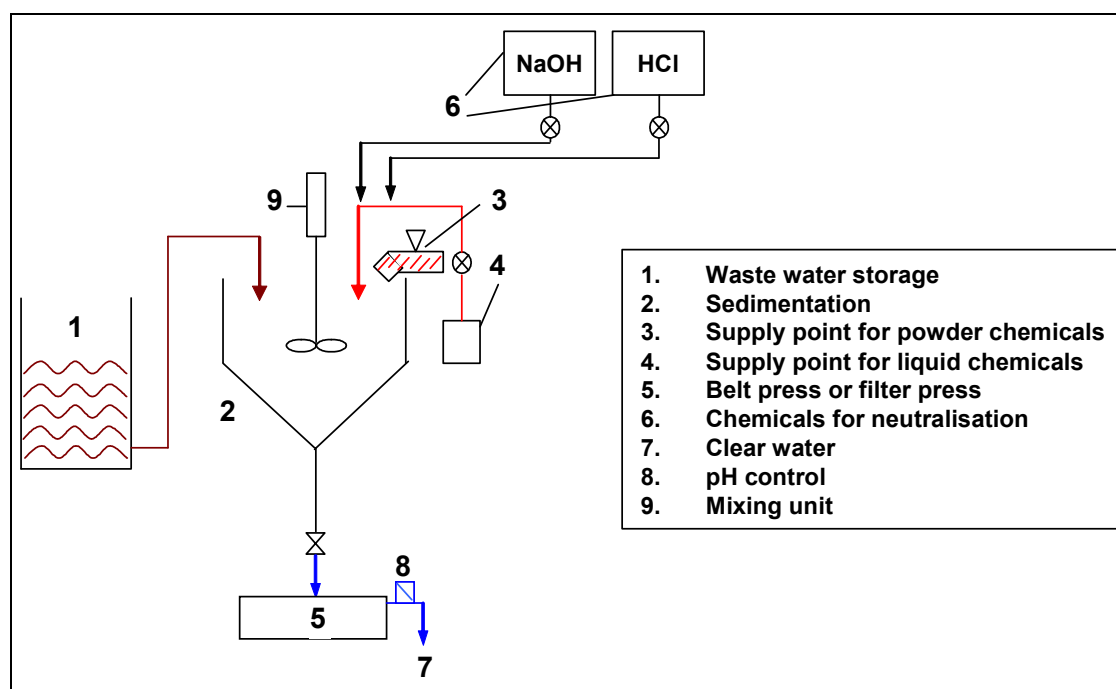


Figure 20.2: Scheme of waste water treatment applied in a wet separation spray booth [63, Vito, 2003] with reference to Kluthe Benelux BV

Achieved environmental benefits: Removal of TPM (total particulate material). Efficiencies of 98 - 99 % can be achieved. Sometimes the paint can be re-used.

Cross-media effects: There is residual waste water which can often be re-used, and contaminated sludge that has to be disposed of.

Operational data: Waste water is normally cleaned by applying flocculation and coagulation. The water is led across cascades or circulated via air introduction.

Applicability: Wet separation spray booths are applicable to water- and solvent-based paints. They are common practice in:

- wood and furniture painting
- the automotive industry
- coating of aircraft components
- coating of trains
- coating of trucks and commercial vehicles.

Economics: Estimated costs for an installation with a capacity to withhold 2 – 5 m³/h waste water and covering a floor surface area of about 4 m² is about EUR 20000 or EUR 1 – 2 per Nm³. This size of installation is suitable for large spraying zones with several water curtains.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [76, TWG, 2004]

20.7.4.2 Paint-in-paint spray booth

Description: Overspray in a paint spraying process is partly collected by a screen made of Teflon. The temperature of the screen is only a few degrees Celsius and, therefore, a layer of condensation is formed on the screen. Paint that is collected on the screen will flow downwards because of gravity into a reservoir or a belt. This collected paint is re-used.

Achieved environmental benefits: Typically 33 - 50 % of the overspray can be re-used.

Cross-media effects: Solvent consumption increases in the case of solvent-based paints.

Operational data: Different designs are available, also as an integrated part of an automated spraying zone or line. Cleaning the screen after a colour change takes about five minutes.

Applicability: This process is applicable for 1-component, solvent- and water-based paints. It can be applied in automated and manual spraying activities. It is, however, less suitable for small series with many colour changes and for paints with a short shelf life.

It is sometimes applied in the painting of wood and furniture, but not widely used due to the many colour changes necessary.

Economics: Energy costs for cooling the screen are about EUR 1000 per year. Savings include a reduction of raw material because paint is re-used and less waste paint needs to be disposed of.

The system is economically viable for companies applying 15 tonnes of paint or more per year. Reported payback times of six case studies are in the range 1.5 – 5 years.

Driving forces for implementation: No data submitted.

Example plants: Six case studies cited in the first reference (see Reference literature, below).

Reference literature: [63, Vito, 2003] [76, TWG, 2004]

20.7.4.3 Water emulsion techniques

Description: Paint overspray emulsion techniques can be installed to eliminate water booth usage and paint sludge waste. The paint overspray is concentrated in an emulsion and is removed off site. The paint material can theoretically be re-used, but in practice is not.

Achieved environmental benefits: This process eliminates booth water usage by 100 % and waste sludge production by >95 %. A particle separation of over 99 % with a remaining particle content of <3 mg/m³ in the exhaust airflow is achieved.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: This process can be applied to water-based as well as 1-component, solvent-based paint application booths and is used in some sites in the automotive industry.

Economics: Cost savings can be achieved through saving water (the water emulsion is recirculated in the booth) and decreased cleaning. Installation costs are typically EUR 1 million.

Driving forces for implementation: Decreased cleaning.

Example plants: Ford, Germany.

Reference literature: [68, ACEA, 2004] [76, TWG, 2004]

20.7.4.4 Cold plate spray booths

Description: Cold plates are used for recycling overspray. Overspray in a spray booth settles onto a cooled metal wall, runs down into a collection system and is returned to the application process.

Achieved environmental benefits: Typically most of the overspray can be re-used. Material consumption decreases.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: This technique is used for recycling waterborne lacquers and paints.

Economics: The price level of these spray booths is between EUR 25000 – 60000 for air output flows of 5000 – 10000 m³/h.

Driving forces for implementation: No data submitted.

Example plants: Airtech, Denmark.

Reference literature: [76, TWG, 2004, 128, TWG, 2005]

20.7.5 Water treatment techniques to reduce waste water and wastes and for treatment of waste water

The general purpose of the measures described in the following sections is to avoid material losses and emissions to water, reduce water usage and consequently reduce the need for waste water treatment. To do this, several well known unit operations for phase and material separation are applied. Most of these techniques are described in full detail in the STM BREF [59, EIPPCB, 2005].

20.7.5.1 Multiple (cascade) rinsing

Description: The process steps degreasing, phosphating and electrocoating are followed by rinsing to remove adhering surplus material from the product. To minimise water consumption, a rinsing cascade of more than one rinse tank is used. Water flow from tank to tank is opposite to the material flow direction. The successive dilution steps improve the rinsing and reduces the amount of water required to achieve the required dilution of contaminant at the surface. More information and options for multiple rinsing are described in the STM BREF.

Carryover material from the first tank can be fed back in the process bath. This can be assisted by concentration techniques described in Section 20.4. Further techniques are described in the STM BREF.

Achieved environmental benefits: Saving of materials returned to the process tank. There is a significant reduction in the consumption of fresh water and in waste water production.

Cross-media effects: May lead to higher concentrations of pollutants in the waste water.

Operational data: Necessary to avoid quality problems in the painting process.

Applicability: Cascade arrangements are commonly applied in pretreatment processes, e.g. in the automotive industry, in coil coating (see Section 14.4.1.2), and in the coating of agricultural and construction equipment.

Economics: Lower costs for fresh water and waste water treatment.

Driving forces for implementation: Quality, cost reduction, and is a legal requirement in some MSs.

Example plants: Commonly applied.

Reference literature: [13, DFIU and IFARE, 2002] [59, EIPPCB, 2005] [76, TWG, 2004] [58, ECCA, 2004]

20.7.5.2 Use of ion exchangers

Description: An ion exchanger serves for bath maintenance and water savings in the phosphating and passivation steps; see Figure 20.3. Here, ion exchange can be used for the removal of metallic ions, which are carried over from the phosphate basin into the first rinsing bath.

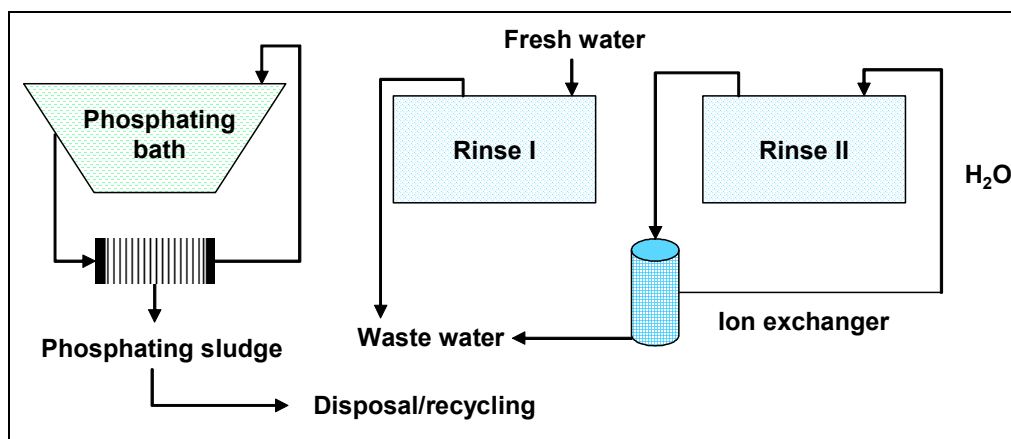


Figure 20.3: Schematic of a phosphating unit with an ion exchanger [13, DFIU and IFARE, 2002]

Achieved environmental benefits: Reduction of water consumption in the rinsing cascade. Smaller and more concentrated amounts of waste.

Cross-media effects: Consumption of raw materials and energy for regenerating the ion exchanger. Wastes from regeneration are produced.

Operational data: There is an increased technical maintenance effort and possibly an impairment of operational safety if the service is not carried out by experts due to contamination with germs, and permanent mechanical abrasion of the particles may arise.

Applicability: This is commonly applied in the automotive industry and in the coating of agricultural and construction equipment.

Economics: Savings from fresh water and waste water treatment.

Driving forces for implementation: Quality of rinsing and production processes, cost reduction, and is a legal requirement in some MSs.

Example plants: VW Wolfsburg, Germany.

Reference literature: [13, DFIU and IFARE, 2002, 76, TWG, 2004]

20.7.5.3 Membrane filtration

Description: Several types of membrane filtration processes are applied with aqueous pretreatments, e.g.

- regeneration of the degreasing bath by removing oil is done by ultrafiltration
- neutralisation agents released during electrocoating diffuse through built-in anion exchange membranes and are passed into solution in the anolyte circulation
- ultrafiltration is used to separate electrocoat paint solids carried over into the rinse-water, which are fed back to the immersion bath, see multiple rinsing, Section 20.7.5.1.

Further details of these are given in the STM BREF.

Achieved environmental benefit: Retention of raw materials. Reduction of water consumption. Waste water is reduced in quantity and contaminants are more concentrated.

Cross-media effects: Production of waste and waste water flows that need treatment.

Operational data: No data submitted.

Applicability: These techniques are commonly applied in the automotive industry.

Economics: Lower costs for fresh water and waste water treatment.

Driving forces for implementation: Quality of rinsing and production processes, cost reduction, and is a legal requirement in some MSs.

Example plants: Commonly applied.

Reference literature: [59, EIPPCB, 2005] [76, TWG, 2004]

20.7.5.4 Bath desludging

Description: With spray and bath degreasing of car bodies from the body shop, particles are introduced in the cleansing bath. With time, the bottom of the cleansing bath basin is covered with sludge. These residues are removed manually after pumping the fluids temporarily into reserve tanks (counter tanks). The same procedure is done periodically with iron phosphate sludge which is produced in the phosphating process.

These and other maintenance techniques are described in the STM BREF.

Achieved environmental benefit: Material conservation is made by extending the operational life of pretreatment baths.

Cross-media effects: Production of waste.

Operational data: Desludging frequency is strongly interdependent with other bath maintenance operations. Usually, degreasing baths are cleaned every two to six months and phosphate baths monthly to yearly.

Applicability: This technique is commonly applied in the automotive industry.

Economics: Savings in making up fresh solutions.

Driving forces for implementation: Quality of pretreatment. Prolongation of bath lifetime. Reduction of material consumption. Cost savings by reduction of material purchasing and waste water treatment.

Example plants: Commonly applied.

Reference literature: [59, EIPPCB, 2005] [76, TWG, 2004]

20.7.5.5 Process solution filtration

Description: Particles are continuously removed from the process fluids by filtration. Usually sand filters or woven fabric filters are applied.

These and other maintenance techniques are described in the STM BREF.

Achieved environmental benefit: Material conservation is made by extending the operational life of pretreatment baths. Reduction in reworking.

Cross-media effects: Production of waste (filtrates and filters).

Operational data: Necessary to avoid quality problems in the painting process.

Applicability: This technique is commonly applied in the automotive industry.

Economics: Savings in making up fresh solutions and reworking reject products.

Driving forces for implementation: Quality.

Example plants: Commonly applied.

Reference literature: [59, EIPPCB, 2005] [76, TWG, 2004].

20.7.5.6 Continuous discharge of paint sludge

In wet separation spray booths, the service life of the water can be increased up to one year by the continuous discharge of paint sludge.
[13, DFIU and IFARE, 2002]

20.7.5.7 Decantation system

Decantation systems in wet separation spray booths increase the service life of the water. This technique is commonly applied in:

- the automotive industry
- coating of trucks and commercial vehicles
- coating of trains.

[13, DFIU and IFARE, 2002]

20.7.5.8 Coagulation of paint solids in wet cleaners

Description: In spray painting, excess spray (overspray) arises, which in industrial painting plants or spray booths is captured by wet washers. The water needed for cleaning the waste air is circulated in a closed system. Retained overspray or paint sludge has to be removed from this water to maintain proper operation conditions.

Overspray from solvent-based paints does not usually form a dispersion in water. It therefore forms a flotation coagulate carpet, which is easy to remove. If adsorbents are used for detackifying, the overspray is distributed within the cleaning. It can be removed in a bypass or in the main flow path. Clarification of the water is performed by precipitation and/or flocculation agents.

Water-based paints, by contrast, consist very largely of components which will form a suspension in water. The same separation methods are used as for solvent-based paints.

Achieved environmental benefit: Reduction of water consumption in the circulation system.

Cross-media effects: The coagulate has to be removed from the water circuit and must be disposed of.

Operational data: No data submitted.

Applicability: These techniques are commonly applied in the automotive industry.

Economics: Lower costs for fresh water and waste water treatment.

Driving forces for implementation: The operation of a wet scrubber is necessary for removal of paint particles from the waste air. Continuous coagulation is the best method to maintain a high life-time of the water cycle.

Example plants: Commonly applied.

Reference literature: [76, TWG, 2004]

20.8 Drying and/or curing

Drying is one of the most energy consuming processes. Drying is used for:

- drying of paint
- drying of ink
- drying of adhesives
- drying of retained water or other liquids from pretreatment or rinsing zones
- gelling and solidification of adhesives or underbody protection materials
- pretreatment of workpieces (against cold surfaces or trapped air in the lacquer finishing of wood).

20.8.1 Evaporation processes

20.8.1.1 Conventional drying by convection

Description: Heated air is circulated in the drier or oven to transport heat to the workpiece. The air is in direct contact with the object or surface to be dried. The drying time depends on the object or substrate, the type of coating and the coating thickness, and varies between a few seconds to a full hour.

For the drying of water-based coatings or a pre-drying step of wet-on-wet layer constructions, dehumidified air is used, with convection driers with an additional dehumidification step. Due to the uptake of water, the drying times can be significantly reduced.

The driers are built as flat-line driers, nozzle-driers, tray systems or tower driers. The energy demand heavily depends on the heat losses of the drier.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: Drying time and drying temperature influence the surface quality. There is a risk of dust inclusions in the wet layer. Drying times are rather long and the energy demand is high. However, a high level of automation is possible and there is high flexibility in employing this drying technique.

Due to the consistent heating in convection drying, the risk of overheating is low, even if short standstills of the conveyors occur.

Drying by circulating air can be combined with infrared radiation curing (thermal reactor) to decrease the drying time and reduce the energy consumption. This combination is applied in wood and furniture painting, although it is reported that this is not a common practice throughout the EU-25.

Applicability: In driers used for fast moving, continuous substrates such as paper and plastic foil webs or continuous streams of small objects such as beverage cans, the drying time is measured in seconds and the length of the drier in centimetres. Not the temperature, but the airflow is most important. Energy can be saved by recirculating air, but this is limited by the need to avoid fire or explosion and to avoid odour in the end-product. Driers are heated by flame, steam, thermal oil or electricity.

Applicable to all heatsetting coating or printing materials, either solvent-based or solvent-free. There is no limitation on layer thickness or pigmentation. The geometry of the coated substrate is not relevant; however, it should be heat resistant.

Convection driers can be used for drying layers of water-based paints, for a pre-drying step or for wet-on-wet layer constructions. They are commonly applied in the coating of plastic bumpers, in coil coating processes, in wood and furniture painting, in the manufacture of adhesive tapes and in the automotive industry.

Convection driers are commonly applied in the manufacturing of abrasive.

Economics: The costs for drying amount up to 15 - 20 % of the total energy costs of the painting line in the automotive industry.

A 10 minute convection drier applied in the wood and furniture coating industry with an installed electrical load of 30 kW and an air output of 1500 m³/h cost EUR 60000 in 2000. The electrical control and conveying unit is excluded.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [12, UBA Germany, 2002] [76, TWG, 2004] [128, TWG, 2005]

20.8.1.2 Inert gas convection drying

Description: The inert gas is heated with gas or steam via heat exchangers or fuel oil. By applying inert gas instead of normal air, solvent loads of $>1200 \text{ g/m}^3$ nitrogen are possible.

Achieved environmental benefits: Inert gas can contain much more solvent than normal air. For an inert gas drying process, for example, a gas volume of 2000 m^3 is circulated for a solvent amount of 400 kg/h . Air drying would need up to 10 times as much volume to meet 40 % of the LEL value.

Energy is saved and waste gas treatment systems can be designed for smaller capacities compared to the use of normal air. The flammability is reduced.

Cross-media effects: No data submitted.

Operational data: Where inert gas is used for drying, condensation may be used as a technique for recovering solvents (see Section 20.11.5).

Applicability: Applicable to new and existing plants and installations. However, retrofitting might be difficult.

This technique is commonly applied as a pre-drying step in the manufacturing of adhesive tapes.

The technique is not applicable where driers need to be opened regularly. Opening the drier needs purging, i.e. replacing air by the inert gas. This is costly and takes time. This is the reason why it is not applied in industries where job changes are a daily occurrence such as all printing processes, e.g. flexible packaging.

It also is not applied in the manufacturing of abrasives, in coil coating, in the automotive industry, or in the coating of wood or furniture.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [14, DFIU and IFARE, 2002] [76, TWG, 2004] [146, CEI-BOIS, 2006]

20.8.1.3 Induction drying

Description: Electromagnetic coils mounted close to the painted coil induce oscillating currents within the metal that can be tuned to generate heating rates of hundreds of degrees per second.

Achieved environmental benefits: Electrical heating is very controllable and efficient with no local emissions.

Cross-media effects: Use of electricity to replace gas and subsequent translocation of emissions to generating plants.

Operational data: For existing situations, there is a necessity to redesign the waste gas treatment unit because the heating times are much shorter compared to conventional driers.

Applicability: This technology is routinely used for metal tempering and annealing, but is also appropriate for rapid paint curing. Applied if the substrate or object to be dried conducts electricity. It might be applicable as a replacement or supplement to existing gas fired ovens. The potentially very high electricity demand may limit the applicability.

In the printing of metal packaging, it is applicable to all heatset coating or printing materials and on ferromagnetic substrates. However, coating formulations may need fine-tuning for different heating rates. There may be some limitations on the paint film thickness achievable with the very fast heating rates.

Induction is mainly used in special applications such as the hardening of structural bonding (adhesives) in the automotive industry. Used in a few lines in coil coating.

Because it requires a metal substrate, it is not applied in printing, the manufacturing of abrasive, the manufacturing of adhesive tape or the coating of wood or furniture. It is also not applied in the winding wire industry.

Economics: Only economically viable for new installations or when an oven requires replacing.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [58, ECCA, 2004] [76, TWG, 2004] [146, CEI-BOIS, 2006]

20.8.1.4 Radiation drying (microwave and HF)

Description: In this process, the wet paint layer is heated via electromagnetic microwaves. The two available techniques are microwave drying and high frequency drying (HF). Due to the impact of these electromagnetic waves, the dipoles are oscillated and, thus, the electromagnetic energy is transferred into heat energy. In this way, the contained water is evaporated rapidly and needs to be extracted.

HF driers consist of a high frequency generator, the transmission unit, collector electrodes and the appropriate flashing-off zone for removal of the evaporated water. Alternatively, the wet paint layer is heated via electromagnetic microwaves. Evaporation and drying takes place from the inside of the paint layer to its outside. The heating is homogenous.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Electromagnetic wave driers are exclusively applicable to water-based coatings and inks, and non-metallic substrates.

HF driers are commonly applied in the manufacturing of abrasives, but are not applied in the manufacturing of adhesive tapes or in the winding wire industry.

Microwave drying is applied for the coating of wood, for workpieces prior to assembly and for pieces with small dimensions as large products need a large MW oven with higher energy costs. Its use in practice is doubtful. It is not applied in the manufacturing of abrasives, and in the manufacturing of adhesive tape.

Economics: A two minute microwave drier applied in the coating of wood and furniture industry, with an installed electrical load of 60 kW and an air output of 1500 m³/h cost EUR 75000 in 2000. Electrical control and conveying units are excluded.

A two minute HF drier applied in the coating of wood and furniture industry, with an installed electrical load of 120 kW and an air output of 1500 m³/h cost EUR 150000 in 2000. Electrical control and conveying units are excluded.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005] [146, CEI-BOIS, 2006]

20.8.2 Radiation curing processes

Description: Radiation curing is based on resins and reactive diluents (monomers) which react together on exposure to, e.g. ultraviolet light (UV) or high energy electron beams (EB). The resins are generally polyesters, polyurethanes or epoxies, with acrylate or methacrylate functionality, though other coating chemistries may also be used. The formulations are liquid, but are solvent-free and curing can be very fast, just a few seconds, generally at ambient or slightly raised temperatures.

Sections 20.8.2.1, 20.8.2.2, 20.8.2.3 and 20.8.2.4 describe different types of radiation curing techniques in detail.

Achieved environmental benefits: A complete elimination of solvent use in the coating system. There are normally no significant emissions during curing and the cured coatings no longer contain volatile components. There is improved energy efficiency along with minimal gas consumption as high temperature ovens and exhaust incineration may no longer be needed.

Cross-media effects: There may be some potential for low level emission of VOCs as reactive organic monomers are used in the formulations.

Operational data: No data submitted.

Applicability: Radiation cured coatings have become well established in the wood coating and printing industries for the coating of flat pieces and sheets, but so far they have not been so successful in coatings for metal. Coil coating places very great demands on the coating system, especially in adhesion, flexibility, and durability. There have been considerable development efforts from coil coaters and coating suppliers to meet these demands, but so far there is no completely successful application of radiation cured coil coatings, see Section 22.14.2.

Economics: No data submitted.

Driving forces for implementation: Elimination of solvents, and energy efficiency.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004] [146, CEI-BOIS, 2006].

20.8.2.1 Infrared radiation curing

Description: For infrared radiation curing, the workpiece is heated via absorption of infrared radiation. The drying process starts from the inside to the surface. The intensity of the infrared radiation depends on the wavelength range and therefore of the temperature of the radiator. The absorption of the rays depends on the surface smoothness, the colour or lightness and its chemical composition.

Achieved environmental benefits: Lower energy demand compared to driers applying circulated air.

Cross-media effects: Due to the radiant heat from the driers, solvents are evaporated as for conventional heating processes.

Operational data: It is a fast heating technique (1 – 5 seconds in the case of NIR medium or long wave, but IR may take longer) and, when the temperature of the substrate during paint curing is low, it requires only short cooling times. The solvent composition needs to be adjusted to the energy of the radiation.

There is a risk of the formation of shades on edges and in niches.

Different radiators are available, according to the wavelength used. Flow path or programme controlled installations are applied according to drying and surface quality conditions.

Applicability: There is no limitation of layer thickness, except where very fast cure times are required (e.g. where the substrate is moving rapidly, as in coil coating).

The geometry of the coated or printed substrate is not relevant. However, it should be heat resistant. In some cases, the temperature can be too high for wood, where there are risks of staining and burning.

Infrared curing is used on a small number of coil coating lines. For existing situations in coil coating, there is a need to redesign the waste gas treatment unit because the heating times are much shorter compared to conventional driers.

The technique is commonly applied in the automotive industry for the pre-drying of topcoats that are applied by the wet-on-wet technique. It is also increasingly used in adhesive tape manufacturing.

It is not applied in the manufacturing of abrasives.

In the printing industry, it is no longer used due to improved inks. The disadvantages of using infrared radiation curing were the heat produced in the pile of the printed sheets and the blocking (i.e. the printed image reproduces itself on the back of the sheet above).

Economics: Investment costs are relatively low; however, retrofitting existing driers can be costly. In the coil coating industry, this technique is only economically viable for new installations or when and oven requires replacing.

Driving forces for implementation: No data submitted.

Example plants: Opel Eisenach GmbH, Germany.

Reference literature: [13, DFIU and IFARE, 2002] [58, ECCA, 2004] [76, TWG, 2004] [128, TWG, 2005] [146, CEI-BOIS, 2006]

20.8.2.2 Near-infrared radiation (NIR) curing

Description: NIR emitters operate at very high temperatures, producing very short wavelength infrared radiation at very high power density. Absorption of the specific wavelength by the coating and short dwell times can reduce the heating of the substrate.

Achieved environmental benefits: No data submitted.

Cross-media effects: High demands for electrical power. NIR requires a reliable high power electrical supply.

Operational data: For the coating of wood, the NIR technique achieves the shortest drying and cycle times.

Applicability: Due to very short (1 – 5 seconds) curing times, this technique is very suitable for heat sensitive materials such as wood and plastic. Powder coatings are commonly cured by applying NIR curing as well as water-based paints on wood.

NIR curing is starting to be used in coil coating for the fast curing of thin coatings and in powder coatings. Its extension into general processing lines will depend on further proving trials.

It is not applied in the manufacturing of abrasives, in the manufacturing of adhesive tapes, in the winding wire industry or in the automotive industry.

Economics: No data submitted.

Driving forces for implementation: Shorter more compact ovens, high speed, controllable power.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

20.8.2.3 Ultraviolet (UV) curing

Description: The electrical discharge in gases is used as a radiator for UV curing. Most commonly, mercury vapour lamps are used for this purpose. The radiation starts a chemical cross-linking within the paint or ink layer. UV curing requires the presence of a photo initiator.

Achieved environmental benefits: Energy consumption is low. UV cured systems use less or no solvent.

Cross-media effects: Ozone emissions occur and the ozone is commonly extracted and routed to an ozone eliminator with catalysts or to a thermal oxidiser. Mercury vapour lamps are used, which contain small amounts of mercury and can be disposed of through suitable waste treatment facilities.

Operational data: Wooden or plastic substrates can show a yellowing and may become brittle. This technique requires little floor space and curing occurs within a few seconds (high speed).

Applicability: Applicable to new and existing installations.

Applicable to unsaturated polyesters, polyacrylates, epoxy resins, etc. Especially applicable to clear coats and glazes up to high layer thicknesses. For pigmented coatings, UV curing is only applicable for small layer thicknesses. Also UV curing inks are dried via UV curing.

The coated or printed substrates should be resistant to UV curing and preferably flat or two dimensional. The curing of powder coated three-dimensional wooden or plastic parts is more complicated, however, well performing drying systems are available.

UV radiation is widely applied to substrates of paper and cardboard. For example, it is applied for the drying of painted furniture, where flat panels can be coated separately and coating is done before assembling the piece of furniture. It is also increasingly applied in the production of adhesive tapes.

In coil coating, the technique is currently under evaluation (see also Section 22.14.2).

It is not applied in the manufacturing of abrasives or in the automotive industry.

Economics: Compared to conventional driers, energy costs can be reduced by up to 70 %. Compared to a conventional gas-fuelled oven (including ventilator) for water-based paints, the energy costs are reduced by 40 - 50 %. In printing, the energy consumption may be as high as with conventional drying. Energy utilisation is reduced by 50 % using flash cure systems, where the lamp only operates when the actual substrate is underneath the lamp. This has economical benefits, for instance, when non-web printing is taking place.

Print run speeds of 3 - 4 times faster are achievable with UV cured systems.

A commonly used UV curing installation with a width of 25 cm costs about EUR 6600 (only likely to be used in label printing, which, as a standalone activity, is outside the scope of this document). The trend is that prices are declining. The operational costs of a unit with 12 lamps of 5.6 kW each, were about EUR 5/hr on energy (Flanders, 2003). However, a UV curing installation of 25 cm is not generally representative for other printing processes.

For example, a compact (one-man) UV paint application plant including a UV curing zone applied in the wood and furniture coating industry cost roughly EUR 40000 in 2000.

There are financial benefits from the faster curing/drying time and the faster production speeds achieved.

The payback time is estimated to be two to three years. This is also taking into account that for applying UV curing paint systems less man-hours are needed.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [76, TWG, 2004] [128, TWG, 2005]

20.8.2.4 Electron beam curing (EB)

Description: EB curing is initialised by an electron beam emitted from a hot cathode tube. Polymerisation and, thus, hardening of the paint is caused by the impact of electrons onto the monomers. A high level of automation is possible. Electrons are accelerated to a high velocity penetrating the coating substance and curing it in a very short time.

Achieved environmental benefits: No data submitted.

Cross-media effects: Radiation imposes a risk to the workers. The workers have to be shielded from the electron beam by lead plates or concrete walls.

Operational data: There is a risk of the substrate becoming brittle and of discoloration.

Very small floor space is required.

Applicability: Applicable to unsaturated polyesters, polyacrylates, polyurethanes, epoxy resins, etc. There is no limit to layer thickness or pigmentation.

All geometries are suitable for substrates transparent to EB radiation (especially paper, wood or foils); for metals, EB is limited to flat substrates. Because of high investment costs, this technique is currently only applied to large surface throughputs.

EB curing is increasingly applied in the production of adhesive tapes.

In the coil coating industry, EB may be considered as an emerging technology.

It is not applied in the manufacturing of abrasives, in coil coating, or in the automotive industry.

Economics: EB curing has higher investment costs than conventional driers. However, the energy consumption of EB curing can be very much lower.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005].

20.8.3 Thermal reactor (combined convection/radiation drying)

Description: A thermal reactor is a radiator that emits infrared radiation as well as convection heat. The infrared radiation is generated by combustion of natural gas or propane.

Achieved environmental benefits: Lower energy demand compared to driers applying only circulated air.

Cross-media effects: No data submitted.

Operational data: Depending on the paint system and kind of production, the total drying time is in the range of 6 to 10 minutes.

Applicability: Applicable to all heatset coating or printing materials, either solvent-based or solvent-free, and powder coatings. Thermal reactors are also suitable for water-based paint systems.

The geometry of the coated or printed substrate is not relevant; however, it should be heat resistant.

Although some costs are given below, the technique is not known to be applied commercially in the coating of wood. There is a risk of staining and burning of the wood if the temperatures are too high.

It is not applied in the manufacturing of abrasives, in the manufacturing of adhesive tapes, in coil coating or in the automotive industry.

Economics: A thermal reactor with a six minute drying time for the coating of wood and furniture industry, with an installed electrical load of 10 kW, an air output of 2000 m³/h heated with natural gas, cost EUR 95000 in 2000. Electrical control and conveying units are excluded.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [146, CEI-BOIS, 2006]

20.9 Cleaning techniques

[148, TWG, 2006, 154, Tempany, 2006, 160, ESVOC CG, 2006]

20.9.1 General principles for cleaning

Description: When selecting the cleaning techniques to be used, the following issues need to be considered.

1. Type of cleaning:

- process equipment cleaning. In all activities, the process equipment will be cleaned. This is of two types:
 - operational or interim cleaning. Cleaning of the application system is necessary at regular intervals, e.g.
 - for colour change and quality reasons. e.g. for spraying cars, after five to ten vehicles and at each colour change
 - cleaning of spray booths is necessary at regular intervals
 - between printing jobs
 - maintenance, periodic or in-depth cleaning. It is periodically necessary to clean application equipment thoroughly to remove accumulated deposits and clean parts of equipment that are more difficult to clean quickly. This usually requires some disassembly.

The type of technique used will depend on whether the equipment is cleaned in situ, or dismantled completely or in part

- substrate or workpiece cleaning. For some activities, such as painting and varnishing, cleaning of the substrate or workpieces to remove grease, dirt, etc. is essential prior to coating. In some activities, such as printing, it is not necessary.

2. Type of contamination:

- for process equipment:
 - non-persistent contamination. The contamination is fresh, e.g. it is non-drying, it still has some of the original solvent present, or its coating reaction is not complete. This type of contamination is easy to remove, e.g. physically by hand (see Section 20.9.3), with the original or similar solvent used in the coating, with low volatility solvents (depending on the need to dry the components, see Sections 20.10.1.1 to 20.10.1.4), in washing machines (see Section 20.9.10), etc.
 - persistent contamination. This may be from dried solvent-based products, UV or other radiation cured products, waterborne, or reactive (2-component) products, etc. Cleaning by hand with volatile solvents is not effective. The parts may be cleaned, for example:
 - in a washing machine (repeatedly if necessary), (see Section 20.9.10)
 - with powerful low volatility solvents (see Section 20.9.6)
 - high pressure water after using powerful solvents, or with an abrasive added (see Section 20.9.12)
 - ultrasonic cleaning (see Section 20.9.13)
 - dry ice blasting (see Section 20.9.14)

- for substrates and workpieces, contamination depends on the previous processes, and may include corrosion from storage, press oils, dirt and debris from cutting, shaping and grinding, finger marks from handling, etc. These and the options for cleaning are discussed in the STM BREF. In this sector, the parts are usually hand cleaned with wipes or rags (see Section 20.9.9) or in water-based detergent systems for high throughputs (see Section 20.9.8). Solvents can be used in washing machines for smaller components (see Section 20.9.10). Ultrasonic or dry ice techniques can also be used (see Sections 20.9.13 and 20.9.14).

3. Choice of technique and/or solvent. The technique and/or the solvent used should:

- be capable of achieving the cleanliness required in the process
- be compatible with the parts being cleaned (whether they are substrates, workpieces or equipment parts)
- be compatible with the process, and the surface treatments. For example, in the printing of flexible packaging the system has to be dry of all solvents before adding new inks. In other activities, the cleaning systems can be compatible with the process and drying may not be necessary
- reduce the emission of solvents and/or minimise the formation of tropospheric ozone (see Section 20.10.2)
- take into account the time available. In some cases, the time available for cleaning is limited; in other cases, cleaning systems that take more time can be used.

In some processes, disassembly of the equipment and some hand cleaning is inevitable for maintenance cleaning.

For operational cleaning, automated systems may be used.

There are overlaps between the techniques discussed in this section and with those techniques discussed in Section 20.10 (Substitution). The factors discussed here are summarised in Table 20.6, with the possible techniques from the two sections. Techniques may also be combined and/or repeated to achieve the necessary cleanliness.

Cleaning techniques		Process equipment		Substrate or workpiece
Section	Technique	Non-persistent contamination	Persistent contamination	
20.9.2	Minimising cleaning	Yes	Yes	Yes
20.9.3	Preparation prior to solvent or other types of cleaning	Yes		
20.9.4	Conventional solvent cleaning	Yes	Yes	
20.9.5	Cleaning with solvents with lower evaporation speed	Yes		
20.9.6	Cleaning with powerful solvents		Yes	
20.9.7	Cleaning with solvents with lower ozone forming potential (OFP)	Yes	Yes	Yes
20.9.8	Water-based cleaning	Yes	Yes	Yes
20.9.9	Cleaning by hand	Yes		Yes
20.9.10	Washing machines using solvents	Yes	Yes	
20.9.11	Cleaning with solvent recovery	Yes		
20.9.12	Cleaning with high pressure water spray		Yes	
20.9.13	Ultrasonic cleaning		Yes	Yes
20.9.14	Dry ice (CO ₂) cleaning		Yes	Yes

Table 20.6: Examples of applicability of cleaning techniques and options

Achieved environmental benefits: Selection of the correct cleaning system can reduce solvent emissions and/or the formation of tropospheric ozone.

Cross-media effects: Changing from conventional techniques may result in more energy use, more waste water for treatment, or more waste being produced.

Operational data: See Description above, and the individual techniques described in Sections 20.9.2 to 20.9.12. Other techniques specifically used in certain industries are also discussed in the industry-specific sections.

Applicability: See Description, above, and individual techniques in Sections 20.9.2 to 20.9.12 and techniques in Section 20.10. Applicability of cleaning techniques in certain industries are also discussed in the industry-specific sections.

Economics: Site and technique specific.

Driving forces for implementation: Workplace health and safety. Quality and customer demands.

Example plants: Cleaning is carried out in all installations.

Reference literature: [4, Intergraf and EGF, 1999, 154, Tempany, 2006]

20.9.2 Minimising cleaning

Description: The following techniques all contribute to minimising cleaning:

- clean working practices
- controlling leaks and spillages (see Section 20.2.1)
 - regular inspection of working and storage areas
 - spillage plans to deal promptly with spillages of all sizes
 - prompt maintenance, such as stopping material leakages
- prevention of corrosion and soiling in storage and handling of materials such as metal workpieces (discussed in conjunction with water-based treatments in the STM BREF).

Achieved environmental benefits: Minimises cleaning materials used, especially solvents.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: All installations.

Economics: Low cost.

Driving forces for implementation: Health and safety: reducing unnecessary exposure to raw and cleaning materials, reducing risk of slips.

Example plants: Widely used.

Reference literature: [4, Intergraf and EGF, 1999] [63, Vito, 2003]

20.9.3 Preparation prior to solvent or other types of cleaning

Description: Removing as much of the coating material, paint or ink as possible from the equipment in its concentrated form reduces the amount of material to be removed using solvents and/or water. Raw material saving techniques may be used, such as described in Section 20.6.3.

Achieved environmental benefits: Reduces the use of solvents, cleaning materials and water that may require pretreatment prior to discharge. Can save raw materials.

Cross-media effects: No data submitted.

Operational data: May increase downtime. May increase staff contact with hazardous materials.

Applicability: Workplace health and safety may limit the application of this technique.

Economics: Low cost, but may increase downtime.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [13, DFIU and IFARE, 2002] [63, Vito, 2003]

20.9.4 Conventional solvent cleaning

Description: Cleaning using solvents can be carried out at room temperature or with heating.

Room temperature cleaning can be carried out manually (with a rag, a brush, a spray or 'fountain') with low toxicity solvents, in open baths or in closed systems.

Cleaning using hot solvents uses closed or semi-closed vessels (e.g. see Sections 20.9.7 and 20.9.8). The flammability risk has to be adequately controlled by working well below the flashpoint or under inert atmospheres.

Achieved environmental benefits: None.

Cross-media effects: Consumption of solvents, emission of VOCs and solvent/paint waste.

Operational data: Cleaning processes with organic solvents account for about 20 % of total VOC emissions from paintshops. 80 % of solvent emissions from cleaning processes can be reduced by using closed systems for the cleaning of guns and applicators. The systems cost EUR 150 - 3000.

In some cases, solvents can be replaced by water-based detergents (see Section 20.9.8).

Applicability: Cleaning processes are necessary in each paintshop.

Economics: See Operational data, above.

Driving forces for implementation: Quality, customer demands.

Example plants: Widely used.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004].

20.9.5 Cleaning with solvents with lower evaporation speed

See the detailed discussion in Sections 20.10.1.1 to 20.10.1.4, where a higher flashpoint is used as a surrogate for a lower speed of evaporation (these data may not be readily available).

20.9.6 Cleaning with powerful solvents

See the detailed discussion in Section 20.10.3. Powerful solvents with low evaporation speed can be used to remove persistent contamination.

20.9.7 Cleaning with solvents with lower ozone-forming potential

See the detailed discussion in Section 20.10.2. A key impact of solvent emissions (tropospheric ozone formation) can be reduced by using solvents with a lower ozone-forming potential. Cleaning solvents, where normally single solvents or simple mixtures are used, is an option for using this technique although it may not be relevant where the solvent vapours are sent to abatement.

20.9.8 Water-based cleaning

Description: Components and sub-assemblies can be cleaned in vats using water-based cleaning or degreasing techniques based on detergent systems. These systems are also used to clean substrates or workpieces for water-based treatment techniques, e.g. see Section 20.7.1.1. There are a range of chemical systems used, based on combining detergents with alkalis and others substances, depending on the substrates and the materials to be removed. These, and their maintenance options, are discussed in the STM BREF.

Achieved environmental benefits: No solvent emissions.

Cross-media effects: May require additional heating. Likely to require subsequent treatment of the waste water.

Operational data: May take longer to clean components than using solvent-based techniques.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: See Section 20.10, Driving forces for implementation.

Example plants: Widely used as a pretreatment for water-based surface treatments.

Reference literature: [59, EIPPCB, 2005]

20.9.9 Cleaning by hand

Description: Parts are cleaned using solvents or water-based detergent systems. Physical rubbing, scrapping or scouring is applied by brushes, rags, abrasive pads, hand tools, etc. depending on the persistence of the contamination. The solvent is applied by rag or brush from a small supply (e.g. jug), tap or spray (fountain) or in open baths. Rags pre-impregnated with solvents can be used (e.g. see Sections 14.4.4.2, 16.2.1, and 20.2.2.1).

Achieved environmental benefits: No data submitted.

Cross-media effects: For conventional solvents, see Section 20.9.3.

Operational data: No data submitted.

Applicability: Some hand cleaning is almost inevitable, although workplace health and safety often limits its use.

Solvent emissions can be controlled by:

- limiting the amount of solvent (e.g. by measuring and restricting the amount to be used in a jug, using pre-impregnated wipes, etc.)
- using volatile solvents by hand, and allowing the spent solvent to overflow immediately into a closed container. No open surface of liquid solvent should be exposed in the workstation close to the object to be cleaned. This also reduces occupational exposure. Equipment is available that consists of a closed drum containing solvents that can be pumped when required through a tap or sprayed onto the object to be cleaned in a partially enclosed work area above the drum. The surplus solvent runs back (through coarse filters) into the drum. The solvent is pumped from the surface of the solvent, leaving contamination to settle out. The solvent may be recycled when it can no longer be used
- using low toxicity solvents that have a high flashpoint, a high boiling point, or a low ozone-forming potential (see Section 20.10.2).

Economics: Low cost.

Driving forces for implementation: Where automated methods do not clean sufficiently or may damage the parts to be cleaned.

Example plants: Widely used.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [160, ESVOCCG, 2006]

20.9.10 Washing machines using solvents

Description: This is an enclosed machine which is loaded with components on a batch basis. The components can be either workpieces to be coated or process machine parts to be cleaned during maintenance. The machine contains solvents which are used to clean the parts by (i) immersion (ii) spray or (iii) a vapour phase of low boiling solvent which condenses on the components, therefore always depositing clean solvent on the components to be cleaned. The solvents are contained, and collected for re-use. The solvent is usually heated.

Achieved environmental benefits: Solvent emissions are reduced significantly compared with uncontained cleaning.

Cross-media effects: The vessel of the machine holding the parts requires venting of the solvent vapours before the contents can be removed. These vented vapours are sometimes released to air.

Energy is used in pumping solvent. Activated carbon is used if absorption cylinders are used, and the carbon needs regenerating or discarding as waste.

Operational data: The emission of solvent vapours from venting can be reduced considerably by venting to a waste gas treatment system in the installation (e.g. see Section 2.4.2.6.3) or to absorption in dedicated cylinders containing activated carbon.

Applicability: See Description, above.

Some cases of difficult deposits or persistent contamination require removal with halogenated solvents. These solvents can be used in fully enclosed systems with treatment of the vented solvents.

Economics: No data submitted.

Driving forces for implementation: Workplace health and safety. Note that the SED sets specific ELVs for some halogenated solvents.

Example plants: Widely used in many industries.

Reference literature: [160, ESVOCCG, 2006]

20.9.11 Cleaning with solvent recovery

Description: Purge solvent is used to clean the guns/applicators and lines between colour changes to prevent cross contamination. Cleaning solvent is used to clean the equipment and booths. The purge and cleaning solvent can be collected, stored and re-used as a solvent feedstock or destroyed. Some modern paintshops are equipped with a recovery installation for the used cleaning agents.

Achieved environmental benefit: 80 - 90 % of cleaning and purge solvent can be recovered for re-use.

Cross-media effects: No data submitted.

Operational data: Problems are reported with 2-component clear coat materials, which frequently lead to clogging of the recovery tank piping.

Applicability: This system can be applied to solvent-based paint application processes and any operation where solvents are used to clean booths. Collected solvent can be treated for re-use within the process or alternatively be dispatched from the site and processed for re-use by the original operator or a third party.

Economics: In the automotive industry, a typical solvent recovery system cost EUR 0.4 million per spray booth to install in 2004.

Driving forces for implementation: Solvent recycling and VOC emission reduction.

Example plants: Standard practice in the automotive industry.

Reference literature: [76, TWG, 2004]

20.9.12 Cleaning with high pressure water spray

Description: Cleaning of machine parts and doctor blades (in printing) is carried out with high pressure water spray and sodium bicarbonate or similar cleaning systems rather than using organic solvent.

Achieved environmental benefits: Reduction of solvent emissions.

Cross-media effects: Increased consumption of water and more waste water will arise.

Operational data: Commonly applied.

Applicability: This technique is used for in-depth cleaning of cylinders and anilox rollers used in flexible packaging. Sodium carbonate is added to the high pressure water.

Economics: No data submitted.

Driving forces for implementation: Workplace health and safety.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999, 76, TWG, 2004]

20.9.13 Ultrasonic cleaning

Description: An ultrasonic cleaner generates high frequency vibrations through a liquid (usually water-based detergents), i.e. ranging from about 20000 to 100000 cycles per second. The vibrations create microscopic bubbles in the liquid that then collapse on items that are immersed in the liquid, creating a cleaning action.

Achieved environmental benefits: No solvent-based cleaning agents are used and VOC emissions are eliminated.

Cross-media effects: Noise levels might increase.

Operational data: No data submitted.

Applicability: Applied in flexible packaging printing for in-depth cleaning of cylinders and anilox rollers.

Economics: No data submitted.

Driving forces for implementation: Workplace health and safety.

Example plants: No data submitted.

Reference literature: [21, Nordic Council of Ministers, 1998] [76, TWG, 2004] [59, EIPPCB, 2005]

20.9.14 Dry ice (CO₂) cleaning

Description: Dried paint or ink can be removed by blasting with dry ice pellets.

Achieved environmental benefits: Solvent emissions are completely avoided.

Cross-media effects: Blasting requires energy and creates noise (in-house) and dust from removed paint or ink.

Operational data: The preparation takes a lot of time as the parts of the machine to be cleaned must be totally isolated to prevent damage to other parts.

Applicability: Widely applicable for maintenance cleaning rather than daily cleaning processes as disassembly of machine parts is usually involved.

In printing, the technique is used to get rid of very persistent contamination on parts of the presses. It is applied every few months for a periodic intensive cleaning in publication gravure and heatset plants, where normally toluene or special mixtures of solvents are used as a cleaning solvent.

Economics: Costs are comparable to conventional cleaning techniques.

Driving forces for implementation: Workplace health and safety

Example plants: Used in publication gravure and heatset plants Europe-wide.

Reference literature: [18, UBA Germany, 2003] [4, Intergraf and EGF, 1999] [76, TWG, 2004] [59, EIPPCB, 2005]

20.10 Substitution: using less harmful substances – general principles

Description: Surface treatment using solvents uses a wide range of chemicals in a wide range of processes. Annex IV, point 2, to the IPPC Directive requires the use of less hazardous substances to be considered.

The use of less harmful substances (substitution) can be achieved in one of three ways:

1. Direct replacement of one substance by a less hazardous one. This is usually limited to simpler systems, for example, replacement of low flashpoint cleaners by high flashpoint ones (see Section 20.10.1).
2. Replacement by different process chemistries or techniques using less hazardous substances. This is used where there is no direct replacement. Different coating process chemistries give treatments with different properties, even for the same materials. For examples, see Table 20.7. This is the principle route for replacing harmful substances in this sector, and is dealt with in the appropriate activity and industry chapters.
3. Eliminating the surface treatment process in the installation and using, for example, pre-coated materials in production (e.g. for producing white goods or construction panels). This type of substitution may be shown to be environmentally beneficial (e.g. in life cycle studies) and may be considered by an operator to achieve various objectives including reducing VOC emissions. However, the IPPC Directive refers to the installation and the activities used. This type of substitution (in effect, cessation of the process within the installation) is therefore not a technique likely to be considered in determining BAT and is not discussed further in this reference document.

Low solvent coatings	High solids
	2-component (chemically inter reacting)
	Water-based
	Powder slurry
Solvent-free coatings	Hot melts
	Powder coating
	Powder polyester coating
	Radiation curable coating

Table 20.7: Examples of solvent substitutes used in the STS sector

Substitution not only applies to solvents used in cleaning substrates, equipment and facilities, but also to other components used in the processes, such as pigments, preservatives, binders, surface active agents, etc.

Some substances are covered by other European and/or national legislation or guidance, and the risk phrases supplied with manufacturers' data can be a useful start to identifying materials with significant health and environmental hazards. The following are possible hazard attributes for substances used in this sector:

- **adverse physiological effects** (see Section 20.10.4):
 - substances with the risk phrases R45, R46, R49, R60 and R61
 - substances with the risk phrases R40 and R68 may be considered for replacement, but primarily for occupational health reasons if a risk of exposure exists
- **physico-chemical effects**: the following risk phrases are not regarded as measures of environmental impact (except where subject to [134, EC, 2003]): explosive, oxidising, extremely flammable, highly flammable and flammable
- **photochemical oxidant formation (ozone-formation potential, OFP)**: see Chapter 1 and Section 20.10.2
- **stratospheric ozone depletion potential (ODP)** (see Section 20.10.3)
- **global warming potential (GWP)**: the GWP of a substance is a measure of the extra amount of heat that is trapped in the atmosphere when one kilogram of the substance is released instantaneously into it, relative to the case when 1kg carbon dioxide is released
- **ecotoxic effects**: these are described by the labelling accompanying the raw materials set out in the Marketing and Use Directive as amended [98, EC, 1976]. In this sector, aquatic toxicity as defined by the risk phrase R50/53 may be one of the most relevant where there is a risk of contact with water, such as where solvent-based systems that are replaced with predominantly water-based systems. These may require the addition of biocides, or the raw materials may have intrinsic aquatic toxicity, or there is a risk of spillage, see Section 20.3.3
- **odour**: many VOCs have an odour. In certain circumstances emissions of VOCs can give rise to localised odour nuisance problems (see Section 20.15). There is no EU-wide measure for odour, although methods exist in various MS
- **damage to material**: information can be found on corrosiveness or other properties of VOCs which might lead to the damage of materials. However, such damage is unlikely to occur at any distance from the point of discharge, due to dilution through dispersion. For these reasons such VOCs are not considered hazardous, although POCP (see Section 20.10.3) takes account of ozone formation that may lead to ozone attack on certain materials.

Achieved environmental benefits: Reduction in the use of harmful substances, e.g. solvents, and the amounts subsequently entering the environment, either planned (e.g. in waste gases) or unplanned (e.g. fugitive emissions, leaks, accidents in handling, etc.).

There may be other improvements in environmental performance, such as the saving of energy in the process or in waste gas treatment, the use of less raw material in the process or waste water treatment, less water usage, the production of less waste, and lower emissions of noise or dust, etc.

Cross-media effects: These effects depend on the individual alternative techniques. Some may have effects such as increased energy usage, increased waste production or increased water or raw material consumption. Some alternative materials may increase health and safety risks, have a higher photochemical reactivity (see Section 20.10.2) or increase other environmental risks. One simple approach for assessing if the health risks are increased is to use the Vapour Hazard Ratio (see Applicability, below). Further information can be found in the ECM REF.

Operational data: See Sections 2.4.1.2, 2.4.2.2, 2.4.3.2, 3.4.5, 4.4.2, 5.4.2, 6.4.3, 7.4.2, 8.4.2, 9.4.2, 10.4.2, 11.4.7, 12.4.2, 14.4.3, 15.4.2, 16.4.4 and 17.4.3.

Applicability: Substitution decisions have to be made on a case-by-case basis, and the substitution must adequately achieve the final performance characteristics required (i.e. have suitable functionality). In all cases, it is essential to discuss the changes with the customer in advance of making the substitution. It is good practice not make changes without full knowledge of the final performance characteristics required. Because of the risk of failure to meet these characteristics, it is advisable for both operator and customer to monitor quality and performance to, and exchange information on, the required specification.

In some processes using single substances, such as toluene in publication gravure printing, it is not currently possible to replace toluene.

Given the wide range of chemicals used in this sector, it is doubtful that all chemicals with potential to cause harm to the environment can be suitably replaced. Some processes may depend on harmful substances where there is no suitable substitute or the cross-media effects (see above) outweigh the benefits.

To assist with comparing possible alternative substances, ratios may be derived. For example, for physiological effects, the Vapour Hazard Ratio (VHR) compares the tendency of a product to evaporate with its OEL (Occupational Exposure Limit) as shown below:

$$\text{VHR} = \frac{\text{Equilibrium vapour concentration (at 20 °C)}}{\text{OEL}}$$

As a consequence:

- for products with a similar OEL, choose the product of lowest volatility
- for products with a similar volatility, choose the product with a higher OEL.

Where the data are less easy to interpret, the calculation may have to be made.

Other factors, such as toxicity and ecotoxicity can be judged on a simple basis, such as using a substance with a lower risk phrase. Alternatively, other metrics (such as ozone forming reactivity, see Section 20.10.2, can be used. In some case, such as with OFP, a ratio analogous to VHR could be developed.

Economics: Substitutes may be more cost effective but this needs to be determined on a case-by-case basis. They may enable the installation to meet more than one set of legislative requirements (see Driving forces for implementation, below). Savings may be found in, for example:

- decreased energy, water and raw material usage
- decreased waste gas and waste water treatment
- increased health and safety compliance in the workplace
- improved quality and reliability of the process.

Driving forces for implementation: Health and safety of employees is a major driver for using less harmful substances. (Note: care should be taken with replacing for occupational health reasons to ensure the replacements are in fact less harmful according to all the evidence available).

Other environmental legislative drivers are, e.g. the Solvent Emissions Directive, and a PARCOM recommendation for materials discharged to water. In some cases, the solvent reduction achieved can result in lowering the solvent use below the levels considered for IPPC or other regulation.

Example plants: See Sections 2.4.1.2, 2.4.2.2, 2.4.3.2, 3.4.5, 4.4.2, 5.4.2, 6.4.3, 7.4.2, 8.4.2, 9.4.2, 10.4.2, 11.4.4.2, 12.4.2, 14.4.3, 15.4.2, 16.4.4 and 17.4.3.

Reference literature:[59, EIPPCB, 2005], [89, Envirowise, 2003, 97, EIPPCB, 2005, 123, EC, 1999, 128, TWG, 2005, 168, ESIG, 2005]

20.10.1 Replacement of cleaning agents (substitution)

[128, TWG, 2005]

See Section 20.9. The evaporation speed of solvents determines the amount of solvent that will evaporate during the cleaning activity and the later storage of the contaminated wipes (a standard test is used: DIN 53170). The evaporation speed of traditional solvents, e.g. in printing, toluene and ethyl acetate, is higher than the evaporation speed of solvents with medium and high flashpoints. Consequently, the evaporation during cleaning can be reduced by using the latter. Data on the evaporation speed can be obtained from the supplier, if not provided to the user of the solvent. If this information is not available, the flashpoint of a solvent is a good indication of its evaporation speed, and all lower flashpoints should be indicated on the packaging of the solvent.

Using medium and high flashpoint cleaning agents also has some health and safety advantages, because the exposure of personnel to the evaporated solvents will be reduced. However, as very low OELs sometimes occur, e.g. 1 or 2 ppm versus 150 ppm for ethyl acetate, these advantages occur when the alternative cleaning agent meets the following criteria:

- there is not a substantially lower occupational exposure limit
- the change in solvent does not lead to heating being required
- the solvent is not dried by forced evaporation with HP air.

As the coating is usually most readily soluble or resuspended in the original solvents, occasional use of traditional low flashpoint cleaning agents will be necessary to assist in difficult cleaning tasks. A small amount of these (e.g. some 5 % of the total) will have to be kept in stock. For example, HBS or other low volatility solvents are not applicable to all printing plants. Inks that are based on volatile solvents, when dry, dissolve easily in the same solvent which they originally contained. Using solvents other than the original solvent is generally counterproductive. One of the reasons is that it is not possible to use existing machinery for in-house distillation and re-use when changing to HBS. In-house filtering systems are under development for HBS. Other examples of the occasions where volatile cleaning agents will need to be used are the following (see Section 20.9):

- cleaning dampening rollers
- maintenance
- cleaning UV curing inks
- difficult colour changes.

Where alternative solvents with lower volatility/higher flashpoint are used for cleaning floors, these solvents do not (by definition) evaporate rapidly, and therefore leave the floor slippery. It is therefore necessary to dry the floors, sometimes with small quantities of volatile solvents.

[148, TWG, 2006]

20.10.1.1 Cleaning agents with a flashpoint of >40 °C

Description: The evaporation speed of traditional solvents is significantly higher than the evaporation speed of solvents with a flashpoint of >40 °C. Consequently, the evaporation during cleaning can be reduced by using medium flashpoint solvents. These solvents may be useful as an intermediate step when switching from volatile cleaning agents to less volatile cleaning agents.

Achieved environmental benefits: Reduction of VOC emissions to air of up to 40 % compared to high flashpoint solvents (see Section 20.10.1.2) are reported. There is less risk of soil contamination. As less solvent evaporates, solvent consumption decreases.

Cross-media effects: No data submitted.

Operational data: Medium flashpoint solvents may not be as effective and efficient in cleaning as traditional solvents and the cleaning will require more time.

Applicability: Not used in all industries, see Section 20.10.1.2, below.

Economics: In printing, as cleaning may require more time and as press time is very expensive, the use of lower volatility solvents rapidly becomes prohibitively expensive if indeed press time is lost. For example, loss in production time due to slower evaporation of the solvent can easily run up costs of over EUR 1000 per hour in heatset printing.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [35, Aminal, et al., 2002] [76, TWG, 2004] [54, BMLFUW Austria, 2003]

20.10.1.2 Cleaning agents with a flashpoint of >55 °C

Description: The evaporation speed of traditional solvents can be some 100 times higher than the evaporation speed of solvents with a flashpoint of >55 °C. Consequently, the evaporation during cleaning can be reduced dramatically by using high flashpoint solvents.

Achieved environmental benefits: Reduction of VOC emissions to air depends on the situation at the start: changing from solvents with a flashpoint of <21 °C achieves a reduction of about 90 %; changing from solvents with a flashpoint of 21 - 55 °C can result in a reduction of about 50 %. Another advantage is that there is less risk of soil contamination. As less solvent evaporates, solvent consumption decreases.

Cross-media effects: Paper losses may increase, as after intermediate cleaning it takes longer for the cleaning agents to disappear which might result in the breaking of the web.

Operational data: High flashpoint solvents may not be as effective and efficient in cleaning as traditional solvents, but with experience, the results tend to become acceptable. Cleaning with high flashpoint solvents will require more time, although with training and experience this time loss will be reduced to an acceptable level.

In Germany, an agreement has been made between the health and safety organisation and the heatset offset printing industry, so they use only cleaning agents with a flashpoint of >55 °C, and with an aromatic content of below 1 %. Although the main driver is occupational health, the use of high volatility/high ozone creation potential solvents has reduced considerably by replacing conventional 'white spirit' type solvents.

Applicability: These solvents are applied in manual and automatic cleaning. They are commonly applied in heatset where mixtures of VCAs and high flashpoints (55 – 100 °C) are often used in order to attain the right drying speed.

In flexible packaging, high flashpoint solvents are commonly used in small quantities to remove very persistent contaminations. For daily cleaning of cleaning machines, however, these high

flashpoint cleaning agents are not commonly used, although some experiments are being carried out which have not been successful yet.

Economics: In printing, as cleaning may require more time and since press time is very expensive, the use of lower volatility solvents rapidly becomes prohibitively expensive if indeed press time is lost. For example, loss in production time due to slower evaporation of the solvent can easily run up costs of over EUR 1000 per hour in heatset printing.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [29, Netherland, 1996] [76, TWG, 2004] [168, ESIG, 2005]

20.10.1.3 Cleaning agents with a flashpoint of >100 °C

Description: Cleaning agents which have a flashpoint of >100 °C are also called high boiling solvents (HBS). They show even less evaporation (nearly zero) than solvents with a flashpoint of >55 °C.

Achieved environmental benefits: The main advantages are that during storage of used solvents and contaminated wipes, less evaporation takes place than when using solvents with a lower flashpoint. The risk of soil contamination from solvent-enriched air is also reduced. Another advantage is that the exposure of the workforce is reduced to a minimum.

Cross-media effects: The less solvent that evaporates, the more that is left as waste to be treated or disposed of. Cleaning with HBS requires an after-cleaning that is carried out with water. The water consumption and effluent discharge will also increase, because HBS is normally diluted with water. Water HBS mixtures can be treated by applying a filtration after which the HBS can be re-used and the water residue can normally be discharged into the sewerage system.

Operational data: In heatset offset, applying HBS requires a different working method compared to conventional solvents. The results of applying HBS are, therefore, variable, however, often the results are favourable. This is mostly the case where presses are cleaned by hand.

Where automatic cleaning systems are used, it should be understood that there are no manufacturers' objections against the use of HBS. Some automatic systems may be damaged by the use of these products. Automatic systems from before 1996 might especially require some adaptations in the dosing and spraying systems.

Applicability:

- applicable to heatset offset printing plants
- HBS can be applied in manual and automatic cleaning.

Economics: Generally, this technique is self-funding, however, the following conditions have to be taken into account:

- except for automatic cleaning in old plants where the retrofitting costs may be high
- modern automatic cleaning units, if they still use high volatility solvents, only use a few ml per cleaning cycle
- even a small loss in production time per cleaning cycle makes this technique very expensive if expressed as EUR/kg not emitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [21, Nordic Council of Ministers, 1998] [29, Netherland, 1996] [76, TWG, 2004] [54, BMLFUW Austria, 2003] [128, TWG, 2005]

20.10.1.4 Vegetable cleaning agents (VCAs)

Description: Vegetable cleaning agents (VCAs) are included in the group of cleaning agents with a flashpoint >100 °C (see Section 20.10.1.3). The first generation of VCAs were simply refined vegetable oils, which were found to be rather thick and difficult to handle. The present generation of VCAs are mono-esters of different fatty acids with differing degrees of saturation (iodine numbers) and fatty acid content (acid numbers). Automatic cleaning systems especially constructed to be used with VCAs are available.

Achieved environmental benefits: These VCAs are made from a renewable source and will, therefore, not increase the emissions of greenhouse gases. Other advantages are that during the storage of used solvents and contaminated wipes, less evaporation takes place than when using solvents with a lower flashpoint. The risk of soil contamination is also reduced. Another advantage is that the exposure of the workforce is also reduced to a minimum.

Cross-media effects: Cleaning with VCAs requires an after-cleaning with only water. Subsequently more waste water arises. Water VCA mixtures can be treated by filtration after which the VCA can be re-used and the water residue can normally be discharged into the sewerage system. Some VCAs may have human toxicological impacts.

Some VCAs are reported to possibly contain up to 15 % solvents or toxic ingredients (although these have not been defined further). Obviously, such VCAs may not add any environmental value or health and safety protection. The use of VCAs discussed in this section are based on VCAs that are free of solvents and toxic ingredients.

Operational data: Applying VCAs requires a different working method compared to conventional solvents, therefore, the results are variable; however, often the results are favourable. This is mostly the case where presses are cleaned by hand. However, training and the gaining of experience helps.

In the printing industry, where automatic cleaning systems are used in offset printing plants, it should be understood that there are no manufacturers' objections against the use of VCAs. Some automatic systems may be damaged by the use of these products. Automatic systems from before 1996 might especially require some adaptations in the dosing and spraying systems. Sometimes seals have to be replaced.

Applicability: Applicable in sheetfed offset plants. In coldset and heatset web offset processes, it is used only for the final cleaning of the press. This is because during printing, the rinse-water can easily break the paper web. A survey carried out in Denmark showed that about 65 % of the sheetfed offset printers use VCAs regularly, only using volatile solvents when it is necessary to remove dried ink. The consumption of VCAs at those plants accounts for about 2 % of all the solvents used. Other reports, e.g. from the Netherlands, show that these cleaning agents are not applicable in heatset and not always in sheetfed. It is also reported that in heatset the difference in emissions between HBS and VCAs does not justify the extra costs and time lost.

The uses of VCAs should be limited to those whose toxicology and other cross-media effects are known.

Economics: Often VCAs are four times more expensive than conventional cleaning agents. However, the volume of VCAs needed to clean a constant blanket surface is 1/2 of the volume of conventional cleaning agents. Generally, this technique is self-funding, however, the following conditions have to be taken into account:

- automatic cleaning in old plants where the retrofitting costs may be high
- modern automatic cleaning units, if they still use high volatility solvents, only use a few ml per cleaning cycle
- even a small loss in production time per cleaning cycle makes this technique very expensive if expressed in EUR/kg not emitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [21, Nordic Council of Ministers, 1998] [11, IMPEL, 2000] [76, TWG, 2004]

20.10.1.5 Powerful non-volatile solvents

Description: Powerful solvents such as n-methyl-2-pyrrolidone (boiling point 202 °C, flashpoint 95 °C) and ethanolamine (boiling point 170 °C, flashpoint 85 °C, vapour pressure 0.2 mm Hg) can be used where a powerful solvent action is required, usually in cleaning. They can replace halogenated solvents (see Section 20.10.3).

Achieved environmental benefits: Reduced emissions to air and reduced hazardous waste production.

Cross-media effects: When used at room temperature, powerful low volatility solvents have no emissions and limited health and safety equipment is needed. However, when used at a higher temperature to improve their effectiveness, these advantages disappear. At the end of 2006, n-methyl-2-pyrrolidone was under scrutiny and may be classified as a CMR.

Operational data: No data submitted.

Applicability: Applicability depends on the specific use (see Section 20.9). Substitution has been applied successfully in the printing industry (through legislation and EU-wide industry agreements), in friction lining manufacturing, and is commonly applied in all industry sectors.

Economics: More expensive than traditional solvents.

Driving forces for implementation: Health and safety in the workplace.

Example plants: See Applicability, above.

Reference literature: [4, Intergraf and EGF, 1999] [12, UBA Germany, 2002] [76, TWG, 2004] [128, TWG, 2005] [148, TWG, 2006]

20.10.1.6 Water-based cleaning

See Section 20.9.8.

20.10.2 Using solvents with lower ozone-forming potential (OFP)

Description: Different VOCs react differently when they are emitted to the air: this is referred to as ozone-forming reactivity or potential. VOC reactivity is not a static function of a compound, but varies with the ambient conditions. Temperature, the amount of sunlight available and the concentration of NO_x as well as other VOC compounds in the air can have an effect on the potential for a particular compound to form ozone. Meteorology also plays an important role. Assigning a reactivity value to VOCs is, therefore, a complicated task.

The most common scales used to compare the reactivity of different VOCs are:

- the photochemical ozone creation potential (POCP) (discussed in the ECM REF)
- the maximum incremental reactivity (MIR), derived for regulation in California, US.

An alternative scale called IDOP – maximum integrated downwind ozone production – has been developed in the UK. IDOP is expressed in ppb ozone per VOC emission rate in tonnes per hour. Only about 100 IDOP values have been calculated for individual substances, and it is recommended that more assessments be conducted before applying IDOP routinely. This is a suitable field for future research (see Concluding Remarks, Section 23.4). As MIR is calculated for Californian climatic conditions, this leaves POCP as the most suitable option to work with currently.

The use of a scale for OFP allows a mixture of VOCs to be summed (see the ECM REF). However, the OFP is usually used in assessing the effect of substances already volatilised (e.g. in spray booths, driers) and released, such as in modelling. Where the substances are not automatically volatilised (e.g. for some cleaning materials), this may need to be taken into account. The Swan Eco-label uses an effective ozone creation potential, POCP_(effective) (the POCP multiplied by the relative rate of evaporation). An approximate surrogate is to use vapour pressure multiplied by the POCP (see Annex 24.7):

The impact of a solvent mixture on ozone formation for materials can then be expressed as:

$$\text{POCP}_{(\text{effective})} = \sum_1^n x_1(\text{POCP}_{(\text{effective})1}) + x_2(\text{POCP}_{(\text{effective})2}) + \dots + x_n(\text{POCP}_{(\text{effective})n})$$

Where:

x_1 is the concentration of substance 1 in the mixture
 $(\text{POCP}_{(\text{effective})1})$ is the effective ozone creation potential (this equals POCP where all the solvent is volatilised in the process).

A similar formula (but using weight volatilised instead of concentration) can be used to compare the effects of the release of different amounts of different solvents released from different formulations.

Figure 20.4 below shows graphically how the formula works when assessing if a substitution proposal achieves an environmental benefit. VP_n is the vapour pressure of n components (as a first approximation; this sum approach assumes no physico-chemical interaction between the different components, which is likely to be a 'worst case' approach).

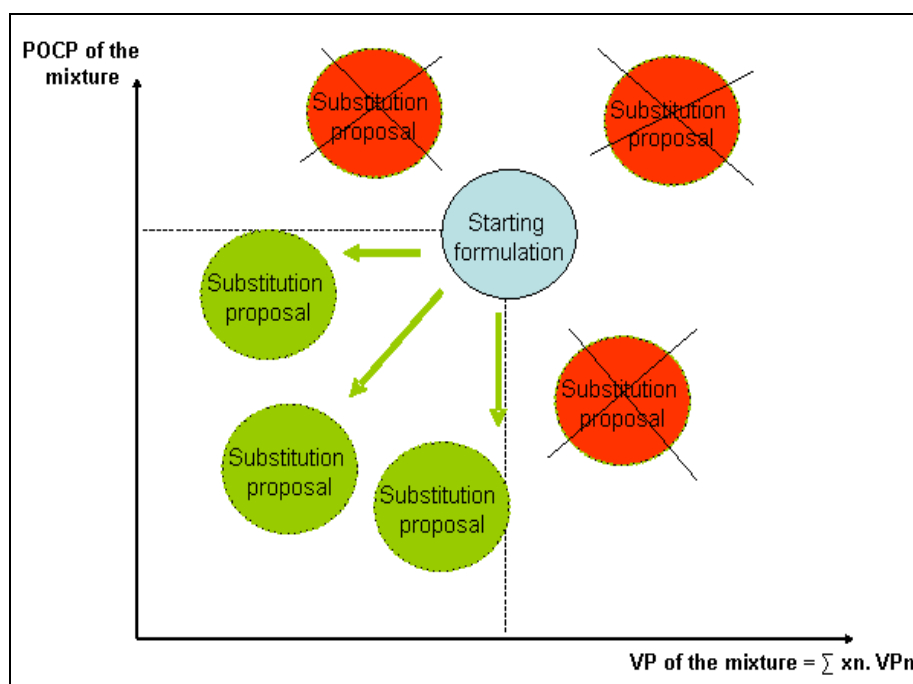


Figure 20.4: Assessment of potential substitutions by POCP

Achieved environmental benefits: The direct replacement of high reactivity light aromatic solvents, e.g. toluene, xylene and solvent naphtha (C9 aromatics), with lower reactivity alternatives offers the potential for VOC-related POCP reductions of about 20 - 40 % (see Applicability, below).

Some aromatic solvents are classified as dangerous for the environment (R51/53: exceptions include toluene, xylenes and ethyl benzenes) so their replacement might be beneficial for the aquatic environment as well, depending on the selected replacement products.

Cross-media effects: Chlorinated VOCs tend to have low ozone-forming reactivity, but high stratospheric ozone-depleting potentials as well as toxic effects.

Operational data: See Applicability, below.

Applicability: While OFP is the scientific reasoning behind the need to reduce emissions of VOCs, the use of OFP is in its early stages and cannot be used to show compliance with existing legislation such as SED (at operator level) and National Emissions Ceilings (at Member State level).

The technique is not applicable in installations where solvent emissions are adequately abated or prevented, such as by waste gas treatment, see Section 20.11.

The VOC reactivity calculations show that, although there is some variation in the relative rankings of individual VOCs, the light aromatic solvents are shown to be the most reactive products in terms of ozone formation by all three scales (and the same was found with other scales that have been tested in the US). In general, replacing light aromatic products in surface treating formulations can result in a significant reduction in the OFP of the final product in spite of the uncertainties associated with POCP (or other reactivity) values. However, it is important to note that although chlorinated VOCs generally have low values in ozone formation scales, they should not be used to replace non-chlorinated VOCs, as they have high ODP values (see Section 20.10.3), as well as health and safety impacts.

Complex systems, such as automotive paints (and some types of printing inks), may contain up to about 30 different solvents. This sophisticated mixture of solvents is used to achieve particular specifications, such as colour, drying, durability, etc. Changing these to decrease the overall $POFP_{total}$ while meeting the quality requirements would require a major investment by the industry (see Economics, below) and could not be achieved by one automotive manufacturer or installation in isolation. However, it may be implemented over a longer time period as a consideration with the ongoing formulation of paints (e.g. through REACH, see Driving forces for implementation, below) and is a suitable field for future research (see Concluding Remarks, Section 23.4).

In some processes using solvents with a higher OFP, these solvents cannot be replaced for technical reasons. This can be the case even where there is a single principle solvent used in the processes, such as toluene in publication gravure printing.

OFP can be used (within the limitations described in this section) to guide replacements for other hazards (as described in Section 20.10) to make sure these replacements decrease (or at least do not increase) the overall OFP. This is important to consider where substitution is used to achieve emission targets. It may be used where other measures cannot achieve the associated emission values or are not technically applicable (such as having unfavourable cross-media effects). It may be most readily used for simple systems, such as guiding replacement for cleaning solvents (see Sections 20.9 and 20.10.3) and solvent carriers for wood preservation (see Chapter 18). Where OFP is used, then the POCP figure can be used where the solvent is evaporated and the $POCP_{effective}$ should be used where evaporation is only partial (e.g. with some cleaning techniques).

Economics: The automotive industry estimates a cost for implementation for automotive paints in the range of EUR 100 million to 3500 million and a timescale of approximately 10 years. In addition, there are likely to be hidden costs for implementing this type of change in production, where new solvent systems may not have the same characteristics.

Driving forces for implementation: Policy and regulations decreasing the formation of ground level ozone (UNECE Gothenburg Protocol and EU National Emissions Ceilings Directive 2001/81/EC), CAFÉ (Clean Air For Europe), REACH, etc.

Light aromatic solvents have relatively low occupational exposure limits, so from an occupational health point of view, their replacement can be favourable as well.

Ethyl benzene, a component of industrial xylene, is undergoing an EU risk assessment under the Existing Substances Regulation 793/93/EEC. Toxicological tests on ethyl benzene have shown some carcinogenic activity in rats and mice and as a result, the International Agency for Research on Cancer has classified ethyl benzene as a Group 2B carcinogen (possible carcinogen to humans).

Example plants: Applied by local air pollution control authorities in the US, in particular, MIR is used by Californian regulators and industry.

Reference literature: [4, Intergraf and EGF, 1999] [76, TWG, 2004] [96, European Solvents Industry Group, 2005] [97, EIPPCB, 2005] Swan Eco-label [www.Svanen.nu] [148, TWG, 2006, 169, Lemoine, 2006, 170, Tempany and Lemoine, 2006, 172, May, 2006]

20.10.3 Replacement of halogenated solvents

Description: Halogenated solvents can be replaced by less hazardous solvents, e.g. where an powerful solvent action is required for cleaning. Powerful solvents such as n-methyl-2-pyrrolidone and ethanolamine can be used (see Section 20.9.5). Where paints are based on halogenated solvents, alternative paint systems can be used (see Section 20.7).

Achieved environmental benefits: Reduced hazard of emissions during handling and to air and reduced hazardous waste production.

Cross-media effects: No data submitted.

Operational data: Chlorinated hydrocarbons are sometimes used for degreasing surfaces in the production of friction lining, and as the solvent for some coatings for agricultural and construction vehicle coating.

In flexible packaging, halogenated solvents such as methylene chloride were used to remove persistent contamination. However, they have been replaced by non-volatile solvents such as n-methyl-2-pyrrolidone and ethanolamine.

Applicability: Applicability depends on the specific technique and its use. Substitution has been applied successfully in the printing industry (through legislation and EU-wide industry agreements), in friction lining manufacturing, and is commonly applied in all industry sectors. Paint systems are available that can replace paints using halogenated solvents.

Economics: No data submitted.

Driving forces for implementation: Health and safety in the workplace. The SED sets an emission limit value of 20 mg/Nm³ where the mass flow of halogenated VOCs with the risk phrase R40 is equal to, or greater than, 100 g/h.

In Germany, the use of halogenated solvents is considered obsolete.

Example plants: Halogenated solvents have been replaced on a wide scale (e.g. in Germany)

Reference literature: [4, Intergraf and EGF, 1999] [12, UBA Germany, 2002] [76, TWG, 2004] [128, TWG, 2005]

20.10.4 Replacement of solvents and other materials with CMR properties (substitution)

Description: Other substances and/or different techniques can be used to replace substances or preparations, which, because of their contents of VOCs are classified as carcinogens, mutagens or toxic to reproduction under Directive 67/548/EEC, and are assigned or carry the risk phrases R45, R46, R49 R60, R61.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Substitution has been applied successfully in the printing industry. For replacement of solvents: Installations have replaced solvent-degreasing with non-solvent cleaning, although the solvents replaced may not always be CMR solvents (see Section 20.10.1.6).

Economics: No data submitted.

Driving forces for implementation: Health and safety in the workplace, SED, the Marketing and Use Directive.

Example plants: Most paintshops in Germany and many electroplating shops handling comparable substrates in Europe.

Reference literature: [98, EC, 1976, 123, EC, 1999] [128, TWG, 2005]

20.10.5 Water-based cleaning agents

Description: In paintshops with water-based paints, alcohol or glycol/water mixtures (butyl glycol/water) are used instead of pure organic solvents.

Achieved environmental benefits: Reduced solvent consumption.

Cross-media effects: While the solvent content can be significantly reduced, it should be noted that water-based cleaners may contain up to 15 % solvent. If additional drying is required between the cleaning and following processes, then energy consumption may be increased.

Operational data: Water-based cleaning agents can be used in conjunction with biological treatments.

Applicability: Water-based cleaning agents are used in the automotive industry where water-based paints are used.

Water-based cleaning agents, are not available for offset printing. They are also not available for publication gravure or for flexible packaging when solvent-based inks, paints and adhesives are used.

There may be problems with using water-based cleaning agents when the following process is solvent-based. It may also entail additional drying between cleaning and the following treatment.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Automotive and coil coating plants in Europe. Many electroplating shops in Europe (handling similar substrates to paintshops).

Reference literature: [4, Intergraf and EGF, 1999] [76, TWG, 2004] [128, TWG, 2005]

20.11 Waste gas treatment

This section discusses applied treatment systems for waste gases containing solvent. It not only discusses the different types of treatments that are available, but also the design and layout. The section also covers techniques to optimise or minimise the airflow that has to be treated and techniques to recover the abated solvents, such as distillation. Figure 20.5 gives an overview of application ranges of the available VOC abatement technologies up to 2000. Industry comments that wet scrubbing is only used for particulate removal, condensation needs to be combined with inert gas drying and is used for much higher concentrations and regenerative incineration (oxidation) is applied much more widely today (<5000 - >100000 m³/h) [76, TWG, 2004].

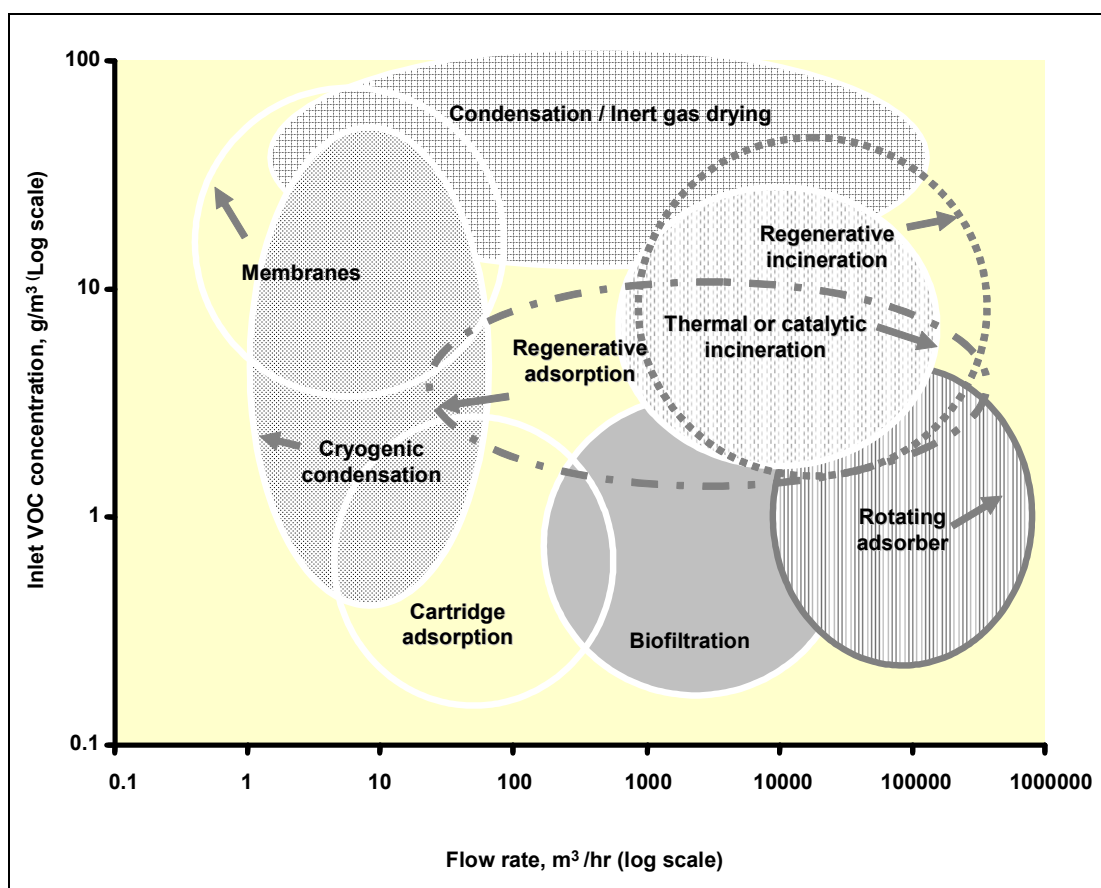


Figure 20.5: Overview of application ranges of the available VOC abatement technologies [60, ESIG, 2000]

20.11.1 Design, optimisation and management of extraction and abatement techniques

20.11.1.1 System selection, design and optimisation

Description: Air extraction systems containing solvents are usually primarily designed to keep atmospheres within working areas and equipment well below the LEL and the solvent concentrations lower than the OEL (which may be larger than the area kept below LEL). The extraction of key point sources of solvents may be led to waste gas treatment systems. In some cases, (such as washing machines using solvents), the air is exhausted to treatment with the primary aim of reducing solvent emissions. Also, in many cases, the original purpose of treating the waste gas was to reduce odour.

The design of the extraction systems should take into account:

- the amount of air to be extracted
- the likely level of solvents
- the type of treatment and its cost-benefit and cross-media effects
- the number of hours per year in operation.

Extraction of a large volume of air in proportion to solvent increases the size of the abatement system and may increase the amount of energy required as support fuel for combustion.

Fugitive emissions that are not caught by extraction systems and waste gas treatment may often form the major part of the solvent emissions (for example, see Section 2.3). This must be considered when designing an extraction and abatement system.

An example of considering the cross-media effects between flexographic printing with water-based and solvent-based inks is given in the ECM REF [97, EIPPCB, 2005].

Annex 24.9 provides a summary of waste gas treatment techniques (oxidation, adsorption, condensation and biological treatment) and their applicability. A comparison of the removal efficiencies of the most widely used techniques is given for different types of solvents at different inlet concentrations. [148, TWG, 2006]

The following considerations can assist in the system selection, design and optimisation, although expert guidance may be sought:

- **discontinuous emissions:** for discontinuous processes, variable and small loads techniques such as simple thermal oxidation (incineration) or adsorption (e.g. on cartridges) are most cost-effective
- **selection of thermal treatment for continuous operation** [112, Verspoor and manufacturer], 2005]: where the emissions are continuous, and multiple bed oxidisers are considered. Energy demands for air extraction and for support fuel are higher. Table 20.8 shows treatment required to achieve different emission levels.

VOC concentration in waste gas after treatment (mgC/Nm ³)	Treatment required
20 mg C as 24 h average	3-bed oxidiser
50 mg C as 24 h average	2- or 3-bed oxidiser (depending on maximum inlet VOC)
100 mg C as 24 h average	2-bed oxidiser
20 mg C at all times	3-bed oxidiser
50 mg C at all times	3-bed oxidiser
100 mg C at all times	3-bed oxidiser

Table 20.8: Influence of the emission value on choice of 2 or 3 bed oxidiser [112, Verspoor and manufacturer], 2005]

The investment costs of 2-bed oxidisers are 10 to 15 % lower than for 3-bed oxidisers. In combustion plants with regenerative preheating (regenerative thermal oxidation, RTO plants), by far the greatest share of process energy is recovered by integrated heat exchangers (>95 %). Therefore, the energy requirement in the waste gas treatment for achieving 20 mg/m³ of treated gas is not significantly higher than the energy needed for achieving only 50 mg/m³ or 100 mg/m³. However, there is higher energy consumption for the main fan of the extraction system, and higher maintenance costs. If process temperatures are lowered because higher VOC concentrations in treated gas are permitted, CO emissions may rise considerably

- **effect of energy consumption below autothermal conditions:** for the effect on the running cost of the incinerator when the average solvent content structurally reduces over time, due to (for instance) a decrease in solvent content of the coating materials in use, see Figure 20.6. This shows data for an incinerator on a flex pack plant. The amount of gas used after the autothermal point increases exponentially for medium and low flows.

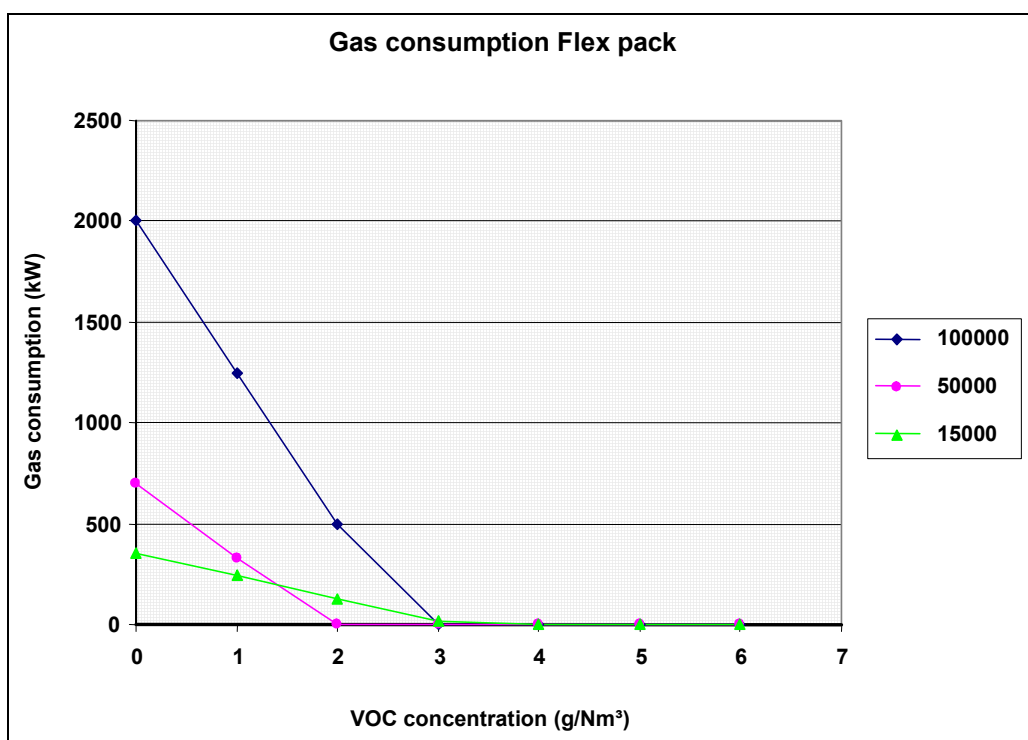


Figure 20.6: Example of gas consumption below autothermal point for flex pack [112, Verspoor and manufacturer], 2005]

- cost-benefit of energy consumption to control low solvent emissions:** the ECM REF describes ways of calculating and interpreting cross-media effects for alternative process options by collating emissions into seven environmental effects (themes). These effects can be compared using scales of relative effect for the individual substances released or their toxicities (see also Section 20.10). However, it is difficult to compare one effect against another, such as photochemical ozone formation against global warming potential, and further cross-media evaluation is required.

An alternative method to compare these different effects is to compare the costs of the negative externalities (damages or negative marginal social costs), in this case the damage to the environment including human health. There may be fewer data available for this, but data are available for emissions to air (see below, in this section). This technique may be used to compare the effectiveness of different courses of action. For example, burning a support fuel to achieve lower VOC emissions in waste gas can be compared with further measures to reduce fugitive emissions. The tonnes of CO₂ released a year can be calculated for burning additional fuel to destroy a known amount (in tonnes) of VOC emission (e.g. reducing the emission levels from 10 to 3 mg C/m³ for a described waste gas flow). These can then be multiplied by the relevant marginal social cost and compared. Comparing the damages for CO₂ with those for VOC are simplistic: changes in NO_x also need to be taken into account (if known). Also, the CO₂ contribution from the burnt VOC should be added in.

Recent data on a range of marginal social costs of climate change gives a central illustrative estimate of EUR 20 to 25/t CO₂ for 2000, rising to EUR 34/t CO₂ in 2020 (see Annex 24.8) [116, AEA, et al., 2005]. The EUA trading price of carbon was EUR 19 to 23/t CO₂ during summer 2005 and down to EUR 15 during summer 2006. Most studies predict an EUA between EUR 5 and 10/t CO₂ for the period 2005 to 2007, and between EUR 10 and 25/t CO₂ for the period 2008 to 2012.

Data from the cost benefit assessment for CAFE (see the ECM REF) give damages for VOC per tonne emission. The range of average values under different sets of assumptions for the EU-25 (without Cyprus) is EUR 950 to 1400/t emission. The lowest and highest values for individual countries range from EUR 140 to 4000/t emission. These are using a SOMO 35 approach with different sensitivities of the analysis. The countries vary in population density and differing low level ozone formation impacts so national or local figures could be used for individual installations.

When comparing these two sets of data, it is important to bear in mind that some impacts may be excluded and there are modelling assumptions and significant statistical uncertainties. Also, these figures are derived for estimating costs and benefits at a national, EU or international level, and may not transfer well to a calculation for an individual installation or take into account its local environmental quality standards.

On an EU level, a range of average VOC damages compared with a central bound of CO₂ costs gives a range of 32 to 140 tonnes of CO₂ to abate one tonne of VOC (40000 to 175000 m³ of natural gas), see Table 20.9. However, these cost ratios give a cost of abatement of one tonne of VOC of between EUR 14000 and 63000, which exceeds the marginal damage of VOC per tonne by 10 to 66 times (based on a cost of gas of EUR 7.52 to 10.48 per GJ in 2006). Two countries (Belgium and the Netherlands) use cost benefit benchmarks of EUR 3200 and EUR 4500 (respectively) as the total cost per tonne of VOC abated. This would indicate that these comparisons significantly exceed the economic feasibility of burning this amount of gas on an EU-25 level. (It may be that the marginal social cost of CO₂ used is too low).

These values do not take into account any CO₂ any NO_x impacts derived from oxidising VOCs.

Marginal social costs of climate change EUR/t CO ₂	Marginal damages for VOC EUR/tonne emission	Tonnes of CO ₂ to abate 1 tonne VOC	'000 m ³ of natural gas to abate 1 tonne VOC*
10	950	95	119
10	1400	140	175
20	950	48	60
20	1400	70	88
30	950	32	40
30	1400	46	58
* Based on a density of natural gas of 0.8 kg/m ³ at STP			

Table 20.9: Comparison of marginal social costs of climate change with marginal damage costs from VOC emissions (see Annex 24.8)

- **influence of limit value for CO:** the CO value out of the incinerator mainly depends on the combustion chamber, temperature and the residence time of the exhaust gas inside the combustion chamber. To lower levels for CO means:
 - increasing the combustion chamber temperature (results in higher running costs). Usually it is enough to increase the combustion temperature to about 850 °C. At VOC concentrations near or above the autothermal point, this will be automatically achieved. The total influence on running and capital costs with regard to lower CO levels can be seen as negligible
 - increasing the combustion chamber size to have a longer residence time (results in higher investment costs)
- **balance between CO, NO_x and VOC reduction:** no data submitted
- **maintenance:** see Section 20.11.1.2, below.

Achieved environmental benefits: VOC and odour reductions can be achieved where there is waste gas treatment.

Cross-media effects: Energy consumption in air extraction systems can be significant. Energy consumed to reach low VOC concentrations can be significant. Noise can be a significant factor. Burning 40000 to 175000 m³ of natural gas to destroy 1 tonne of VOC may not be sustainable.

Operational data: No data submitted.

Applicability: Cost-benefit of energy consumption to control low solvent emissions: Comparing the marginal social costs for CO₂ with those for VOC is currently over-simplistic. There are synergies as well as anti-synergistic effects between air pollution and greenhouse gas emissions. It is important to bear in mind that some impacts may be excluded (such as reducing CO₂ emissions may also reduce NO_x, SO_x and possibly PM_{2.5}). This makes costs and benefits complex to allocate. There are also modelling assumptions and significant statistical uncertainties. Also, these figures are derived for estimating costs and benefits at a national, EU or international level, and may not transfer well to a calculation for an individual installation or take into account its local environmental quality standards.

Economics: See Applicability, above.

Driving forces for implementation:

- extraction: workplace health and safety
- all considerations: odour, SED, national legislation.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004] [97, EIPPCB, 2005] [128, TWG, 2005, 165, ECN, 2005] [116, AEA, et al., 2005, 166, AEA and Institute, 2005] [67, EIPPCB, 2003] ec.europa.eu/environment/air/cafe/activities
www.engineeringtoolbox.com/gas-density-d_158.html
 Energy costs: Eurostat <http://epp.eurostat/ec.europa/eurostat>.

20.11.1.2 System maintenance

Description: All waste gas systems need maintenance, both preventative and for breakdowns. Untreated emissions can be minimised by:

- planned maintenance (see Section 20.2.6). Where it is necessary to shut down key emission abatement equipment (and this may include some days for cooling before the equipment can be touched), the emissions can be minimised by carrying out maintenance:
 - during low or no-production times (e.g. vacation shutdown periods)
 - during periods when emissions will have least impact, i.e. for VOC emissions, during periods of low sunlight levels, low probability of inversion layers, etc. This is dependent on weather, time of year and local conditions
- monitoring key equipment for problems such as vibration, emission leaks and planning repairs (as above)
- using decentralised/dedicated treatment systems so breakdown/repair only affects the systems in question (see Section 20.11.1.6)
- dealing with breakdowns and detected faults as rapidly as possible.

Achieved environmental benefits: Reduction in overall emission loads. Generally, defects in incineration equipment can give rise to VOC emissions equivalent to 0.4 % of the annual input per day, see Section 2.4.2.5.4.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004].

20.11.1.3 Bypassing peak emission flows (peak shaving)

Description: The maximum airflow of each drier is designed to cope safely with the maximum amount of solvent input per unit of time that may need to be dried (for example in flexible packaging, 100 % coverage of substrate with a thick layer of varnish). The maximum airflow of the plant equals the sum of all the maximum airflows from each drier. This is the theoretical capacity requirement of the incinerator (if there is no bypassing). However, the maximum airflow for the whole plant is very rarely achieved because (a) most driers do not need to evacuate the maximum amount of solvent most of the operating time, and (b) machines are standing idle for significant periods (in flexpack, at full capacity, the machines are idle 50 % of the time). The result is that the last 20 % of an incinerator's theoretical capacity would hardly ever be used.

Achieved environmental benefits: A significant reduction in energy consumption, and because the capacity of the abatement equipment needed is lower, smaller ventilators are needed and less additional fuel may be needed to run thermal abatement techniques.

Cross-media effects: No data submitted.

Operational data: Simulations were carried out at a virtual flexible packaging plant with a solvent input of approximately 1000 tonnes per year and a maximum airflow of 80000 m³/h. Each step in Table 20.10 shown below represents a change in capacity of 2000 m³/h and a marginal additional investment of approximately EUR 20000 - 30000.

Incineration capacity as % of maximum airflow	kg solvent bypassed per year	Solvent bypassed as a % of plant solvent input	Marginal EUR/t for abatement
92.5 – 95.0	240	0.024	24000
90.0 – 92.5	990	0.099	5800
87.5 – 90.0	1290	0.129	4470
85.0 – 87.5	2270	0.227	2560
82.5 – 85.0	4040	0.404	1450
80.0 – 82.5	6190	0.619	950
77.5 – 80.0	9040	0.904	670

Table 20.10: Emissions and costs in relation to incineration capacity [4, Intergraf and EGF, 1999]

Applicability: This technique can be used in conjunction with peak/trough smoothed by adding low solvent concentration waste gas streams when the treatment capacity is under utilised, see Section 20.11.1.4.

Designing abatement equipment for less than the maximum waste gas flow is acceptable where it can be expected that the maximum load will be achieved very rarely in operation. In this case, the possibility for exceeding the operational maximum load (and going to bypass) can be minimised through a machine management system.

In addition, the untreated waste gases that occur in the case of bypassing must be taken into account in the solvent management plan as part of the total waste gas emissions. This technique may not be usable where waste gas emission limit values are applied, and therefore, the technique is likely only to be usable when using a reduction scheme.

Economics: The ECM REF quotes average marginal damages (including health effects) per tonne of VOC emitted as ranging from EUR 950 to 2800 across the EU-25: costs will vary according to the location and individual calculations can be up to EUR 8000 for individual countries.

On an annual basis, bypassing less than 1 % of the solvent emissions reduces the capacity need and thus savings on both investment and running costs by up to 50 %. It can be more cost-effective to reduce fugitive emissions by an extra few per cent than to design the abatement equipment for the full ventilation capacity.

Driving forces for implementation: Cost-benefit and EMS, see Section 20.1.2.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [76, TWG, 2004] [97, EIPPCB, 2005] [128, TWG, 2005]

20.11.1.4 Utilising over-capacity – smoothing variations

Description: See Section 20.11.2.4. Existing waste gas treatment (e.g. incinerators) is generally not used to full capacity since more often than not, one of the surface treatment modules (press, spray booth, drier, etc.) is idle or a number of driers are not used. During this time, the excess capacity can be used for the local extraction described in Section 2.4.2.5.2. This needs extra ducting and a system that protects the incinerator from being overloaded through bypassing these low concentration airflows in the few cases where the full capacity is needed for the presses.

Achieved environmental benefits: Reduction of solvent emissions. Lower energy consumption than constant extraction (see Section 2.4.2.5.2).

Cross-media effects: The solvent concentrations in the resulting airflow need attention. They will be lower than before and may fall outside the incinerator's design range for autothermic operation and need additional fuel consumption.

Operational data: Implementation of the SED. Workplace health and safety. Control of exposure levels.

Applicability: No data submitted.

Economics: There is a cost of over EUR 100000 to retrofit this system. Running costs are lower and additional capital costs (such as a larger incinerator) can be avoided.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004]

20.11.1.5 Maintaining solvent concentration to treatment by variable frequency drives

Description: Most central waste gas treatment systems use a variable frequency drive fan to modulate the airflow to match the exhaust from the equipment that may be in operation.

Achieved environmental benefits: Reduction of solvent emissions while minimising energy consumption for extraction and combustion support.

Cross-media effects: None.

Operational data: No data submitted.

Applicability: Flexible packaging printing is a batch process. Individual presses may be offline 30 - 50 % of the time for set-up and changeover. During this time of press inactivity, if an oxidiser dedicated to one press is used, it must continue to burn fuel to maintain the temperature.

This is particularly important for regenerative thermal oxidisers, so only solvent-laden air is burnt and often autothermal operation can be sustained where no additional fuel is required.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004]

20.11.1.6 Dedicated/decentralised waste gas treatment systems for each point source

Description: Each single printing or painting line can have a dedicated waste gas treatment system. For example, if it is integrated in the drier(s), the system allows the heat of the waste gas to be easily used to heat up the air in the driers.

The presses or coating line are not dependent on one central waste gas treatment system. For example, for publication gravure, the advantage of each press having its own dedicated waste gas adsorption system is that when the activated carbon bed needs to be cleaned, it only affects one press. Cleaning a central adsorption system often involves several presses.

Achieved environmental benefits: Compared to the common central waste gas treatment system, higher removal efficiencies can be achieved. This is possible because the capacity of the treatment system matches exactly what is required on the printing or painting line. Making adjustments to the plant, e.g. expanding the plant with an extra press or coating line is easier with dedicated treatment systems than with one central system.

When integrated in the drier, this technique minimises calorific losses and thus energy consumption as waste heat can be used very efficiently.

The effects of breakdown or maintenance can be reduced.

Cross-media effects: No data submitted.

Operational data: See Description, above.

Applicability: Applied in publication gravure printing plants. Also applicable in heatset offset printing processes, because one press has only one drier which can be integrated with a thermal waste gas treatment and the energy saving on the drier may pay for the additional investment. In both cases, it is only applicable for new presses.

It is used as a standard technique in the automotive industry.

Not applied in packaging gravure printing plants, whose adsorption systems are centralised and have several absorbers. Each adsorber can be individually closed for maintenance without affecting emissions and the working of the press run.

Not applied in the coil coating industry.

Economics: This technique is more expensive than a central waste gas treatment system; however, depending on the existing system, energy savings can be significant. Installing a dedicated waste gas treatment system to a new press is cheaper than expanding the existing treatment system.

Driving forces for implementation: No data submitted.

Example plant: Volkswagen AG, Wolfsburg, Germany.

Reference literature: [18, UBA Germany, 2003] [54, BMLFUW Austria, 2003] [13, DFIU and IFARE, 2002] [128, TWG, 2005]

20.11.1.7 Central waste gas treatment

Description: In flexible packaging, there is no advantage to dedicated waste gas treatment. Presses are equipped with 8 to 12 driers and all driers from different presses are normally routed to one central thermal treatment. The reason is that emission control equipment for individual presses must typically be situated on the roof immediately above the press. Limitations of the roof support strength prohibit the use of larger, heavier control equipment. A central gas treatment system, such as a regenerative thermal oxidiser, located adjacent to the building can be built with adequate size for greater residence times and superior thermal efficiencies.

Flexible packaging printing is also very much a batch process. Individual presses may be offline 30 - 50 % of the time for set-up and changeover. During this time of press inactivity, a press specific oxidiser must continue to burn fuel to maintain the temperature. Most central waste gas treatment systems use a variable frequency drive (see Section 20.11.1.5) to modulate the airflow to match the exhaust from any number of presses that may be in operation. Since the regenerative thermal oxidiser is only burning solvent-laden air, it can often sustain autothermal operation where no additional fuel is required.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [18, UBA Germany, 2003] [54, BMLFUW Austria, 2003] [13, DFIU and IFARE, 2002] [76, TWG, 2004]

20.11.2 Containment and collection of waste gases

This section describes the containment and collection of waste gases from coating applications and drying processes. The handling and storage of solvents is discussed in Section 20.2.2.1. The choice of collection and treatment systems is also discussed in the CWW BREF [67, EIPPCB, 2003].

20.11.2.1 Encapsulation/enclosure

Description: Parts of the machinery or whole lines can be encapsulated/enclosed to avoid the release of fugitive emissions. Enclosure may also be for workplace health and safety, to reduce the risk of injuries from machinery or to reduce noise.

Achieved environmental benefits: Reduces fugitive emissions and noise. Reduces volume of air to be extracted (and therefore energy used) and reduces size of, and energy used in, any waste gas treatment.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Widely applicable for, e.g. publication gravure printing machines.

Economics: No data submitted.

Driving forces for implementation: Workplace health and safety.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004, 128, TWG, 2005].

20.11.2.2 Air seals on the entrance and the exit of the ovens/driers

See also Sections 20.11.2.1 and 14.4.8.2.

Description: Air seals at the entrance and on the exit of the oven/drier assist in the prevention of fugitive emissions.

Achieved environmental benefits: Reduction of fugitive emissions.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Commonly applied in the coil coating industry. Driers usually require negative pressure (see Section 20.11.2.3).

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [58, ECCA, 2004], [76, TWG, 2004] [128, TWG, 2005]

20.11.2.3 Negative pressure in drying

See also Sections 20.11.2.1 and 14.4.8.2.

Description: Ovens/driers are maintained at negative pressure to minimise the escape of VOCs. Typically, the volume of air injection is 70 – 75 % of the exhausted volume.

Achieved environmental benefits: Reduction of fugitive VOC emissions. Negative pressure causes air to flow into the oven and favours the capture of VOC vapours from the wet coating entering the oven.

Cross-media effects: No data submitted.

Operational data: Need of an extraction system.

Applicability: Commonly applied in the coil coating industry.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [58, ECCA, 2004], [76, TWG, 2004]

20.11.2.4 Air extraction from coating processes

Description: Air may be extracted from the application machinery used in the main process, such as printing presses, coil coating lines or automotive coating lines. The application equipment may be open (in reality, extraction is from the whole room: this is used in some industries for health and safety reasons) or partially or wholly enclosed. The extracted air may be treated.

Achieved environmental benefits: Reduction of fugitive solvent emissions.

Cross-media effects: Extraction requires energy. Noise levels might increase.

Operational data: The area where solvent-based raw materials are mixed, e.g. for achieving a certain viscosity or colour, can be equipped with an extraction system and the solvent-laden air is routed to a waste gas treatment system.

Applicability: Generally applicable.

In flexography and packaging gravure, the air is extracted from the ink mixing areas but not normally incinerated.

In flexible packaging, modern varnishing machines may be completely encapsulated and encapsulation ventilated by negative pressure driers. All emissions are sent to an incinerator.

In coil coating plants, the emissions from process equipment, which are insignificant in comparison with the operation of the driers, are vented directly to the air. Due to the high volume of airflow involved, large quantities of energy would be required to abate the air stream. The use of energy would exceed the environmental benefit that might be gained from the abatement. The air from the driers (and from coating in newer installations) are extracted and treated by thermal oxidation.

For the coating of large components such as aircraft bodies and ships, containment and extraction may be impracticable.

Economics: No data submitted.

Driving forces for implementation: Workplace health and safety.

Example plants: No data submitted.

Reference literature: [18, UBA Germany, 2003] [58, ECCA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.11.2.5 Air extraction from drying processes

Description: The driers and ovens are equipped with an air extraction system routing the solvent emissions to the waste gas treatment.

Achieved environmental benefits: Reduction of fugitive solvent emissions.

Cross-media effects: Extraction requires energy. Noise levels might increase.

Operational data: No data submitted.

Applicability: Generally applicable.

Economics: No data submitted.

Driving forces for implementation: Workplace health and safety.

Example plants: No data submitted.

Reference literature: [18, UBA Germany, 2003] [58, ECCA, 2004] [76, TWG, 2004]

20.11.2.6 Air extraction from the cooling zone

Description: After drying/curing, cooling may take place. The area where cooling is carried out may be enclosed. The waste gases containing solvent can be extracted and subsequently routed to abatement equipment.

Achieved environmental benefits: Reduced VOC emissions.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Commonly applied to coil coating installations (see Section 14.4.8.7).

Economics: High costs are involved.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [58, ECCA, 2004], [76, TWG, 2004]

20.11.2.7 Air extraction from cleaning processes

Description: The areas where machine parts and equipment are cleaned, either by hand or automatically, are equipped with an air extraction system routing the solvent emissions to the waste gas treatment.

Achieved environmental benefits: Reduction of fugitive solvent emissions.

Cross-media effects: Extraction systems require energy. Noise levels might increase.

Operational data: Machinery for cleaning may be used infrequently and at irregular intervals. Connecting them to abatement equipment may require extra capacity that is rarely used.

Applicability: See Section 20.9.

Cleaning by hand leads to very low solvent concentration and extraction may be needed to stay way below the OEL. It is not usually practical to send this low concentration waste gas to an incinerator.

Cleaning automatically: ventilation of washing machines is required before opening the machine. There are very high concentrations, but during a short time. It is usually practical to send to an incinerator, especially at times when the waste gas treatment is not in full use. This is used in package printing plants because they are normally equipped with a waste gas treatment system.

Not applicable in the winding wire industry because of the high boiling point of the solvents in the enamel.

Economics: Costs will depend on the existing extraction system and on the capacity of the waste gas treatment technique. Retrofit might, therefore, be very expensive. However, small incinerators could be fitted to automatic washing machines.

Driving forces for implementation: Workplace health and safety.

Example plants: No data submitted.

Reference literature: [18, UBA Germany, 2003] [58, ECCA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.11.2.8 Air extraction from storage of raw materials and wastes

Description: For safety reasons, new material stores, waste containing solvents, e.g. contaminated wipes and solvent-based residues stored in containers (see Section 20.2.2.1) may have an individual air extraction point(s). The extraction point should be set at a low level as the solvent vapours are heavier than air.

Achieved environmental benefits: Reduction of fugitive emissions if the waste gas is treated.

Cross-media effects: Noise levels might increase. Energy consumption for extraction increases.

Operational data: Commonly applied in publication gravure plants.

Applicability: Applicable in new and existing plants and all closed storage for wastes containing solvent. Whether the extracted air is fed to waste gas treatment will depend on the volume and concentration. The VOC concentrations are usually low.

Economics: The costs are low when compared to the total cost of the solvent recovery system. The savings for each kg of toluene recovered are about EUR 0.50. The extra capacity needed does, however, cost money. The cost per kg not emitted is high.

Driving forces for implementation: Workplace health and safety.

Example plants: No data submitted.

Reference literature: [18, UBA Germany, 2003] [58, ECCA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.11.3 Pretreatment, filtration and scrubbing

20.11.3.1 Increase of the internal solvent concentration

Description: Allowing the solvent-laden air to circulate in the driers or in spray booths (after sufficient particle separation and dehumidification) will increase the solvent concentration in the air and subsequently increase the solvent reduction efficiency of the waste gas treatment system. This can also be called ‘internal concentration’.

The reduction of the airflow is limited by the need to avoid risks of fire and explosions: the smaller the airflow, the higher the solvent concentration and thus the greater the danger of fire and explosions. A prerequisite for applying this technique in driers is, therefore, the installation of a lower explosion limit control to assure that the ventilation rate in the driers is designed in such a way that the maximum solvent concentrations that can possibly occur does not exceed a certain percentage of the LEL of the solvents concerned.

Table 20.11 shows % LEL that are considered safe in flexible packaging printing:

Situation	Maximum % LEL
Driers heated by open flame or electricity	25
Driers heated by open flame or electricity with extensive safety features	50
Driers heated by thermal oil or steam	50

Table 20.11: Maximum allowable levels of LEL in the driers in flexible packaging printing [4, Intergraf and EGF, 1999]

Apart from internal concentration, ‘external’ concentration is also possible by applying, for example, an adsorption step prior to incineration; see Section 20.11.6.1.

Achieved environmental benefits: In flexo or packaging gravure plants, where no measures have been taken to reduce the airflow from the driers, the average solvent concentration in the waste air may be no more than 1 to 2 g/m³.

For solvents like ethanol, ethyl acetate or MEK, the LEL at the relevant operating temperatures is somewhere near 50 g/m³. A level of 25 % LEL will be some 10 or 12 g/m³. This will be the maximum concentration in each individual drier, and this concentration cannot be reached in all the driers at the same time. Where measures have been taken to reduce the airflow, the average solvent concentration can rise to 4–6 g/m³. These levels allow regenerative incineration without the extra addition of fuel.

Reduced energy input at lower temperatures as the air has already been heated and retains residual heat, therefore recirculated air requires less energy to reach the optimum (booth) air temperature.

Cross-media effects: No data submitted.

Operational data: Where the cost of the abatement equipment is not an issue, large safety margins are often employed. These, however, need to be re-evaluated when an investment in abatement equipment is necessary. The safety margin determines the maximum airflow and, therefore, the minimum size of the abatement equipment.

It is reported that recirculation without active LEL control can be carried out. The maximum recirculation allowed depends on safety regulations. Often 25 % LEL is allowed when heating is done by steam or thermal oil. Where heating is electric or by open flame, the rules may be stricter.

In the automotive industry, higher recirculation can be achieved in water-based paintshops as lower solvent content means occupational exposure limit (in manual booths) or explosive limit (in automated booths) takes longer to reach. However, recirculation can be restricted by the tighter operating parameters required in the water-based spray booth for temperature and humidity.

Applicability: In situations where low solvent concentrations are combined with a large exhaust airflow rate, a certain solvent concentration is necessary for economic treatment. Increasing the solvent concentration in the airflow is applicable to conventional driers and to spray booths.

For driers, this technique is commonly applied in the printing processes publication gravure (for improving the toluene recovery), flexography and packaging gravure, and in the automotive industry. In publication gravure, new presses have such large airflows that expanding existing recovery installations is not economical. Also, permits for new presses tend to have stricter ELVs, which add to the difficulty of expanding existing recovery installations.

It is commonly applied in the manufacturing of abrasives, where the maximum speed of the production line is at 50 % LEL of the substance with the lowest inflammation point: the line speed is electronically controlled to this level.

Economics: The cost of increasing solvent concentrations and reducing the airflow depends not only on the age and build of the presses, but also the size of the reduction which is achieved. Where end-of-pipe abatement is to be installed, it is generally wise to reduce the airflow until the marginal cost of further reductions become equal to the marginal cost of the additional capacity of the abatement equipment. For incinerators applied in printing plants, this is approximately EUR 10 – 15 per m³/h.

Reduction of the airflow also reduces energy consumption. As less air is used, less needs to be heated. In situations where the drying temperatures are low (40 to 60 °C), these savings in themselves do not generally warrant the investment.

Driving forces for implementation: Lower capital investment, lower running costs of abatement equipment, including lower energy requirements.

Example plants: Ford plants in Europe. All modern packaging gravure presses.

Reference literature: [18, UBA Germany, 2003] [4, Intergraf and EGF, 1999] [12, UBA Germany, 2002] [13, DFIU and IFARE, 2002] [68, ACEA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.11.3.2 Increase of the external solvent concentration

Description: The concentration of solvent in the air can be increased by a continuous circular flow of the spray booth or drier through adsorption equipment. This equipment can include:

- fixed bed adsorber with activated carbon or zeolite polymers
- fluidised bed adsorber with activated carbon
- rotor adsorber (concentrator wheel) with activated carbon.

Achieved environmental benefits: A transmission of the solvent load into an external hot air stream in the ratio 1:6 to 1:30 (depending upon the raw gas concentration) is achieved. A comparatively small waste gas flowrate can be economically disposed of via incineration or condensation for re-use, for example, as a cleaning solvent.

Cross-media effects: Increased energy use.

Operational data: In the automotive industry, the air stream must be treated prior to the adsorption phase to remove particulate matter; otherwise the function of adsorption would be affected. A level below the 1 – 3 mg/m³ is necessary, which can be done by a number of techniques including:

- wet electrostatic precipitation
- high pressure venture
- cassette filters.

Applicability: This technique is only used where the cost of increasing the concentration and reducing airflow is less than the cost of additional treatment capacity. This is not applicable where concentrations are high enough for autothermic incineration.

It is usually applied where huge airflows with very low concentrations need to be treated (e.g. 250000 m³/h with 0.25 g/m³), and even at these flows, the cost-benefit is not certain, as there are increased operational costs (for fans, heating and cooling, etc.).

It is also limited to certain kinds of solvents. They must release from the zeolite to the carbon at reasonably low temperatures otherwise they clog the carbon and reduce its lifespan.

In the automotive industry this technique is commonly used for waste gas from solvent-based spray booths. It can be used in water-based spray booths, but this is usually uneconomical due to the reduced solvent content of the airflow.

This technique is also commonly applied in adhesive manufacturing.

Rotor adsorbers (concentrator wheels) with activated carbon or zeolite polymers experience a dramatic reduction in effectiveness when the solvent gas temperatures exceed 38 °C. Driers on presses producing flexible packaging have typically exhaust waste gases with temperatures exceeding 38 °C. This makes rotor concentrators a poor choice for the flexible packaging industry. Not used in publication gravure, heatset and flexible packaging printing.

Economics: The cost of concentrating solvent for re-use versus buying in material means that this application is implemented dependent on local cost conditions and the price of buying virgin material.

Driving forces for implementation: Reduced VOC emissions and possibility of re-use of the waste gas.

Example plants: Ford plants in Europe.

Reference literature: [68, ACEA, 2004] [76, TWG, 2004] [128, TWG, 2005].

20.11.3.3 Increasing the external air concentration using a plenum

Description: Plenum is defined as an air-filled space in a structure that receives air from a blower for distribution (as in a ventilation system). In this technique, it is the key part of a system for the external recirculation of air from driers in order to increase the solvent concentration and reduce the net air volume to be treated by an abatement technique.

Exhaust air from several driers, often from several different coating machines, is sent to one large chamber – the plenum. The driers take a large percentage of their inlet air from this chamber. The driers supplement their inlet air from the surroundings of the coating machine. Thus, more air will be sent to the plenum than will be taken from it by the driers. The excess air from the plenum is sent to an end-of-pipe abatement technique.

The solvent concentration in the plenum is constantly measured. The concentration in the air extracted from the plenum by the driers is allowed to rise to close to 25 % LEL. The driers take sufficient fresh air from their surroundings that in their exhaust the concentration will not exceed 25 % LEL. When the concentration in the plenum gets too high for this purpose, more air is extracted from it and the air volume in the plenum is supplemented with fresh air.

The plenum is an alternative to internal air recirculation in driers.

Achieved environmental benefits: The net air volume to be treated by the abatement technique is very much reduced. Autothermic operation of the abatement technique becomes possible. Energy recovery from incineration becomes possible.

Cross-media effects: Energy is also saved because the net amount of air to be heated in the driers is reduced to the amount taken from their surroundings.

Operational data: Where driers are applied without any internal recirculation and otherwise the outlet solvent concentration would be no more than one or two grams per m³, the net airflow to be treated by the abatement technique may be reduced by up to 80 %.

Applicability: Applicable in situations where low solvent concentrations in outlet drier air occur and internal recirculation of drier air is not technically possible or disproportionately expensive due to the large number of driers in the plant. Such situations may, for instance, occur where several older flexographic or gravure presses are used with eight or more driers each.

The inlet temperature of all the driers will be the same. This may cause difficulties when some driers require high temperatures and others not.

Economics: The plenum is not a cheap technique. Where internal recirculation in the driers is possible and the number of driers is limited, the net cost of internal recirculation combined with a larger oxidiser may be cheaper.

Driving forces for implementation: Where applicable (see above) and economically advantageous compared with alternatives.

Example plants: LPF, Leeuwarden, the Netherlands.

Reference literature: [167, Verspoor and Sitmae Consultancy, 2005]

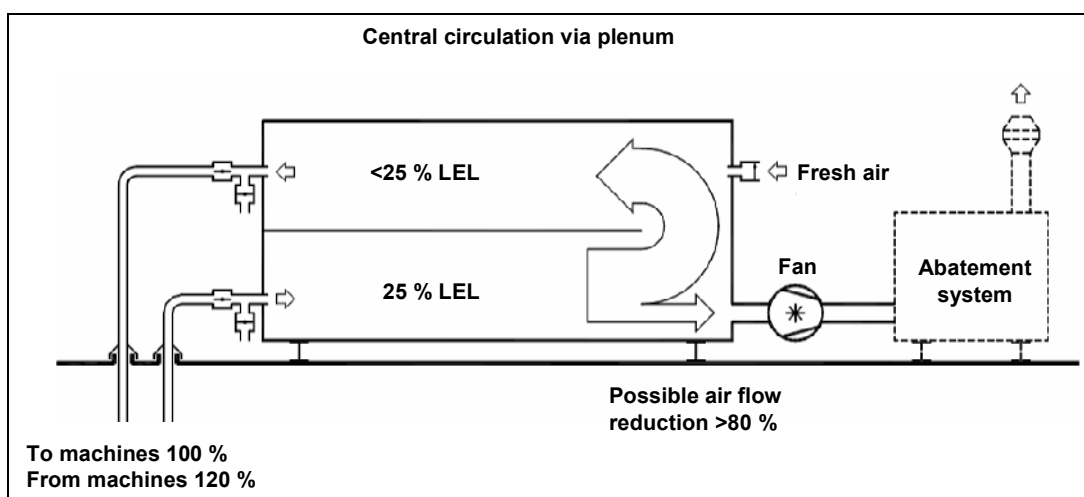


Figure 20.7: Plenum chamber

20.11.3.4 Membrane filtration

Description: This is a concentration technique, where the VOC rich gas is passed through an organic selective membrane module.

Achieved environmental benefits: The VOCs in the VOC rich permeate can be recovered, e.g. by applying condensation (see Section 20.11.5) or adsorption (see Section 20.11.6).

Cross-media effects: Energy is required for filtering. Retentate arises that needs to be disposed of eventually after further treatment.

Operational data: No data submitted.

Applicability: Membranes work better on specific molecules.

The technique is not applied in the winding wire industry, because the solvents cannot be re-used in the process. Not applied in the metal packaging or the automotive industries.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [60, ESIG, 2000] [76, TWG, 2004]

20.11.3.5 Venturi particle separation

Description: The waste gas containing paint particles is accelerated with water droplets using a venturi system. Intensive mixing takes place, followed by separation of the heavier particles. If water-based paint is applied, the separated paint can be re-used.

Achieved environmental benefits: A particle separation of over 99 % is reached and a remaining particle content of <3 mg/m³ (for new scrubbers) and <5 mg/m³ (for conventional lateral scrubbers) in the waste air are achievable (see Section 20.11.3.8).

The efficiency for the recycling of overspray is in the range of 50 - 90 %, depending on the type of paint processed.

Cross-media effects: Noise levels might increase. The water droplets result in a waste water fraction.

Operational data: With spraying of paint, an overspray normally arises which may need to be captured and treated. Venturi systems are normally applied as a primary separation step of paint materials. This primary separation is necessary in order to ensure a safe operation of the entire plant, to allow air recirculation and to meet working and environmental legal requirements.

Applicability: Venturi systems are normally applied as a primary separation step of paint materials.

Not applied in the winding wire industry as separation is not necessary and re-use is not possible. Also not applied in vehicle paintshops.

Venturi techniques are also efficient methods for reducing dust.

Economics: No data submitted.

Driving forces for implementation: Reduction in particulate emissions to the air.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [68, ACEA, 2004] [76, TWG, 2004]

20.11.3.6 Dry filter systems

Description: Dry filter systems are used to eliminate particles from the waste gas. Commonly applied dry filter systems are:

- labyrinth filters
- paper filters
- mats ('paintstop-filter').

Dry filters show good separation efficiencies for paint particles in waste air from, e.g. spray booths. However, they have significantly shorter service lifetimes for the separation of sticky paint sprays than for other dust types and require high maintenance efforts when used with these substances.

Achieved environmental benefits: Efficiencies for the removal of particles are in the range of 85 – 95 %. Labyrinth filters commonly achieve removal efficiencies of 85 %, paper filters 90 % and 'paintstop-filters' 95 %.

Cross-media effects: Filtering requires energy and generates waste and noise. The risk of fire is higher compared to wet separation techniques.

Operational data: With the spraying of paint, normally an overspray arises which may need to be captured and treated. Dry filters might be applied as a secondary separation step after the venturi system described in Section 20.11.3.5. The dry filter might serve as pretreatment for the solvent concentration (see Section 20.11.3.2). The remaining particle content depends on whether the cleaned waste gas of the spray booth is directly supplied to a waste gas cleaning installation. For a post-separation of paint particles after venture washers, additional paint particle separators can become necessary. In particular, if a recirculating airflow aimed at solvent recovery exists or a protection of subsequent installation parts (rotor, heat exchanger) is required, secondary separation methods are applied.

Applicability: Dry filters are increasingly applied in wood and furniture painting. They are commonly applied in the manufacture of abrasives. Also, widely used in conjunction with associated activities, such as sanding, cutting and sawing, etc.

This technique is not commonly applied in large vehicle paintshops in the automotive industry.

Economics: Investment costs are low, but operational costs are high.

Driving forces for implementation: Workplace health and safety.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [63, Vito, 2003] [68, ACEA, 2004] [12, UBA Germany, 2002] [67, EIPPCB, 2003, 76, TWG, 2004, 128, TWG, 2005]

20.11.3.7 Electrostatic filter (precipitator)

Description: Electrostatic filters (precipitators) are used to eliminate particles from the waste gas. Particles are charged within an electrostatic field and migrate towards condensation plates. The particles are removed: in wet systems, this is by washing with water.

Achieved environmental benefits: No data submitted.

Cross-media effects: Noise levels might increase. With wet electrostatic filters, there is the production of a wet waste, and waste water which may require treatment.

Operational data: With the spraying of paint, an overspray normally arises which might need to be captured and treated. Electrostatic filters are normally applied as a secondary separation step after the venturi system described in Section 20.11.3.5. The electrostatic filter might serve as pretreatment for the solvent concentration (see Section 20.11.3.2).

Applicability: No data submitted on actual use.

It is not applied in the automotive industry, in the manufacturing of abrasive or in the coating of ship and aircraft components.

Economics: In general, there is a higher installation cost associated with electrostatic precipitators than for dry filters, but the operating cost is lower.

Installation/investment cost: EUR 60 to 300 for systems of 30000 to 200000 Nm³/h. Operational costs: EUR 0.05 to 0.1 per 1000 Nm³/h for systems bigger than 50000 Nm³/h. Additional costs and environmental impacts for removing the sludge, energy costs (0.17 - 0.35 kWh/Nm³) for the basic installation, and the ventilator fan consumes an additional 0.17 - 0.5 kWh/Nm³ published in 2004).

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [67, EIPPCB, 2003, 68, ACEA, 2004] [76, TWG, 2004] [146, CEI-BOIS, 2006] [145, VITO, 2004]

20.11.3.8 Scrubber

Description: Paint particles in the waste gas are separated in airflowed scrubber collectors by intensive mixing of waste air with water. Water scrubbers may also be used to remove dust and other contaminants such as NO_x (see Section 20.11.9.3).

In the automobile industry, a special type of scrubber called a venturi scrubber (based on the venturi principle) is used to obtain an excellent mixture of the particulates with the water. It is used without any other pretreatment for the separation of paint overspray from effluent air.

Achieved environmental benefits: Reduced particulate emissions to air. In an airflowed scrubber, the paint particles are separated to around 90 % (after the primary separation described in Section 20.11.3.5).

Cross-media effects: Filtering requires energy and might generate noise, waste and waste water.

Operational data: With the spraying of paint, normally an overspray arises which might need to be captured and treated. Scrubbers are normally applied as a secondary separation step after the venturi system described in Section 20.11.3.5. The scrubber might subsequently serve as a pretreatment for increasing the solvent concentration (see Section 20.11.3.2). The remaining particle content depends on whether the cleaned waste gas of the spray booth is directly supplied to a waste gas cleaning installation. For post-separation of paint particles after venturi washers, additional paint particle separators can become necessary. In particular, if a circulating airflow aimed at solvent recovery exists or a protection of subsequent installation parts (rotor, heat exchanger) is required, secondary separation methods are applied.

Applicability: See Description, above.

Not applied in the winding wire industry.

Economics: Capital cost: EUR 2000 up to 30000 per 1000Nm³/h (scrubber with recirculation pump); cost is strongly dependent on the application, e.g. type of impurities in the gases.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005] [145, VITO, 2004]

20.11.4 Oxidation

Annex 24.9 provides a summary of waste gas treatment techniques (oxidation, adsorption, condensation and biological treatment) and their applicability. A comparison of the removal efficiencies of the most widely used techniques is given for different types of solvents at different inlet concentrations [148, TWG, 2006].

When natural gas is used as additional fuel, emissions of unburnt CH₄ can occur that are normally below 50 mg/m³.

If the solvent mixture contains elements other than H, C or O, hazardous, toxic and/or corrosive by-products may be formed. Solvents containing halogenated compounds form aggressive flue-gases. When these flue-gases contain nitrogen, they form NO_x and when they contain sulphur, they form SO_x. Oxidation of ducting and vents may occur.

20.11.4.1 Fuel supplement in process heating

Description: The waste gas to be treated is sent to an existing heater (e.g. boiler) as combustion air and complementary fuel.

Achieved environmental benefits: Solvent emissions are treated and the emissions of the boiler will not change because solvents are used instead of fuel.

Cross-media effects: No data submitted.

Operational data: The prerequisite for using an existing boiler is that it must be operational and able to receive vapours at all times when vapours are produced. Boilers usually work continuously, but the solvent load can be discontinuous. Low levels can be achieved for halogenated solvents where required; however, lower VOC levels may require additional fuel.

The concentration range of the inlet gas is only limited because of the maximum LEL values and the airflow range that can be treated depends on the capacity of the existing boiler.

This technique can treat all types of solvents and solvent mixtures and no specific pre- or post-treatment is needed; however, it is common practice to apply a proper CO control.

Applicability: This technique is easy to apply and is most appropriate for existing boilers with sufficient capacity and for production processes with a high energy demand.

Not applied to halogenated solvents containing sulphur or nitrogen or other hazardous solvents (See Cross-media effects, above).

It is not applied in the winding wire industry, in vehicle paintshops, in publication gravure (which uses solvent recovery), heatset or flexible packaging (no existing heaters of sufficient capacity).

Economics: The cost increases with the distance of the process to the boiler; however, in general this is a low cost technique.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [60, ESIG, 2000] [75, Jansen, 2005] [76, TWG, 2004] [128, TWG, 2005]

20.11.4.2 Thermal oxidation

Description: Oxidation of VOCs in a simple oxidation chamber by chemical reaction with oxygen from the exhaust air.

Achieved environmental benefits: A removal efficiency of >99 % (24 hours average) can be achieved; however, this depends on the inlet concentration. Commonly achieved concentration levels after treatment are in the range of 20 – 50 mg C/m³, and even lower levels can be achieved. Lower levels can also be achieved for halogenated solvents where required; however, lower VOC levels may require additional fuel.

Maximum levels for phenol and formaldehyde of below 20 mg/m³ are reported in abrasive manufacturing.

Also used for the abatement of odour.

Cross-media effects: A significant amount of additional fuel is needed to achieve the required burning temperatures: the energy consumption is higher than recuperative and regenerative oxidation. Emissions of NO_x , CO and CO_2 occur; the maximum level for each of these substances is normally below 200 mg/m^3 .

Noise levels may increase.

Operational data: Solvents in the waste gas are normally destroyed by temperatures of $680 - 750 \text{ }^\circ\text{C}$ and this ensures an almost complete combustion of the solvent load. The oxidisers normally operate with parameters adjusted for balanced minimum total emissions.

The concentration range of the inlet gas is only limited because of the maximum LEL values. The start up time of the system is only five minutes. There are no limits to the inlet temperature.

The oxidiser should operate continuously when it is fitted with a lining system, because the lining system has to be kept warm. The amount of fuel required to keep it warm during idling times is an important consideration for systems not operating continuously.

The dust concentration should be $<3 \text{ mg/Nm}^3$, but can be higher when incinerating organic dust particles.

The units can be integrated in the drier or applied as a central system for several driers.

After thermal oxidation, cleaned gas concentrations of 10 mg C/m^3 are reached in the automotive industry.

Applicability: Especially suitable for high VOC concentrations ($5 - 16 \text{ g/Nm}^3$).

Small to medium flowrates $<25000 \text{ Nm}^3/\text{h}$ can be treated. This technique is most economically applied to flowrates in the range of $5 - 1000 \text{ Nm}^3/\text{h}$ and is most appropriate for batch processes, e.g. for some hours per day or week or some weeks a year. It can treat all types of solvents and solvent mixtures and no specific pre- or post-treatment is needed.

It is commonly applied in the manufacturing of abrasives especially in situations where recovered heat cannot be utilised. The technique is also applied in the automotive industry and in the coating of trucks and commercial vehicles. It was also commonly applied in the heatset printing processes; however, nowadays regenerative incineration is preferred instead.

This technique has not been applied in the winding wire industry.

Economics: As an investment, this technique is the lowest cost type oxidiser. However, operational costs are high because a lot of additional fuel is needed. Large capital and increased plant running costs.

Driving forces for implementation: Control of odour nuisance.

Example plants: No data submitted.

Reference literature: [35, Aminimal, et al., 2002] [12, UBA Germany, 2002] [54, BMLFUW Austria, 2003] [13, DFIU and IFARE, 2002] [60, ESIG, 2000] [75, Jansen, 2005] [76, TWG, 2004] [128, TWG, 2005] [145, VITO, 2004]

20.11.4.3 Recuperative thermal oxidation

Description: The principle of destroying the solvents by burning is the same as described in Section 20.11.4.2. However, energy is saved because the waste hot air is utilised for heating the incoming cold solvent-laden air or routed back to the drying process. Although heat exchangers are applied, additional fuel might still be necessary.

Achieved environmental benefits: Close to 100 % destruction of VOCs can be achieved and commonly achieved emission levels are $<20 \text{ mg C/m}^3$ (24 hours average) or $<30 \text{ mg C/m}^3$ (hourly average). Compared to thermal oxidation, 50 – 70 % energy can be recuperated as total heat in the heat exchanger.

Typical achieved emission levels in the coating and printing of metal packaging are in the range of $20 - 50 \text{ mg C/Nm}^3$. In this sector, and specifically in drum manufacturing, a commonly achieved removal efficiency of 95 % with a maximum of 97 % is reported. Cleaned gas concentrations of 10 mg C/m^3 are reached in car manufacturing processes. In the coil coating industry, typically achieved emissions levels are in the range $20 - 50 \text{ mg C/m}^3$.

Cross-media effects: NO_x , CO_2 and CO emissions occur. Noise levels might increase.

Although this technique uses less energy than a thermal oxidiser (see Section 20.11.4.2), it still consumes a considerable amount of energy if the inlet VOC concentration is below the autothermal limit, which is about $2 - 3 \text{ g/m}^3$. The burner always needs a pilot flame (consuming energy).

Operational data: The concentration range of the inlet gas is only limited because of the maximum LEL values and with low VOC levels more fuel has to be added. The maximum inlet temperature is $400 \text{ }^\circ\text{C}$. Temperature control is needed. The VOC concentration after treatment can also be controlled continuously.

The energy released by the oxidiser comes from both gas and solvent burning. Because of the high temperature of incinerated fumes, a large part of the energy can be recovered in exchangers for use in:

- preheating of the fumes before incineration at around $500 \text{ }^\circ\text{C}$ (to reduce the gas consumption in the incinerator)
- preheating of the air injection in the oven at a maximum of $400 \text{ }^\circ\text{C}$, especially in the case of ‘hot air convection’ ovens (to reduce or eliminate the gas consumption in the ovens)
- water heating (for process and/or sanitary use).

In the case of technologies such as ‘infrared’ or ‘induction’ drying, there is not enough data available to determine the effect on prime energy requirements. However, it is known that the same opportunities for energy recovery do not exist.

Lower levels can be achieved for halogenated solvents where required.

Applicability: Small to medium flowrates of $<25000 \text{ Nm}^3/\text{h}$ can be treated. This technique is most economically applied to flowrates in the range of $1000 - 15000 \text{ Nm}^3/\text{h}$ and it is most appropriate for continuous processes and waste gas with a solvent concentration of $6 - 12 \text{ g/m}^3$. It can treat all types of solvents and solvent mixtures and no specific pre- or post-treatment is needed. This technique can operate both continuously and discontinuously because it has a relatively short start up time of less than one hour.

This technique is commonly applied in the:

- printing industry, always with additional fuel
- coil coating industry
- automotive industry
- drum manufacturing industry
- metal packaging industry. However, high VOC concentrations can cause quality problems for colour coatings, e.g. whites can be discoloured.

It is only sporadically applied in the coating of ships and not applied in the winding wire industry.

Economics: If the operating temperatures are $>700\text{ }^{\circ}\text{C}$, temperature-induced material fatigue can reduce the lifetime of the heat exchangers to 8 - 12 years. Investment costs are between EUR 150000 and 250000 for installations with $10000\text{ m}^3/\text{h}$ throughput.

Driving forces for implementation: Recuperative thermal oxidation is applied for energy reasons, i.e. Kyoto agreement.

Example plants: No data submitted.

Reference literature: [35, Aminal, et al., 2002] [12, UBA Germany, 2002] [13, DFIU and IFARE, 2002] [60, ESIG, 2000] [63, Vito, 2003] [75, Jansen, 2005] [76, TWG, 2004] [79, SEFEL, 2004] [58, ECCA, 2004] [128, TWG, 2005]

20.11.4.4 Regenerative thermal oxidation – dual bed

Description: This oxidiser is a dual bed system in which each bed is filled with ceramic packaging. One bed is used to preheat the gas stream to be treated; the other is heated by the flue-gases that arise from the oxidation. The flow is reversed on a regular basis to switch the preheat and the heat recovery beds. Some unburned VOCs are emitted during switch over.

Regenerative oxidisers that receive an inlet gas with a VOC concentration above the autothermal level are called ‘flameless oxidisers’. Flameless operation can also be reached by using a direct fuel injection (only with gaseous fuel) and a sufficient concentration of oxygen in the crude gas.

Achieved environmental benefits: This system can achieve emission levels in the range of $10 - 20\text{ mg C/Nm}^3$ (24 hour average) and removal efficiencies in the range of 95 – 99.5 %. The generated surplus energy may be re-used and can result in significant overall energy savings.

Cleaned gas concentrations of 10 mg C/Nm^3 are reached in the automotive industry. In flexo and packaging gravure, levels in the range of $10 - 20\text{ mg C/Nm}^3$ can be achieved. At this level the residual emission is $<0.5\%$ and the removal efficiency is logically $>99.5\%$.

In abrasive manufacturing, the regenerative oxidiser can typically work autothermally with solvent concentrations above $2 - 3\text{ g/m}^3$. At waste air volumes of up to $66000\text{ Nm}^3/\text{h}$, the installations achieve emission values of $<20\text{ mg C/Nm}^3$ (half hourly mean value). Maximum levels for phenol and formaldehyde are below 20 mg/Nm^3 .

Cross-media effects: None if compared to conventional thermal oxidisers. Emission levels of CO , CO_2 and NO_x are normally below 100 mg/m^3 . The CH_4 levels are normally below 50 mg/m^3 .

Incineration requires energy (gas), mainly during the start-up operations.

Low NO_x formation can be achieved by applying low combustion temperatures in the range of 750 - 820 °C, or even below 750 °C. Typical achieved emission concentration is <50 mg/m³.

Noise levels might increase.

Operational data: When the solvent concentration in the air to be treated is in the range of 1.5 – 3 g/m³, the system is autothermal and no additional fuel needs to be added. The thermal energy of the outgoing air of the waste gas treatment system is utilised for the warming up of the crude gas by alternating the heat transfer beds. With concentrations of 4 – 6 g/m³ the excess heat can be recovered and, for example, used in production processes. To achieve these values, the concentration of the drier airflow may require concentration as described in Section 20.11.3.1.

The system is sensitive to the presence of dust in the feed because it will plug the ceramic packaging, however, some level of combustible dust can be accepted. The temperature is controlled and after treatment, the VOC concentration can also be controlled continuously.

In the average flexo and packaging gravure printing plant, the amount of excess heat is greater than can be utilised. The main heat consumers are the driers on the presses. Oxidising one gram of solvents can heat one m³ of air by approximately 25 °C. There are approximately 3 to 4 g/m³ available: enough energy to heat each m³ by 75 – 100 °C. The required temperature rise for the drying air is, however, on average only some 30 °C. This means that, for more than half the recovered heat, other possibilities have to be found. Sometimes the surplus energy is sold to neighbouring plants. The recovered heat then needs to be transported. For this purpose, steam or thermal oil is suitable. Most driers however operate with an open gas flame or electricity. Using the excess heat from the oxidiser for the driers would imply replacement of all the driers: an investment that could never be recovered with the decrease of the energy costs alone.

In the coating and printing of DWI, the excess heat may be used for certain operations, e.g. in the cleaning process and for heating the incoming air to the driers.

In coil coating, the fumes are oxidised in twin chambers which are preheated alternately. The chambers are preheated by the fumes from the other chamber in operation. A gas burner is used for starting the installation but normally not in steady conditions. It can process a very low VOC concentration in the fumes. The energy released by the oxidation only comes from the burning solvent. Due to the energy efficiency of the regenerative oxidiser, exhaust temperatures are low, reducing the opportunity for energy recovery. Because of the process, the main part of the energy is recovered for the oxidation itself, the rest of the energy can be recovered in exchangers for preheating the air injection in the oven (at a low temperature) and for water heating (for process and/or sanitary use).

Applicability: This technique is commonly applied to an airflow in the range of >1500 - 70000 Nm³/h for one dual bed unit. For flows >70000 Nm³/h, multibed systems are more economic. The maximum inlet temperature is 400 °C. The maximum VOC inlet concentration will be limited by a 25 % LEL value for safety reasons, typically 12 g/m³ (for solvents such as toluene, ethylacetate or ethanol with typical LEL values of about 40 or 50 g/m³). The safety margin is necessary to prevent explosions in the ceramic beds.

However, to achieve an emission of <20 mg C/Nm³ (removal efficiency ~ 98.75 %), a VOC inlet concentration of <1.5 g/m³ is needed.

This technique can treat all types of solvents and solvent mixtures. However, with sticky substances, a regular 'burn-out' is required. With silicon hydrocarbons, regular cleaning is needed and therefore should be avoided.

This technique is most commonly applied to continuous processes. When it is applied to discontinuous processes it is normally on stand-by mode and at a certain temperature. The start up time is one to four hours.

Regenerative oxidisers of this type are commonly applied in:

- flexo and packaging gravure printing plants
- heatset offset printing plants
- the manufacturing of abrasives
- the coating and printing of metal packaging (except in drum manufacturing)
- coil coating
- the automotive industry.

This technique is only occasionally applied in shipyards and is not applied in the winding wire industry.

Economics: The investment for a regenerative oxidiser is higher than that of a recuperative oxidiser. The investment and operational costs of end-of-pipe abatement equipment are largely determined by the maximum airflow that needs to be treated. The investment can be estimated as: minimum EUR 200000 for a capacity of up to 10000 m³/h, plus EUR 10 - 15 for each additional m³/h. This includes a simple centralised collection duct, but not the cost for optimisation of the airflow (see Section 20.11.3.1). The fuel demand is low, so the electric fan mainly determines the running costs. The operating costs are some EUR 15000 per year for treating 10000 m³/h.

The recovery and transportation of excess heat requires additional investment. This investment is such that it can only be recovered with lower energy costs if all the excess heat can actually be used and if no additional investments are necessary to be able to use this heat.

Driving forces for implementation: No data submitted.

Example plants: AMCOR Flexibles in Gent, Belgium. HFP Bandstahl GmbH & Co KG in Bad Salzungen, Germany.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [35, Aminal, et al., 2002] [12, UBA Germany, 2002] [13, DFIU and IFARE, 2002] [60, ESIG, 2000] [63, Vito, 2003] [75, Jansen, 2005] [76, TWG, 2004] [79, SEFEL, 2004] [58, ECCA, 2004] [128, TWG, 2005]

20.11.4.5 Regenerative thermal oxidation – three bed or rotating air distributor

Description: See Section 20.11.4.4 for the description of the technique, however, instead of two beds (dual bed), three beds are now installed. The third bed is called the ‘purge bed’. Multibed systems (five or seven beds) are also available. Instead of multibed systems, one-vessel systems with a rotating air distributor are available. These one-vessel systems are composed of several zones (beds or pie wedges).

Achieved environmental benefits: A three bed system or a rotating air distributor can achieve emission levels in the range of 10 – 20 mg C/Nm³ (24 hour average) and removal efficiencies in the range of 98 - 99.9 % depending on inlet concentrations and operation conditions. This can be achieved because, compared to a dual bed system, no untreated VOC emissions occur due to switching the direction of the gas flow. Compared to a conventional oxidiser, a significant energy saving is achieved. The generated surplus energy may be re-used.

Cross-media effects: Compared to a conventional oxidiser, energy is needed to power larger fans needed to drive the exhaust air through the heat exchangers. Emissions levels of CO, CO₂ and NO_x are normally below 100 mg/m³, and of CH₄ normally below 50 mg/m³. Noise levels might increase.

Operational data: This technique is commonly applied for airflows in the range of >1500 - 120000Nm³/h for one three bed unit. For flows >70000 Nm³/h, multibed systems are more economic. The maximum inlet temperature is 400 °C. The maximum VOC inlet concentration will be limited by the maximum LEL value, theoretically 12 g/m³.

The system works autothermally with VOC concentrations in the range of 1.5 – 3 g/m³, but the system is also applicable with concentrations of >3 g/m³. With concentrations above the autothermal point, excess heat can be recovered and re-used.

This technique is most commonly applied to continuous processes. When it is applied to discontinuous processes, it is normally on stand-by mode and at a certain temperature. The start up time is one to four hours.

It can treat all types of solvents and solvent mixtures; however, with sticky substances a regular 'burn-out' is required. With silicon hydrocarbons, a regular cleaning is needed and, therefore, should be avoided.

The system is sensitive to the presence of dust in the feed; however, some level of combustible dust can be accepted.

Applicability: Regenerative oxidisers of this type are commonly applied in:

- flexo and packaging gravure printing plants
- heatset offset printing plants
- the manufacturing of abrasives
- the coating and printing of metal packaging
- coil coating
- the automotive industry.

The technique is only occasionally applied in shipyards and is not applied in the winding wire industry.

Economics: Compared to the dual bed system, the additional investment is about 25 %.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [60, ESIG, 2000] [63, Vito, 2003] [75, Jansen, 2005] [76, TWG, 2004] [128, TWG, 2005]

20.11.4.6 Catalytic oxidation

Description: Oxidation of VOCs is made in the presence of a catalyst (usually platinum). Because of the catalyser, the required temperatures in the oxidation process can be reduced to 250 - 400 °C. However, in winding wire manufacturing, the temperature in the oxidation process is in the range of 500 – 750 °C. Exhaust heat can be recovered and recuperative or regenerative types of heat exchangers can be applied.

Achieved environmental benefits: Removal efficiencies of 95 - 99 % are achieved. The typically achieved concentration range is 10 – 50 mg C/Nm³. Compared to thermal oxidation (see Section 20.11.4.2), less additional fuel is needed. Applying a catalyser in combination with recuperation of the exhaust heat requires less energy than recuperative oxidation without a catalyser, see Section 20.11.4.3.

Typically achieved emission levels in winding wire production are 5 g VOC/kg product for wires with an average diameter of above 0.10 mm, and 10 g VOC/kg product for wires with an average diameter of below 0.10 mm. Legal emission limit values of 20 mg C/m³ are reported to be met.

In the printing industry, the above-mentioned removal efficiencies can be achieved under the following condition: a flow of 1000 – 30000 Nm³/h or higher and a VOC concentration of >1 - 2 g/Nm³. Typical levels in heatset printing (although rarely used currently) and in the coil coating industry are in the range 20 – 50 mgC/Nm³.

Cross-media effects: Catalysts must be replaced/recharged periodically. Additional fuel is needed; however, less compared to thermal oxidation. Noise levels might increase.

Typically achieved emission levels of CO and NO_x are <50 mg/m³.

In the winding wire industry, reported emission levels for NO_x are about 10 g/kg product for wires with a diameter of an average above 0.10 mm, and 12.5 g/kg product for wires with a diameter of an average below 0.10 mm (see Section 20.11.9). However, this is dependent on the quantity of N-containing solvent in use.

Operational data: VOC concentrations of up to 5 g/Nm³ can be treated. This technique can be applied for airflows in the range of 10 – 30000 Nm³/h. However, it is most suitable for discontinuous airflows of up to 10000 Nm³/h.

At inlet temperatures above 400 °C, no preheating is required to reach the start temperature of the catalyst. Normally, oil is not used as a fuel, due to the sulphur content and related toxicity to the catalyst.

This technique can be operated continuously or discontinuously, however, when continuously operated, the lifetime of the catalyst is limited to about 15000 – 25000 hours.

All types of solvents and solvent mixtures can be treated. However, the presence of contaminants which could poison the catalyst must be checked. If the inlet concentration is too high, it may lead to overheating and damage to the catalyst. This technique is also very sensitive to the presence of dust or droplets in the feed and therefore pretreatment of the airflow is required. It is also sensitive to changes in the inlet concentration. Halogenated or silicon hydrocarbons and silicons may also cause problems.

Applicability: This technique, including the recuperation of the exhaust heat, is commonly applied in the winding wire industry. It is rarely used in the coil coating industry. The automotive industry has tested this technique, but due to problems with blinding, it has not been generally applied.

Catalytic oxidation is used in a limited number of cases in the printing industry, and only in heatset printing processes. Nowadays, in these situations, regenerative oxidation is preferred to catalytic oxidation.

Economics: The usual cost issue of this technique is the catalyst that needs to be exchanged at the end of its lifetime and this can only be checked by regular measurements. However, in general the costs are comparable to those for a regenerative oxidiser.

The prices below are representative for the Flemish wood industry and based on realistic theoretical working parameters. Equipment suppliers that provided the information stressed that it is impossible to extrapolate the costs of the examples on the basis of flows and VOC loads, so the numbers are purely indicative and valid at the time estimations were made (November 2004).

Price quoted by supplier A:

- 1) Flow: 15000 Nm³/h
 - VOC inlet concentration: 1500 mg/Nm³, VOC emission: <20 mg/Nm³
 - Price: EUR 325000
- 2) Flow: 59000 Nm³/h
 - VOC inlet concentration: 300 mg/Nm³, VOC emission: <50 mg/Nm³
 - Price: EUR 628000 to 770000.

Price quoted by supplier B:

- 1) Maximum flow: 15000 Nm³/h
 - VOC inlet concentration: 1500 mg/Nm³, VOC emission: <90 mg/Nm³
 - Price: EUR 300000.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [35, Aminal, et al., 2002] [12, UBA Germany, 2002] [58, ECCA, 2004] [60, ESIG, 2000] [63, Vito, 2003] [64, EWWG, 2004] [75, Jansen, 2005] [76, TWG, 2004] [128, TWG, 2005] [146, CEI-BOIS, 2006]

20.11.4.7 UV oxidation

Description: Solvent-laden air is routed through a series of UV lamps. VOC molecules are fragmented by the short wavelength energy and ozone is formed from the oxygen. The ozone reacts with the fragmented VOC molecules which lead it to partly oxidise. The subsequent unit contains a catalytic agent (mainly TiO₂), the oxidation of the ozone and VOC molecules continues and the excess ozone is destroyed.

Achieved environmental benefits: For a waste gas with a VOC concentration of 0.5 g/Nm³, the removal efficiency is about 95 %. VOC concentrations in the treated waste gas of 25 - 50 mg/Nm³ are achievable.

Cross-media effects: Energy consumption from the lamps and exhaust ventilator together are 50 kWh per 1000 m³ waste gas treated. The lamps emit O₃ (which is destroyed), and contain mercury which has to be disposed of with suitable precautions. Noise levels might increase.

Operational data: The temperature of the waste gas should not exceed 60 °C and the humidity should be less than 85 %.

The technique was originally developed to achieve odour reduction and for the destruction of toxic substances. However, increasingly the technique is used for the complete destruction of VOCs, especially in waste gases containing low concentrations (on average <0.5 g/Nm³ and occasionally peaks of <1.0 g/Nm³).

Applicability: Applicable to the wood and furniture painting industry when applying solvent-based paints. However, the technique is currently not applied in this industry.

Not applied in the vehicle paintshops.

The technique is currently applied in the metallurgical industry and in electronics to treat VOC emissions from spray booths where solvent-based paints are applied.

Economics: In an installation that can treat several 10000 m³/h, investment costs are about EUR 5000 – 7000 per 1000 m³/h waste gas. After 8000 hours the UV lamps need to be replaced; costs are about EUR 0.06 – 0.2 per 1000 m³/h waste gas. Energy costs are about EUR 4 per 1000 m³/h waste gas. The operational costs (including lamps, energy and catalyser) are in the range EUR 3 – 25 per kilo VOC removed.

In the specific situations where this technique is used, UV oxidation has been reported to be cheaper compared to adsorption to activated carbon or any type of thermal oxidation. However, no data exist to confirm this applies to IPPC size installations.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [35, Aminal, et al., 2002] [13, DFIU and IFARE, 2002] [60, ESIG, 2000] [63, Vito, 2003] [76, TWG, 2004] [128, TWG, 2005].

20.11.5 Condensation

Annex 24.9 provides a summary of waste gas treatment techniques (oxidation, adsorption, condensation and biological treatment) and their applicability. A comparison of the removal efficiencies of the most widely used techniques is given for different types of solvents at different inlet concentrations [148, TWG, 2006].

The VOC rich gas is cooled to the point where a significant portion of the vapours condense. Heavy, low volatile solvents can be recovered at room temperature; highly volatile solvents need to be cooled well below 0° C to recover about 95 % or more. Cooling this low has the important disadvantages of high energy costs and water freezing the cooling elements. Cooling just above 0° C avoids ice, but condenses water, and this may end up in the recovered solvent, necessitating expensive dehydration.

Typically in condensation processes, the solvents can be re-used. The different condensation techniques are discussed in the following sections.

20.11.5.1 Direct cooling

Description: The VOC rich gas is cooled by direct contact with a cold stream in a scrubber. The technique cool sorption combines the effects of absorption and direct contact condensation.

Achieved environmental benefits: VOCs can be recovered and possibly re-used. The removal efficiency is higher on concentrated streams.

Cross-media effects: Energy is required for cooling.

Operational data: This technique applied alone may not meet some of the statutory requirements for concentration levels in waste gas.

Applicability: Cool sorption is often used as a first clean up step for waste gases.

This technique is not applied in printing processes, the winding wire industry or in vehicle paintshops.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [60, ESIG, 2000] [76, TWG, 2004] [128, TWG, 2005]

20.11.5.2 Indirect cooling

Description: The VOC rich gas is cooled in a heat exchanger using cooling water or another medium at temperatures above 0 °C.

Achieved environmental benefits: VOCs can be recovered and possibly re-used. The removal efficiency is higher on concentrated streams; however in general, it is a low efficiency process.

Cross-media effects: Energy is required for cooling. Waste water will arise which may need to be treated before discharge.

Operational data: This process may be useful on concentrated streams with low volatile solvents; however, it is usually combined with another treatment.

Applicability: Condensation by applying temperatures above 0 °C is only applicable to low volatile solvents. This technique is applied in heatset offset printing processes, where inks based on low volatile solvents are applied.

A serious drawback of this technique when used in heatset offset printing processes is that IPA is not removed from the waste gas. Plants using >25 tonnes solvents per year are therefore facing difficulties in meeting the emission limit of 20 mg C/Nm³ (set in the Solvent Emissions Directive). The offensive smell of the heatset waste gases is not completely eliminated.

This technique is not applied in the winding wire industry or in vehicle paintshops.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [60, ESIG, 2000] [76, TWG, 2004] [128, TWG, 2005]

20.11.5.3 Refrigeration

Description: The VOC rich gas is cooled in a heat exchanger using a refrigerated medium at temperatures below 0 °C. Usually a two condenser system is used alternately in condensation and in defrosting mode.

Achieved environmental benefits: VOCs can be recovered and possibly re-used. The removal efficiency is higher on concentrated streams.

Cross-media effects: Energy is required for cooling. Noise levels might increase.

Operational data: Humidity in the waste gas will cause icing to occur, requiring de-icing at regular intervals. Usually a condensation step at temperatures above 0 °C is used upstream to reduce the water content.

Applicability: Gases with high water vapour contents are less suitable because of the increased icing effect. This process may be useful on streams with high volatile solvents. This technique is applied in adhesive tape manufacturing, in new and existing plants.

This technique works best on waste gases with a very high solvent concentration of several 100 g/m³. For these types of waste gases, closed drying systems using inert gas (N₂) are required because of the LEL value, which is about 20 g/m³ at 40 °C. However, closed drying systems using inert gas can only be successfully used where the drier does not need be opened too often. After testing, it showed that it was for this reason that the technique is not applicable in flexible packaging printing, where the job changes several times per day and the driers need to be opened too frequently.

This technique is not applied in other printing processes or in vehicle paintshops.

Economics: The capital costs of an adhesive tape manufacturing example plant with a capacity of 400 kg/hr for the condensation installation were about EUR 0.88 million in 1992. Operating costs for adsorption and condensation together were about EUR 0.51 million/yr. Variable costs were about EUR 1.12 million/yr and fixed costs about EUR 1.38 million/yr.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [60, ESIG, 2000] [76, TWG, 2004] [128, TWG, 2005]

20.11.5.4 Cryogenic treatment

Description: The highly volatile solvent-rich gas is exposed to very low temperatures, usually by using liquid nitrogen.

Achieved environmental benefits: Theoretically, very high removal efficiencies can be achieved if the temperatures are low enough. However, practically, the temperatures will not be lower than -95 °C and at this temperature, low concentration levels cannot be achieved.

Removal efficiencies of 99 % or more can be achieved resulting in concentrations in the treated gas of 1 – 5 g/Nm³. This can, for example, be achieved by treating a gas flow of 0 – 1000 Nm³/h with an ingoing VOC concentration in the range of 200 – 1000 g/Nm³. The recovered VOCs can be re-used.

Cross-media effects: Energy is required for cooling the liquid nitrogen. Noise levels might increase.

Operational data: The vaporised nitrogen can be used in the plant for blanketing purposes. If post-treatment is necessary, often an adsorption technique is applied.

Applicability: This technique is mainly applied to relatively small gas flows (up to 50 m³/h) and on batch emissions. Continuous systems with a capacity of 250 m³/h or more are less frequently applied.

This technique is applied for the treatment of waste gases from paint application and driers. However, it is not applied in wood and furniture painting, the winding wire industry, the coil coating industry, printing processes or vehicle paintshops.

Gases with a high water vapour content are less suitable because this will lead to the formation of ice.

Economics: Investment costs are about EUR 500000 per 1000 Nm³/h waste gas, excluding the storage facilities for nitrogen.

Energy costs are negligible. Costs for nitrogen use are about EUR 0.12 per kilo nitrogen assuming a capacity of 1000 Nm³/h waste gas treated.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [60, ESIG, 2000] [63, Vito, 2003] [76, TWG, 2004] [128, TWG, 2005]

20.11.5.5 Condensation above freezing point

Description: Condensation above freezing point requires very high solvent concentrations (preferably several 100 g/m³). Only a part of the solvent is condensed. The air with the remainder of the solvent cannot be emitted, but is sent back to the drying process. This in turn requires (for safety reasons) a closed loop of inert gas, and not ordinary air in which the solvent concentration is always at a very high level (for example, inlet 100 g/m², outlet 200 g/m²).

Achieved environmental benefits: Solvent recovery and low emissions from a sealed system.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [128, TWG, 2005]

20.11.6 Adsorption

Annex 24.9 provides a summary of waste gas treatment techniques (oxidation, adsorption, condensation and biological treatment) and their applicability. A comparison of the removal efficiencies of the most widely used techniques is given for different types of solvents at different inlet concentrations [148, TWG, 2006].

20.11.6.1 Adsorption using activated carbon or zeolites

Description: The technique is used to adsorb VOCs on the surface of activated carbon or zeolite. It is also commonly applied as a ‘concentrating up’ pretreatment to achieve a more concentrated waste stream that can be incinerated more economically.

During operation of the activated carbon (or zeolite) bed in the adsorption column or rotating adsorption wheel, more and more solvent will build up in the bed. At a certain time, the efficiency of the adsorption bed will decrease and the outlet concentration will start to increase. At this point, the adsorption needs to be reactivated and the solvents may be recovered or destroyed. Desorption is often performed by sweeping with a hot gas stream (nitrogen, air, or steam), but can also be done by vacuum (pressure swing adsorption). In cases where the waste gas flow is small (e.g. to solvent washing machines) the adsorbent may be regenerated off-site (see Section 20.13.7.2).

After a longer period, the adsorbent cannot be fully reactivated by removing the solvent, and requires a different type of reactivation (usually by heat treatment). This can be done on-site or off-site (see Section 20.13.7.1). If activated carbon or other adsorbents are used which cannot be regenerated, the activated carbon is disposed of (see Section 20.13.7.3).

Continuous monitoring of the outlet concentration is needed to check if the adsorption efficiency of the activated carbon is still sufficient (see Section 20.11.6.2).

Beds can be used in parallel and/or in sequence. In the case of a 2-bed system, one is in adsorption mode and the other in desorption mode, or in the case of a 3-bed system, two are used in adsorption mode and one in desorption mode.

Achieved environmental benefits: Adsorbers can achieve a removal efficiency of >99 %; however, this is related to the inlet concentration. For example, with an inlet concentration of >7 g/m³, removal efficiencies of >99 % can be achieved. VOC concentrations of <50 mg C/m³ (24 hour average) can be achieved with levels of <20 mg C/m³ being possible.

In the automotive industry, adsorption materials such as carbon fibre paper, zeolites and activated carbon are used. A transmission of the solvent load into an external hot-air stream in the ratio of 1:6 to 1:30 (depending upon raw gas concentration) is achieved.

In adhesive tape manufacturing, emission concentrations of 70 – 90 mg/m³ are achieved in the cleaned gas. Lower concentrations can be achieved; however, only by a reduction in adsorption periods and are, hence, correlated to an increased steam production. The recovery process (see Section 20.13.7.1) normally uses 2 to 3 kg steam per kg recovered solvent to achieve emission concentrations of 70 – 90 mg/m³.

Desorption and reactivation reduce carbon consumption. The condensed steam can be re-used for cleaning the adsorber and as boiler water. The drying air can also be recycled after the desorption process.

Cross-media effects: In processes for the recovery of the solvents, steam is used and thus water and energy are used. The condensed steam contains traces of solvents. Noise levels might increase. Waste water arises from recovering the activated carbon.

Finding an optimum adsorption/desorption cycle means finding a balance between an acceptable emission concentration and the resources needed (i.e. energy, absorbent which needs replacing periodically, water), and the waste water generated for cleaning the carbon bed when using steam.

Requires a careful balance of the gas flows as unpredictable exothermic reactions are possible (see Operational data, below).

Operational data: Adsorption is not applicable to reactive compounds such as aldehydes and ketones because they may polymerise on the activated carbon, leading to overheating. The polymers will not desorb, therefore, MEK and similar products are not suitable. However, this problem can be overcome if proper safety measures are implemented, such as always desorbing the system before weekends and holidays, and installing automatic sprinkler systems.

It is also not applicable to gases with a relative humidity of >60 %, because water vapours will also adsorb on the activated carbon, reducing the adsorption capacity available for VOCs. Hydrophobic zeolites are available which do not have this problem. The system is sensitive to the presence of dust in the feed, because it will plug the adsorbent bed.

Adsorption wheels can be applied as a pretreatment to thermal oxidation. This leads to a reduction in the energy requirements of thermal oxidation (see Section 20.11.4.2). It also reduces the physical size of a thermal oxidiser when used together.

Applicability: This technique can be applied to waste gases with solvent concentrations of >0.8 g/m³. LEL limits do not play a role. The system can be applied to single solvents and mixtures. When single solvents that are not miscible with water are adsorbed, regeneration can be done with steam. When mixtures of solvents are adsorbed, regeneration has to be done with heated nitrogen and temperatures in the range of 150 - 300 °C.

Airflows in the range of 1000 to 1 million m³/h can be treated. For the upper end of the range, a 14 bed unit would be needed. The capacity of one bed depends only on the transportation of the system. The system can work continuously and discontinuously, and technically has a lifetime of more than 30 years. However, during this time it is likely to need to be adapted or renewed for environmental requirements, changes to process equipment and/or solvent systems, etc. making the economic life shorter.

This technique is applied in all publication gravure printing plants and is commonly applied in the automotive industry, the coating of trucks and commercial vehicles and in adhesive tape manufacturing as the concentration step prior to incineration. To a lesser extent, it is applied in processes using mixtures of solvents, such as in flexo and packaging gravure, although in Italy this technique has already been used for years to recover ethyl acetate.

Adsorption is especially suitable when concentrations of up to 4 g/m³ have to be removed from the waste gas. However, it is also applied to concentrations of 10 or 12 g/m³. In general, it is applicable for gases containing medium to low concentrations of VOCs. Only small molecules can be adsorbed and desorbed. In the automotive industry, there are some applications used for the cleaning of air from spray booths; typical inlet concentrations are between 300 - 1200 mg/m³.

Some low volatility solvents may adhere to the activated carbon permanently and quickly reduce the adsorption capacity with early replacement of the activated carbon as a result.

Adsorption and recovery of toluene used in the publication gravure processes is common practice. Toluene adsorbs well to activated carbon and is easily retrieved by heating the carbon with steam. The steam and solvent vapours are condensed to remove the toluene. The condensed steam can have a toluene concentration of between 380 – 540 mg/l and a stream of air bubbles is used to strip the toluene from the water. With stripping, this stream can have a concentration of toluene in the range 1 – 10 mg/l. After being treated, the waste water is discharged or re-used as, for example, cooling water or steam. The toluene is in part re-used and in part sold back to the ink manufacturers. This recovery process normally uses some 3 – 6 kg of steam per kg of recovered toluene. For a standard four press plant, about 7000 tonnes of toluene per year are recovered by using 20000 to 30000 tonnes of water.

In processes where solvent mixtures are applied, such as in the flexo and packaging gravure, adsorption and recovery are both more difficult. Ethanol and ethyl acetate do not adsorb to carbon as well as toluene and subsequently larger carbon beds are required. Steam cannot be utilised for the recovery, because these solvents dissolve in water. Therefore, usually a hot inert gas, such as N₂ is used. To separate the recovered solvent mixture, a distillation process is necessary.

In adhesive tape manufacturing, the recovery process normally uses 2 to 3 kg steam per kg recovered solvent to achieve emission concentrations of 70 – 90 mg/m³.

In the Netherlands and the Flanders region of Belgium, this technique is not applied in flexo and packaging gravure.

Economics: In general, this technique is twice as expensive as oxidation. The investment in solvent recovery will be EUR 0.5 million – 1 million more than the investment in an oxidiser. However, there is a payback from the recovered solvent. The investment in solvent recovery will be EUR 0.5 million – 1 million more than the investment in an oxidiser. Zeolite as the adsorption medium is about 10 times more expensive than activated carbon, and is commonly applied for concentrating-up purposes.

It should be noted that adsorption units can be designed for achieving very low emission values by increasing the total surface of the activated carbon or by applying shorter adsorption cycles. However, it has to be considered that both options result in higher investment and operational costs and a higher energy consumption.

The capital costs of adsorption equipment in an adhesive tape manufacturing example plant with a capacity of 800 kg/hr were about EUR 2.7 million in 1992. Operating costs for adsorption and condensation together were about EUR 0.51 million/yr. Variable costs were about EUR 1.12 million/yr and fixed costs about EUR 1.38 million/yr.

In the case of flexo and packaging gravure, investment and running costs for adsorption and subsequent solvent recovery are higher than those of any thermal treatment. The running costs are between EUR 0.15 and 0.25 per recovered kg of solvent. The costs for recovery are EUR 0.10/kg solvent and savings are EUR 0.60 - 0.70/kg solvent recovered, if the solvent is re-used on site. Where the solvent consumption is less than 500 tonnes per year, it is very unlikely that solvent recovery will be an economically attractive alternative to oxidation.

In packaging gravure processes, if ethyl acetate generally makes up over 90 % of the total solvent used, the re-usable amount may be such that the plant becomes almost self sufficient and no longer needs to buy ethyl acetate for dilution purposes.

The prices below for activated carbon adsorption are representative for the Flemish wood industry and based on realistic theoretical working parameters. Equipment suppliers that provided the information stressed that it is impossible to extrapolate the costs of the examples on the basis of flows and VOC loads., so the numbers are purely indicative and valid at the time estimations were made (November 2004).

- installation rental: EUR 6052 - 8544/year
- purchase of the installation: EUR 22355 - 23740/unit
- price quoted for: 10000 Nm³/h and 500 mg VOC/Nm³ (220 working days/year, 8 hours/day, VOC emission standard 90 mg/m³ and time load of 50%):
 - activated carbon: EUR 8316 for 5400 kg (lasting 82 working days) = EUR 22311/year
- price quoted for: 1000 Nm³/h and 500 mg VOC/Nm³ (other working conditions equal):
 - activated carbon EUR 8316 for 5400 kg (lasting 823 working days) = EUR 2230/year.

Driving forces for implementation: May be more economic than oxidation techniques.

Example plants: Ford, Daimler Chrysler, VW, Renault, Audi, Toyota plants across Europe. RSDB in Etten-Leur, the Netherlands; and the Italian packaging gravure industry which recovers and re-uses ethyl acetate.

Reference literature: [4, Intergraf and EGF, 1999] [35, Aminal, et al., 2002] [14, DFIU and IFARE, 2002] [60, ESIG, 2000] [62, CITEPA, 2003] [75, Jansen, 2005] [76, TWG, 2004] [128, TWG, 2005] [63, Vito, 2003] [147, Presti, 2005] [147, Presti, 2005] [146, CEI-BOIS, 2006].

20.11.6.2 Continuous monitoring of the adsorber performance

Description: Monitoring equipment is available to continuously control the performance of the adsorber, e.g. continuously comparing the level of contaminants in the raw gas and those in the treated waste gas.

Achieved environmental benefits: Reduction of untreated emissions because a poorly functioning adsorber can rapidly be detected and corrective action can be taken.

Cross-media effects:

Operational data: In case the system consists of two or more parallel adsorption units, the monitoring can be used to switch from one to the next. It is reported that, in the automotive industry where concentration variations are small, measurements once a week or even less frequently are normally carried out by portable equipment.

It is common practice in publication printing plants. In publication gravure, control of the carbon bed recovery cycle is carried out by concentration measurements and at fixed time intervals. This helps to decide when the coal-bed in the toluene adsorption systems has to be cleaned. Since the solvent content of the drying air is variable, these two methods of controlling the carbon bed recovery cycle may switch the adsorbers either too soon or too late. Too soon leads to excessive energy consumption, too late increases emissions disproportionately.

Applicability: This technique is applicable to new and existing adsorbers, independent of the type of industry. Continuous monitoring is only required if concentrations are large or in the case where parallel adsorption equipment is used. It is not needed where the absorber is an integral part of an abatement system and there are no releases to the air. It is also applicable to solvent recovery (see Sections 20.13.7.1 and 20.13.7.2).

Economics: It is reported that the cost of the installation of four continuous measuring VOC devices including the software and access platforms was EUR 2 million in 2004.

Driving forces for implementation: No data submitted.

Example plants: VW Hannover, Germany (cabin air treatment from solventborne filler application).

Reference literature: [18, UBA Germany, 2003] [128, TWG, 2005]

20.11.7 Absorption to liquid

Annex 24.9 provides a summary of waste gas treatment techniques (oxidation, adsorption, condensation and biological treatment) and their applicability. A comparison of the removal efficiencies of the most widely used techniques is given for different types of solvents at different inlet concentrations [148, TWG, 2006].

20.11.7.1 Absorption to water

Description: Absorption (or wet scrubbing) to water is a mass transfer between a soluble gas and a solvent – often water – in contact with each other.

Achieved environmental benefits: Removal of gaseous pollutants, such as NO_x, hydrogen halides, SO₂, ammonia, hydrogen sulphide or VOCs (if water soluble, such as IPA, ethanol, etc.).

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Not applied in vehicle paintshops or printing.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [67, EIPPCB, 2003] [128, TWG, 2005]

20.11.7.2 Absorption to oil and recovery

Description: Solvents in the waste gas can be recovered by absorption into organic oils followed by distillation.

Achieved environmental benefits: The recovered solvent can be re-used. In the cleaned gas, concentrations of $<30 \text{ mg/m}^3$ can be achieved.

Cross-media effects: Depending on the details of the applied technique, about $0.1 - 0.5 \text{ m}^3$ waste water, from humidity in the air, can arise per tonne of solvent recovered. However, usually no waste water arises at all, because it is separated in the distillation equipment and re-used for cleaning or converted into steam for stripping. Noise levels might increase.

Operational data: This technique is only used for pure solvents due to economic reasons. The technique is suitable for waste gas loads with a minimum of 2 g/m^3 .

Applicability: Applicable in new and existing plants. This technique is reported in one flexible packaging plant for coating and lamination; however, it is not commonly used because of cost.

It is not applied in the winding wire industry, because the solvents cannot be re-used in the process. It is not applied in other printing processes, coil coating processes, the metal packaging industry or in the automotive industry, because these industries generally use mixtures of solvents.

Economics: The technique is more expensive than absorption using activated carbon.

Driving forces for implementation: No data submitted.

Example plants: The flexible packaging company Bischof und Klein in Germany, where ethyl acetate is recovered by absorption in phthalic acid ester.

Reference literature: [14, DFIU and IFARE, 2002] [76, TWG, 2004] [128, TWG, 2005]

20.11.8 Biological treatment

Annex 24.9 provides a summary of waste gas treatment techniques (oxidation, adsorption, condensation and biological treatment) and their applicability. A comparison of the removal efficiencies of the most widely used techniques is given for different types of solvents at different inlet concentrations [148, TWG, 2006].

Description: The waste gas is routed through a biofilter or bioscrubber where micro-organisms remove the solvent. The temperature of the waste gas should not exceed 40 °C. The technique is discussed in the CWW BREF [67, EIPPCB, 2003].

Achieved environmental benefits: Removal efficiencies of between 75 - 95 % are achieved.

Cross-media effects: Odour nuisance might occur. Noise levels might increase.

Operational data: This technique was tested in a heatset printing plant. However, it was not successful because of the changing solvent concentrations and the variations in, and quantities of, solvents used.

Applicability: Biological treatment is applicable for diluted biodegradable streams and, therefore, is often applied for odour control. Biofilters are especially suitable for treating low levels of mainly hydrophobic pollutants such as hydrocarbons and aromatics (e.g. toluene and xylene). Biofilters are especially suitable for pollutants that easily dissolve in water, such as ethers, esters, ketones, alcohols and compounds containing nitrogen.

In the printing industry, the use of this technique is not efficient when the solvent concentration is $>1.5 \text{ g/m}^3$. In heatset, where the concentrations are normally $1 - 2 \text{ g/m}^3$, this technique was tested and the results were negative. In flexible packaging, biological treatment systems have been used meeting an emission limit of 100 mg/m^3 . It has also been successfully used in the UK in coating operations.

In the painting of furniture and wood sectors in Germany, only one plant applies this technique to reduce the odour nuisance due to solvent emissions.

It is sometimes applied in the manufacturing of abrasive and it is not applied in the automotive or the winding wire industries.

For prolonged shutdown periods, biofilters may require nutrient input to replace the solvent feed.

Economics: Investment costs are in the range EUR 5000 – 20000 for a capacity of $1000 \text{ m}^3/\text{h}$ waste gas. Operational costs vary from EUR 10 – 50 per 1000 m^3 gas treated regarding an installation with a capacity of $5000 \text{ m}^3/\text{h}$.

The prices below are representative for the Flemish wood industry and based on realistic theoretical working parameters. Equipment suppliers that provided the information stressed that it is impossible to extrapolate the costs of the examples on the basis of flows and VOCloads, so the numbers are purely indicative and valid at the time estimations were made (November 2004).

Flow: $10000 \text{ Nm}^3/\text{h}$:

- VOC inlet concentration: 500 mg/Nm^3 , VOC emission: $t: <90 \text{ mg/Nm}^3$
- price: EUR 135000 to 250000.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [35, Aminal, et al., 2002] [13, DFIU and IFARE, 2002] [60, ESIG, 2000] [63, Vito, 2003] [12, UBA Germany, 2002] [76, TWG, 2004] [146, CEI-BOIS, 2006]

20.11.9 NO_x abatement techniques

The NO_x emissions are from the thermal oxidation of VOCs in waste gases. This can be increased where solvents containing nitrogen are emitted. Studies in the winding wire industry have been carried out (see Section 3.3.3.1), and the estimated contribution from the industry is 1 to 2.7 ktonnes per year. The conclusion was not that it was technically or economically feasible within the industry to apply NO_x treatment techniques (see the following sections). This conclusion is analogous to other installations. The total amount emitted due to solvents containing nitrogen was low, so that the use of solvents containing nitrogen was likely to decrease with the application of REACH, etc. Furthermore, the winding wire industry was not a significant source of NO_x and therefore it was generally not sustainable or technically or economically viable to add secondary waste gas treatments. See Section 3.3.3.1.

The use of solvents containing nitrogen is generally low across the STS sector and this is not a significant source of NO_x. The most effective means of reducing NO_x emissions across the sector is optimising the oxidation conditions not only for VOC destruction, but to minimise NO_x formation (see Sections 20.11.1 and 20.11.4).

[54, BMLFUW Austria, 2003] [163, EWWG, 2005] [170, Tempany and Lemoine, 2006]

20.11.9.1 Selective non-catalytic reduction (SNCR)

Description: Waste gases containing high levels of NO_x can be treated by SNCR. The technique is fully described in the CWW BREF. NO_x are reduced by the action of urea or ammonia injected into the furnace without a catalyser. The reaction requires a high temperature (850 - 1050 °C). The efficiency is between 50 and 70 % with an NH₃:NO ratio of 2.5:1.

Achieved environmental benefits: Significant reduction of NO_x.

Cross-media effects: Energy for heating the waste gases. Use of ammonia and loss of ammonia as slip. Noise levels might increase.

Operational data: In the winding wire industry, the waste gas from the abatement technique connected to the enamelling ovens for reducing VOC still contains high levels of NO_x. This waste gas potentially can be routed through an SNCR.

Applicability: For industries using solvents containing nitrogen, which release significant NO_x, e.g. after drying (evaporation/curing).

A study in Austria for winding wires states that with this technique NO_x levels of 100 mg/m³ (as NO₂) for nitrogen-free solvents and 150 mg/m³ for solvents containing nitrogen can be achieved (but see Economics, below).

Economics: Costs are higher than for SCR. Capital costs per 1000 Nm³/h are in the range of EUR 7500 – 32000 and operating costs per tonne NO_x removed are in the range of EUR 500 - 5000.

SNCR is not applied in the winding wire industry for economic reasons.

Driving forces for implementation: Local air quality. Transboundary air pollution.

Example plants: No data submitted.

Reference literature: [54, BMLFUW Austria, 2003, 67, EIPPCB, 2003]

20.11.9.2 Selective catalytic reduction (SCR)

Description: Waste gases containing high levels of NO_x can be treated by SCR. The technique is described in the CWW BREF. NO_x are reduced by the action of ammonia in the presence of a catalyser. The reaction requires a temperature of 280 - 400 °C. The efficiency is a reduction in the NO_x content of the waste gases by up to 90 % with an NH₃:NO ratio of 0.7 - 1:1.

Achieved environmental benefits: Significant reduction of NO_x.

Cross-media effects: If the waste gases are ducted to one central SCR unit, energy may be required to reheat the waste gases. Ammonia and a catalyst are used in the SCR. There is likely to be loss of ammonia as slip. Noise levels might increase.

Operational data: In the winding wire industry, the waste gas from the abatement technique connected to the enamelling ovens for reducing VOC still contains high levels of NO_x. This waste gas can potentially be routed through an SCR.

Applicability: Applicable for industries using solvents containing nitrogen, which release significant NO_x, e.g. after drying (evaporation/curing).

A study in Austria for winding wires states that with this technique NO_x levels of 100 mg/m³ (as NO₂) for nitrogen-free solvents and 150 mg/m³ for solvents containing nitrogen can be achieved (but see Economics, below).

Economics: Capital costs per 1000 Nm³/h are in the range EUR 2300 – 3900 and operating costs per tonne NO_x removed are in the range EUR 700 - 1200.

An example calculation for a NO_x abatement system for groups of winding wire enamelling machines to remove 44 tonnes NO_x per year shows an investment of about EUR 985000 and operational costs for heating gas and ammonia of EUR 11000 per tonne NO_x removed.

SNCR is not applied in the winding wire industry for economic reasons.

An example calculation on the economics of NO_x abatement using SCR in an SME can be found in the in the STM BREF

Driving forces for implementation: Local air quality. Transboundary air pollution.

Example plants: No data submitted.

Reference literature: [67, EIPPCB, 2003] [66, UBA Germany, 2003] [76, TWG, 2004] [54, BMLFUW Austria, 2003] [128, TWG, 2005] [59, EIPPCB, 2005].

20.11.9.3 Water scrubber

Description: NO_x can be removed from waste gases by scrubbing and the technique is discussed in the CWW BREF. Scrubbing can be by using a single or multiple towers, and with water or with alkali solutions.

Achieved environmental benefits: The emitted NO_x consists of >98 % NO₂. Levels of <100 mg/Nm³ can be achieved using water, with a removal rate of 95 – 99 %.

Cross-media effects: Noise levels might increase.

Operational data: Either scrubbers would have to be installed on each waste gas outlet, or the waste gases ducted together to one central scrubber unit. An example of the complexity is winding wire installations, which may have about 40 - 170 lines.

Applicability: Applicable for industries using solvents containing nitrogen, which release significant NO_x, e.g. after drying (evaporation/curing). This technique is not applied in the STS sector.

The multiple installation or the combining of flows to one central treatment unit combined with lack of expertise in applying this are likely to make this technique technically and economically unviable in this sector.

Economics: The cost of installing multiple scrubber units or collecting all the waste gas flows to one central treatment point is likely to be high.

Driving forces for implementation: Local air quality. Transboundary air pollution.

Example plants: No data submitted.

Reference literature: [94, EIPPCB, 2004] [67, EIPPCB, 2003].[128, TWG, 2005]

20.12 Waste water treatment

Waste water treatment may be carried out on-site or off-site. Off-site treatment requires the discharge of waste waters with low concentrations of pollutants. For the STS sector, the treatment of waste water may become a problem when solvent-based products are replaced by water-based alternatives, e.g. when there are soluble solvents, polymers and plasticisers in the waste water. Waste water treatment is described extensively elsewhere, such as in the CWW BREF [67, EIPPCB, 2003] and for this sector in [93, Agences de l'Eau de France, et al., 2002]. More information on waste water treatment techniques for water-based activities can be found in the STM BREF [59, EIPPCB, 2005].

Techniques to reduce waste water, including treating waste water from paint spray booths, are discussed in see Section 20.7.5.

Where treatment is required, and using techniques described below, and in the documents referred to above, the following levels appropriate to this sector can be achieved [117, ACEA, 2005] [121, UK, et al., 2003]:

- BOD (where discharged to a river or controlled water) <100 mg/l
- COD (where discharged to a municipal waste water treatment plant) <2500 mg/l
- suspended solids (where discharged to a municipal waste water treatment plant <1000 mg/l

20.12.1 Flocculation

Description: In flocculation, the water being discharged is passed through a tank containing a flocculent, often a bentonite product or a polyacrylate, and the particles are absorbed onto or form a floc around the flocculent molecules and separated from the effluent (see Section 20.12.2).

Achieved environmental benefits: Removal of the settleable solids from the effluent. This can reduce the BOD and therefore the amount of subsequent treatment required in the waste water treatment plant.

Cross-media effects: Increase of waste sludge.

Operational data: No data submitted.

Applicability: This technique is applicable to any process involving suspended solids in the waste water.

Economics: No data submitted.

Driving forces for implementation: Compliance with the waste water discharge limit values.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [76, TWG, 2004] [59, EIPPCB, 2005] [93, Agences de l'Eau de France, et al., 2002] [128, TWG, 2005]

20.12.2 Separation

Description: After flocculation (see Section 20.12.1), flotation, sedimentation or filtration can be applied. To separate the coagulated sludge from paint booths from the water either sedimentation or flotation can be applied (see also Section 20.7.5.8). Flotation and sedimentation are based on the difference in density to achieve a phase separation; for sedimentation, the sludge sinks to the bottom; for flotation, the sludge floats to the surface. The sedimentation process can be improved by the use of a parallel plate or lamella separator, the flotation process is improved by using dissolved air. In the case of sedimentation, the concentrated sludge is pumped from the separator; in flotation, the sludge is scraped mechanically from the top of the liquid in the tank.

Techniques are described in more detail in the reference literature.

Achieved environmental benefits: Solids levels are reduced, including some hazardous substances.

Cross-media effects: Increase of waste.

Operational data: No data submitted.

Applicability: These techniques are commonly applied in the automotive industry. In the winding wire industry, the water-based wire drawing emulsion is treated by sedimentation and filtration.

Economics: No data submitted.

Driving forces for implementation: Compliance with the discharge waste water limit values.

Example plants: Widely applied.

Reference literature: [4, Intergraf and EGF, 1999] [59, EIPPCB, 2005] [67, EIPPCB, 2003] [76, TWG, 2004] [93, Agences de l'Eau de France, et al., 2002] [128, TWG, 2005]

20.12.3 Electroflocculation

Description: This technique is used to assist the re-use of process water and as a preliminary treatment system prior to discharge.

Achieved environmental benefits: Reduction of VOCs from the waste water. Elimination of paint sludges by skimming. Reduced water consumption.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: The technique is used in flexible packaging plants that use large amounts of water-based inks. This, however, does not imply that the quantities of waste water are also large. Indeed, very little waste water polluted with ink is generated when using water-based inks, if the cleaning techniques are aimed at reducing the amount of water to be discharged. In smaller flexible packaging plants, the amount of waste water containing ink can be so small that it can be treated as liquid waste or be discharged to a municipal waste water treatment plant.

Economics: Investment costs for an installation with a capacity for treating 15 m³/h was about EUR 100000 (1999). The uptake will be dependent upon the sewage treatment charges. Reduction in costs may be possible where restrictions on plants are lifted for improved quality of effluent discharge.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [76, TWG, 2004] [93, Agences de l'Eau de France, et al., 2002]

20.12.4 Vacuum distillation

Description: Vacuum distillation is a technique that uses a vacuum to extract VOCs from the waste water. It is an evaporative recovery system where a vacuum is applied to lower the pressure, so the distillation can be carried out at a lower temperature. This saves heating costs and also prevents less stable substances from decomposing under the high temperatures that would be required at atmospheric pressure.

Achieved environmental benefits: Reduction of VOCs from the waste water. Reduced waste water volumes.

Cross-media effects: Noise levels might increase. Energy is consumed for heating and vacuum pumping.

Operational data: No data submitted.

Applicability: Not used in vehicle paintshops.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [21, Nordic Council of Ministers, 1998] [76, TWG, 2004] [93, Agences de l'Eau de France, et al., 2002] [128, TWG, 2005]

20.12.5 Biological treatment

Description: If the waste water has been subject to preliminary detoxification and its biodegradable fraction is sufficient, biological treatment can be used.

Achieved environmental benefits: Reduced BOD and COD levels.

Cross-media effects: Noise levels might increase.

Operational data: Waste water containing phenol and fluoride from the abrasive manufacturing industry or containing solvents from the printing industry can be treated using a bioreactor or a biofilter. In the abrasive manufacturing industry, biological treatment is applied after neutralisation, fluoride precipitation, and filtration.

Applicability: Applicable to new and existing plants with waste waters containing solvents.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [12, UBA Germany, 2002] [76, TWG, 2004] [93, Agences de l'Eau de France, et al., 2002] [128, TWG, 2005]

20.12.6 Ultra and nanofiltration and reverse osmosis

Description: With ultra and nanofiltration (UF and NF) and reverse osmosis, the contaminated water passes along a semi-permeable diaphragm under high pressure, which lets through small molecules such as water but not larger particles. The concentration of the contamination increases as the waste water is repeatedly recycled past the filter. The difference in the techniques is the pore size of the filters and therefore the molecules that are filtered out.

Achieved environmental benefits: The filtered residue, e.g. paint or ink, can sometimes be recovered and re-used, and the cleaned water recycled or discharged to waste water (see Section 20.7.5.3). This technique can reduce the volumes of hazardous waste generated.

Cross-media effects:

- filtered waste water is, if not recycled, discharged to the sewerage system
- all filtration systems require energy
- noise levels might increase.

Operational data: Waste water can arise from cleaning activities, but, for example, also in spray booths where water is used for removing the overspray arising when paint is being sprayed, by degreasing processes, or by applying electro-immersion coating. In the electro-immersion coating applied in the automotive industry, and, in general, in the coating of vehicles, filtration can be used for paint recycling and complete demineralisation of water by allowing a closed loop (see Sections 20.4.1, 20.4.1.2 and 20.4.1.3). Integration into the large cascade can be without UF if demineralised rinsing water is used.

In degreasing, high amounts of water are also used. UF serves as a bath maintenance measure in the degreasing step, that allows (see Section 20.7.5):

- higher quality of the degreasing bath
- an extension of service lifetime
- reduction of necessary cleaning agents
- higher availability of the plant.

Applicability: This technique is applied in printing plants where large amounts of water-based inks, paints and adhesives are used, e.g. in packaging printing. It is also commonly applied in the automotive industry, and in the coating of agricultural and construction equipment.

Careful selection of the membrane is necessary as some solvents, especially ketones and esters can attack the membrane and make the process inoperable.

Economics: In the automotive industry, costs for installing a UF or NF plant is typically in the range EUR 0.5 million - 1 million.

Driving forces for implementation: No data submitted.

Example plants: Opel Eisenach GmbH, Germany.

Reference literature: [21, Nordic Council of Ministers, 1998] [18, UBA Germany, 2003] [13, DFIU and IFARE, 2002] [68, ACEA, 2004] [76, TWG, 2004] [93, Agences de l'Eau de France, et al., 2002] [59, EIPPCB, 2005] [128, TWG, 2005]

20.13 Waste minimisation and treatment of wastes containing solvent

Annex IV (point 3) to the IPPC Directive requires the consideration of '*furthering the recovery and recycling of substances generated and used in the process and of waste, where appropriate*'.

The following sections show techniques used to minimise waste through recovery and re-use.

See also Section 20.6.3 on minimisation of raw material consumption and Section 20.7.5 for measures to reduce the loss of raw materials in process waters.

20.13.1 Recovery of used solvents from the process

Description: Used solvents, e.g. used for cleaning, can be treated for re-use, e.g. by filtration or distillation (see Sections 20.13.2.1 and 20.13.2.2). Both recovery and re-use can be done on site or off-site. For example, where pig-clearing systems or purge systems are applied, solvents are used on-site to clean the system after each change of colour – called the purges. Modern paint supply equipment includes recovery of the purge solvents. Solvents can also be disposed of as hazardous waste to an off-site solvent recovery installation. There, the clean solvents are re-used, but not necessarily by the same user.

Cleaning can be carried out in washing machines, where the solvent is recovered and re-used internally (see Section 20.9). Halogenated VOCs can be used for this technique, in conjunction with closed storage and waste systems.

Achieved environmental benefits: Reduced amounts of hazardous waste and reduced consumptions of fresh solvents. By re-using the hazardous waste (in this case solvent), its life cycle is expanded.

In the automotive industry, typically 80 - 90 % cleaning and purge solvents can be recovered, either on site or off site, for re-use.

Cross-media effects: Noise levels might increase. Storage risk increased for hazardous materials.

Operational data: For filtration and distillation in an economical manner, generally large quantities (several tonnes at a time) are required and are usually contracted out. This implies storage of large amounts of both clean and used solvents. There should be adequate storage for both receiving used solvents waiting to be removed and for the returned clean solvent: the amounts should be equal if usage remains unchanged.

In coil coating processes, solvents from waste paints are commonly recovered and re-used in cleaning activities. The remaining solid waste is usually incinerated off-site.

Applicability: Applicable in plants using large quantities of solvents. Recovery of cleaning agents is commonly applied in:

- publication gravure, heatset offset, and flexo and packaging gravure plants. However, only in publication gravure and offset plants using more than 200 litres cleaning agents a week
- the coating and printing of metal packaging
- furniture painting, e.g. in the coating of wooden kitchen and bathroom furniture
- the winding wire industry
- the automotive industry.

The cleaning of purge solvents is applicable in all industries applying piping systems, e.g. paints or inks supply and is commonly applied in the automotive industry.

Care must be taken to ensure that solvents recovered by distillation or filtration (or any other method) are only used where technical specifications are fulfilled. They can alternatively be used for other applications, or reworked to meet the specification required (although this is usually more expensive than buying fresh solvent).

Economics: A saving will be incurred because of reduced consumption of solvents and a reduced amount of hazardous waste. In large plants, the savings will approximately outweigh the investment. For example, the investment costs for the recovery of cleaning agents might be in the range of EUR 3000 - 150000, depending on, e.g. size, tank capacity and automation.

Re-using hazardous used solvents is a cost-effective activity. The utilisation of hazardous used solvents is productive for the company that generates used solvents, because the company does not have to pay for the disposal of hazardous waste. The company that processes the used solvents gets the necessary amount of input solvent cheaply, and the end user who needs processed used solvents in its manufacturing processes gets the raw material at a competitive price.

The installation of a typical solvent recovery system in the automotive industry costs EUR 0.4 million per spray booth.

Driving forces for implementation: Solvent recycling and VOC emission reduction.

Example plants: Ford plants in Europe.

Reference literature: [4, Intergraf and EGF, 1999] [13, DFIU and IFARE, 2002] [62, CITEPA, 2003] [68, ACEA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.13.2 Treatment of used solvents for re-use

20.13.2.1 Filtration

See also Section 20.13.1.

Description: Dirty cleaning solutions, e.g. of HBS or VCA, can be filtered. The solvents can be re-used and the water residue can normally be discharged to the municipal waste water system.

Achieved environmental benefits: Less waste water and less use of fresh solvents.

Cross-media effects: Filtration requires energy and the water residue is discharged. Noise levels might increase. The impact upon the aquatic environment has not been considered sufficiently. Any dissolved HBS or VCA will drastically affect the chemical oxygen demand and biological oxygen demands of the water being discharged to the municipal waste water system.

Operational data: Experiments are being carried out in the Netherlands with low volatility cleaning agents in cleaning machines for flexible packaging. Filtration and re-use of these cleaning agents is an important part of these experiments.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [18, UBA Germany, 2003] [76, TWG, 2004]

20.13.2.2 Distillation

See also Section 20.13.1.

Description: Solvent-based waste such as inks, paints, paints and adhesives can be distilled to recover the solvent and to reduce the amount of hazardous waste. Special purpose distillation equipment exists.

Achieved environmental benefits: The amount of hazardous waste is reduced and the solvent can be re-used, e.g. for cleaning.

Cross-media effects: Distillation requires energy. However, compared to incineration, which creates CO₂ and also uses energy, it is likely that distillation and re-use saves energy. Noise levels might increase.

Operational data: The distillation equipment must be installed and operated with care. Cleaning agents with a high flashpoint generally also have a high boiling point. For these solvents, only vacuum distillation equipment can be applied (see Section 20.12.4); in these situations membrane filtration may be used (see Section 20.12.6). It is reported that relatively small vacuum distillation units (50 litres) are readily available. Furthermore, membrane filtration can be expensive and many of the solvents used can attack the membrane. Cleaning machines that have distillation equipment attached are available.

In publication gravure plants (where toluene is the sole ink diluter) the equipment for the distillation of cleaning agents may be, if suitable, also used for waste ink. Distilling waste inks only is not cost-effective.

Applicability: Applicable in new and existing installations. Applicable to solvent-based inks and adhesives.

No distillation of the waste ink is carried out in publication gravure because only four colours are used and there is little waste ink.

In packaging gravure, distillation of waste inks is used decreasingly because there is less waste inks due to the application of automated mixing of inks (see Section 20.6.3.1).

Where on-site distillation is not cost effective, external distillers can be used, e.g. in publication gravure.

Used in the automobile industry if the recovered solvents can be used for processes with a lower quality requirement, such as general cleaning.

Economics: Investment costs start at EUR 10000 for smaller vacuum distillation plants, depending on, e.g. size, tank capacity and automation. There is an additional cost if the existing equipment for the distillation of cleaning agents can be used.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [14, DFIU and IFARE, 2002] [58, ECCA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.13.3 Disposable cleaning wipes

Description: Cleaning can be done with disposable and re-usable wipes. Once dirty, the disposable wipes are thrown away and treated as hazardous waste. This normally implies incineration.

Disposable wipes are generally made of synthetic fibres. Per unit of weight, they can contain many times more cleaning agent and dirt than re-usable wipes. After use, they are incinerated together with their contamination. Since disposable wipes are light, the incineration of the sludge from the cleaning of re-usable wipes offers little advantage over incineration of completely disposable wipes.

Disposables have far better adsorption properties than re-usable wipes thus less weight and volume is needed. The amount of transportation involved is, consequently, also much smaller.

Achieved environmental benefits: There is no clear environmental difference between re-usable and disposable wipes. There is no environmental preference for either.

Cross-media effects: Raw materials are consumed in the production of disposables.

Operational data: An important factor in the choice for disposable wipes is the damage that may be done to very sensitive surfaces such as offset plates and gravure cylinders by a re-usable wipe that is not completely free of contamination from previous uses.

Applicability: Disposable wipes are commonly used in all types of industries, e.g. in the printing and coil coating industry.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [58, ECCA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.13.4 Re-usable cleaning wipes

Description: Cleaning can be done with disposable and re-usable wipes. Re-usable wipes are normally rented. Once dirty, they are returned to the rental company, where they are washed and put back into circulation.

Re-usable wipes are made of natural textile fibres. After use, they are washed with solvents and then dried. The contaminated solvent is distilled and the sludge is incinerated as hazardous waste. The washing, drying and distillation processes for re-usable wipes give rise to solvent emissions.

Since re-usable wipes are far less adsorbent than disposables, a far greater weight and volume is needed. The amount of transportation involved is consequently larger for the same amount of cleaning. However, re-usable wipes generate less waste than disposable wipes.

Achieved environmental benefits: There is no clear environmental difference between re-usable and disposable wipes. There is no environmental preference for either.

Cross-media effects: No data submitted.

Operational data: Re-usable wipes are stronger and thicker than disposable wipes. This makes them fit for use in situations where manual force and repetitive movement are necessary to clean the object. This force is not used on delicate surfaces.

Applicability: Re-usable wipes are commonly used in all types of industries, e.g. in the printing and coil coating industry.

Re-usable cleaning wipes are too hard for the finishing of wooden workpieces.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [18, UBA Germany, 2003] [58, ECCA, 2004] [76, TWG, 2004]

20.13.5 Recovery of used solvents from wipes

Description: The majority of solvents in wipes are removed by draining by gravity, a wringer, or a centrifuge prior to transport.

This technique is an answer to the bad practice of using too much solvent and pouring the excess used solvents over the wipes in order not to have to dispose of them separately.

Achieved environmental benefits: The recovered solvents can be used again for cleaning, or if too dirty, distilled and re-used (see Section 20.13.2.2). Less weight has to be transported. Reduced emissions during storage and transportation.

Cross-media effects: Emissions on-site from the handling required for removing the solvents from the wipes. Noise levels might increase.

Operational data: Commonly applied in the printing industry in the US.

Applicability: Applicable to all printing plants using solvent wipes. The wipes might be re-usable or disposable.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [53, US EPA et al., 2003] [76, TWG, 2004]

20.13.6 Re-usable containers

Description: Many raw materials are supplied in re-usable containers, such as IBC containers with a capacity of approximately 1 tonne, or standard 200 litre metal drums, etc. These containers can be returned for re-use or re-used for containing solvents. Incorporation of a liner that is unreactive to the contents and can be disposed of can eliminate the damage to the 200 litres open top drum and make re-use easier.

Achieved environmental benefits: Reduced waste.

Cross-media effects: Before re-use, the containers need to be cleaned, normally off site.

Operational data: Large offset printing plants apply a direct supply of ink by piping systems. Solvents used as cleaning agents are also commonly contained in re-usable containers. Less waste containers and large containers makes direct ink supply to the presses via piping systems possible.

A disadvantage might be that the re-use of empty ink and solvent containers require the return of these containers to the manufacturers. As the trade in inks is international, empty metal containers would have to be collected, stored and then shipped across Europe.

Applicability: Applicable to all plants using large quantities of materials.

In heatset web offset printing, the standard colours of offset inks are supplied in re-usable containers.

In flexible packaging, the many different colours used restrict its applicability. The amount per colour does not warrant sending containers back to the supplier, with the possible exception of white ink, some paints and some adhesives. The containers in which the inks have been supplied are re-used in house. They are used to mix colours, to dilute inks and to transport the inks to the presses. They are frequently cleaned and re-used many times over.

Re-usable bulk containers for paint are commonly applied in coil coating plants. They are also supplied in the winding wire industry and sent back to the supplier after use.

Economics: Ink and solvents supplied in large quantities in re-usable bulk containers are often cheaper and less waste has to be disposed of.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [4, Intergraf and EGF, 1999] [58, ECCA, 2004] [76, TWG, 2004] [128, TWG, 2005]

20.13.7 Treatment of used activated carbon

Adsorption may be used to treat waste gases (see Section 20.11.6.1). When the surface of the adsorbent has adsorbed nearly as much as it can, the efficiency of adsorption decreases. The adsorbent is then usually regenerated by desorbing the retained solvents (and other materials). This may be carried out on-site (see Section 20.11.6.1) or off-site (see Section 20.13.7.2, below). The adsorbent also collects materials that are not desorbed, and these occupy increasing proportions of the surface area, leading to a decrease in the removal efficiency of target pollutants. The adsorbent may be regenerated by heat treatment (see Section 20.13.7.1)

20.13.7.1 On-site recovery of the used activated carbon and other adsorbents

Description: As well as solvents in the waste gases, the carbon also adsorbs materials that are not desorbed in the regeneration/solvent removal process (see Section 20.11.6.1), such as non-recoverable solvents, retarders and plasticisers. This causes the efficiency of used adsorbent to fall after a period of time. The adsorbent can, in certain cases, be regenerated on-site or off-site by heat treatment.

Achieved environmental benefits: Prolongs the life of the adsorbent.

Cross-media effects: Energy used in regeneration. The heat treatment may give rise to emissions from the adsorbed materials and their breakdown products.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: There are savings in purchasing fresh adsorbent; however, the energy costs need to be considered.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [128, TWG, 2005].

20.13.7.2 Off-site regeneration/solvent removal of the used activated carbon and other adsorbents

Description: Waste gases loaded with solvents are routed through an adsorber with activated carbon or other adsorbent. This might be a canister containing the adsorbent which is placed on the vent. Once saturated, the canister with the adsorbent is returned to the supplier for regeneration. Where the waste gas contains several different solvents, recovery of the solvents is a complicated process. Regeneration in this case can be done more effectively by specialised companies.

Achieved environmental benefits: Reduced adsorbent consumption.

Cross-media effects: Regeneration off-site requires a type of adsorbent that is strong enough to be transported.

Operational data: No data submitted.

Applicability: Canisters are especially suitable for small flowrates with low loading; high loading would require frequent cartridge changes. These are often used to abate odours.

Especially suitable for plants applying one type of solvent.

Not applied in vehicle paintshops, but in other workpiece paintshops in the automotive industry.

Economics: For an airflow of 7000 m³/h and <20 t/yr of solvents, costs are over EUR 100000 per year. However, for small flows, applying canisters is a low investment system.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [35, Aminal, et al., 2002] [14, DFIU and IFARE, 2002] [60, ESIG, 2000] [75, Jansen, 2005] [76, TWG, 2004] [128, TWG, 2005]

20.13.7.3 Incineration of the used activated carbon or other adsorbents

Description: If the activated carbon or other adsorbents cannot be regenerated, they are usually disposed of by incineration.

Achieved environmental benefits: Carbon or other adsorbents that are only used once can generally adsorb more solvents than those that can be regenerated.

Cross-media effects: The total amount to be incinerated is greater because not only the solvent, but also the carbon is incinerated, and consequently more carbon is consumed.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [35, Aminal, et al., 2002] [14, DFIU and IFARE, 2002] [60, ESIG, 2000] [128, TWG, 2005].

20.13.8 Waste water sludges

Techniques for treating and managing waste water sludges are described in more detail in the STM BREF [59, EIPPCB, 2005] and in the CWW BREF [67, EIPPCB, 2003], as well as in specialist texts such as [93, Agences de l'Eau de France, et al., 2002].

20.13.8.1 Centrifuges

Description: Centrifuges are used for enforced draining of paint sludge. Paint sludge is disposed of, whereas the fluid is usually fed back into the waste water treatment process.

Achieved environmental benefit: Easier handling of waste. Less solid or sludgy waste to dispose of.

Cross-media effects: No data submitted.

Operational data: Water contents of 50 - 70 % can be reached.

Applicability: These techniques are applied in the automotive industry if the water content after sedimentation or flotation is still too high. In the case of phosphate sludge, filter presses can be used instead.

Economics: Lower costs for transport and disposal of paint sludge.

Driving forces for implementation: Cost reduction, legal requirements.

Example plants: VW, Emden, Germany.

Reference literature: [59, EIPPCB, 2005] [76, TWG, 2004]

20.13.8.2 Filter press

Description: Separated phosphate sludge from sedimentation (such as from a lamella separator) is often dewatered using filter presses with woven fabric filters.

Achieved environmental benefit: Easier handling and disposal of the waste. Reduced waste volume and weight.

Cross-media effects: No data submitted.

Operational data: Water contents of 40 – 60 % can be reached.

Applicability: These techniques are commonly applied in the automotive industry.

Economics: Lower costs for transport and disposal of paint sludge.

Driving forces for implementation: Cost reduction, legal requirements.

Example plants: Commonly applied.

Reference literature: [59, EIPPCB, 2005] [76, TWG, 2004]

20.14 Dust abatement

For in-process techniques to reduce dust or particle emissions from spray booths, see Sections 20.7.4.1, 20.7.4.2 and 20.7.4.3. For end-of-pipe dust abatement, see Section 20.11.3 – Waste gas pretreatment).

20.15 Odour abatement

Many processes using solvent have odour impacts. However, in-process and end-of-pipe waste gas measures to reduce solvent emissions as well as the installation of high stacks for waste gas emissions also resolve these, see Sections 20.10 – Substitution and 20.11 – Waste gas treatment).

20.15.1 Venting tanks during deliveries of solvent-based materials

Description: During deliveries of materials containing solvent, the vapour in any pipe line and the head space of the tank are vented or they may be back-vented (see Section 20.2.2). Where back-venting is not used or impracticable, for example: due to long pipe runs, back pressure, or contractual agreements over deliveries, and displaced air vents are used, they should be sited in such a way as to prevent the arising of offensive odour beyond the site boundary.

Achieved environmental benefit: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Commonly applied.

Reference literature: [121, UK, et al., 2003] [128, TWG, 2005] [164, Verspoor, 2006]

20.16 Noise abatement

Description: It is good practice to reduce noise from the installation so impact upon sensitive targets is not significant. Noise can be generated:

- in process, especially by rapidly moving machinery (such as folders and cutters in printing processes, equipment for stamping and drawing, fast moving conveyors, etc.)
- by associated activities and equipment such as air compressors, air/waste gas extraction systems, waste gas oxidisers, etc.

Noise can be eliminated or reduced by:

- in process and engineered solutions:
 - engineering noise control measures where required, such as installation of silencers to large fans, use of acoustic enclosures
 - avoiding selection of equipment with high or tonal noise levels, etc.
 - enclosing presses and other sources of noise
- management systems:
 - effective preventative maintenance on noisy plants, e.g. replacing bearings on fan motors
 - delivery transport can also have an impact locally, and can be managed by reducing deliveries and/or managing delivery times
 - effective plant operation includes closure of delivery bay and workplace doors.

Achieved environmental benefits: Reduced noise. Effective preventative maintenance on fans and motors can reduce energy demand.

Cross-media effects: Use of silencers can lead to an increase in energy as pressure drops increase.

Closing bay doors can increase demands on internal ventilation and cooling.

Operational data: Site-specific.

Applicability: Applicable to new and existing plants such as heatset and publication gravure (where folders/cutters are usually enclosed), but not in the web printing process (where the product is on rolls).

Economics: Case specific, but there is usually no payback. Increased cost of ventilation with delivery bay and workplace doors closed.

Driving forces for implementation: Prevention of noise complaints. Compliance with occupational health legislation (which often results in noise sources being enclosed preventing high levels outside the installation).

Example plants: Widely used.

Reference literature: [111, Eurofer, 2003] [128, TWG, 2005]

21 BEST AVAILABLE TECHNIQUES FOR SURFACE TREATMENT USING ORGANIC SOLVENTS

Introduction

In understanding this chapter and its contents, the attention of the reader is drawn back to the preface of this document and in particular the fifth section of the preface: 'How to understand and use this document'. The techniques and associated consumption and/or emission levels, or ranges of levels, presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for surface treatment using organic solvents: these are related to solvent emissions to air, consumption of energy, solvent emissions to waters (particularly groundwaters), soil contamination by solvents, and wastes
- examination of the techniques most relevant to address these key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of the techniques
- selection of the best available techniques (BAT) and the associated consumption and/or emission levels for this sector in a general sense, all according to Article 2(11) and Annex IV of the Directive.

Expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG) has played a key role in each of these steps and in the way in which the information is presented here.

On the basis of this assessment, techniques, and as far as possible consumption and emission levels associated with the use of BAT, are presented in this chapter that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where consumption or emission levels 'associated with best available techniques' are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither consumption nor emission limit values and should not be understood as such. In some cases it may be technically possible to achieve better consumption or emission levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The consumption and emission levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of 'levels associated with BAT' described above is to be distinguished from the term 'achievable level' used elsewhere in this document. Where a level is described as 'achievable' using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous chapter. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

It is intended that the general BAT in this chapter are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way they will assist in the determination of appropriate 'BAT-based' conditions for the installation or in the establishment of general binding rules under Article 9(8). It is foreseen that new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable consumption and emission levels when using specified techniques. The appropriate limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Some aids to understand this chapter

1. The sector 'Surface Treatment using Solvents' covers a wide group of industries which are diverse in complexity, size and nature of the activities (addressed in Chapters 2 to 19). The techniques to be considered in the determination of BAT are considered in the Section 4 of each industry chapter. However, the same key environmental issues are found in all the industries, and the techniques for addressing them have also been assessed for their generic application in more than one industry, with the result that the majority of techniques are described in Chapter 20. It is therefore strongly recommended to read this BAT Chapter (Chapter 21) in conjunction with Chapter 20, as well as the Section 4s of Chapters 2 to 19, which describe the relevant industries. To help the user, cross-references to Chapter 20 and other relevant sections have been given in this chapter (Chapter 21).

2. In this chapter, the BAT conclusions for the sector are set out on two levels. Section 21.1 deals with generic BAT conclusions, i.e. those that are generally applicable to the whole sector. The sections from Section 21.2 onwards contain BAT conclusions for the specific industries. So BAT for any specific surface treatment installation is the combination of:

- the generic or common techniques for the sector (Section 21.1)
- the industry specific techniques applicable to the particular case (Section 21.2 onwards).

If there are known exceptions when a BAT is not applicable in certain circumstances or cases, this issue is noted in the appropriate section.

3. Where water-based surface treatment processes (as defined in Annex 2.6 to the IPPC Directive,) are operated in conjunction with solvent-based processes (as defined Annex 6.7 to the IPPC Directive,) the relevant BAT for the water-based treatments can be found in the STM BREF⁶. The STM BREF applies mainly to water-based cleaning/degreasing, passivation, phosphating or other water-based chemical treatment and to rinsing with water. The techniques and related BAT for replacing solvent-based processes by water-based processes are described in this document

4. Additional techniques and supporting information can be found in other IPPC reference documents, in particular the CWW BREF⁷, the Storage BREF⁸ and the Monitoring REF⁹. BAT

⁶ The BAT reference document on the Surface Treatment of Metals and Plastics [59, EIPPCB, 2005]

⁷ The BAT reference document on the Waste Water and Waste Gas Management/Treatment in the Chemicals Sector 67 EIPPCB (2003). "Reference document on Best Available Techniques in Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector", European Commission.

⁸ The BAT reference document Emissions from Storage 91 EIPPCB (2005). "Reference document on Best Available Techniques on Emissions from Storage".

⁹ The reference document on the General Principles of Monitoring 113 EIPPCB (2003). "Reference Document on the General Principles of Monitoring".

conclusions in these documents have not been validated for solvent coating processes but where similar physical and/or chemical conditions exist and considering the economic viability, the conclusions may be applied in this sector.

Some key issues to help users/readers of this chapter

During the preparation of this document, several important issues became apparent when considering the key environmental issues. Knowledge of these issues may help users/readers:

5. Many installations in this sector are already subject to other specific regulations concerning their emissions to air – in some cases for years. Regulations have included the application of emission limit values (ELVs) for some substances released to air. In particular, the Council Directive 1999/13/EC (the Solvent Emissions Directive) includes various ELVs for waste gas, fugitive and total emissions as well as an alternative reduction scheme with target emissions and directions on replacing hazardous solvents (substitution), (see the Preface and Annex 24.2).

6. When interpreting the emission levels and performance levels associated with the use of BAT as reported in this chapter, it is essential that the user/reader understands:

- emission and performance values quoted as associated with the use of BAT are not the same as emission limit values (ELVs), in particular in the SED (see the Introduction, above)
- across the EU, where there is a matter for national or local competence, ELVs are set and enforced in different ways
- compliance with ELVs in permits and legislation naturally results in emission and performance values that are below those ELVs
- emission values can be expressed in different ways, such as averages over differing time scales (e.g. one hour, 24 hours, at all times), in different concentration terms (e.g. mgC/Nm³, mg VOC/m³, etc.)
- the emission levels and performance levels associated with the use of BAT are given in production related terms where possible (such as VOC as wt- % of input of ink solids, g/m² e-coat area, kg of VOC per kg of solids input, etc.). In most cases, the terms relate to the SED and are used by industry and regulators to show compliance with the SED ELVs or the reduction scheme. The same terms are used here to benefit from the existing data and for consistency. They are explained further in Annex 24.2.

7. BAT require a consideration of costs, benefits and cross-media effects (see Introduction, above). For these reasons, it is not anticipated that an installation would operate with all parameters at the lowest levels in all the ranges associated with BAT.

8. The speed at which an individual or a selection of BAT can be implemented in an installation, and the position of that installation in ranges of levels associated with BAT may depend on factors such as (see [97, EIPPCB, 2005]):

- whether the installation is new or existing, and the age and design of the equipment
- the position of the installation in its investment cycle
- the complexity of processes and the actual selection of techniques in operation
- for a new plant or major upgrade, the stage of commitment to a selection of techniques
- the production capacity, volumes and the mix of products being produced
- the type of treatments being applied and quality requirements (such as colour matching)
- the space available
- cost, 'availability' and robustness of techniques in the time scale required by the operator
- the time required to make changes to activities (including any structural changes) within the installation and how this is optimised with production requirements
- the costs, benefit and cross-media impact of an ongoing reduction of solvent emissions

- new and emerging techniques which may assist in achieving lower VOC emissions at lower financial and cross-media costs.
9. Development: some operators and/or suppliers can produce satisfactory results with a technique which others have used without success in apparently analogous situations or do not regard as an investment route to achieve a guaranteed environmental outcome. There may be significant development time (years) before a technique is operating stably at its lowest consumption and/or emission levels, is fully commercial and/or can be applied to other activities.
10. Environmental improvements will not necessarily be achieved steadily, (e.g. year-on-year, 2 % decrease in emissions, 5 g/m² improvement every five years, etc.), because significant step changes are likely to depend on, for example, capital investment, major engineering work, and the availability of substitutes on the market, as discussed above.
11. Customer demand (including from internal customers, such as marketing departments) may apply pressure in two ways:
- conversely to environmental improvements, to use treatments or achieve finishes that can only be delivered by using techniques that consume significant quantities of VOC solvents, with associated emissions, e.g. metallic paint finishes for buses
 - equally, some finishes or standards can only be achieved using solvent-free or low solvent processes, such as 2-component adhesives in flexible packaging.

21.1 Best available techniques applicable in all industries in the sector

BAT FOR ENVIRONMENTAL MANAGEMENT

A number of environmental management techniques are determined as BAT. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

12. BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to individual circumstances, the following features (see Section 20.1.1):

- definition of an environmental policy for the installation by senior management (commitment of the senior management is regarded as a precondition for a successful application of other features of the EMS)
- planning and establishing the necessary procedures
- implementation of the procedures, paying particular attention to
 - structure and responsibility
 - training, awareness and competence
 - communication
 - employee involvement
 - documentation
 - efficient process control
 - maintenance programme
 - emergency preparedness and response
 - safeguarding compliance with environmental legislation.
- checking performance and taking corrective action, paying particular attention to
 - monitoring and measurement (see also the Reference document on Monitoring of Emissions)
 - corrective and preventive action
 - maintenance of records
 - independent (where practicable) internal auditing in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained.
- review by top management.

Three further features, which can complement the above stepwise, are considered as supporting measures. However, their absence is generally not inconsistent with BAT. These three additional steps are:

- having the management system and audit procedure examined and validated by an accredited certification body or an external EMS verifier
- preparation and publication (and possibly external validation) of a regular environmental statement describing all the significant environmental aspects of the installation, allowing for year-by-year comparison against environmental objectives and targets as well as with sector benchmarks as appropriate
- implementation and adherence to an internationally accepted voluntary system such as EMAS and EN ISO 14001:2004. This voluntary step could give higher credibility to the EMS. In particular EMAS, which embodies all the above-mentioned features, gives higher credibility. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

13. Specifically for this industry sector, it is also important to consider the following potential features of the EMS:

- planning to reduce the environmental footprint of an installation (see BAT 14, below)
- internal industry and installation benchmarking on a regular basis, including:
 - consumptions of raw materials, energy and water, including efficient use of these inputs
 - emissions to air and to water and generation of waste
- choice of input materials
- giving consideration to the environmental impact from the eventual decommissioning of a unit at the stage of designing a new plant or modification to an existing plant
- giving consideration to the development of cleaner technologies.

14. BAT is to minimise the environmental footprint of the installation by planning actions and investments in the short, medium and long-term to achieve ongoing improvements, considering the cost-benefits and cross-media effects (see Section 20.1.2), supported by all of the following:

- internally monitoring and benchmarking the consumptions and emissions, see Section 20.1.3
- implementing a solvent management plan, see Section 20.3.1
- understanding the interrelation of these consumptions and emissions in the process(es)
- identifying areas for improvement and meeting BAT
- assigning priorities to actions and investments identified
- developing an implementation timetable.

INSTALLATION DESIGN, CONSTRUCTION AND OPERATION

Prevention of unplanned releases/emissions

15. BAT is to design, construct and operate an installation to prevent pollution from unplanned emissions by the identification of hazards and pathways, simple ranking of hazard potential and implementing a three-step plan of actions for pollution prevention (see Section 20.2.1). This is particularly useful to prevent the contamination of groundwaters and soils, and to assist in site decontamination on cessation of activities. The complexity of the approach will vary according to the size and complexity of the installation and the hazard potential identified. To minimise unplanned releases, the steps should include measures to address all the bullet points below:

Step 1:

- allow sufficient plant dimensions
- contain areas identified as being at risk from any chemical spillage by using appropriate materials to provide impervious barriers, including identifying any possible access to sewers, such as drains and inspection hatches, and sealing them appropriately
- ensure the stability of the process lines and components (including temporary and infrequently used equipment).

Step 2:

- ensure storage tanks used for risk materials are protected by using construction techniques such as double skinned tanks or by situating them within contained areas
- ensure operating tanks in process lines are within a contained area
- where liquids are pumped between tanks, ensure the receiving tanks are of sufficient size for the quantity to be pumped or a fail safe level control system is installed
- ensure there is either a leak identification system or contained areas are regularly checked as part of the maintenance programme.

Step 3:

- carry out regular inspection and test programmes
- have emergency plans in place for potential accidents, which will include:
 - site major incident plans (appropriate to size and location of the site)
 - emergency procedures for chemical and oil spillages
 - containment facility inspections
 - waste management guidelines for dealing with waste arising from spillage control
 - identification of suitable equipment and regularly ensuring it is available and in good working order
 - ensure staff are environmentally aware and trained to deal with spillages and accidents
 - identification of the roles and responsibilities of persons involved.

Storage of chemicals and wastes

16. BAT is to reduce fire and environmental risk in the storage and handling of hazardous materials, especially:

- solvents
- solvent-based raw materials
- waste solvents and contaminated cleaning materials

by using techniques described in Sections 20.2.2 and 20.2.2.1:

- storing only small amounts of hazardous raw materials necessary for production at the point of application
- storing larger quantities separately
- back-venting bulk storage tanks when filling where this is appropriate (see Section 20.2.2)
- having high level alarms on all fixed storage tanks
- having unique filling points for bulk materials
- storing solvents, waste solvents and waste cleaning materials (where fire safety practice allows) in sealed containers.

Additional information can be found in the Storage BREF.

Plant construction and operation

17. BAT is to minimise consumptions and emissions, such as by:

- automating surface treatment techniques as applicable to the activity and industry, see Section 20.2.3
- ensuring all staff are trained for their tasks in operating, cleaning and maintenance activities, see Section 20.2.4
- maintaining written up-to-date operational procedures and process manuals, see Section 20.2.4.
- optimising the activities, see Section 20.2.5 and BAT 14, above
- operating a planned maintenance system, as described in Section 20.2.6. This is important to reduce unplanned emissions and is part of an EMS, see BAT 12.

MONITORING

18. BAT is to monitor VOC emissions in order to be able to minimise them (see Section 20.3). A solvent management plan is the key technique to understand the consumption, use and emission of solvents, especially fugitive VOC emissions, see Section 20.3.1.

Additional techniques and information can be found in the Monitoring REF.

BAT is to use the relevant techniques referred to in Section 20.3.2 where direct measurements are used to determine emissions to air, such as emissions of VOC or particulates in waste gases, volumetric flow, etc.

19. BAT is to calculate solvent balances regularly (depending on the size of the emission) although key parameters can be established and substituted for regular control purposes (see benchmarking, Sections 20.1.1.(j), 20.1.2 and 20.3.1).

20. Certain equipment (e.g. fans, vents, waste gas treatment systems, etc.) has a large effect on the solvent balance. To ensure that emissions remain as estimated by the key parameters, it is BAT to ensure that such equipment is maintained regularly (see Sections 20.2.6 and 20.11.1.2). Where critical equipment (such as fan motors, drive pulleys or waste gas treatment) is changed, either the original specifications should be maintained (such as ensuring the motors have exactly the same specifications, drive pulleys are the same diameters, etc.), or the system should be recalibrated by direct measurement.

WATER MANAGEMENT

21. Water consumption in this sector is generally low, except where water-based techniques for substrate or workpiece pretreatment are used (see Paragraph 3). More information, as well as BAT and consumption and emission levels relating to these are discussed in detail in the STM BREF.

REDUCING, RE-USING AND RECYCLING RINSING WATER AND RAW MATERIALS

22. BAT is to conserve raw materials and water for water-based treatment techniques, such as by:

- cascade (multiple) rinsing, see Section 20.4.1.3
- recovering the raw materials and/or water by using techniques such as:
 - ion exchange, see Section 20.4.1.1
 - membrane separation or other concentration techniques, see Section 20.7.5.3
- using control measures to minimise the use of rinsing water (see Section 20.4.1.4).

Re-use/recycling of cooling water

23. Where water is used to cool equipment, process lines, etc., BAT is to reduce water consumption by using closed cooling systems and/or using heat exchangers, see Section 20.4.1.2.

ENERGY MANAGEMENT

24. BAT is to maximise energy efficiency and minimise energy losses by applying the measures in Section 20.5.

BAT for planning to reduce energy consumptions, gathering and using energy-specific data and maintenance techniques are given in BAT 12, 13 and 14.

BAT 28 deals with the selection of the treatment systems that optimised energy usage including drying and curing.

BAT 37 deals with optimising energy in solvent emissions to air and waste gas treatment.

Key techniques to reduce energy consumption are:

- maintenance and adjustment of equipment to the correct settings
- minimising the volume of air being moved, maximising the amount of solvent captured with minimum air intake, etc.
- minimising reactive energy losses by correcting the power factor ($\cos \phi$) between the voltage and the current peaks to ensure it lies permanently above 0.95
- avoiding or controlling high instantaneous demands during start up (e.g. by converting connections from star to delta for low loadings, using automatic delta to star converters, using soft-starters, etc.)
- using motors with appropriate power and/or using variable speed motors
- install energy efficient equipment, notably motors. Such equipment can be specified for new installations, refurbishments or for replacing defective equipment.

RAW MATERIAL MANAGEMENT (SEE SECTION 20.6)

Controlling environmental and toxicological impacts

25. BAT is to minimise the environmental impact of emissions by ensuring that the raw materials used have the lowest possible environmental impacts. This is especially important when substituting, or changing processes or suppliers (see Sections 20.6.2, 20.7, and 20.10).

Minimising raw material consumption (see Section 20.6.3)

26. BAT is to minimise raw material consumption by one or more of the following techniques:

- automated mixing systems, see Section 20.6.3.1
- programmable scales, see Section 20.6.3.1
- computerised Pantone matching systems, see Section 20.6.3.1
- re-use of returned inks or coatings, see Section 20.6.3.2
- re-use of recovered inks or coatings, see Section 20.6.3.3
- direct piping of inks or coatings from storage, see Section 20.6.3.4
- direct piping of solvents from storage, see Section 20.6.3.5
- batch painting/colour grouping, see Section 20.6.3.6
- pig-clearing systems, see Section 20.6.3.7.

COATING PROCESSES AND EQUIPMENT

Water-based pretreatments

27. The BAT for water-based pretreatments including:

- degreasing
- bath maintenance
- water and waste minimisation
- waste water reduction

are described in the STM BREF, see Paragraph 3 of this chapter. Examples are given in Sections 20.7.1.2 and 20.7.5.

DRYING/CURING FOR ALL SURFACE TREATMENTS

Coating systems, application and drying/curing techniques

28. When selecting a surface treatment process(es) (including drying/curing) either for a new plant or when upgrading an existing one, BAT is to select the system that:

- minimises:
 - solvents emissions
 - energy usage
- maximises raw material efficiency.

Generic techniques for coating are described in Sections 20.7.2 and 20.7.3. Other industry-specific coating and printing techniques are given in the industry-specific chapters.

Drying/curing techniques are usually the largest component of the energy consumption. Generic options are given in Section 20.8. Other industry-specific coating and printing techniques are given in the industry-specific chapters.

The choice of drying/curing technique will be limited by factors such as the type of surface treatment (e.g. specific paint or ink types are needed to react with UV or IR radiation) and other factors such as:

- those mentioned in the introduction to this chapter especially Paragraph 8
- substrate type, size and shape
- quality and type of finish required, including thickness
- the overall treatment system (i.e. previous and subsequent coats)
- the application technique to be used
- whether end-of-pipe waste gas abatement techniques are applied.

Total VOC emission levels associated with BAT are given in the industry-specific sections. Emission levels (or removal efficiencies) for various waste gas treatment techniques are given in Section 20.11.

CLEANING

Cleaning systems

29. BAT is to conserve raw materials and reduce solvent emissions by minimising colour changes and cleaning as described in BAT 26 (see Section 20.6.3).

Cleaning techniques

30. When cleaning spray guns, it is BAT is to minimise the release of solvent by collecting, storing and reclaiming for re-use the purge solvent used to clean coating spray guns and/or lines: 80 to 90 % can be re-used, see Section 20.9.3.

31. BAT is to minimise VOC emissions by using non-solvent or low solvent emission cleaning techniques such as one or more of those described in Section 20.9 (see Table 21.1 below):

Cleaning techniques		Process equipment		Substrate
Section	Technique	Non-persistent contamination	Persistent contamination	
20.9.2	Minimising cleaning	Yes	Yes	Yes
20.9.3	Preparation prior to solvent or other types of cleaning	Yes		
20.9.4	Conventional solvent cleaning	Yes*	Yes*	
20.9.5	Solvents with lower evaporation speed	Yes		
20.9.6	Cleaning with powerful solvents		Yes	
20.9.7	Cleaning with solvents with lower ozone forming potential (OFP)**	Yes	Yes	
20.9.8	Water-based cleaning	Yes	Yes	Yes
20.9.9	Cleaning by hand	Yes		Yes
20.9.10	Washing machines using solvents	Yes	Yes	
20.9.11	Cleaning with solvent recovery	Yes		
20.9.12	Cleaning with high pressure water spray		Yes	
20.9.13	Ultrasonic cleaning		Yes	Yes
20.9.14	Dry ice cleaning		Yes	Yes
* Conventional solvents should be used in conjunction with techniques to minimise emissions, such as in sealed washing machines venting to waste gas treatment, etc., as described in Section 20.9. Exceptions are given in Section 20.9.9				
** See BAT 36				

Table 21.1: Cleaning: techniques to use to reduce VOC emissions

USE OF LESS HAZARDOUS SUBSTANCES (SUBSTITUTION)

The applicability of the following BAT in each industry is discussed in the individual industry Chapters 2 to 19 and BAT Sections 21.2 to 21.19.

32. BAT is to reduce solvent emissions by selecting non-solvent or low solvent techniques, as discussed in the generic sections such as for:

- cleaning (see BAT 29, 30 and 31, and Section 20.10.1)
- the individual industry (Sections 21.2 to 21.19)
- coating (see Section 20.7)
- inking techniques (see Section 2.4).

33. BAT is to reduce adverse physiological effects by replacing solvents which have any of the following the risk phrases: R45, R46, R49, R60 and R61 with less hazardous solvents. This is to be achieved in accordance with Article 5(6) of Council Directive 1999/13/EC. Sections 20.9 and 20.10 describe alternative solvents and cleaning techniques.

34. BAT is to reduce the ecotoxic impacts of substances by using less hazardous substances in place of substances with the risk phrases R58 and R50/53 (where alternatives exist, see Section 20.10).

35. BAT is to reduce stratospheric (high level) ozone depletion by using less hazardous substances in place of substances with the risk phrases R59. In particular, all halogenated or partially halogenated solvents with the risk phrase R59 used in cleaning should be replaced or controlled using the options set out in BAT 31 and 32.

36. BAT is to seek to minimise the formation of tropospheric (low level) ozone:

- by using VOCs or mixtures with lower ozone formation reactivity where other measures to reduce fugitive or unabated solvent emissions to meet emission levels associated with BAT are not possible or not technically applicable, such as having unfavourable cross-media effects (see Section 20.10.2)
- where solvents are changed, by ensuring the substitution achieves a reduction in ozone formation reactivity (see Section 20.10.2). Note that the comparison should be made on the basis of the OPF load emitted to the troposphere (i.e. OPF x weight of solvent evaporated).

Replacing highly reactive aromatic solvents with alternatives of lower reactivity may reduce the reactive VOC emissions by 20 - 40 %.

However, this technique cannot be used for:

- complex formulations such as automotive paints and inks
- replacing solvent systems where no other technology currently exists, e.g. publication gravure.

Where the substitution can be shown not to increase the overall ozone-forming potential, substitution can be made by using solvents with a flashpoint of >55 °C.

EMISSIONS TO AIR AND WASTE GAS TREATMENT

37. For solvents, it is BAT is to use one or a combination of:

- minimising emissions at source (see industry specific sections)
- recovering solvents from the emissions in waste gases (see Sections 20.11.5 and 20.11.6)
- destruction of solvents in waste gases (see Sections 20.11.4 and 20.11.8)
- recovering the heat generated where VOCs are destroyed (see Sections 20.11.4.3 to 20.11.4.6)
- minimising the energy used in extraction and destruction of VOCs (see Section 20.11.1).

These can be achieved by designing, operating and maintaining an installation (see Sections 20.1.2 and 20.2) to achieve the consumption and emission levels associated with a selection of BAT given for specific industries in Sections 20.1.2 and 20.2 onwards. Waste gas treatment may not be necessary where the reduction in the emission of solvents may be achieved by other measures, such as substitution. Such replacement by low solvent materials can lead to excessive energy demands for operating end-of-pipe techniques such as thermal oxidisers. These techniques may be decommissioned where negative cross-media effects outweigh the benefits of destroying VOCs.

Solvent recovery from waste gases uses more energy than incineration, it is not as effective in capturing solvents and often the recovered solvents cannot be re-used because of either contamination with water or other solvents. With solvent mixtures, the recovered mixture often does not retain the same balance of ingredients or, therefore, properties.

38. Where solvent recovery is considered, BAT is to seek to ensure that most of the recovered material is re-used (it may not be possible in all cases to re-use the material on site). This re-use should not include burning as a fuel, as it is more effective to use autothermal oxidation, which simultaneously achieves lower solvent emission levels. Solvent recovery for new installations or upgrading of existing installations without re-use of the solvent is not BAT.

39. BAT is to seek opportunities to use excess heat from thermal oxidation. These may be within or external to the installation which may assist in matching the energy type produced (e.g. steam generated) to the potential use.

When recovering heat from the thermal oxidation of solvent emissions, all of the following apply:

- there must be excess energy to recover
- it must be technically possible to recover the energy
- the energy must be available in a usable form (e.g. high enough temperature, usable as steam, etc.)
- there must be a use for the energy at the same time as the excess heat occurs.

40. BAT is to save energy in the extraction and treatment of waste gases by reducing the volume extracted. This can be achieved by measures described in Section 20.11.2. However, some techniques may be limited by the need to maintain safe working atmospheres in the installation, the amount of residual solvent that can remain in the coated product, the smell of the products, and other quality requirements.

41. Where waste gases are extracted, BAT is to reduce solvent emissions and energy consumption while making the best use of high cost equipment by using the techniques given in Sections 20.11.1.3, 20.11.1.4, and 20.11.1.5.

42. Where waste gas treatment is applied, BAT is to optimise the solvent concentration to the treatment, and in thermal oxidation treatments to maintain autothermic conditions by using one or more of the following:

- optimising the concentration in the gas flow using techniques described in Sections 20.11.1.3, 20.11.1.4, and 20.11.1.5.
- minimising the amount of gas to be treated, see Sections 20.11.1 and 20.11.2, and bypassing peak flows (see Section 20.11.1.3)
- pretreating the gas to protect the treatment system and optimise solvent concentration as described in Section 20.11.3. However, if the effluent air is hot, it cannot be pretreated by absorption, e.g. see BAT 82.

43. Where particulate emissions are associated with paint spraying, BAT is to reduce emissions by applying either or both:

- in-process techniques such as described in Sections 20.7.4.1, 20.7.4.2 and 20.7.4.3
- end-of-pipe techniques described in Sections 20.11.3.5, 20.11.3.6, 20.11.3.7 and 20.11.3.8.

The following levels can be achieved:

- 5 mg/m³ or less for existing installations (e.g. for automotive applications, using conventional lateral scrubbers in conjunction with venturi particle separation)
- 3 mg/m³ or less for new installations (e.g. for automotive applications, using new scrubbers in conjunction with venturi particle separation).

Split view

The industry for the coating of furniture and wood recorded a split view against these values. According to the information in Sections 17.4.7.1 and 17.4.7.4, the emission values considered to be associated with BAT are 10 mg/m³ or less for all installations.

This value is based on what they believe to be economically and technically viable in the industry.

WASTE WATER TREATMENT

44. It is BAT to minimise emissions to water by (in this order):

- minimising emissions into water using techniques referred to in BAT 21, 22 and 23
- carrying out waste water treatment using pretreatment techniques described in Sections 20.12.1 to 20.12.4
- carrying out biological treatment (see Section 20.12.5), generally in a separate municipal waste water treatment plant.

Techniques for biological waste water treatment can be found in the CWW BREF. Other techniques and associated emission values are discussed in the STM BREF.

For specific installations, concentration levels should be considered in conjunction with the loads emitted from the installation, the installation's technical specification, e.g. throughput, as well as other BAT, especially measures to reduce water consumption (see the STM BREF).

45. Where solvents may be in contact with water, BAT is to prevent a hazardous level of solvent (e.g. explosive or potentially harmful to workers) in the atmosphere of receiving sewers by preventing unplanned discharges (See Section 20.2.1) or by ensuring a safe discharge level. A suitable level can be calculated, see Section 20.3.3.1.

46. Where the BOD or COD load is significant to the subsequent treatment, it is BAT to control the amount of organic chemicals that are difficult to treat in WWTPs by monitoring the ratio of COD:BOD in waste waters, see Section 20.3.3.2.

47. BAT is to monitor raw materials and effluents to minimise the emissions of materials toxic to the aquatic environment (see Section 20.3.3.3). Where such materials are found in quantities that may have an impact on the environment, quantities of materials discharged can be reduced by one or more of the following techniques:

- using less hazardous materials (see Section 20.10)
- reduction of material used and losses in production (see BAT 19 and 20)
- treatment of the waste waters (see Section 20.12 or the CWW BREF, and the STM BREF if the activities are in conjunction with activities described in that BREF).

Where such materials are discharged, BAT is to monitor the discharge in a manner and frequency suitable to minimise the risk of breach of permit conditions (see the Monitoring REF).

Paint shops

48. For paintshops where water is used in the process, treatment may be required prior to discharge. BAT is to use one or a combination of techniques described in Sections 20.7.5 and 20.12 for process water pretreatment. For direct discharge to surface waters the following ranges can be met:

- COD 100 - 500 mg/l
- suspended solids 5 - 30 mg/l.

49. For wet scrubber systems capturing paint overspray, BAT is to reduce water consumption and effluent treatment and discharges by reducing the frequency of tank emptying by both:

- optimising transfer efficiency (see Section 20.7.3)
- minimising the build-up of paint sludge (see Sections 20.7.5.6, 20.7.5.7 and 20.7.5.8).

MATERIALS RECOVERY AND WASTE MANAGEMENT

50. BAT is to reduce material usage, as described in BAT 26. BAT is also to prevent material losses, and recover, re-use and recycle materials. Of these, prevention and reduction of material losses are the priority. These can be achieved by applying a selection of the techniques described in Sections 20.1.2, 20.3.1, 20.6, 20.7 (especially Sections 20.7.3 and 20.7.5). BAT 14, 17, 18 and 25 are also relevant.

Recovery of used solvents

51. BAT is to recover and re-use solvents, either internally or using external contractors, as described in Sections 20.13.1, 20.13.2 and 20.13.5, see BAT 38 and 39 above.

52. BAT is to either reduce the number of containers disposed of by employing re-usable containers, re-use the containers for other purposes, or recycle the container material, see Section 20.13.6.

53. Where activated carbon or zeolite adsorption systems are used, BAT is to recover both the solvents and the absorption media, as described in Section 20.13.7.

54. After applying BAT 50 to 53 and where wastes cannot be recovered on- or off-site, it is BAT to minimise the hazardous contents and manage as wastes, using a selection of techniques from Sections 20.10, 20.13, and 20.13.8.

DUST ABATEMENT

55. See BAT 43.

ODOUR ABATEMENT

56. Where odour emissions cause nuisance at sensitive locations (usually due to the emission of VOCs), BAT is to reduce the odour using the techniques used to control VOC emissions, such as:

- changing the type of process (for example, see Sections 4 in Chapters 2 to 19 and Sections 20.7 and 20.10)
- changing the materials used (for example, see Sections 20.7 and 20.10)
- using waste gas treatment (see Section 20.11)
- the installation of high stacks for waste gas emissions.

NOISE

57. BAT is to identify significant noise sources and potential sensitive receptors in the vicinity of the installation (see Section 20.16).

58. Where noise may have an impact, BAT is to reduce the noise by using appropriate control measures (see Section 20.16), such as:

- effective plant operation, for example:
 - closure of bay doors
 - minimising deliveries and adjusting delivery times
- using engineered controls such as installation of silencers to large fans, use of acoustic enclosures, avoiding the installation of equipment with high or tonal noise levels, etc.

GROUNDWATER AND SOIL PROTECTION AND SITE DECOMMISSIONING

59. BAT is to prevent emissions to groundwater and soil, and thereby aiding site decommissioning by applying the techniques described in BAT 15 and 16.

21.2 Best available techniques for printing

The Introduction to this chapter (in the Section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

BAT conclusions are given for three printing processes that are likely to be found operating above the threshold as found in Annex 1, 6.7 to the IPPC Directive:

- heatset offset, see Section 21.2.1
- flexography and packaging gravure, (including associated varnishing and lamination) see Section 21.2.2
- publication gravure, see Section 21.2.3.

Other printing processes may be found in the same installation as associated activities, or occasionally operating above the threshold. For such activities, where specific BAT are not described, the generic BAT for the sector set out in Section 21.1 apply.

21.2.1 BAT for heatset web offset

Reduction of solvent emissions

The VOC emissions from heatset printing consist of IPA emitted from the dampening solutions (see BAT 61) from cleaning agents (see BAT 62) and the stack emissions from driers (see BAT 63).

60. BAT is to reduce the sum of fugitive emissions and the VOCs remaining after waste gas treatment (see Table 2.9, and Section 2.3.2.1) by using a combination of the techniques in BAT 61, BAT 62 and BAT 63 as well as the generic BAT described in Section 21.1. Emission values associated with these techniques are (see Section 2.3.2.1):

- for new or upgraded presses, 2.5 to 10 % VOC expressed as wt-% of the ink consumption
- for existing presses, 5 to 15 % VOC expressed as wt-% of the ink consumption.

The use of wt-% of the ink consumption enables the measures taken to be assessed, whereas using % solvent input does not (see Section 2.3.2.3.1), as several of the techniques to be used involve a reduction of the solvent input itself.

IPA in dampening solutions

61. BAT is to reduce the emission of IPA by printing using low IPA concentrations in the dampening solution by using all or a combination of the following techniques shown in Table 21.2:

Technique	Cross-reference	Applicability
Replacement of IPA in the dampening solution	2.4.1.3.1	All
Optimising the concentration of IPA in the dampening solution	2.4.1.3.2	All applying IPA
Ceramic, metal and hydrophilic distributing and plate rollers	2.4.1.3.3	Retrofit possible, generally with hydrophilic rollers
Exact adjustment of the inking rollers	2.4.1.3.4	Retrofit not possible
Cooling the dampening solution	2.4.1.3.6	All
Cooling the dampening rollers and plate cylinders	2.4.1.3.7	Retrofit not possible
Removal of IPA solutions overnight from the dampening unit	2.4.1.3.8	All
Filtering the dampening solution	2.4.1.4	Required when running low IPA concentrations
Controlling the hardness of the water for the dampening solution	2.4.1.5	Retrofit possible

Table 21.2: Heatset printing techniques to reduce IPA usage in the dampening solution

Note that IPA emissions associated with the top half of the ranges given in BAT 60 are associated with ‘difficult’ jobs. The definition of ‘difficult’ is subjective and depends on the factors below. BAT is therefore to carry out trials to determine the lowest possible IPA consumption for the presses and the lowest possible volatility for cleaning agents (see Cleaning, BAT 62, below). The top half of the emission ranges can only be considered to be associated with BAT if this optimisation has been demonstrated (see Section 2.3.2.1).

For example, ‘difficult’ jobs involve one or more of the following factors:

- changes in the surface of the paper requiring numerous fine changes to settings of the press
- situations of high ink coverage where IPA prevents the occurrence of white spots
- new wide, fast presses.

Lower levels of skill, education and experience of operators also contribute to higher emissions, and BAT 17 addresses training needs.

Waterless offset has no VOC emissions from the dampening solution, and may be used in sheetfed printing (see Section 2.4.1.8). Generally, its maximum possible run length is considered lower than that required for heatset work, and it is currently rarely used for this process, although this may change in the future.

Cleaning

62. BAT is to reduce other fugitive VOC emissions by the following techniques in Table 21.3:

Technique	Cross-reference	Applicability
Replacement and control of VOCs used in cleaning	2.4.1.8.1	All
High pressure water cleaners for dampening rollers	2.4.1.8.2	Only for molleton rollers
Automatic cleaning systems for printing and blanket cylinders	2.4.1.8.3	All. Retrofitting costs are high

Table 21.3: Heatset techniques to reduce fugitive emissions from cleaning

Waste gas collection and treatment

63. BAT for waste gases and fugitive emissions is to both:

- reduce emissions of VOC by applying extraction and thermal, catalytic, recuperative or regenerative incineration of air from the driers using a combination of techniques described in Section 20.11.
- reduce VOC emissions by applying the maintenance techniques in Section 20.11.1.2.

64. It is not BAT to apply concentration techniques to the waste gas as this causes problems with odour with the finished product, see Section 2.3.2.3.1.

65. As the ventilation airflows resulting from the ventilation of the pressroom and press enclosure are large and their VOC concentrations are very low, it is therefore not BAT to treat the air from the extraction of the pressroom or the press enclosure. There is a better cost-benefit for applying BAT 60 to 63.

66. Presses are usually encapsulated, but this is for health and safety reasons, and usually does not assist in reducing VOC emissions.

21.2.2 BAT for flexography and packaging gravure (flexible packaging printing)

Reduction of solvent emissions

67. BAT is to reduce the sum of fugitive emissions of VOC and the VOCs remaining after waste gas treatment, using a combination of techniques described below in Table 21.4 and generic BAT in Section 21.1. Emission values of VOC associated with these techniques (see Section 2.3.3.3.1) are given for the three scenarios that occur in the industry (the reference emission is as derived in the SED, see Annex 24.2):

Scenario 1: installations where all production machines using solvent-based inks, varnishes and adhesives are connected to waste gas abatement equipment and where other production machines are (almost) solvent-free, e.g. solvent-free adhesive, waterborne inks, etc.

- with oxidation, total emissions 7.5 - 12.5 % of the reference emission
- with solvent recovery, total emissions 10.0 - 15.0 % of the reference emission.

Scenario 2: in existing installations, where there is waste gas abatement equipment, but not all solvent-based production machines are connected due to technical or economic reasons. These installations will be using a reduction scheme (see Annex 24.2) combining:

- abatement equipment for some machines
- low fugitive emission processes with the solvent-based processes on machines which are connected to the abatement equipment
- substitution.

Scenario 2.1: the sum for the emissions for the machines that are connected to the abatement equipment is:

- with incineration, 7.5 - 12.5 % of the reference emission relating to those machines
- with solvent recovery, 10.0 - 15.0 % of the reference emission relating to those machines.

Scenario 2.2: for the machines not connected to waste gas treatment, BAT is to use one of the following techniques:

- use low solvent or solvent-free products on these machines
- connect to the waste gas abatement equipment at the times when there is capacity (for instance when permanently connected machines are standing idle)
- preferentially run high solvent content work on machines connected to waste gas abatement.

Scenario 3: where installations have no waste gas abatement equipment and are using substitution (see Annex 24.2), it is BAT to follow the progress in the developments of low solvent and solvent-free inks, varnishes and adhesives, and to continuously decrease the amount of solvents consumed, see BAT 13 and 14.

Where in scenario 1 or scenario 2.1, an installation has a solid:solvent ratio of higher than 1:5.5 for the total of the solvent-based inks, varnishes and adhesives, the emission values may not be attainable. In these cases, where the solvent:solid ratio cannot be reduced, it is BAT to cover the ink fountains or apply chamber doctor blades and to apply other techniques, such as those given in Table 21.4.

Technique	Cross-reference	Applicability
Substitution using water-based inks, UV-curing or electron beam-curing	2.4.2.2	Not applicable on equipment where waste gas is treated
Substitution using water-based, high solids, UV-curing or solvent-free adhesives and varnishes or co-extrusion	2.4.2.4	Not applicable on equipment where waste gas is treated
Extract and treat air from driers	2.4.2.5	Where little or no substitution has taken place. Not applicable on some existing equipment with high airflows and low VOC concentrations
Extraction from the presses and other production areas: Covering ink fountains or using chamber doctor blades	Table 2.33 and 2.4.2.5.2	All
Concentration of solvents in waste gas flow	20.11.3.1	Where waste gas is treated
Extract and treat air from automatic cleaning machines	2.4.2.5.1 20.9.10	Where waste gas is treated
Optimisation of incinerator usage	2.4.2.5.3	Where waste gas is treated
Optimisation of VOC concentration to incinerator by variable speed fan	20.11.1.5	Where waste gas is treated
Automatic and timely closure of bypass systems	2.4.2.5.5	Where waste gas is treated
Substitution using low or non-VOC cleaning materials	2.4.2.6.1 20.9	All
In-press cleaning of cylinders	20.9.10	New presses
High pressure water cleaning	20.9.12	Limited to in-depth cleaning and anilox rollers
Other non-solvent cleaning techniques	20.9, 20.10	All

Table 21.4: Flexography and packing gravure techniques to reduce VOC emissions

Waste gas collection and treatment

68. BAT for waste gases and other fugitive emissions is to:

- reduce emissions of VOC by applying extraction and treatment of air from the driers using a combination of techniques described in Section 20.11
- apply a selection of the techniques in Section 20.11.1.1 to minimise energy consumption and to optimise the waste gas treatment
- reduce VOC emissions by applying the maintenance techniques in Section 20.11.1.2.

69. Where thermal waste gas treatment is used, BAT is to seek opportunities to recover and use any surplus energy, see Section 20.11.4.4.

21.2.3 BAT for publication gravure

Reduction of solvent emissions

70. BAT is to reduce the sum of fugitive emissions and the VOCs remaining after gas treatment:

- for new plants, to 4 to 5 %, using techniques 1, 2, 3, 6, 10 and 11 in conjunction with 8, or 8 and 9 in Table 21.5
- for existing plants, to 5 to 7 %, using techniques using 1, 2, 10, 11 and one of 4, 5, 6, or 7 in Table 21.5 expressed as a percentage of the total solvent (toluene) input as described in Sections 2.3.4.1 and 2.3.4.3.1. These ranges also include using a combination of the energy consumption in BAT 71 as well as generic BAT in Section 21.1.

	Technique	Cross-reference	Applicability
1	Waste gas treatment by adsorption and recovery of toluene	20.11.6.1	All
2	Using retention inks	2.4.3.2.2	All
3	Increasing drying time	2.4.3.3.2	New only
4	Continuous air extracting from the driers	2.4.3.3.4	Existing if waste gas treatment capacity is sufficient
5	Enclosed press air is routed to waste gas treatment discontinuously	2.4.3.3.5	Existing
6	Enclosed press air is routed to waste gas treatment when solvent is handled in the press area and there is airflow to the pressroom	2.4.3.3.6	New. Retrofit not possible
7	Discontinuous air extraction from the press, driers, and pressroom	2.4.3.3.7	Existing
8	Air extraction from the press, driers, and pressroom when solvent is handled in the press area and there is airflow to the pressroom	2.4.3.3.8	New
9	Closed loop air ventilation	2.4.3.3.9	New if the cost benefit is sufficient
10	Air knives on the printed web	2.4.3.3.10	New
11	In-press cylinder cleaning	2.4.3.4.1	New

Table 21.5: Publication gravure techniques to reduce VOC emissions

The use of water-based inks is not currently recommended or often specified, as it significantly increases the difficulty of recycling the printed products.

71. It is BAT to prevent the excessive use of energy by using the optimum number of regenerations required to maintain emissions within the emission values expressed in BAT 70, see Section 20.11.6.1.

Waste water from toluene recovery

72. Steam condensates from toluene recovery are usually discharged to municipal waste water treatment plants. It is BAT to reduce the emissions of toluene to municipal sewers to 10 mg/l or less by air stripping, see Section 2.3.4.3.3. The level discharged should be maintained below a level where a harmful atmosphere may occur in the sewer (see Section 20.3.3.1) as well as minimising the impact in the water cycle.

21.3 Best available techniques for winding wire manufacturing

The Introduction to this chapter (in the Section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

Energy consumption

73. BAT is to minimise energy consumption after drying the wire by cooling the wire using room and/or exterior air (see Section 3.4.2.1).

Reduction of solvent emissions

74. BAT is to minimise total VOC emissions by one or both of the following techniques as well as the generic BAT in Section 21.1:

- using low solvent-based materials and/or processes (in-process, see Sections 3.4.4, 3.4.5, and others in Section 20.10)
- using a suitable combination of the waste gas treatment techniques as described in Section 3.4.6 (see also Section 20.11).

Total emission values (including fugitive emissions) for VOC associated with these techniques are (see Section 3.3.3.1):

- for non-fine wires (>0.1 mm diameter) 5 g/kg or less (g VOC/kg product)
- for fine wires (0.01 - 0.1 mm diameter) 10 g/kg or less.

Solvent emissions from lubricant coatings

75. BAT is to follow progress in developments reducing emissions from lubricant coatings (such as low or no solvent techniques, see Section 3.4.5.6) and to seek to reduce VOC emissions further.

21.4 Best available techniques for the manufacturing of abrasives

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

Reduction of solvent emissions

76. BAT is to reduce total VOC emissions by one or more of the following techniques in conjunction with the generic BAT described in Section 21.1:

- using low or no solvent-based bonding materials. This can be done when water cooling is not required during the process, e.g. for the manufacture of dry grinding abrasives (see Sections 4.4.2.1 and 20.8)
- increasing the internal solvent concentration in the driers (see Sections 4.4.4.1 and 20.11.3.1)
- using a suitable combination of the waste gas treatment techniques described in Section 20.11 (see also Section 4.4).

Total emission values for VOC associated with these techniques are 9 - 14 wt- % of the solvent input (see Section 4.3.1).

21.5 Best available techniques for the manufacturing of adhesive tape

The Introduction to this chapter (in the section 'Some aids to understand this chapter', Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

Reduction of solvent emissions

77. For the production of tapes using solvent-based adhesives, BAT is to reduce VOC emissions by using a combination of the following techniques in conjunction with the generic BAT described in Section 21.1:

- using non-solvent-based adhesives when manufacturing a lower quality range of packaging and masking tapes, as well as double-sided tapes (see Section 5.4.2 and 20.10)
- using one of the following waste gas treatments or combinations: a+b, a+c, b, or c, where:
 - a) condensation (see Sections 5.4.5.1 and 20.11.5.3) after a pre-drying step using an inert gas drier (see Sections 5.4.4.1 and 20.8.1.2)
 - b) adsorption (see Sections 5.4.5.2, 20.11.6.1 and 20.13.7.1) with a recovery efficiency of more than 90 % of the solvent input and direct emissions after this abatement technique of less than 1 %
 - c) oxidisers with energy recovery (see Section 20.11.4)

Emission values associated with these techniques are total VOC emission of 5 wt-% or less of the solvent input (see Section 5.3.1).

Where production uses water-based and hot melt adhesives (see Section 5.4.2) only very small quantities of solvents are used, such as in cleaning, and there are virtually zero emissions. However, they can only be used for specific types of tape and applications.

21.6 Best available techniques for the coating of cars

The Introduction to this chapter (in the section 'Some aids to understand this chapter', Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

78. The paint process in vehicle manufacturing is highly complex and fully integrated, see Section 6.4.1. Choices of paint and application systems impact heavily on choices of driers and waste gas treatment. As some techniques are incompatible, BAT cannot be ascertained for each individual step.

Energy consumption

79. Section 6.3.2.3 shows that 38 to 52 % of the total energy consumption of a typical body paint and assembly plant for cars is used in the paintshop. BAT is therefore to minimise the energy consumption in the selection and operation of painting, drying/curing and associated waste gas abatement systems discussed in BAT 78 and 80.

Joint BAT

80. BAT is to minimise solvent emissions, as well as energy and raw material consumptions, by selecting paint and drier systems in accordance with BAT 28 and Sections 6.4.1, 6.4.2, 6.4.3, 6.4.4, 6.4.5 and 6.4.7, in conjunction with waste gas treatment techniques described in BAT 37 to 42.

Emission values of VOC associated with the BAT referred to above are 10 - 35 g/m² (see Section 6.3.3.1), (or 0.3 kg/body + 8 g/m² to 1.0 kg/body +26 g/m² equivalent) where the emissions and the surface area as the e-coat area are determined according to Annex 24.5.

Two installations have achieved 10 g/m² or less (shown in Figure 6.2) by using a combination of:

- greenfield site and new plant
- novel green technologies
- techniques that may not be usable elsewhere, e.g. the finishes achieved do not currently meet other manufacturers' quality requirements.

81. BAT for existing plants is to establish and implement plans to reduce consumptions and emissions (see BAT 13) and to achieve the emission values in BAT 81, bearing in mind the cross-media effects and cost benefits, high capital costs and long payback periods to achieve these values. It is important to note the following:

- the investment costs and payback periods are discussed in Section 6.1, and other factors affecting implementation of BAT can be found in Paragraph 7
- there are two types of techniques that can applied to reduce VOC emissions:
 - (a) techniques that can be implemented in a shorter time scale such as those given in Table 21.6 below (such as one to three years):

Section	Techniques	Specific groups of techniques to consider
20.1	Environmental Management Systems	Ongoing improvement (Section 20.1.2)
20.2	Installation design, operation and management	Automation (Section 20.2.3) especially of spaying and paint delivery (see also Section 20.6)
20.6	Raw material management	All
20.7.3	Paint application processes and equipment	Changing to more efficient spraying systems: HVLP, Section 20.7.3.9 Airless spraying, Section 20.7.3.11 Electrostatically assisted high rotation bells, Section 20.7.3.15 Electrostatically assisted high rotation discs, Section 20.7.3.16 Electrostatically assisted compressed air, airless and air assisted, Section 20.7.3.17
20.9	Cleaning techniques	
20.10.1	Replacement of cleaning agents (substitution)	(noting substitution BAT 31 to 36)
20.11	Waste gas treatment	

Table 21.6: Vehicle coatings: techniques to reduce VOCs that can be implemented in the shorter term

(b) techniques that achieve major step decreases in VOC emissions. These involve changing the type of paint system and/or the paint application system and/or the drying system (see BAT 79, above). This usually involves either a new installation or a complete refurbishment of a paintshop and requires significant capital investment.

An important factor, therefore, in the decision of what is appropriate at a particular existing installation is the age of the paintshop (see Section 6.1, and the factors affecting implementation of BAT, Paragraph 6).

It may be both technically beneficial (i.e. a greater reduction in VOC emissions achieved over a longer period) and more cost-effective to delay implementation until a rebuild, e.g. where the paintshop is near the end of its investment cycle. In other cases, such a delay may offer little benefit.

82. Where spray booth waste gas treatment is applied to reduce VOC emissions, BAT is to concentrate the VOC as a pretreatment using techniques described in Section 20.11.3.2. In the automotive industry, it is achievable to concentrate the VOC by a factor in the range 1:10 and 1:15.

This BAT does not apply to waste gases from oven abatement due to the high waste gas temperature (see Section 20.11.3.2).

Particulate emissions to air

83. BAT to reduce airborne particulates are addressed in BAT 43.

Materials efficiency

84. Emission levels associated with BAT to minimise solvent consumption are included in the emission levels for VOC in BAT 80.

85. It is BAT to optimise transfer efficiency of coatings. The following techniques have the highest transfer efficiencies (see Section 20.7.3):

- robot application (see Section 20.2.3)
- dipping instead of spraying
- electrostatic application
- HVLP (high volume low pressure) guns
- booth optimisation.

However, there are technical limitations. For example, conventional spray guns and manual spraying may be necessary for restricted areas where HVLP (high volume low pressure) or electrostatic guns cannot be used, or cannot obtain quality or meet operational requirements, such as in low volume manufacturing.

Emissions to water

86. BAT for wet scrubber systems are described in BAT 49

87. BAT to minimise water pollution are addressed in BAT 44 to 49.

Waste

88. BAT is to minimise waste production from painting by both:

- reducing paint overspray generation by optimising transfer efficiency
- either dewatering paint sludge before disposal, recycling paint sludge or using the water emulsion technique (see Sections 20.7.5.6, 20.7.5.7 and 20.7.5.8).

21.7 Best available techniques for the coating of vans, trucks and truck cabs

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

89. The paint process in vehicle manufacturing is highly complex and fully integrated, and is further complicated for trucks and commercial vehicles for technical and economic reasons, see Sections 7.3.3.1 and 7.4. Choices of paint and application systems impact heavily on choices of driers and waste gas treatment. BAT cannot therefore be ascertained for each individual step.

Joint BAT

90. BAT is to minimise solvent emissions, as well as energy and raw material consumptions, by selecting paint and drier systems in accordance with BAT 28 in conjunction with waste gas treatment techniques described in BAT 37 to 42.

The total solvent emission values of VOC associated with the BAT referred to above are (see Section 7.3.3.1):

- for the coating of new truck cabs 10 - 55 g/m²
- for the coating of new vans and trucks 15 - 50 g/m²

where the emissions and the surface area as the e-coat area are determined according to Annex 24.5.

91. BAT for the planning and implementation of reductions in consumptions and emissions are given in BAT 81.

92. BAT is to reduce solvent emissions from cleaning to 20 g/m² or less using good practice in housekeeping, cleaning, and substitution techniques, such as those referred to in Sections 20.2.2, 20.9 and 20.10 (see Section 7.3.3.1).

93. BAT is to reduce solvent emissions from the application of noise dampening and floor covering materials by the use of solvent-free polyurethane or PVC materials applied with airless spraying (see Section 8.2.8).

Particulate emissions to air

94. BAT to reduce airborne particulates are addressed in BAT 43.

Materials efficiency

95. Emission levels associated with BAT to minimise solvent consumption are included in the emission levels for VOC in BAT 92.

96. BAT to maximise transfer efficiency of coatings are described in BAT 85 (see Section 20.7.3).

Emissions to water

97. BAT for wet scrubber systems are described in BAT 49.

98. BAT to minimise water pollution are addressed in BAT 44 to 49.

Waste

99. BAT to minimise waste production from painting are described in BAT 88.

21.8 Best available techniques for the coating of buses

The Introduction to this chapter (in the section 'Some aids to understand this chapter', Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

100. The paint process in vehicle manufacturing is highly complex and fully integrated, and is further complicated for buses for technical and economic reasons, see Sections 8.3.3.1 and 8.4. Choices of paint and application systems impact heavily on choices of driers and waste gas treatment. BAT cannot therefore be ascertained for each individual step.

Joint BAT

101. BAT is to minimise solvent emissions, as well as energy and raw material consumptions, by selecting paint and drier systems in accordance with BAT 28 in conjunction with waste gas treatment techniques in accordance with BAT 37 to 42.

The emission values of VOC associated with BAT referred to above are 92 - 150 g/m² for the coating of new buses (see Section 8.3.3.1), where the emissions and the surface area as the e-coat area are determined according to Annex 24.5.

102. BAT for the planning and implementation of reductions in consumptions and emissions are given in BAT 81.

103. BAT is to minimise solvent emissions from cleaning to 20 g/m² or less using good practice in housekeeping, cleaning, and substitution techniques such as those referred to in Sections 20.2.2, 20.9 and 20.10 (see Section 8.3.3.1).

104. BAT is to reduce solvent emissions from the application of noise dampening and floor covering materials by the use of solvent-free polyurethane materials applied with airless spraying (see Section 8.2.8).

105. BAT is to minimise solvent emissions by using pre-coated (coil-coated) materials for the construction of vehicles (see Section 9.3.3).

Particulate emissions to air

106. BAT to reduce airborne particulates are addressed in BAT 43.

Materials efficiency

107. Emission levels associated with BAT to minimise solvent consumption are included in the emission levels for VOC in BAT 101 and 103.

108. BAT to maximise transfer efficiency of coatings are described in BAT 85 (see Section 20.7.3).

Emissions to water

109. BAT for wet scrubber systems are described in BAT 49.

BAT to minimise water pollution are addressed in BAT 44 to 49.

Waste

110. BAT to minimise waste production from painting are described in BAT 88.

21.9 Best available techniques for the coating of trains

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

Solvent emissions to air

111. BAT is to reduce VOC emissions by using a combination of the following techniques in Table 21.7 as well as the generic BAT described in Section 21.1:

Technique	Section	Applicability
Material specific techniques:		
Application of water-based ground coats, primers and topcoats	9.3.3 and 9.4.2.1	
Application of a conventional clear coat	9.3.3 and 9.4.1	Only for two-layer lacquer finishes
Water-based primers and underbody protection in combination with thick layer materials	9.3.3 and 9.4.1	
Water-based primers and fillers	9.3.3 and 9.4.2.1	
Use knifing fillers with low styrene content	9.3.3	
Use high solid paints	9.4.2.2	For 1-coat topcoat where water-based topcoat not used
Use pre-coated (coil-coated) materials for new construction of rail vehicles	9.3.3	
Process specific techniques:		
Application of dipping, conventional or electrocoat	20.7.2.3	
Application of solvent-free polyurethane noise dampening and floor covering materials	8.2.8	Where noise dampening and floor covering is applied
Reduction of painted surfaces, for example, by the use of adhesive foils for decorative designs or as graffiti protection	9.3.3	
Efficient application devices: HVLP, airless and air assisted airless spraying	9.3.3 and 9.4.3.2	
Recycling of cleaning agents via distillation of solvent containing paint wastes and paint sludge	9.3.3, 20.13.1 and 20.13.2.2	
Thermal oxidiser to treat the waste gases	9.3.3 and 9.4.6.5	Waste gases from the driers

Table 21.7: Trains: techniques to reduce solvent emissions to air

The emission values of VOC associated with these techniques are 70 – 110 g VOC/m² of the painted area, see Section 9.3.3.1 (see Annexes 24.2. This is not the e-coat area, as determined according to Annex 24.5).

Particulate emissions to air

112. BAT is to reduce particulate emissions by applying a suitable combination of the following techniques:

- improving absorption efficiency through venturi centrifugation (see Section 20.11.3.4)
- scrubbers (see Section 9.4.6.2)
- dry filter systems (see Section 9.4.6.3)
- electrostatic filters (see Section 9.4.6.4).

The emission values associated with these techniques are 3 mg/m³ or less.

21.10 Best available techniques for the coating of agricultural and construction equipment (ACE)

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

Solvent emissions to air

113. Paint and application systems may be interdependent, and the selection of waste gas collection and treatment also depends on these choices. It is BAT to select a paint and drier system in accordance with BAT 28 in conjunction with waste gas treatment systems in accordance with BAT 37 to 42. Suitable techniques can be selected from Table 21.8, Table 21.9 and Table 21.10 below, as well as from BAT 114 and 115.

In the expert judgement of the TWG, emission levels of VOC associated with the BAT referred to above are either:

- emissions of 20 - 50 mg C/m³ in waste gas and 10 - 20 wt- % of solvent input for fugitive emissions or
- overall emissions of 0.2 - 0.33 kg VOC per kg of solids input.

Technique	Cross-reference	Applicability
2-component epoxy primer waterborne, 2-component topcoat waterborne	20.7.2.3	
Water-based dip coating, two stages	20.7.2.3	
Electrocoating + waterborne dip coating	20.7.2.3	
Electrocoating + 2-component topcoat (solventborne or waterborne) sprayed on visible surfaces	20.7.2.2, 20.7.2.3	
Powder coating	20.7.2.5	New or upgraded plant

Table 21.8: ACE: techniques related to coating materials

Technique	Cross-reference	Applicability
Switch from spray application to conventional dip coating	20.7.3.3	Where components are a suitable size
Switch from spray application to electrocoat primer	20.7.3.4	Where components are a suitable size
Switch from two layer system to single layer electrocoating	20.7.3.4	Where components are a suitable size
Switch to powder coat top coat	20.7.3.18	New or upgraded plant

Table 21.9: ACE: application techniques

Techniques	Cross-reference	Applicability
Filtering of particle emissions	20.11.3.5	Where water-based coatings are used
Enclosure of pretreatment installation and exhaust air treatment	20.11 and 20.11.3.7	Solvent coatings
Abatement of oven exhaust air	20.11	Solvent coatings
Abatement of dipping tank exhaust air (adsorption, incineration)	20.11	Solvent coatings

Table 21.10: ACE: waste gas treatment techniques

Substitution

114. It is BAT to use other coating systems in place of paints based on halogenated solvents (see BAT 33 and 34). Other coating systems are readily available (see Sections 20.7 and 20.10).

For halogenated cleaning solvents, see BAT 33 and 35.

115. It is BAT to use dip coating (see Sections 10.2, 10.4 and 10.4.3) on components prior to assembly to:

- reduce solvent emissions by reducing spray
- improve materials efficiency (depending on coating thickness required)
- reduce the amount of airflow and therefore size and energy consumption of extraction and abatement equipment.

Particulate emissions to air

116. BAT to reduce airborne particulates are addressed in BAT 43.

21.11 Best available techniques for the coating of ships and yachts

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

117. The sale and use of antifouling containing tributyltin oxide (TBTO) is controlled by EU legislation, see Section 11.2.3. Options for less ecotoxic antifouling coatings are described in Section 11.4.5.

118. BAT is to minimise the emissions to the environment by ensuring that the BAT in this section are included in the dry dock discipline for the installation.

Solvent emissions to air

119. BAT is to reduce VOC emissions by a combination of the following techniques in conjunction with the generic BAT described in Section 21.1:

- using water-based, high solids or 2-component paints (with or without using hot spraying, see Section 11.4.4.2) instead of traditional solvent-based paints (see Section 11.4.2). The extent of substitution may be limited by the customer requirements and the technical requirements for the coating
- reducing overspray and increasing application efficiency (see Section 11.4.6) by keeping the overspray at the bottom of the dry dock by:
 - the use of nets, water curtains or other methods
 - limiting spraying in weather conditions where the wind intensity and direction will increase overspray
- for new construction, spraying the sections constructed prior to assembly (‘block stages’) in enclosed areas (see Section 11.2.1)
- extracting air from enclosed areas where spraying is carried out and applying a suitable combination of the waste gas treatment techniques described in Section 20.11 (see also Section 11.4.6.3).

Particulate emissions to air

120. BAT is to reduce dust particulate emissions to air by one or more of the following techniques:

- containing the dust and any abrasive and removed paint particles within the dock or the slipway by:
 - the use of nets and/or water curtains or another similar method
 - limiting paint removal with an abrasive in weather conditions where the wind intensity and direction will increase dust drift
 - the use of shroud blasting or vacuum blasting, high pressure water or slurry blasting, (see Sections 11.4.3.2, 11.4.3.3, 11.4.3.4) according to technical requirements.

121. BAT is to reduce waste water contamination by removing paint residues, leftovers and containers, used abrasives, mud, oil residues and any other scrap materials from the dock before flooding. These materials are to be kept in containers for proper management, e.g. re-use and/or disposal (see Sections 11.3.3.1 and 20.12).

21.12 Best available techniques for the coating of aircraft

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

122. Aircraft construction and maintenance needs type approval for safety, and the manufacturers’ corrosion protection guarantee lasts for 25 years. This may limit some BAT options, as only specific paint systems can be utilised.

123. BAT is to eliminate the emissions of Cr(VI) to the water environment by using alternative passivation processes in place of Cr(VI) for wash primer where type approval exists (see Section 12.4.3).

124. BAT is to reduce VOC emissions by all or a combination of the following techniques in conjunction with the generic BAT described in Section 21.1:

- using high solids or 2-component paints in place of higher solvent content materials (see Section 12.4.2.1)
- encapsulating/enclosing waste gases at the point of application and for component parts (see Sections 12.3.1.1 and 12.4.5.3) as components are 80 % of surface area
- applying a suitable combination of the waste gas treatment techniques described in Section 20.11 (see also Section 12.4.5) waste gases
- reduction or replacement of solvents used in cleaning (see Sections 20.9 and 20.10), automation of cleaning equipment (see Section 20.2.3) such as measuring solvent used for cleaning, and reduction in emissions in storing and use (see Sections 20.2.2.1 and 20.2.3) especially the use of pre-impregnated wipes for cleaning.

Particulate emissions to air

125. BAT is to reduce dust emissions by either:

- improving absorption efficiency through venturi separation (see Section 12.4.5.1)
- using a scrubber (see Section 12.4.5.2).

The associated emission values are 1 mg/m³ or less.

21.13 Best available techniques for the coating of other metal surfaces

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

Joint BAT

126. Paint and application systems may be interdependent and will be selected for the type of workpiece and substrate to be coated. The selection of waste gas collection and treatment also depends on these choices. It is BAT to select paint and drier systems in accordance with BAT 28 in conjunction with waste gas treatment techniques in accordance with BAT 37 to 42.

Solvent emissions to air

127. BAT is to reduce VOC emissions by using one or a combination of the following techniques in conjunction with the generic BAT described in Section 21.1:

- low solvent paints (see Section 20.7.2)
- VOC abatement techniques in BAT 126.

In the expert judgement of the TWG, emission values of VOC associated with these techniques are 0.1 to 0.33 kg VOC/kg solid input (as discussed in Annex 24.2). These levels do not apply where metal automotive components are coated in an installation and where these emissions are included into the mass emission rate calculation for the serial coating of vehicles (see Sections 21.6, 21.7 and 21.8).

128. BAT is to use other coating systems instead of paints based on halogenated solvents (see BAT 33 and 34). Other coating systems are readily available (see Sections 20.7 and 20.10).

For halogenated cleaning solvents, see BAT 32 and 35.

Materials efficiency

129. BAT is to reduce material consumption (including solvent use) by using high efficiency application techniques (see Section 20.7.3).

21.14 Best available techniques for coil coating

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1. The industry uses water-based pretreatment processes (e.g. degreasing, electroplating, conversion coatings, etc.) and BAT relating to these are discussed in the BAT reference document on the STM BREF, see Paragraph 3.

Energy consumption

130. BAT is to reduce energy consumption using a selection of the techniques in Section 20.5 and energy recovery from thermal waste gas treatment, see Section 20.11. Consumption values associated with BAT are shown in Table 21.11 (see Section 14.3.2.3):

Energy used/1000 m ² of substrate	Minimum	Maximum
Electricity used as kWh/1000 m ² of aluminium	270	375
Electricity used as kWh/1000 m ² of steel	250	440
Fossil fuels as MJ/1000 m ² of aluminium	4000	9800
Fossil fuels as MJ/1000 m ² of steel	3000	10200

Table 21.11: Coil coating: energy consumption for coating of aluminium and steel substrates

Solvent emissions to air

131. BAT is to reduce solvent emissions by a combination of techniques such as from Table 21.12 as well as the generic BAT described in Section 21.1. The emission values of VOC associated with these techniques are (see Section 14.3):

- for new plants: 0.73 - 0.84 g/m² for waste gases, and 3 – 5 % for fugitive emissions
- for existing plants: 0.73 - 0.84 g/m² for waste gases, and 3 – 10 % fugitive emissions.

See Section 14.3.3.1. Existing plants will only achieve the lower values of the range when they are significantly upgraded.

Technique	Cross-reference	Applicability
Substitution		
High solids coatings	14.4.3.1	Not all applications
Water-based coatings	14.4.3.2	Not all applications
Powder coatings ⁽¹⁾	14.4.3.3	Near zero VOC emissions, but odour problems
Laminated film coatings	14.4.3.4	Not all applications
Coating		
Roller coating	14.4.4.1	⁽²⁾ All
Waste gas collection and treatment		
Air seals on entry and exit	14.4.8.1	⁽²⁾ All
Negative pressure air in process areas	14.4.8.2	⁽²⁾ All
Extraction and treating air from coating preparation area	14.4.8.3	⁽²⁾ All new plants: low VOC concentration
Extraction and treating air from paint application	14.4.8.4	⁽²⁾ All: 8 % of VOC source
Extraction and treating air from drier/oven	14.4.8.5	⁽²⁾ All: 95 % of processed VOCs
Extraction and treating air from cooling zone	14.4.8.6	New plants: 1 – 2 % VOCs
Cleaning	14.4.4.2	
Management of wastes containing solvent	20.2.2.1 and 20.13	
⁽¹⁾ Powder coating can achieve near zero VOC emissions, but cannot be used for all applications for technical reasons. It also frequently needs waste gas treatment for odour.		
⁽²⁾ All = non-powder coat processes, where these techniques may be used for other reasons, such as for odour control.		

Table 21.12: Coil coating: a selection of techniques to control solvent consumptions and emissions

Waste

132. BAT is to recycle the steel and aluminium from residual substrates, see Section 14.3.3.3.

21.15 Best available techniques for the coating and printing of metal packaging

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

Energy consumption

133. BAT is to reduce energy using the techniques in Section 20.5 and energy recovery from thermal waste gas treatment, see Section 20.11. Consumption values associated with BAT for DWI cans (see Section 15.3.2) are:

- natural gas 5 – 6.7 kWh/m²
- electricity 3.6 – 5.5 kWh/m²
- recovered energy (where energy can be recovered, but not possible where emission levels are met by substitution) 0.3 – 0.4 kWh/m².

Solvent emissions to air

134. BAT is to reduce solvent emissions. The emission values of VOC in Table 21.13 (see Section 15.3.3.1): are associated with using a selection of techniques referred to in Table 21.14 as well as the generic BAT described in Section 21.1.

	VOC emission level at application (g/m ²) ⁽²⁾	
	Solvent-based	Water-based
Food contact		
• DWI drink cans	6.7 – 10.5	3.2 – 4.5
• sheet for ends, cans and components	4 – 93	1 – 30
• drums	90 – 100	
Non-food contact		
• sheet for ends, cans and components	4 – 93	1 – 30
• drums	60 – 70	11 – 20
Print paint		
• sheet for ends, cans and components ⁽¹⁾	2.5 – 13	1 – 6
Notes:		
⁽¹⁾ UV ink and paint applications are limited to non-food and special applications but can achieve lower values than reported in this table		
⁽²⁾ Values also include fugitive emissions		

Table 21.13: Metal packaging emission values for solvents associated with BAT

Technique	Cross-reference	Applicability
Replacement of coating and inks (substitution)	15.4.1, 15.4.2	
Application techniques	15.4.3	
Printing	15.4.4 (see also relevant sections and BAT for printing)	
Waste gas collection and treatment	15.4.5, 20.11	
Minimisation and treatment of solvent containing wastes	20.13	

Table 21.14: Metal packaging techniques to reduce solvent emissions

Emissions to water

135. BAT is to minimise emissions to water. The emission levels indicated in Table 21.15 can be met by using a suitable combination of techniques mentioned in Sections 15.4.6 and 20.12.

Compound	Concentration (mg/l)
COD	350 or less
AOX	0.5 – 1
HC	20 or less
Sn	4 or less

Table 21.15: Metal packaging: emission levels for waste water

21.16 Best available techniques for the coating of plastic workpieces

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

136. Where water-based pretreatment systems are used, the BAT and consumption values are discussed in the STM BREF, see Paragraph 3.

137. Paint and application systems may be interdependent and will be selected for the type of workpiece and substrate to be coated. There may also be incompatibility between paint systems. The selection of waste gas collection and treatment also depends on these choices.

Joint BAT

138. BAT is to reduce solvent consumption and emissions, maximise efficiency of paint application and minimise energy use by selecting paint and drier systems in accordance with BAT 28 in conjunction with waste gas treatment techniques discussed in BAT 37 to 42.

Solvent emissions to air

139. BAT is to reduce VOC emissions by using one or a combination of the following techniques in conjunction with the generic BAT described in Section 21.1.

- low solvent paints (see Section 20.7.2)
- VOC abatement techniques in BAT 138, 140 and 141.

In the expert judgement of the TWG, emission values associated with these techniques are 0.25 to 0.35 kg VOC/kg solid input (see Section 16.3.2.1, and using units as discussed in Annex 24.2). These levels do not apply where plastic automotive components are coated in an installation and where these emissions are included into the mass emission rate calculation for the serial coating of vehicles (see Sections 21.6, 21.7 and 21.8).

140. For new or upgraded installations, BAT is to reduce solvent emissions by giving priority to water-based systems.

141. For simple polypropylene areas, BAT is to reduce solvent emissions and water usage by hand-wiping with solvent-impregnated wipes (see Section 16.2).

Particulate emissions to air

142. BAT to reduce airborne particulates are addressed in BAT 43.

Materials efficiency

143. BAT is to minimise material consumption (including solvent use) and raw material losses by increasing transfer efficiency raw material management techniques. The following are key techniques but have technical limitations (see Sections 16.2 and 16.4):

- pretreat the plastic surface by fluoridation preparation
- high efficiency application techniques such as (see Section 20.7.3):
 - automating the coating application (efficiencies of 45 to 85 % can be achieved, depending on geometry)
 - using electrostatically assisted high rotation bells
 - using of HVLP or electrostatic applicators
 - batching colours.

Emissions to water

144. BAT for wet scrubber systems are described in BAT 49:

- optimising transfer efficiency (see Section 20.7.3)
- minimising the build-up of paint sludge (see Sections 20.7.5.6, 20.7.5.7 and 20.7.5.8).

145. BAT to minimise water pollution are addressed in BAT 44 to 47

Waste

146. BAT to minimise waste production from painting are given in BAT 88.

21.17 Best available techniques for the coating of furniture and wood materials

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

147. Paint and application systems may be interdependent and will be selected for the type of workpiece and substrate to be coated. There may also be incompatibility between paint systems. The selection of waste gas collection and treatment also depends on these choices.

Joint BAT

148. BAT is to reduce solvent consumptions and emissions, maximise efficiency of coating application and minimise energy use by selecting paint and drier systems in accordance with the techniques in Table 21.17, the generic BAT described in BAT 28 and the waste gas treatment systems described in BAT 37 to 42

Solvent emissions to air

149. The emission values of VOC associated with BAT 148 are:

- 0.25 kg or less of VOC/kg of solids input
- or
- the values in Table 21.16:

Paint system organic solvent content	Solvent content (wt-%)	Emission reduction measures	VOC emission (g/m ²)
High	65	High efficiency application techniques and good housekeeping	40 – 60
Medium	20		10 – 20
Low	5		2 – 5

Table 21.16: Wood coating: VOC emissions for various paint systems using some primary emission reduction measures

Technique	Cross-reference	Applicability
Substitution		
Water-based coatings	17.4.3.1	Not possible with oak
Power coatings – conventionally dried	17.4.3.2	Only MDF
Radiation cured coatings	17.4.3.3	Only flat workpieces
Coating		
Rolling and filling by using reverse coaters	17.4.4.1	Only flat pieces
Curtain coating (casting)	17.4.4.2	
Conventional dipping	17.4.4.3	
Vacuum coating	17.4.4.5	
Powder coating – electrostatically assisted spraying	17.4.4.9	
Flooding	17.4.4.4	
Waste gas collection and treatment		
Spray booths with particulate abatement	17.4.5	
Waste gas treatment techniques	17.4.4.6 and 20.11	Where other techniques are not available, or do not achieve suitable levels
Management of wastes containing solvent	20.2.2.1 and 20.13	

Table 21.17: Wood coating techniques to reduce solvent consumption and emission, and increase efficiency of coating

Particulate emissions to air

150. BAT is to minimise the emission of particulates from spraying by using wet or dry filter systems on waste gases from spray, such as described in Sections 20.11.3.5, 20.11.3.6 and 20.11.3.7, and in Section 17.4.5. Emission levels associated with these techniques are given in BAT 43.

Split view

The industry recorded a split view against the values shown in BAT 43. According to the information in Sections 17.4.7.1 and 17.4.7.4, the emission values considered to be associated with BAT are 10 mg/m³ or less for all installations.

This value is based on what they believe to be economically and technically viable in the industry.

Materials efficiency

151. BAT is to optimise raw material use by the application techniques in Table 21.17 and Section 17.4.1.

21.18 Best available techniques for wood preservation

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

152. Due to the toxicity of the components in the treatment systems (see Section 18.1), BAT 15 and 16 relating to the prevention of unplanned releases to waters and soil are emphasised.

Solvent emissions to air

153. BAT is to reduce emissions of VOC solvent by using vacuum impregnation with water-based or high concentration pesticide solvent systems (see Sections 18.4.2 and 20.10), or with waste gas treatment for solvent systems (see Section 20.11). Activated carbon or condensation may be particularly suited to the intermittent nature and varying sizes of the activities.

154. BAT is to use a final vacuum stage in the process cycle to remove excess solvent/carrier.

The reduction of VOC emissions associated with BAT 153 and this BAT 153 are (see Section 18.3.3.1):

- 99 % reduction can be achieved using water-based systems
- 70 % reduction can be achieved using solvent-based systems with waste gas treatment.

155. For solvent systems, a significant amount of solvent is released after the wood has been treated. BAT is therefore to reduce the effect of these solvents by using solvent systems with lower ozone-forming potentials (see Section 20.10.2).

156. It is not BAT to spray, as spraying has an overall application efficiency of only 10 - 15 % (see Section 18.1).

Emissions to soil and water

157. For both water-based and solvent-based systems, BAT is to drain the surplus pesticide system in contained areas (see Section 20.2.1). The collected pesticide can either be re-used or disposed of as hazardous waste.

21.19 Best available techniques for mirror manufacturing

The Introduction to this chapter (in the section ‘Some aids to understand this chapter’, Paragraph 2) sets out how the BAT in this section relate to the generic BAT in Section 21.1.

Solvent emissions to air

158. BAT is to reduce solvent consumptions and emissions (mainly xylene) by a combination of the following techniques and the generic BAT described in Section 21.1:

- using high solids paint, see Section 19.4.2.1
- curtain coating application (nearly 100 % application efficiency) see Section 19.4.3.1.
- enclosing main solvent-using areas, extracting and thermally treating the waste gas.

Manufacturers not operating continuously may need to use alternative waste gas treatments (see Section 19.4.5).

The emission values of VOC associated with these techniques are 1 to 3 g/m² for the waste gas (2 to 3 % of the solvent input) and 5 to 10 g/m² fugitive emissions (8 to 15 % of the solvent input), see Section 19.3.3.1.

Replacement of hazardous materials (substitution)

159. BAT is to reduce the use of hazardous materials by using low lead paint (see Section 19.4.2.1).

Emissions to water

160. Guidance on BAT relating to water-based surface treatment processes in this industry and the treatment of related emissions to water and the associated emission levels are given in the STM BREF.

22 EMERGING TECHNIQUES FOR SURFACE TREATMENT USING SOLVENTS

An emerging technique is understood in this document as a novel technique that has not yet been applied in any industrial sector on a commercial basis. This section contains those techniques that may appear in the near future and that may be applicable to the surface treatment using organic solvents sector.

22.1 Printing/coating

22.1.1 UV curing flexography

Description: It is likely that UV curing flexo printing, for purposes other than beverage cartons, will be developed in the future.

Achieved environmental benefits: Reduced VOC use and emissions.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004]

22.2 Winding wire manufacture

22.2.1 Waxing of fine wires

Description: Techniques are being considered to reduce the solvents emission from the final drying of wax on fine wires (0.01 – 0.1 mm.).

Achieved environmental benefits: Reduction of VOC consumption and emissions.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004].

22.3 Manufacture of abrasives

22.3.1 High speed drying and hardening processes

Description: For several years, patents have been established aiming at faster drying and hardening of the bond materials. The new processes include, for example, the application of UV radiation or microwaves.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Within the next few years, none of the present developments will change or influence the production processes at existing abrasive production plants.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: No data submitted.

22.4 Manufacture of adhesive tape

No data submitted.

22.5 Coating of cars and light vans

[13, DFIU and IFARE, 2002] [76, TWG, 2004]

22.5.1 Improved water-dilutable 1- and 2-component clear coating

Description: New products in the form of improved water-dilutable 1- and 2-component clear coating systems as well as ‘very high solid’ 2-component clear coating systems (with a solids content of up to 90 wt-%) are expected in the future.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: No data submitted.

22.5.2 Developments in powder coating

Description: The application of powder topcoating on a larger scale is expected. According to statements from paint producers, a variety of pigmented finish coating systems based on powder are already available; however, these are not yet in serial application. According to industry, this may be due to the difficulty in colour mixing, making recycling impossible. The current powder coats do not meet most European manufacturers requirements for durability and physical and chemical resistance.

Achieved environmental benefits: No data submitted.

Cross-media effects: Some health and safety considerations with the powder coatings (see Sections 20.7.3.18 and 20.7.3.19).

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: DaimlerChrysler in the US has planned to completely coat the Jeep Wrangler with powder coats from 2004 onwards. BMW in Germany has now converted one production unit to powder coating. However, white top coat cannot be achieved satisfactorily, and this is produced on the repair line.

Reference literature: [128, TWG, 2005] [162, Eurocar, 2005]

22.5.3 Low cost conversion concept

This technique has been referred to in literature provided [13, DFIU and IFARE, 2002]. According to vehicle industry experts, it does not exist, while paint supply industry experts think it refers to the water-based base coat system with reduced flash-off, see Section 20.7.2.4.

22.5.4 Increased use of pre-coated materials

Description: A further development may be an increasing share of completely finished coil coating parts so that certain painting processes will no longer be performed by the car manufacturer (see Chapter 14).

Achieved environmental benefits: Because coil coated materials are coated before forming (shaping) and completion of sub-assemblies (e.g doors), the application and extraction techniques enable a lower VOC emission per m² coated than post-forming painting.

Cross-media effects: VOC emissions (although reduced) remain but are transferred to the production of the coil coated materials.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: No data submitted.

22.5.5 Polyurethane (PU) paint systems

Description: Paint systems based on a polyurethane can be already burned-in at temperatures below 100 °C. This allows the lacquer finish of both metal bodies and plastic mounted parts within a single painting process. A so-called 'in-line lacquer finish' would solve the problem of the colour adjustment between the metal body and the coloured plastic parts.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: The wide range of PU-based paint systems is available for all layers of the paint structure, ranging from the primer to the finish coating as well as for sound absorption and underbody protection. The low burn-in temperatures allow for the use of a wide range of plastics.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: No data submitted.

22.5.6 Reduction in paint layers

Description: A reduction in the number of paint layers is to be expected, as primers and base lacquers are united into one material applied in one paint film. Primerless systems using 2-component water-based base coat are being introduced. Primerless systems reduce application steps from four to three and ovens from three to two. Base coat thickness is slightly increased to cover the underlying electrocoat and to protect it against the impact of UV radiation.

Achieved environmental benefits: Materials and energy are saved and at the same time the emissions from the painting process decrease.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: Primerless systems may lead to substantial cost savings.

Driving forces for implementation: No data submitted.

Example plants: In commercial use at DaimlerChrysler Rastatt, Germany; SEAT Martorell, Spain; Mini Oxford, UK; and VW, Mexico. Further plants are scheduled for transformation.

Reference literature: [128, TWG, 2005].

22.6 Coating of trucks and commercial vehicles

No data submitted.

22.7 Coating of buses

No data submitted.

22.8 Coating of trains

No data submitted.

22.9 Coating of agricultural and construction equipment

No data submitted.

22.10 Coating of ships and yachts

22.10.1 Hot electrostatic air mix

Description: This technique can be used indoors and outdoors. Because of the heating of the paint, the right viscosity can be gained so less VOC is emitted. Note that production can be lower than with conventional techniques.

Achieved environmental benefits: Reduced VOC emissions.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Applicable indoors, for example with maintenance and repair work, and outdoors, in combination with S-shaped windscreens.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plant: In the Netherlands, a pilot is being carried out to use hot electrostatic air mix techniques on ships.

Reference literature: [76, TWG, 2004]

22.10.2 Replacement of antifouling paints based on biocides (substitution)

22.10.2.1 Paints with natural biocides

Description: Natural biocides are produced, for example, by some coral species as a protection against fouling.

Achieved environmental benefits: This antifouling system does not contain heavy metals or biocides.

Cross-media effects: No data submitted.

Operational data: These substances show a lower persistence due to a better biodegradability rating compared to inorganic materials such as copper compounds or TBT.

Applicability: Paints containing natural biocides are still being tested.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002].

22.10.2.2 Coatings with special surface properties for a reduction of fouling

Description: Coatings with a special surface structure such as micro-roughness can be used for a reduction of fouling.

Achieved environmental benefits: This antifouling system does not contain heavy metals or biocides.

Cross-media effects: No data submitted.

Operational data: A pilot project for the testing of environmentally sound antifouling paints was carried out by an environmental regulator, a green NGO and paint manufacturers. During the study, this type of coating performed the best out of all biocide-free materials.

Applicability: Applicable to all ships.

Economics: Costs are claimed to be comparable to other tin- and copper-free antifoulings.

Driving forces for implementation: SED. Water pollution legislation and policies.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002] [69, Watermann, et al., 2003] [128, TWG, 2005]

22.11 Coating of aircraft

No data submitted.

22.12 Coating of other metal surfaces

No data submitted.

22.13 Coil coating industries

No data submitted.

22.14 Coating and printing of metal packaging

22.14.1 Low solvent content coating (waterborne paint)

Description: The solvent percentage depends on the mechanical and chemical performance requirements. No further data submitted.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Currently, no suitable high performance water-based internal lacquers are available.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004]

22.14.2 Radiation curing processes

Description: For a general description, see Section 20.8.2. No commercial application is known for coil coating applications. See also Section 14.4.7.2.

Achieved environmental benefits: Reduces solvent emissions.

Cross-media effects: No data submitted.

Operational data: Radiation curing may become an important technology for new lines but it is difficult to see how it could be a viable replacement for a conventional solvent-based coating as a retrofit on an existing line. In its current state of development, radiation curing cannot meet the specifications for the whole range of coil coating products. Small scale trials continue with development products. UV lamps or EB units will need to be installed on lines wishing to run radiation cured coatings. These factors mean that a changeover to radiation cured coatings is not feasible for coil coating installations at present.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004] [58, ECCA, 2004]

22.15 Serial coating of plastic workpieces

Description: Currently, research is underway into the development of thermal curing low temperature powders and UV curing powder coatings.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: Early results are promising for the application capability of such powder systems for some plastic parts. Water-based in mould coating systems applied to the coating of steering wheels are at a testing stage.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004]

22.16 Coating of furniture and wood materials

22.16.1 Power coating

Description: At present, research into the application of powder coatings for the woodworking industry is strongly associated with the development of new generations of powder coating materials, which have more suitable melting and curing processes. Powder coating systems cross-linking by UV radiation are still at an early stage of their development, but UV cured powders are already used in production for, e.g. MDF and flat wood panels. At present, the electrostatically assisted application of powder coatings onto non-conductive wood and wood materials is under development.

Achieved environmental benefits: In this context, the earthing of electric charges via freshly produced wet lacquer film has been examined. This painting principle has been used for furniture fronts and has produced the following results:

- in comparison to the low pressure procedure (HVLP), electrostatic high rotation atomisation increases the application efficiency by approx. 35 %, and accordingly the material efficiency by approx. 30 %
- it reduces the generation of waste (paint) by approx. 80 %.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: So far, electrostatically assisted painting processes can only be applied in rare individual cases in wood processing. Therefore, further research is necessary.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [13, DFIU and IFARE, 2002]

22.16.2 Peroxide and IR bleaching

Description: A new method for bleaching has been developed which combines peroxide application and infrared radiation. No further data submitted.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: www.altonic.fi

22.16.2.1 Non-thermal plasma treatment

Description: In the waste gas, a plasma is created at low temperatures (30 – 120 °C) by routing the waste gas through two electrodes with an alternating current of 20 – 30 kV. In the plasma, the VOC vapours react very quickly with oxygen to form CO₂ and water vapour.

In a plasma, the molecules of the gasflow are in a partly ionised condition. This condition is normally achieved by extremely high temperatures, such as that caused by lightning. However, it can also be created at ambient temperatures if enough energy is added.

Achieved environmental benefits: Efficiencies of 97 - 99.9 % are achieved without heating the waste gas. The installation for this technique is very compact compared to thermal oxidation and also consumes far less energy.

Cross-media effects: Energy consumption of 0.5 – 3.0 kWh electric energy per 1000 m³ waste gas treated.

Operational data: Different layouts are available. Sometimes the space between the electrodes is filled with small glass balls to amplify the electric field.

Applicability: This technique has only been commercially applied for a few years to reduce odour emissions and sometimes to treat waste gases containing VOC. At the moment, the technique is used as a pilot in a demonstration project applied to treat VOC emissions from the drying of wood. The technique was expected to be commercially applied to this application in 2004.

In theory, there is no restriction in applications concerning the VOC concentrations in the waste gas; however, it is currently applied for treating low concentrations. Also small or large flows can be treated.

Economics: No data on cost are available yet. However, this technique is expected to be cheaper than thermal oxidation or adsorption.

Driving forces for implementation: No data submitted.

Reference literature: [63, Vito, 2003] [76, TWG, 2004]

22.17 Wood preservation

No data submitted.

22.18 Manufacture of mirrors

No data submitted.

22.19 Waste gas treatment

22.19.1 Electrically heated carbon adsorption tubes

Description: Carbon adsorption tubes can be mounted on individual printing/coating application lines and used to adsorb VOCs. The VOCs can then be recovered by passing a current through the electrically conducting carbon tubes.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: No data submitted.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: Small scale trials have been shown to be successful in the UK.

Reference literature [76, TWG, 2004]

22.20 Waste water treatment

22.20.1 Wet separation spray booth – with SiO₂ particles

Description: Overspray in a spray booth where surfaces are sprayed with paint materials can be intercepted by applying a water curtain. The water-paint mixture is captured and treated in a reservoir below the spray booth. SiO₂ particles are added to the water reservoir and while floating at the surface are adsorbing the paint particles. When the SiO₂ particles are saturated with paint, they are removed from the reservoir and are recovered as a new paint.

Achieved environmental benefits: VOC emissions are reduced and the recovered paint and SiO₂ particles can be re-used in a new paint.

Cross-media effects: Arising of waste water which can often be re-used.

Operational data: The process is fully developed and ready for commercialisation; however, it is not yet available on a large scale.

Applicability: Wet separation spray booths are common practice in wood and furniture painting and in the automotive industry. They are applicable to water- and solvent-based paints.

The technique is currently not applied on a commercial level.

Economics: Not known yet.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [63, Vito, 2003]

23 CONCLUDING REMARKS

23.1 Timing of the work

The kick-off meeting of the Technical Working Group (TWG) was held in March 2003 and the first draft was issued for consultation in May 2004. The second draft (with BAT proposals) was issued for consultation in October 2005. The final TWG meeting was held in June 2006.

23.2 Sources of information and progress of the work

Eighteen industries are discussed in this document, using approximately 150 information sources. The type, quantity and quality of data varied according to the industry.

The Solvent Emissions Directive (SED) also applies to all the industries in this sector. Some reports were prepared by Members States and the industries concerned on good practice and potential BAT to assist implementation of the directives before work started on this document, and these formed the basis of the first draft. Reports from two Europe-wide studies prepared to implement the SED and UNECE Protocols controlling VOCs¹⁰ were also used. Some of the documents supplied considered the industry at the much lower SED thresholds, which caused some difficulty, particularly in identifying process descriptions and techniques for the IPPC BAT discussion. However, it should be noted that the TWG has clarified these issues through the information exchange and has drawn conclusions based on the data for installations exceeding the IPPC capacities.

Good practice or BAT guides were received from the following MS: Austria, Belgium, France, Germany, the Netherlands, the Nordic Council and Spain, predominantly on printing and painting. There was little other data on consumptions and emissions from MS.

The role of industry in providing data and clarifying issues was crucial. This was considerably assisted by most of the industries discussed and their suppliers and consultants participating in ESVOCCG¹¹. Suppliers and consultants have an important overview and played a significant role in providing and clarifying data on techniques, consumptions and emissions.

Major BAT studies, guidance documents, industry surveys, etc. were supplied (among others) by: printing, winding wires, adhesive tape, automotive industries, coating of ships (from Portugal), metal packaging, coil coating and mirrors. Some industries also used their own shadow TWGs to provide co-ordinated industry responses. Seven industry associations, together with ESIG, provided substantial contributions, and estimated their costs to be EUR 1.36 million (an average of EUR 191000 per association). In all, ESVOCCG estimates the total industry contribution to the information exchange to be about EUR 2.2 million.

A major source of data has been the comments from the TWG to the two drafts: nearly 2000 in each case. Further information has also been exchanged to clarify individual techniques and comments.

¹⁰ Documents from DFIU/IFARE (including ISACOAT studies) prepared for the implementation of SED were used in several chapters. EGTEI data were prepared in support of the UNECE Protocols to reduce the transboundary transport of VOCs and NO_x. As a result of this information exchange, some of the EGTEI documents have also been updated in consultation with the industries concerned.

¹¹ ESVOCCG: the European Solvents VOC Coordination Group co-ordinates the solvent industries' responses to the relevant European policy proposals and legislation under the auspices of CEFIC.

Concluding Remarks

Information also came from site visits to installations demonstrating potential BAT for printing, packaging, manufacture of winding wires, vehicle assembly, can coating and furniture painting in France, the Netherlands and Germany. Meetings with ESVOCCG and ACEA¹² also contributed to the exchange.

EGTEI synopsis sheets are prepared to assist the collection of national data on emissions the RAINS model. These contain data for the cost benefit at a European level of the application of key abatement techniques in various industries, and these data have been used to check the BAT conclusions, add background information on industries, and in some cases to support the derivation of BAT. Equally, the participation of CITEPA (the authors) in the TWG also enabled the verification and updating of some of the synopsis sheets, leading to more consistency. The EGTEI approach is necessarily limited in complexity, and cannot consider all the possible techniques for BAT, and does not take into account other BAT considerations, such as cross-media effects or the technical characteristics of individual products or BAT at an installation level. The data therefore do always not map easily into the BREF format and methodology. However, the data are useful at a high level and are fully referenced in the document.

To minimise repetition, as many techniques as possible that could be considered for use by more than one industry were discussed generally in Chapter 20. A major section of this is on waste gas treatment, and a sub-group meeting was held to facilitate the drafting of this and reaching BAT conclusions. Because so many different processes and combinations of techniques were being discussed, each with their own variability, it was agreed that the focus of the BAT conclusions should be to find emission ranges associated with suitable combinations of the best available techniques. It was also agreed that these ranges should be based on meaningful production-related measures for each industry, such as VOC emitted in g/m² treated or per kg of solids input. These emission ranges are usually the same as those used for the SED implementation, to reduce confusion.

Many of the data were focused predominantly on VOC emissions and there was a significant lack of data on other issues for integrated process control and reduction of consumptions. In common with other BREF projects, there was a lack of quantitative data in many areas.

Data received on the magnetic tape industry showed that there were only three installations in the EU, and one of these had 80 % of the European market. On the basis that this industry is being replaced by other types of recording data, an information exchange was not considered to be resource-effective. Information received on the shoe manufacturing industry showed that none in the EU reached the IPPC thresholds. For friction linings, less than 10 German companies account for half the European production, with only about 20 % of production using solvent-based processes. Again, an information exchange was not considered to be resource effective. Both of these processes should be considered for the first review.

No data were received on the manufacture of boats using polyester resins, so it remains unclear if this activity is within the scope of this document.

It is reported that some installations processing semi-conductors and some printing of wallpapers may use solvents for degreasing above the IPPC thresholds, but no data were received.

¹² ACEA: the European association of automotive manufacturers.

23.3 Degree of consensus

Industry asked for clarification of the definitions of 'organic solvents' and 'consumption capacity' in Annex 1 (6.7) to the IPPC Directive. At the conclusion of the information exchange, it could be seen that the exchange had dealt with information on organic solvents being defined as VOCs (as defined in the Solvent Emissions Directive, Council Directive 1999/13/EC). It could equally be seen that, in determining conclusions on BAT, the exchange had focused on installations whose actual use of solvents exceeded the consumption capacity thresholds stated in the IPPC Directive (where the use in the activity included solvents recovered from waste gas emission abatement equipment). Interpretation of these capacity thresholds is discussed in the context of work carried out by DG Environment to develop some guidance on the interpretation of certain provisions of the Directive.

A high level of consensus was achieved overall on the techniques to be considered and the BAT conclusions, with one split view requested by industry.

23.4 Gaps in knowledge and recommendations for future research and information gathering

The following gaps in knowledge were identified as a consequence of the information exchange. Some are described in the main text, others under development are described in Chapter 22, Emerging Techniques. They are summarised here with proposals for future work:

23.4.1 General issues:

Industries considered. As noted above, this document does not discuss the manufacture of magnetic tapes, self-adhesive labels, friction linings, boat construction using resins, semi-conductors and wallpapers.

Recommendation: Data should be gathered on these industries to assess if they should be considered for inclusion in the review of this document.

EGTEI synopsis sheets. As noted in Section 23.2, above, these have provided helpful data. However, the approach often does not map readily into the BREF format and methodology.

Recommendation: Maintain liaison with CITEPA/EGTEI and consider using EGTEI data to a greater extent particularly for any update or review. Also, ensure CITEPA/EGTEI are aware of developments in BAT.

Energy usage. This is probably the next most important issue in this sector after VOC emissions. However, for process techniques, it has been almost impossible (there are a few exceptions) to derive BAT or consumption values related to production for energy.

Recommendation: More data are required on the energy usage associated with techniques, and related to production throughput measures. These would be most helpful if they are related to the same production measures used for VOC emissions.

Energy used in EoP techniques and quantifying the cross-media and economic effects of abatement. Attempts have been made to quantify these issues, but insufficient data were available (see specifically the metal packaging industry, below). One option is comparing marginal social costs of burning natural gas to abate VOCs, particularly at low concentrations, but available costs have been prepared on different bases and the costs have uncertainties attached to them (particularly those for CO₂).

Recommendation: More information is required to help determine the selection of investment routes (cost-benefit of abatement verses more efficient application and low solvent techniques) and to determine when it is possible to turn off waste gas treatments when low solvent substitutions have been made (see the metal packaging sector for more detail).

Using less hazardous substances: using solvents with lower ozone formation potential (OFP). No discussion on VOC emissions would be complete without a discussion of ozone formation and the differing potentials of the various solvents to form ozone. The technique is referred to in the ECM REF, and the STS TWG exchanged important and helpful information. The conclusion was the technique can only be currently considered BAT in limited circumstances for several reasons:

- it is not necessary where adequate waste gas abatement exists
- there are several comparative scales (all derived by complex models). The most commonly referred to in Europe is POCP, which lists some 130 substances (not all of them solvents) and this is used in modelling for EU and MS policy requirements rather than in practical applications, such as informing process development
- these scales cannot currently be used to show compliance with legislation such as SED, although substitution on this basis would assist meeting the objectives of the SED and IPPCD
- OFP scales are not used when deriving complex formulations such as paints and inks. The costs of applying this and deriving new formulations are high and the time scales long, so using them as a basis for substitution in these mixtures is not currently feasible. This would be better achieved as part of other exercises, particularly under REACH, where the issue can be considered as one of several factors, and development costs can be shared.

While controlling the emission of VOCs will assist in controlling ozone formation, the anticipated benefits will not be achieved if the total ozone-formation load (mass released x OFP) remains higher than anticipated. As an example, one of the widely-applicable BAT options is the use of high solids paints. However, during the final TWG meeting it was noted that to achieve the required dispersion of the pigments, more powerful solvents are used. These may be from types of solvent with significantly higher ozone forming potentials, so while the VOC emission may be significantly reduced, the expected reduction in ozone formation may not be realised.

Recommendation: More research and information is therefore required to:

- assess the use of the OFP worldwide in regulation
- ensure that the most appropriate OFP scale and/or the most suitable scale is developed for future EU initiatives use, e.g. to give data on a wide range of commonly used solvents, and to aid development as an emissions control technique
- assist the development and application of this technique in paints, inks and other surface treatments containing VOC, e.g. under REACH
- assess the impact of paints and surface treatments recently developed as substitutes to meet SED requirements and determine their effectiveness in reducing the EU, MS and local burdens of ozone.

NO_x from solvents containing nitrogen. These are used in some of the processes discussed. It is unclear to what extent oxidation of these is a major source of NO_x, and if this will change in the future, as other initiatives are likely to lead to a decline in the use at least one solvent containing nitrogen

Recommendation: More information is needed on the amount of solvents containing nitrogen used in the EU, and projected future usage and to calculate the amount of NO_x these solvents contribute to the EU and local burdens.

The use of high efficiency application techniques. Although these are often given as BAT, or are included in a group of techniques to consider to achieve emissions associated with BAT, they are often not recognised as having an effect on VOC emissions if these are calculated, for example, as kg VOC/kg solids input. In these cases, both VOC and solids used are reduced, and the kg/kg ratio remains the same. This may prevent the more rapid application of BAT in some industries, and would include minimising raw material consumption. Decreased VOC emissions are shown where calculated against a production output parameter, such as VOC g/m².

Recommendation: More data are required on the applicability of these techniques in some industries, and more guidance is required on how to calculate the VOC emissions.

The use of novel techniques in waste gas treatment. There was little information available on more recent, non-traditional techniques to treat waste gases which might be able to reduce capital investment, reduce energy consumption and/or running costs, such as UV oxidation, non thermal plasma, and carbon absorption tubes mounted in individual treatment lines (an emerging technique). The lack of information may be due to poor take up, in turn caused by the lack of information to base investment decisions on. There was also contradictory information on biological treatment, with both reported successes and failures, which require further clarification of the applicability of this technique.

Recommendation: Seek further information on these and other possible techniques, cost-effectiveness and cross-media effects, and support research into the development of alternative waste gas treatment techniques.

Novel technique for materials recovery in spray booths. Overspray in paint booths is frequently intercepted by water curtains. An emerging technique is described using SiO₂ particles to enable the paint to be recovered, but little information was supplied.

Recommendation: Seek further information on these and other possible techniques, cost-effectiveness and cross-media effects, and support research into the development of alternative material recovery techniques.

Secondary aerosols. These were identified at the final TWG plenary meeting as an emission that had not been discussed during the information exchange.

Recommendation: More information is required to determine if and in which processes this may be an environmental problem. If a problem is identified, then information on the extent and its control will be required.

23.4.2 Industry specific issues

Flexographic printing: Some beverage cartons are printed using solvent-free UV curing flexographic inks. These use UV curing inks which could be developed for other applications.

Recommendation: Research to support the wider application of solvent-free UV inks and other surface treatments.

Publication gravure printing: A considerable amount of energy is used in regenerating adsorption beds used to control toluene emissions. To remove the maximum amount of toluene involves increasing the absorption cycles and therefore energy. The toluene emission level at which the energy consumption starts to climb exponentially is not known and requires a series of trials.

Recommendation: A series of trials is needed to derive data establishing the toluene emission as a percentage of the total toluene input with the minimum optimum energy usage. The trials can be carried out in existing installations.

Concluding Remarks

Winding wires: The remaining area of significant VOC emission is from the application of lubricants. The industry provided data demonstrating that it was not economically or technically viable to enclose and treat the air required to evaporate the solvent from the lubricant. Developments in BAT have centred on the use of solvent-free lubricants, but these are limited by (i) wire size, and (ii) these lubricants not meeting all customer specifications.

Recommendations: Research is required to develop further solvent-free lubricant systems that meet the necessary performance requirements, and to assist with the gaining of the performance specifications for existing options.

Abrasives: Emerging techniques for faster drying and hardening of the bonding materials have been identified, for example, using UV or microwave radiation and probably low or no solvent.

Recommendation: More information is required on these techniques.

Coating of cars, vans, trucks and truck cabs, and buses: There was less information available on commercial vehicles and buses than for cars. Energy was identified as a major concern, but there is difficulty in establishing comparable data, even within the same company.

The following are in development and may contribute to future BAT:

- improved water-based 1- and 2- component clear coating
- very high solids clear paints (up to 90 % solids)
- increased use of pre-coated materials, reducing the painting in the assembly installation. Because coil-coated materials are coated before forming (shaping) or assembly, the application and extraction techniques enable a lower VOC emission per m² coated than post-forming painting
- powder coating is used in the US and one or two plants in the EU. It is not widely used in Europe, as it does not meet manufacturers quality specification for chemical and physical durability
- low cost conversion concept (LCCC). This technique has been described and reference plants identified, but there seems to be doubt about its definition (i.e. is the naming and description wrong) and/or existence. Typical water-based basecoat systems used to achieve low emission levels need high capital investment. The LCCC is claimed to use paints with similar characteristics, but use less energy and require less equipment change and less capital investment. Supply industry information was given on water-based coatings with reduced flash-off requirement, which is in commercial use in at least two plants, and this is described
- polyurethane (PU) paint systems enable both metal bodies and plastic parts to be painted together in a single process. It is unclear what the effect this will have on VOC emissions, although lower oven temperatures are likely to save energy
- reduction in paint layers as primers and base coats are merged, such as by using 2-component water-based basecoats, resulting in reduced emissions of VOC, waste and waste water and a reduction in energy consumption.

Recommendation: More information is required on the status of these techniques, their cross-media effects, applicability and economics. Powder coating can achieve low VOC emission levels, but more research is required to improve the quality of the finishes to European manufacturers' standards. More data are required on the LCCC concept, to clarify the terminology, and the technique and its benefits.

Coating of trains, agricultural and construction equipment, ships and yachts, aircraft, other metal surfaces, plastics: Very little information was received on these topics, although significant additional information was provided after Draft 2 for ship repair. Conclusions were drawn for other metal surfaces and plastics based on the automotive (OEM) installations and the expert opinion of the TWG.

Recommendation: More data are required in these areas to improve the quality of the BAT conclusions. Data on the manufacturing and coating of new ships and yachts (particularly using polyester resins) are needed. The shipping industry (and others) may not understand that high solids paints (with lower solvent emissions) may be more expensive per kg, but the same price per m² treated: more information needs to be made available on this.

Metal packaging: There is little information on the application of some potential BAT (low solvent or solvent-free water-based coatings) as their application in the industry is hindered. To deal with the original higher solvent concentration techniques, large waste gas oxidisers are installed, which deal with high volumes of air, and can be 25 % of the site capitalisation. As solvent emissions are reduced, the solvent concentration in the air stream drops well below the autothermal level, requiring gas as a fuel. No data exist on when to turn off these oxidisers. It is not economically viable to both convert to low solvent or solvent-free coatings and use gas to support combustion of the low level of remaining solvent.

Recommendation: More information is required on when to turn off EoP techniques (see Energy used in EoP techniques, above).

Coil coating: Radiation curing is used in other industries in conjunction with low solvent or solvent free coatings. Development work has been undertaken for its application in coil coating.

Recommendation: More information is required on the status and applicability of radiation curing process. Research may be needed to assist its applicability to existing plants.

Furniture and wood coating: There was limited information on waste gas treatments, especially on the potential to use thermal oxidisers in high solvent applications. Powder coatings (with UV curing) and electrostatic high rotation application have been developed with some success for large flat panels.

Recommendation: More research is required to develop these and similar techniques to a wider range of products to reduce solvent usage.

RTD programme

The EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future document reviews. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface to this document).

23.5 Review of this document

The data on techniques relating to VOC usage and emissions is largely current to the information exchange (2003 to 2006), and unlikely to change until more experience has been acquired in confirming with, regulating for and reporting for the SED and IPPCD. This additional data would also assist with considering the industries not discussed in this document (identified in Section 23.2). The lack of data on other issues (identified in Section 23.4) needs addressing, but this would also benefit from the studies proposed and experience gained in applying the directives. End-of-pipe abatement techniques are predominantly mature, and other techniques such as substitution develop gradually. National documents covering these industries show little need for change seven years after the introduction of the SED. A review may be considered for approximately 2009 to address gaps in data, particularly for the industries that may potentially be within the scope of this document, although it is unlikely that a full review will need to be considered before 2012.

An issue for consideration will be how to update the document if fresh information is available for a minority of the techniques and industries earlier than 2012.

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GLOSSARY

1. General terms, abbreviations, acronyms and substances

ENGLISH TERM	MEANING
Alphanumerics	
2K	2-component, usually used for paints
A	
AC (e.g. paint)	No data submitted.
acid	a proton donor: a substance that liberates hydrogen ions in water solution
aerobic	a biological process that occurs in the presence of oxygen
alkali (base)	a proton acceptor. A substance that liberates hydroxide ions in water solution
anaerobic	a biological process which occurs in the absence of oxygen
AOX	adsorbable organic halogen compounds. The total concentration in milligrams per litre, expressed as chlorine, of all organic halogen compounds (except fluorine) present in a sample of water that are capable of being adsorbed on activated carbon
B	
BAT	best available techniques
biodegradable	that can be broken down physically and/or chemically by micro-organisms. For example, many chemicals, food scraps, cotton, wool and paper are biodegradable
BIW, body in white	a standard term in the vehicle manufacturing industry and refers to the bare metal shell of the vehicle before it has been degreased, dipped and painted
BOD	biochemical (or biological) oxygen demand: a measure of the content of organic matter in water and wastes. It is the amount of dissolved oxygen required by micro-organisms in order to decompose organic matter. The unit of measurement is mg O ₂ /l. In Europe, BOD is usually measured after 3 (BOD ₃), 5 (BOD ₅) or 7 (BOD ₇) days
b.p.	boiling point
BREF	BAT reference document
C	
CAD	computer aided design
CAFE	Clean Air For Europe: the programme that underpins the EU's thematic strategy on air pollution
CBN	cubic boron nitride
CEN	European Committee for Standardization
CMR	carcinogenic, mutagenic and reprotoxic: applied to substances that have all or some of these hazardous properties
COD	chemical oxygen demand: the quantity of oxygen absorbed chemically (by a sample). The test conditions are strongly oxidising using potassium dichromate and oxidises virtually all organic compounds. The unit of measurement is mg O ₂ /l
containment, contained area	(secondary) containment refers to additional protection against storage tank releases over and above the inherent protection provided by the tank container itself. There are two major types of secondary containment for leakages, namely those that are part of the tank construction, such as double tank bottoms (only for aboveground tanks), double skinned and double walled tanks and impervious barriers which are placed upon the soil surface below the tanks [91, EIPPCB, 2005]
cross-media effects	the calculation of the environmental impacts of water/air/soil emissions, energy use, consumption of raw materials, noise and water extraction (i.e. everything required by the IPPC Directive)
CSBR	carboxylated styrene butadiene styrene block copolymer
CTP	computer-to-plate
D	
dH	water hardness degree
DIN	Deutsche Industry Norm
DS	dry solids (content): the mass of a material remaining after drying by the standard method of test

ENGLISH TERM	MEANING
DWI	draw and wall iron: a production method for producing cans
E	
EB	electron beam
EDTA	ethylene diamine tetra acetic acid
EF	emission factors
effluent	physical fluid (air or water together with contaminants) forming an emission
EFTA	European Free Trade Association
EGTEI	See Annex 24.1.1 EGTEI home page: http://www.citepa.org/forums/egtei/egtei_index.htm
EIPPCB	European IPPC Bureau
ELV	emission limit values: the mass, expressed in terms of certain specific parameters, concentration and/or level of an emission, which may not be exceeded during one or more periods of time
EMAS	environmental management and audit scheme
emission	the direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the installation into the air, water or land
EMS	environmental management system
'end-of-pipe' technique	a technique that reduces final emissions or consumptions by some additional process but does not change the fundamental operation of the core process. Synonyms: 'secondary technique', 'abatement technique'. Antonyms: 'process-integrated technique', 'primary technique' (a technique that in some way changes the way in which the core process operates, thereby reducing raw emissions or consumptions)
environmental footprint	a measure of the burden or impact that a product, operation or business places on the environment. For IPPC, this will be: <ul style="list-style-type: none"> the consumption of energy, raw materials and water emissions to air, water, groundwater, and soil; and as waste damage to material property and the impairment or interference with amenities and other legitimate uses of the environment. IPPC includes a consideration of noise and vibration, dust and odour. However, it does not include aspects such as life cycle analysis of products
EOE	easy open ends
EP	electrostatic precipitator
EPDM	ethylene-propylene-diene monomer
EQS	environmental quality standard
ESIG	European Solvents Industry Group
ETL	electrocoating, e.g. electrophoretic dipping and cathodic immersion
EU	European Union
EUA	European Union Allowance: the term used for the trading units for the EU carbon trading scheme in EUR per tonne CO ₂
EVA	ethylene vinyl acetate
EWP	Environmental Working Party
existing installation	an installation in operation or, in accordance with legislation existing before the date on which this Directive is brought into effect, an installation authorised or in the view of the competent authority the subject of a full request for authorisation, provided that that installation is put into operation no later than one year after the date on which this Directive is brought into effect
F	
FID	flame ionisation detection
flat tint	a printed area containing halftone dots that are all the same size, as opposed to a halftone or a vignette. Flat tints are usually just called 'tints'
flocculation	waste water treatment involving gentle stirring whereby small particles in flocs are collected into larger particles so their weight causes them to settle to the bottom of the treatment tank
FOGRA	
footprint	a company's environmental impact determined by the amount of depletable raw materials and non-renewable resources it consumes to make its products, and the quantity of wastes and emissions that are generated in the

ENGLISH TERM	MEANING
	process
fugitive emission	in this document, the SED definition is used [123, EC, 1999]: any emissions not in waste gases of VOCs into air, soil and water as well as (unless stated in the SED) solvents contained in products. They include uncaptured emissions released to the outside environment via windows, doors, vents and similar openings (conversely, see also waste gas)
G	
GDP	gross domestic product
GJ	gigajoule
GRT	gross registered tonnes
GT	grosse tonnes
H	
HBS	high boiling solvents
HDF	high density fibre
HF	high frequency
HP	high pressure
HVLP	high volume low pressure
I	
IBC	intermediate bulk container
IDOP	integrated downwind ozone production: a measure of the reactivity of a solvent in creating tropospheric ozone
IEC	International Electrotechnical Commission
IEF	Information Exchange Forum (informal consultation body in the framework of the IPPC Directive)
immission	occurrence and level of polluting substance, odour or noise in the environment
IMO	International Maritime Organisation
installation	a stationary technical unit where one or more activities listed in Annex I are carried out, and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution
Intergraf EWP	environment working party
IPA	iso propyl alcohol
IPPC	integrated pollution prevention and control
IR	infrared
J	
K	
K1 K2 K3	an indication of flammability used in the Netherlands and Belgium, according to flashpoint: <ul style="list-style-type: none"> • K1: <21 °C • K2: 21 – 55 °C • K3: >55 °C
L	
LCA	life cycle assessment
LCCC	low cost conversion concept
LEL	lower explosion level
LNG	liquefied natural gas
LP	low pressure
LWC	low weight coated
M	
MDF	medium density fibre (boards)
MEK	methyl ethyl ketone
MF	machine finished
MKM	an Environmental Costing Model (MilieuKostenModel), see Annex 24.1.2
monitoring	process intended to assess or to determine the actual value and the variations of an emission or another parameter, based on procedures of systematic, periodic or spot surveillance, inspection, sampling and measurement or other assessment methods intended to provide information about emitted quantities and/or trends for emitted pollutants
MS	Member State of the European Union

ENGLISH TERM	MEANING
N	
n/a	not applicable OR not available (depending on the context)
NC	nitrocellulose
n/d	no data
NEOE	non easy open ends
NF	nanofiltration
NIR	near infrared
NMP	n-methyl-pyrrolidone
NMVOC	non-methane volatile organic compound (see VOC)
NR	natural rubber
O	
oblongs	from canmaking: refers to the shape of a general line container where the top and bottom ends are rectangular in shape with rounded corners
ODP	ozone depletion potential: a relative index indicating the extent to which a compound may cause ozone depletion
OEL	occupational exposure limit
OEM	original equipment manufacturer
OFP	ozone-forming potential
operator	any natural or legal person who operates or controls the installation or, where this is provided for in national legislation, to whom decisive economic power over the technical functioning of the installation has been delegated
OSPAR Convention	1992 OSPAR Convention is the instrument for the protection of the marine environment of the North Atlantic
ozone depletion	destruction of the stratospheric ozone layer, which can be caused by the photolytic breakdown of certain compounds containing chlorine and/or bromine (e.g. chlorofluorocarbons), which catalytically decompose ozone molecules
P	
PA	polyamide
PAH	polycyclic aromatic hydrocarbons
PARCOM	1974 Paris Commission on land based sources of marine pollution. Now superseded by the OSPAR Convention.
PBTs	persistent, bioaccumulative and toxic substances
PCP	pentachlorophenol
PE	polyethylene (polythene)
PET	polyethylene terephthalate
PI	process-integrated
PID	proportional integral derivative
POCP	photochemical ozone creation potential
pollutant	individual substance or group of substances which can harm or affect the environment
PM _{2.5}	particulate matter with an aerodynamic diameter less than or equal to a nominal 2.5 micrometres
POP	persistent organic pollutants
PP	polypropylene
ppb	parts per billion
ppm	parts per million (by weight)
pre-product	a workpiece that is not the final product, but is treated and coated separately. In this document, for example, flat sheets that may be coated and/or printed prior to shaping and adding end pieces to form a can.
primary measure/technique	a technique that in some way changes the way in which the core process operates thereby reducing raw emissions or consumptions (see end-of-pipe technique)
PS	polystyrene
PTFE	polytetra fluoro ethylene
PU or PUR	polyurethane
PVA (or PVAC)	polyvinyl acetate
PVB	polyvinyl butyrate
PVC	polyvinyl chloride

ENGLISH TERM	MEANING
PVdF (or PVF ₂)	polyvinylidene difluoride
PVF	polyvinyl fluoride
Q	
R	
RA	rate of evaporation
RAINS	Regional Air Pollution Information and Simulation for Europe. See Annex 24.1.1. Where RAINS is referred to in this document, it is RAINS version CP_CLE_Aug04(Nov04) For a review of data used in the RAINS-VOC model: http://www.iiasa.ac.at/web-apps/tap/RainsWeb/
REACH	the EC's proposed new regulatory framework for the registration, evaluation and authorisation of chemicals. See: http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm
reference conditions	from standard text – See Chapter 21
RH	relative humidity
right first time	production management quality control technique to enable product quality to be correct within a minimum number of completed items
ROI	return on investment
rto, RTO	regenerative thermal oxidation
S	
SB	solvent-based
SBR	butadiene styrene copolymer
SBS	styrene butadiene styrene (block copolymer)
SCR	selective catalytic reduction
secondary measure/technique	see end-of-pipe technique
SED	Solvent Emissions Directive [123, EC, 1999]
SIS	styrene isoprene styrene (block copolymer)
SME	small and medium enterprise(s)
SNCR	selective non catalytic reduction
SOMO 35	Statistical term: sum of means over 35
specific emission	emission related to a reference basis, such as production capacity, or actual production (e.g. mass per tonne or per unit produced)
STP	standard temperature and pressure
T	
TBT	tributyltin
TCF	totally chlorine-free
TDS	total dissolved solids
TGIC	triglycidyl isocyanurate: a mutagenic substance used in powder coatings
TLV	threshold limit values: guidelines (not standards) prepared by the American Conference of Governmental Industrial Hygienists, Inc (ACGIH) to assist industrial hygienists in making decisions regarding safe levels of exposure to various hazards found in the workplace. A TLV® reflects the level of exposure that the typical worker can experience without an unreasonable risk of disease or injury. TLVs® are not quantitative estimates of risk at different exposure levels or by different routes of exposure
TOC	total organic carbon: a test to assess the amount of organic carbon in a sample
TPB	triphenylborane
TPM	total production management
TWG	technical working group
U	
UF	ultrafiltration
UF	urea formaldehyde
UNO	United Nations Organisation
UP	unsaturated polyester
UV	ultraviolet
V	
VCA	vegetable cleaning agents
VHR	vapour hazard ratio

ENGLISH TERM	MEANING
VOC	volatile organic compounds (see NMVOC)
vp or VP	vapour pressure
W	
waste gas	in this document, the SED definition is used [123, EC, 1999]: the final gaseous discharge containing VOCs or other pollutants, from a stack or abatement equipment into the air.
WFD	Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy.
WGT	Waste gas treatment
white spirit	CAS No: 8052-41-3. Also known as mineral spirits, high flash naphtha, petroleum distillate fractions, Stoddard solvent, petroleum distillates. Used as a paint thinner, a degreaser and a cleaning agent. It is a mixture of saturated aliphatic and alicyclic C7-C12 hydrocarbons with a content of 15-20 % (by weight) of aromatic C7-C12 hydrocarbons and a boiling range of 130 – 230 °C. The C9-C11 hydrocarbons (aliphatics, alicyclics and aromatics) are most abundant, constituting >80 % (by weight) of the total. Flashpoint (fp) and boiling point (initial, bp) according to grade: <ul style="list-style-type: none"> • low flash grade: fp 21 - 30 °C, bp 130 - 144 °C • regular flash grade: fp 31 - 54 °C, bp 145 - 174 °C • high flash grade: fp =>55 °C, bp 175 - 200 °C [188, WHO_IPCS, 1996]
WHO	World Health Organisation
WW	winding wire
WWF	World Wildlife Fund
WWTP	waste water treatment plant
X	
Y	
Z	

2. Common units, measurements and symbols

TERM	MEANING
atm	normal atmosphere (1 atm = 101325 N/m ²)
bar	bar (1.013 bar = 1 atm)
billion	thousand million (10 ⁹)
°C	degree Celsius
cm	centimetre
d	day
g	gram
GJ	gigajoule
h	hour
J	Joule
K	kelvin (0 °C = 273.15 K)
kcal	kilocalorie (1 kcal = 4.19 kJ)
kg	kilogram (1 kg = 1000 g)
kJ	kilojoule (1 kJ = 0.24 kcal)
kPa	kilopascal
kt	kilotonne
kWh	kilowatt-hour (1 kWh = 3600 kJ = 3.6 MJ)
l	Litre
m	metre
m ²	square metre
m ³	cubic metre
mg	milligram (1 mg = 10 ⁻³ gram)
MJ	megajoule (1 MJ = 1000 kJ = 10 ⁶ joule)
mm	millimetre (1 mm = 10 ⁻³ m)
m/min	metres per minute

TERM	MEANING
Mt	megatonne (1 Mt = 10 ⁶ tonne)
Mt/yr	megatonnes per year
mV	millivolts
MW _e	megawatts electric (energy)
MW _{th}	megawatts thermal (energy)
ng	nanogram (1 ng = 10 ⁻⁹ gram)
Nm ³	normal cubic metre (101.325 kPa, 273 K)
Pa	pascal
ppb	parts per billion
ppm	parts per million (by weight)
ppmv	parts per million (by volume)
s	second
t	metric tonne (1000 kg or 10 ⁶ gram)
t/d	tonnes per day
trillion	million million (10 ¹²)
t/yr	tonne(s) per year
V	volt
v/v	volume/volume, usually expressed as a percentage and is the same as vol-%
vol-%	percentage by volume (Also % v/v)
W	watt (1 W = 1 J/s)
w/w	weight/weight, usually expressed as a percentage and is the same as vol-%
wt-%	percentage by weight (Also % w/w)
yr	year
μ	
μm	micrometre (1 μm = 10 ⁻⁶ m)
μS	micro siemens

3. List of chemical elements

NAME	SYMBOL	NAME	SYMBOL
actinium	Ac	mercury	Hg
aluminium	Al	molybdenum	Mo
americium	Am	neodymium	Nd
antimony	Sb	neon	Ne
argon	Ar	neptunium	Np
arsenic	As	nickel	Ni
astatine	At	niobium	Nb
barium	Ba	nitrogen	N
berkelium	Bk	nobelium	No
beryllium	Be	osmium	Os
bismuth	Bi	oxygen	O
boron	B	palladium	Pd
bromine	Br	phosphorous	P
cadmium	Cd	platinum	Pt
calcium	Ca	plutonium	Pu
californium	Cf	polonium	Po
carbon	C	potassium	K
cerium	Ce	praseodymium	Pr
caesium	Cs	promethium	Pm
chlorine	Cl	protactinium	Pa
chromium	Cr	radium	Ra
cobalt	Co	radon	Rn
copper	Cu	rhenium	Re
curium	Cm	rhodium	Rh
dysprosium	Dy	rubidium	Rb
einsteinium	Es	ruthenium	Ru

NAME	SYMBOL	NAME	SYMBOL
erbium	Er	rutherfordium	Rf
europium	Eu	samarium	Sm
fermium	Fm	scandium	Sc
fluorine	F	selenium	Se
francium	Fr	silicon	Si
gadolinium	Gd	silver	Ag
gallium	Ga	sodium	Na
germanium	Ge	strontium	Sr
gold	Au	sulphur	S
hafnium	Hf	tantalum	Ta
helium	He	technetium	Tc
holmium	Ho	tellurium	Te
hydrogen	H	terbium	Tb
indium	In	thallium	Tl
iodine	I	thorium	Th
iridium	Ir	thulium	Tm
iron	Fe	tin	Sn
krypton	Kr	titanium	Ti
lanthanum	La	tungsten	W
lawrencium	Lr	uranium	U
lead	Pb	vanadium	V
lithium	Li	xenon	Xe
lutetium	Lu	ytterbium	Yb
magnesium	Mg	yttrium	Y
manganese	Mn	zinc	Zn
mendelevium	Md	zirconium	Zr

4. SI unit prefixes

Symbol	Prefix	Term	Number
Y	yotta	10^{24}	1 000 000 000 000 000 000 000 000
Z	zeta	10^{21}	1 000 000 000 000 000 000 000
E	exa	10^{18}	1 000 000 000 000 000 000
P	peta	10^{15}	1 000 000 000 000 000
T	tera	10^{12}	1 000 000 000 000
G	giga	10^9	1 000 000 000
M	mega	10^6	1 000 000
k	kilo	10^3	1000
h	hecto	10^2	100
da	deca	10^1	10
-----	-----	1 unit	1
d	deci	10^{-1}	0.1
c	centi	10^{-2}	0.01
m	milli	10^{-3}	0.001
μ	micro	10^{-6}	0.000 001
n	nano	10^{-9}	0.000 000 001
p	pico	10^{-12}	0.000 000 000 001
f	femto	10^{-15}	0.000 000 000 000 001
a	atto	10^{-18}	0.000 000 000 000 000 001
z	zepto	10^{-21}	0.000 000 000 000 000 000 001
y	yocto	10^{-24}	0.000 000 000 000 000 000 000 001

24 ANNEXES

24.1 Models for estimating cost benefit

24.1.1 EGTEI model and synopsis sheets

Description: EGTEI aims to assess the costs of emission reduction techniques and to provide input data to determine total costs for a given sector of activity, depending on various emission reduction scenarios based on technology dependent penetration rates. The EGTEI approach is to:

- improve the representation of pollution control technology costs for a given sector
- reduce uncertainties by working together with the relevant industry stakeholders
- check traceability of data used
- ensure compatibility with the Regional Air Pollution Information and Simulation (RAINS) model, and facilitate the understanding of aggregated data used in RAINS.

Within EGTEI, an emission reduction cost database has been worked out. In this database, a series of background documents has been developed for about 50 sector activities laid down and condensed in a computer tool named ECODAT. Each sector is represented by one or more reference installations (according to operational size), characterised with sets of different parameters: capacity, annual operating hours, production process, combustion technology used, fuel consumption, production data, flowrates of emissions, plant lifetime, etc. ECODAT has been designed to collect country specific data.

EGTEI provides default operating costs calculated on the basis of average European parameters, but it gives to national experts the possibility to introduce specific costs for a given country. To ensure transparency, the method used to assess the costs and the various parameters can be found in the background documents.

Sector representation and cost definition have been developed in close co-operation with industry and national experts. In order to facilitate the national experts' work, it has been necessary to find an equilibrium between the most accurate description of a given sector and the need to minimise statistical data to be collected for cost assessment.

Achieved environmental benefits: EGTEI data sheets are primarily to assist national experts gather data for VOC emissions for RAINS. However, the synopsis sheets contain helpful information to support the consideration of BAT (see Applicability, below).

Cross-media effects: None.

Operational data: See individual data sheets for operational data on each industry type.

Applicability: EGTEI also provides synopsis sheets. These contain a summary of the industries considered, the reference installations considered, primary (in-process) and secondary (end-of-pipe) abatement measures feasible for each level of reference plant and produce default emission values, abatement efficiencies, investment costs, with variable and fixed operating costs for each combination of options. These are summarised at a European level and may be considered when assessing BAT in the industry.

There are synopsis sheets for all the activities covered by the SED, and therefore this document (see Table 24.1). The project resources necessarily limited the number and complexity of techniques considered, but the main options have been identified. The sheets only cover the cost-effectiveness of measures to control NMVOC emissions.

The synopsis sheets do not take into account any BAT considerations such as cross-media effects, nor technical or other characteristics of individual installations, such as types of products and their technical limitations.

Economics: See individual synopsis sheets.

Driving forces for implementation: Supplying data for RAINS.

Example plants: See synopsis sheets.

Reference literature: EGTEI home page: http://www.citepa.org/forums/egtei/egtei_index.htm [132, EGTEI, 2005]

STS BREF Chapter	Use of paint in the coating of vehicles	URL to related EGTEI synopsis sheets	SED Annex II activity code
2	Printing industry		
	Heatset web offset	http://www.citepa.org/forums/egtei/34-Synopsis-sheet-heatset-offset-30-09-05.pdf	1
	Publication rotogravure	http://www.citepa.org/forums/egtei/35-Synopsis-sheet-publication-gravure-30-09-05.pdf	2
	Flexography and rotogravure, in packaging	http://www.citepa.org/forums/egtei/36-Synopsis-sheet-packaging-30-09-05.pdf	3
3	Winding wires	http://www.citepa.org/forums/egtei/23-Synopsis-sheet-winding-wire-29-09-05.pdf	9
4	Manufacture of abrasives	See: Other coating industries:	8
5	Manufacture of adhesive tape (EGTEI: Adhesive application in industry)	http://www.citepa.org/forums/egtei/38-Synopsis-sheet-adhesives-30-09-05.pdf	16
6	Coating of cars	http://www.citepa.org/forums/egtei/15-Synopsis-sheet-car-coating-29-09-05.pdf	Annex IIA.II
7	Coating of trucks and vans	http://www.citepa.org/forums/egtei/20-Synopsis-sheet-truck-coating-29-09-05.pdf	Annex IIA.II
7	Coating of truck cabs	http://www.citepa.org/forums/egtei/21-Synopsis-sheet-truck-cabin-coating-29-09-05.pdf	Annex IIA.II
8	Coating of buses	http://www.citepa.org/forums/egtei/22-Synopsis-sheet-bus-coating-29-09-05.pdf	Annex IIA.II
9	Coating of trains	See: Other coating industries	8
10	Coating of ACE (agricultural, construction and similar equipment)	See: Other coating industries	8
11	Coating of ships and yachts	See: Other coating industries	8
12	Coating of aircraft	See: Other coating industries	8
13	Coating of other metal surfaces	See: Other coating industries	8
14	Coil coating	http://www.citepa.org/forums/egtei/18-Synopsis-sheet-coil-coating-30-09-05.pdf	7

STS BREF Chapter	Use of paint in the coating of vehicles	URL to related EGTEI synopsis sheets	SED Annex II activity code
15	Coating and printing of metal packaging	This industry is not covered by a specific EGTEI synopsis sheet. In part (e.g. rigid metal packaging) addressed in the synopsis sheet 'Other coating industries'. Other parts of the industry are related to flexible packing	3 and 8 (in part)
16	Coating of other plastic surfaces	See: Other coating industries	8
17	Coating of wooden surfaces	http://www.citepa.org/forums/egtei/19-Synopsis-sheet-wood-coating-30-09-05.pdf	10
18	Wood preservation	http://www.citepa.org/forums/egtei/40-Synopsis-sheet-preservation-wood-30-09-05.pdf	12
19	Mirrors	See: Other coating industries	8
General 4 9 10 11 12 13 15 16 19	Other coating industries: Abrasives Trains ACE (agricultural, construction and similar equipment) Ships and yachts Aircraft Other metal surfaces Metal packaging (in part) Other plastic surfaces Mirrors	http://www.citepa.org/forums/egtei/24-26-Synopsis-sheet-general%20industrial-paint-30-09-05.pdf	8
20.9	Cleaning techniques (for surface cleaning of products)	http://www.citepa.org/forums/egtei/27-Synopsis-sheet-surface%20cleaning-30-09-05.pdf	4 & 5

Table 24.1: Table of EGTEI synopsis sheets relevant to this document

24.1.2 Regional environmental costing model (MKM, MilieuKostenModel)

Description: In Flanders, Belgium, an environmental costing model (MilieuKostenModel or MKM) has been developed in parallel with the EGTEI work. With this tool, it is possible to obtain an overview of potential abatement measures, their costs and emission reduction potential, and to find cost efficient or least cost solutions.

The interactions and trade-offs for complex situations are taken into account in the MKM by means of mixed integer programming. The model can be used to optimise (e.g. the least cost solution to reduce emissions, or the marginal cost curve for a particular pollutant) and to simulate (e.g. the impact of more stringent environmental objectives on the least cost solution, or what is the impact of the reduction of polluting activities) for one or multiple pollutants at the same time.

A background report describes the definitions used such as environmental costs and cost efficiency, and the methodology to analyse the cost efficiency of abatement measures.

MKM was devised to determine the costs of environmental policy and to contribute to a more efficient environmental policy by indicating how environmental targets can be realised in a cost effective way. The brief was to:

- develop a coherent database with environmental measures, their reduction potential and costs
- develop a tool to allocate emission reduction efforts between different target groups in a cost effective way
- develop a tool to take into account multiple pollutant effects
- develop a tool to analyse the cost effectiveness of policy instruments
- develop an instrument that can be linked to other models such as ecological models, economic models, (e.g. RAINS).

Depending on the data available, emission sources are identified on an aggregated level (e.g. sector or industry level) or individual source level (e.g. individual companies). The format of the database makes it possible to describe emission sources as individual installations or as so-called 'reference installations'. A 'reference installation' is a representative category of installations for which the same emission abatement measures are available and for which a particular abatement measure has similar abatement results and costs. For each pollutant, emissions are linked to an activity that is the source of the pollution, e.g. amount of solvent consumed. Consequently, the MKM can be used to predict emissions based on the evolution of the activities or emission factor. Also, it is possible to compare data with the input of other models, e.g. RAINS, and link the MKM with, e.g. input-output tables or general equilibrium models.

In addition to emission data, energy consumption, operational hours, capacity, etc. can be entered in the database for each (reference) installation.

For each abatement measure, the following information can be entered in the database: investment costs, operational costs, lifetime, capacity, reduction efficiency.

Achieved environmental benefits: No data submitted.

Cross-media effects: No data submitted.

Operational data: No data submitted.

Applicability: The development of the model is focused on one criterion: cost effectiveness. Nevertheless, other criteria can play a significant role in determining the environmental policy such as environmental effectiveness and feasibility. It is important to mention that the environmental costing model (MKM) is not a tool to carry out an investment analysis for a specific company. The model is a tool to support the Flemish Government in estimating the costs of the environmental policy for different target groups. Such information can be used, for example, to allocate emission reduction efforts between target groups.

Measures discussed in this document that were analysed with this model are, e.g. for the coating sector:

- painting techniques, i.e. conventional (see Section 20.7.2.1), high solids (see Section 20.7.2.2), water-based (see Section 20.7.2.3), powder coating (see Section 20.7.2.5) and UV-cured paint (see Section 20.7.2.4)
- waste gas treatment techniques, i.e. adsorption to activated carbon (see Section 20.11.6), thermal oxidation (see Section 20.11.4.2) and biological treatment (biofilters) (see Section 20.12.5).

More measures are described in this document to reduce VOC emissions, but not all can be analysed with this model.

The following industries can be consulted in the database of the MKM: coating, printing, degreasing, adhesives and automobiles. As an example of the output of the tool, the results for the coating sectors are shown in Table 24.2 and Table 24.3.

*Note: these data are supplied from the MKM and the footnotes should be referred to.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature:

The MKM page: <http://www.emis.vito.be/index.cfm?PageID=371&T=0&S=0>

The background report: (Meynaerts E., Ochelen S., Vercaemst P., Milieukostenmodel voor Vlaanderen – Achtergronddocument, 2003).

[95, Vito, 2005] [128, TWG, 2005]

Technique	Operational cost of paint in EUR per kg	Energy cost in EUR per hour	Residues in EUR/kg	VOC content of paint (presumed to be wt-%)	
Conventional	3.11	6.7	0.3		
High solids	3.5	6.4	0.3	<30 %	
Water-based	8.43	7.21	0.2	7.50 %	
Powder coating	15.39***	2.9	0	0 %	
UV paint	3.78***	3.76	0	3.50 %	
	Investment cost in thousand EUR per 1000 m ³ /h	Activated carbon in EUR per kg	Operational cost	VOC reduction (%)	VOC emission concentration
Activated carbon*	5 – 10	1.2	EUR 0.5 – 2.30 per m ³ /h with initial VOC conc. of 1 – 10 g/m ³	85 %	5 – 100 mg TOC/m ³
Thermal oxidation**	5 – 40		EUR 0.45 – 4.50 per 1000m ³ /h (extra energy)	95 – 99 %	<20 – 50 mg TOC/m ³
*Reduction option when VOC emissions are between 8 to 20 tonnes a year, 85 % reduction					
**Reduction option when VOC emissions are >20 tonnes a year, 95 % reduction					
***Sections 20.7.2.5 and 20.7.2.6 give costs of EUR 30.01 – 5.38/kg for both radiation cured and powder coating paints					

Table 24.2: Average costs and VOC reduction potential of all the measures analysed by the model [95, Vito, 2005]

Industry		Number of employees	Possible in-process measures ¹			Possible end-of-pipe measures	
Metal surfaces	1 - 19	60 % high solid	40 % water-based	50 % powder			
	20 - 199	80 % high solid	40 % water-based	50 % powder			
		100 % high solid		60 % powder		Incinerator	
						Incinerator*	
	200 - 499	80 % high solid		50 % powder			
					Activated carbon*	Incinerator	
						Incinerator*	
	500 - 999	80 % high solid		50 % powder	Activated carbon*		
		80 % high solid				Incinerator	
	1000 - 1000+	80 % high solid					
	100 % high solid	Water-based					
Metal packaging – barrels	20 - 99					Incinerator*	
	100 - 199					Incinerator*	
	500 - 999	Optimise cleaning agents					
Furniture	10 - 499			80 % powder (for those who still use wet coatings)			
	5 - 199		60 % water-based	40 % powder	Activated carbon*		
Ships	10 - 499	60 % high solid					
Trains	10 - 1000+	70 % high solid		30 % powder	Activated carbon*	Incinerator*	
Others	1 - 49	60 % high solid		30 % powder			
	50 - 99		30 % water-based	30 % powder			
	100 - 199	60 % high solid		30 % powder			
	200 - 499	No additional measures					
	500 - 999				Activated carbon		

Continued in following page

Industry		Number of employees	Possible in-process measures			Possible end-of pipe measures	
WOOD	Furniture	1 - 9	30 % high solid	30 % water-based			
		10 - 19	30 % high solid	30 % water-based			
		20 - 49	30 % high solid	30 % water-based	UV paint	Activated carbon*	Biofilter*
				water-based	UV paint		
		50 - 99	30 % high solid	30 % water-based	10 % UV	Activated carbon*	Biofilter*
		100 - 199	30 % high solid	30 % water-based	10 % UV		
	200 - 499	30 % high solid	30 % water-based	10 % UV	Activated carbon*	Incinerator*	
	Cabinet work	1 - 499	30 % high solid	40 % water-based	10 % UV		Incinerator
Others	5 - 199	30 % high solid	40 % water-based	10 % UV			
PLASTICS	Plastic	1 - 4	50 % high solids	<i>30 % water-based</i>			Incinerator*
		5 - 9	50 % high solids				Incinerator*
		10 - 19	50 % high solids				Incinerator*
		50 - 99	50 % high solids	<i>40 % water-based</i>			
		100 - 199		<i>50 % water-based</i>			
		200 - 499	50 % high solids	<i>40 % water-based</i>			Incinerator*
		500 - 999	50 % high solids		UV paint		
<p>1 The percentages of the possible measures relate to maximum technical uptake, they are not based on cost benefit</p> <p>*Not enough data were collected on the survey to draw a conclusion. In these cases, a general rule was used: incinerators are technically applicable when VOC emissions are >20 t/yr and adsorption to activated carbon and biofilters are technically applicable when VOC emissions range from 8 - 20 t/yr. However, Section 20.11 of this document shows choice is related to air volume and concentration, not total consumption</p> <p>Measures in italics were rejected and were not taken up into the model as they have higher costs and lower efficiencies compared to other measures.</p>							

Table 24.3: Possible cost-effective measures for the reduction of VOC emissions per industry
[95, Vito, 2005]

24.2 Calculation of VOC emissions and the units used

[182, ADEME, 2006] [110, EC, 1996, 123, EC, 1999] [148, TWG, 2006]

All activities within the scope of this document are regulated by the SED (Council Directive 1999/13/EC of 11 March 1999) and IPPC applies to the larger installations within SED control. The Preface to this document describes the interface between the two directives. In the interests of better regulation and simplification, this document (the STS BREF) uses the determination of VOC emissions and the values used to express them as described in the SED. This is particularly important for the expression of emission values related to BAT. This implies that installations are able to use the SED reduction scheme where the SED gives no total emission limit values for that industry.

There are various industry exceptions to using the SED values, which are explained in the various sections, such as:

- heatset offset printing, where the emission values related to BAT are expressed as wt-% of the ink consumption. This allows the effect of the BAT to be measured, whereas the % solvent input (which the SED uses) does not
- the coating of trains and manufacturing of mirrors, where the information provided and from which BAT were derived, were based on gm VOC/m² painted
- coil coating and metal packaging, where m² were identified as appropriate production throughout measures
- wood preservation, where the information provided and from which BAT were derived were based on percentage reduction in VOC emission based on solvent input.

24.2.1 Compliance with the Solvent Emissions Directive

The SED regulates the emissions of volatile organic compounds (VOC) due to use of organic solvents in different types of activities and installations.

According to Article 5 of the SED Directive, two different options are offered to demonstrate compliance with the legal requirements:

'All installations shall comply with:

(a) either the emission limit values in waste gases and the fugitive emission values, or the total emission limit values, and other requirements laid down in Annex IIA;

or

(b) the requirements of the reduction scheme specified in Annex IIB.'

For either option, there are specific exceptions where the operator must demonstrate that BAT is being used.

24.2.1.1 Emission limit values (ELVs) and fugitive emissions (SED Annex IIA)

Each type of industry must comply with the values given in the tables in Annex IIA. The ELVs are expressed in mg C/m³ at standard conditions, and fugitive emissions as percentage of the solvent input. Total emission values (where given) are expressed as industry-specific terms, such as g VOC/kg of product (for winding wires), g VOC/m² e-coat surface area for vehicles, etc.

24.2.1.2 Emission reduction scheme (SED Annex IIB)

Annex IIB of the SED states:

‘Principles

The purpose of the reduction scheme is to allow the operator the possibility to achieve by other means emissions reductions equivalent to those achieved if the emission limit values were applied. To that end an operator may use any reduction scheme, specially designed for his installation, provided that in the end an equivalent emission reduction is achieved...’

The implementation and validation of an emission reduction scheme therefore ensures that the yearly VOC emission flux will not be higher than the flux achieved by meeting the emission limit values for all waste gases and fugitive emissions. The interest of an emission reduction scheme for operators is to be able to think of their processes as a whole and to have flexibility about their choices for emission reduction. Additional efforts and investments will be made where they are technically and economically most effective. This is consistent with the IPPC Directive, Article 9(4):

‘... the emission limit values and the equivalent technical parameters and technical requirements referred to in paragraph 3 (permit conditions) shall be based on BAT, without prescribing the use of any technique or specific technology, but take into account the technical characteristics of the installation, its geographical location and the local environmental conditions...’

Annex IIB to the SED describes a reduction scheme where a constant solid content of product can be assumed for coatings, varnishes, adhesives or inks.

A target emission is calculated on based on the annual solids and the fugitive emissions given in Annex IIA. They are expressed as a percentage of the unabated emissions. In the SED, this unabated emission is called the ‘reference emission’. Where no substitution has taken place, the unabated emissions are equal to the solvent input. Where some substitution or other emission controls on fugitive sources have been applied, the unabated emissions need to be estimated. The method in Annex IIB to the SED can generally be used for this purpose. The annual reference emission is calculated as follows (quoted exactly from the SED):

- a) *The total mass of solids in the quantity of coating and/or ink, paint or adhesive consumed in a year is determined. Solids are all materials in coating, inks, paints or adhesives that become solid once the water or the volatile organic compounds are evaporated.*
- b) *The annual reference emissions are calculated by multiplying the mass determined in (a) by the appropriate factor listed in Table 24.4:*

<i>Activity</i>	<i>Multiplication factor</i>
<i>Rotogravure printing; flexography printing; laminating as part of a printing activity; painting as part of a printing activity; wood coating; coating of textiles, fabric film or paper; adhesive coating</i>	<i>4</i>
<i>Coil coating, vehicle refinishing</i>	<i>3</i>
<i>Food contact coating, aerospace coatings</i>	<i>2.33</i>
<i>Other coatings and rotary screen printing</i>	<i>1.5</i>

Table 24.4: Factors in SED for determining annual reference emission values

The target emission can be expressed as wt-% (i.e. % VOC of the solids, more usually as kg VOC/kg solids, as defined in the SED). As the SED allows any equivalent reduction scheme to be used, provided it satisfies the principles outlined in Annex IIB, VOC target emissions may then be expressed as VOC t/yr (for a specific installation of known throughput), kg VOC/m² coated, kg VOC/production item produced.

For example, regarding the flexo and packaging gravure printing process, the calculation is as follows:

The average solvent content of press ready inks, paints and adhesives in flexo and packaging gravure is approximately 80 %. The solid matter in these products accounts for 20 % of the total weight, and thus ¼ of the solvent weight. The unabated emissions ('reference emission') can be estimated by multiplying the weight of all the solids, of both solvent-based and water-based products, by four.

24.2.2 Precision

The Solvent Emissions Directive describes a method, simple at first sight, by which fugitive emissions can be determined in plants where captured solvent vapours are incinerated. The principle of this method is that the amount of solvent sent to the incinerator is subtracted from the total solvent input. The difference between the two quantities must have disappeared; most of it as fugitive emissions.

In practice, this method can suffer from a lack in accuracy. For example, when the method given in the Directive is used, fugitive emissions that are, in reality, amounting to approximately 15 % of the input, can easily be quantified as anything from 0 to over 40 %.

If the difference is calculated between two almost equal numbers such as 'input' and 'captured emissions', then the outcome, which should represent the fugitive emissions, is a relatively small number. The inaccuracy in the resulting small number, however, is equal to the sum of the inaccuracies in the two original, large numbers. Thus, all the inaccuracies in the two original numbers are included in the fugitive emissions.

The main problem lies in the difficulty of quantifying captured emissions. This requires multiplication of the airflow, solvent concentration and time. The airflow and concentration vary over time, and neither can be measured accurately. The error in the result is greater than 20 %.

Options to address the inaccuracies are to determine the fugitive emissions directly (see Annex 24.3) or to derive the unabated emissions from the actual solvent input (see Annex 24.4).

The following example shows how a typical range in concentration and flow can show an 4-fold range in amount of VOC emitted.

Where O_1 is the emission in waste gases.

$$O_1 = \frac{(\text{concentration } c \text{ in mg C/Nm}^3) \times (\text{volume } v \text{ m}^3/\text{hr}) \times (\text{operating hours in time period})}{\text{time period}}$$

For a theoretical installation operating 5760 hours per year (24 hour a day, 5 days a week, 48 weeks a year), with waste gas flows $v = 100000 \text{ m}^3/\text{h}$ and the periodic monitoring giving values varying between 5 and 20 mg C/Nm³. The annual emission calculated for each end of the range:

where $c = 5 \text{ mg C/Nm}^3$, $O_1 = 2880 \text{ kg}$ (2.88 tonnes)

where $c = 20 \text{ mg C/Nm}^3$, $O_1 = 11500 \text{ kg}$ (11.5 tonnes).

Depending on the type of activity and the installation, the variation between the lowest determinand and the highest may be considerable (see the Monitoring REF).

24.2.3 Application efficiency of the coating

Calculating VOC emissions according to the reduction scheme described in the SED, Annex IIB does not take into account an improvement in the application efficiency, because the calculation is based on the ratio of VOC to solids: if the quantity of solids is decreased, the ratio kg VOC/kg solids remains the same. This should be considered when setting emission targets and ELVs. Options are to set a total emission per year or per production unit.

For example, in an installation with a paint consumption of 2000 tonnes per year, the corresponding solvent consumption is 1500 tonnes (75% solvent consumption: i.e. a ratio of 3 kg of VOC/kg of solids). The spray guns have an application efficiency of 20%. According to the SED:

the reference emission target emission = 500 tonnes x 4 = 2000.

the target emissions = 0.25 x reference emissions = 0.25 x 2000 = 500 tonnes of VOC.

Reductions in emissions can be achieved by one or more of the following:

- installing an end-of pipe technique to reduce VOC emissions to 375 tonnes (where the ratio remains 3 kg of VOC/kg of solids)
- by using water-based (WB) paints (for example, the use of 2000 tonnes of WB paints with a solvent consumption of 18.75% gives VOC emissions of 375 tonnes: the ratio is 0.75 kg of VOC/kg of dry matter)
- by applying solvent based paints (with a ratio of 3 kg of VOC/kg of dry matter) with a much higher efficiency: applying the same solvent based paints with an application efficiency of 80% leads to a paint consumption of 500 tonnes (instead of 2000 tonnes) and thus VOC emissions of 375 tonnes.

24.3 Measuring fugitive emissions – direct method

[51, Aminal, et al., 2002] [76, TWG, 2004] [148, TWG, 2006]

Step 1: Identify all sources of fugitive emissions within the plant

All solvent vapours that are not routed to the incinerator escape to the air and contribute to the fugitive emissions. Most industries considered in this document have many sources of fugitive emissions. The following is a case study in some ten flexible packaging plants in Flanders, Belgium, and the Netherlands. However, the principles described in the following steps are readily transferable to other industries. Most plants will have a number of sources and most of these will only result in small or extremely small emissions. In most cases, there are just one to three sources in a plant which make a substantial contribution to the fugitive emissions. More than one emission factor may need to be determined for a source, to improve the accuracy or for convenience.

A flexible packaging plant has many sources of fugitive emissions. The sources identified so far are listed below, although most plants will only have a few of these. In some cases, there may be more sources, or another classification may be more convenient.

Sources of fugitive emissions for flexible packaging are:

- press room ventilation during printing
- drier ventilation during make ready
- drier ventilation while waiting
- local exhaust between press units
- cleaning department
- ink mixing department
- solvent content of water-based inks, paints and adhesives
- solvents used on production machines not connected to the incinerator
- residual solvent in products
- solvent discharged to water
- solvent emissions from waste water treatment plants
- vapour losses from tanks, etc.

Double counting should be avoided. For example, if the ink is mixed next to the press then the evaporated solvent will be removed by the local exhaust between press units and the room ventilation and does not need to be quantified separately.

Step 2: Study the ventilation system and ensure that it works as expected

In production areas in particular, the design of the ventilation system determines which fugitive emission sources are present, and how the emitted quantities must be estimated or measured. The ventilation systems does not normally work as assumed in the plant. Either the system was built in a different way than remembered or recorded, and/or the system control settings were completely changed during the course of time. A ventilation system that actually operates as expected is very rare.

Some examples that were actually encountered in practice are:

- the actual duct system was different from the drawing. Fans and ducts had been installed or removed, and the modifications had not been documented accurately
- automatic positive and negative pressure controls did not operate as designed. Printing plants which expected to be working above atmospheric pressure were actually working at subatmospheric pressure, and the other way round

- some components of the ventilation system showed to have more functions than expected. A fan for aqueous paints on one of the printing units was also found to be connected to the local exhaust between the press units
- significant airflows were shown to exist between different parts of the building.

As long as the operation of the ventilation system is not perfectly in order, there is no point in measuring or estimating fugitive emissions that are affected by it. If the settings of the ventilation system need to be adjusted later, the estimation and measurements will be of no use. Hence, the first action should be to assure complete understanding of the ventilation system in the production areas. The ducting and fans need to be compared with the drawings. The maintenance status should be checked. Poor maintenance and cleaning can reduce the airflow by as much as 50 %. It is good practice to correct any substandard maintenance before carrying out any measurements.

When comparing the design with the current system, questions must be asked such as the following:

- have filters and drive belts been replaced according to suppliers maintenance schedules?
- are the fan blades and heat exchangers clean?
- where are the exhausts?
- where are the inlets for fresh air?
- which exhausts are connected to the same duct?
- which fan serves what part of the system?
- when are dampers and valves automatically opened or closed?
- what automatic controls are incorporated?
- what measurements are provided for them?
- what are the theoretical flowrates of the fans?
- how are the control systems supposed to operate?
- what is the difference between summer and winter control modes?

In most cases, there is a clear difference between theory and practice. It has then to be decided what is actually required and the ventilation settings need to be adjusted accordingly. It then has to be verified if the ventilation system actually produces the required results in the different stages of the production process (e.g. make ready, printing, cleaning, etc.). In practice, this may be relatively easy to do. For example, the direction of the airflow through doors, windows and other openings can be easily established using a thin, narrow strip of plastic film. Fugitive emissions can only be determined once the ventilation system is adjusted as required by plant management. Obviously, management will also need to ensure the improved regime is maintained.

Step 3: Make a substantiated estimate for each source, in the form of an emission factor multiplied by a production parameter

The emissions of every source with emissions that are not negligible have to be estimated. In this step, the order of magnitude needs to be established. Later it will be decided if the emissions are high enough to warrant additional measurements. Obviously, the estimates should have a secure basis, but at this stage the number of measurements should be minimised. The aim is to only use data already available within the plant, and data which are easily measured. Below are some examples of useful information that is already available in the plant, or which can easily be measured:

- fan capacities, as specified by their manufacturer
- information about occupational exposure to solvents
- measurements of residual solvent in products, carried out for customers
- quantity of bulk solvents, inks, paints and adhesives received
- simple experiments in the ink mixing department

- simple solvent balances for the cleaning department, etc.
- concentration measurements with a PID at local exhausts
- verification of the direction of the pressroom ventilation flow.

The example in Table 24.5 relates to a plant with an annual input of 1000 tonnes of solvent. The example clearly shows how only two out of the eleven sources account for over 70 % of the fugitive emissions.

Source	Emissions in kg	% of input	% of fugitive
Pressroom ventilation during printing	9000	0.90	8.0
Drier ventilation during make ready	5400	0.54	4.8
Drier ventilation while waiting	22500	2.25	20.0
Local exhaust between press units	56550	5.66	50.3
Cleaning department	8750	0.88	7.8
Ink mixing department	7500	0.75	6.7
Solvent content of water-based inks, etc.	2500	0.25	2.2
Residual solvent in products	200	0.02	0.2
Solvents discharged in water	-	-	-
Solvent emissions from waste water treatment plant	-	-	-
Vapour losses from tanks, etc.	67	0.01	0.1
Total	112467	11.26	100.1

Table 24.5: Emissions related to sources from a plant processing 1000 tonnes of solvents

At this stage, another option would be to reduce the emissions from the major sources or to eliminate them completely before doing any additional measurements. For example, if sufficient incinerator capacity were available, the local exhaust between press units or the exhaust of the cleaning department could be connected to the incinerator. This would eliminate these sources of fugitive emissions completely.

Step 4: Determine which of the sources need more accuracy

The estimates made in Step 3 are not particularly accurate. However, they clearly indicate that the magnitude of the fugitive emissions varies greatly between sources. Vapour losses from tanks are very small, while the local exhaust between the press units is particularly important.

Now the accuracy of the calculated total fugitive emission needs to be determined. The emission parameters which need more accuracy, must be selected. This is done by a worst case approach: the maximum possible error for each source is estimated, and the resulting maximum potential fugitive emission from the source in question are calculated. The total of all these maximum potential emissions is the 'worst case'.

Most emission estimates made in Step 3 were calculated by multiplying two or more fairly inaccurate figures. For example, a theoretical airflow may have been multiplied by an indicative concentration measurement and an estimated number of running hours. In such a case, the inaccuracy in each of the parameters needs to be estimated separately and this information is used to calculate the potential maximum emissions from each source, as if the largest possible potential error did indeed occur. The result is the maximum emissions possible from the source in question.

The maximum emissions possible from all the different sources are then added up to calculate the maximum overall fugitive emissions; as if the initial emission estimates for each and every sources had been too low. This is a very conservative approach. It is equally likely that the emission estimates were not too low, but too high. In that case, the actual fugitive emissions would be lower than the estimates. In reality, errors to both sides will be made and the actual emissions will be closer to the initial estimate than would be assumed on the basis of the calculation of the potential maximum emissions.

The example in Table 24.6 shows the estimation of the maximum error for each source. Note, however, that a large part of the inaccuracy is due to the limited amount of information about ventilation flows and solvent concentrations.

Source	Fugitive emissions as % of input	Max. error factor	Max. % of input
Pressroom ventilation during printing	0.90	2.25	2.03
Drier ventilation during make ready	0.54	1.50	0.81
Drier ventilation while waiting	2.25	2.00	4.50
Local exhaust between press units	5.66	2.25	12.72
Cleaning department	0.88	2.00	1.75
Ink mixing department	0.75	1.50	1.13
Solvent content of water-based inks, etc.	0.25	1.25	0.31
Residual solvent in products	0.02	1.25	0.03
Vapour losses from tanks, etc.	0.01	1.00	0.01
Total	11.26		23.29

Table 24.6: Example of a possible outcome of the calculation of inaccuracies

The worst case figures obtained in this way can still easily amount to double the original estimate. Some sources will be so small that they would not affect the outcome, irrespective of how precisely they are measured. In this example these are:

- solvent content of water-based inks, paints and adhesives
- residual solvent in products
- vapour losses from tanks.

There is no point in investigating these sources in any greater detail. Two of the sources on the list are clearly much more important than the others:

- local exhaust between press units
- drier ventilation while waiting.

These sources require further investigation, but together they account for over 70 % of the fugitive emissions.

Note: this is only an example! In practice, different sources may be the ones with high or low emissions.

Step 5: Improve the inaccurate estimates for large sources

The scope, depth and detail of the further investigations will depend on the objectives. In most cases, the inaccuracy of only two or three sources will have to be reduced to obtain a significant improvement of the outcome in the worst case approach.

The further investigation needs to be tailored to the specifics of the converting plant. As stated earlier: further investigation is only necessary for sources of fugitive emissions that are both relatively large and uncertain.

This step (Step 5) describes how the inaccuracy of most of the initial estimates can be reduced. In cases where airflow and solvent concentration are being multiplied, an obvious option for improvement of the estimates is to actually measure the concentration. This can be done rather easily by using passive samplers. Where the solvent losses from a source can be determined with scales, the number of weighings could be increased to improve accuracy. As an example, results of the improvement of the accuracy are given in Table 24.7.

Source	Emissions in kg	% of input	% of fugitive emissions
Pressroom ventilation during printing (positive pressure)	9000	0.90	8.0
Cleaning department	8750	0.88	7.8
Ink mixing department	7500	0.75	6.7
Solvent content of water-based inks, etc.	2500	0.25	2.2
Residual solvent in products	200	0.02	0.2
Solvents discharged in water	-	-	-
Solvent emissions from waste water treatment plant	-	-	-
Vapour losses from tanks, etc.	67	0.01	0.1
Subtotal not investigated further	28017	2.81	21.1
Drier ventilation during make ready	8000	0.80	6.0
Drier ventilation while waiting	24750	2.48	18.6
Local exhaust between press units	72200	7.22	54.3
Subtotal of sources investigated in detail	104950	10.50	78.9
Total fugitive emissions	132967	13.31	100
Previous result (before additional investigation)	112467	11.25	

*Note: Subtotal not investigated further as a percentage of fugitive emissions should be 25 %

Table 24.7: An example showing results of the improvement of accuracy

In this example, the additional investigation has greatly increased the accuracy of three of the eleven sources. The worst case now only differs a few per cent from the actual estimate. As an example, the results of the new estimates of the accuracy are given below.

Example: Increased accuracy as shown in Table 24.8 below.

Source and notes	Estimated % of input	Factor max. residual error	Max. % of input improved estimate
Drier ventilation during make ready	0.80	1.20	0.96
Drier ventilation while waiting	2.48	1.20	2.97
Local exhaust between press units	7.22	1.20	8.66
Other sources (unchanged)	2.80		5.24
Total	13.30		17.83
Previous result	11.25		23.28

Table 24.8: An example showing results of the increased accuracy

Please note that here only the potential errors that result in increased emissions are being calculated. Errors resulting in reduced emissions are, however, equally likely.

If the fugitive emissions have to be determined more accurately still, other emission sources can be considered for further investigation. In this example, the cleaning department and pressroom ventilation are likely candidates. One-third of the remaining difference between the actual estimation and the worst case (4.5 %) in this example is associated with the cleaning department, and one-fifth with the room ventilation.

Step 6: Establish a record keeping system from which the annual production parameters can be easily derived

Simplicity starts by choosing the right parameters. Where possible, they should be based on information that is already being collected. However, it should be determined if the figures obtained from other records do in reality accurately reflect the parameter which the emission factor refers to, and caution is needed. Examples of potential discrepancies between the existing records and the required parameters:

- waiting hours and other stops as recorded in the production department may occur both during make ready or during printing. For the calculation of fugitive emissions, however, only the periods in which the printing units contain ink, but are not actually producing, matter
- production hours (as needed to calculate the emissions from the exhausts between the press units) may not, according to production records, include waiting hours and other stops during printing. However, for the calculations, the full period during which the unit contains ink needs to be established
- if some of the ink is not mixed in the ink mixing department but at the press, the resulting solvent losses will go to the press room ventilation and local exhausts. This may lead to double-counting.

Step 7: Calculate the annual emissions from each source by multiplying the production parameters and related emission factors

This step does not need further explanation.

Step 8: Include the results in the annual solvent management plan and compare the fugitive emissions with the limit value

This step does not need further explanation.

Step 9: Determine new emission factors if there is a significant change in the range of equipment, operations or ventilation

New emission factors must be determined if there are significant changes in the plant. A significant change may be a change in the ventilation system of the production areas, purchase of new machines, sale of old machines, a substantial change in the product range, or changes in the operating methods.

Determining the emission factors is not, in practice, a one-off activity. Once the plant becomes accustomed to dealing with fugitive emissions, the awareness of these emissions will also increase. This in turn will lead to improvements in the records, a repeat and recheck of measurements, and a wish to improve the accuracy of less important emission factors. Furthermore, options will be identified to reduce fugitive emissions. This will also lead to new emission factors.

24.3.1 Application to the printing sector

Description: This method was tested in two Flemish flexible packaging plants, a very large packaging gravure plant and a medium sized flexographic plant. It is based upon direct measurements of the fugitive emissions. The capture efficiency is the percentage of the evaporated solvents that are exhausted with the waste gases. The remainder escapes as fugitive emissions.

Introduction and terminology of the alternative (direct) method

Sources of fugitive emissions: Fugitive emissions in a printing plant have many different causes. They arise during printing, cleaning, mixing of inks, transferring of solvents, etc. Each of these activities is a 'source' of fugitive emissions. It is possible to allocate the fugitive emissions in a plant to some 10 or 20 different 'sources'.

Emission factor: The more frequently an activity is undertaken, or the longer it takes, the greater the fugitive emissions will be. Mixing 20 drums of ink will produce twice as many fugitive emissions as mixing 10 drums. Printing for four hours results in greater fugitive emissions than printing for two hours.

An emission factor can be determined for each source. This factor indicates the quantity of fugitive emissions for each time or every hour that the activity is carried out.

Emission factors need to be determined only once. They are specific to a machine and a working method. If neither machine nor working method changes, the emission factor also remains unchanged.

Production parameter: In order to calculate the emission, the emission factor needs to be multiplied with a production parameter. This production parameter is a measure of the activity of the source of fugitive emissions in question. The larger the production parameter, the bigger the fugitive emissions.

Examples: For cleaning operations, the number of times the cleaning unit is used could be employed as the parameter, and for mixing ink the volume of ink that was mixed.

Effective records need to be kept to produce the production parameters.

In short, the method amounts to the following:

- estimate or measure the relevant emission factors and set up a record-keeping system for the annual production parameters. This has to be done only once
- calculations on fugitive emissions have to be carried out each year. This is done by multiplying the production parameters for the year in question by the emission factors.

Obviously, the most difficult step is to determine the emission factors. This is done in two or more stages. The first step is to make a well substantiated estimate. This is done for all the different sources of fugitive emissions. No further action is required for the large number of sources that show very low emissions. The second step is only carried out for a small number of larger sources, where more accurate measurements are taken.

Accuracy

The production parameters can be determined accurately. Preferably, these parameters are figures that are already part of the production records, or that have to be collected anyway for other parts of the solvent management plan.

Examples of such parameters are the number of operating hours of production equipment, the number of orders processed on each machine, the volume of ink purchased, and the number of tonnes of ink mixed. The parameters are always measures of the activity: the higher the parameter, the higher the associated fugitive emissions must be.

The emission factors are a measure of the emissions per unit of activity. For example, the loss of solvent per kilo of mixed ink, or the loss of solvent through the local exhaust between the press units per operating hour.

The accuracy level of the emission factors is variable. The more extensive the measurements and the investigation are, the more accurate the factors will be. The different sources of fugitive emissions do not all need the same level of accuracy.

Accuracy can also be increased by using more than one emission factor for an activity. Instead of using one emission factor for all ink mixing operations, one could distinguish between mixing large and small batches of ink, mixing on hot or cold days, and mixing by hand or by machine. In other words, either one or five different factors could be determined. In the latter case the accuracy will be greater.

To determine more than one emission factor per activity or increasing their accuracy will however, also increase the amount of work. It is not productive to spend a lot of time on a minor source which hardly contributes to fugitive emissions. It is, therefore, advisable to start by estimating the order of magnitude of the emissions from each source, and then afterwards determine which of the sources need the most accurate emission factors.

The required accuracy for a source depends on two different issues:

1. the magnitude of the overall fugitive emissions: if the overall fugitive emissions are considerably below the limit value then the potential error is allowed be relatively large.

Example: At a limit value of 20 % (for the SED), an actual emission of between '5 and 10 %' would be acceptable, but an actual emission of between '15 and 30 %' would not be. In the latter case the accuracy needs to be increased.

1. contribution of the source to the overall emissions: if the accuracy of the overall figure has to be improved then one should focus on the sources which are both relatively large and have a low accuracy.

Example: Given a limit value of 20 % and actual emissions of 15 to 30 %, with a contribution from the ink mixing department of 1 to 2 % and a contribution of the local exhaust between press units of 10 to 20 %, it would obviously be beneficial to improve the accuracy of the second source.

Achieved environmental benefits: The accuracy in monitoring fugitive emissions is considerably improved. The insight gained on the origin and cause of the fugitive emissions, contributes to the reduction of these emissions.

Cross-media effects: No data submitted.

Operational data: The method has been tested in flexible packaging printing plants.

Applicability: Flexible packaging plants applying a destructive abatement technique.

Economics: No data submitted.

Driving forces for implementation: No data submitted.

Example plants: No data submitted.

Reference literature: [76, TWG, 2004]

24.4 The common cases for mass balances

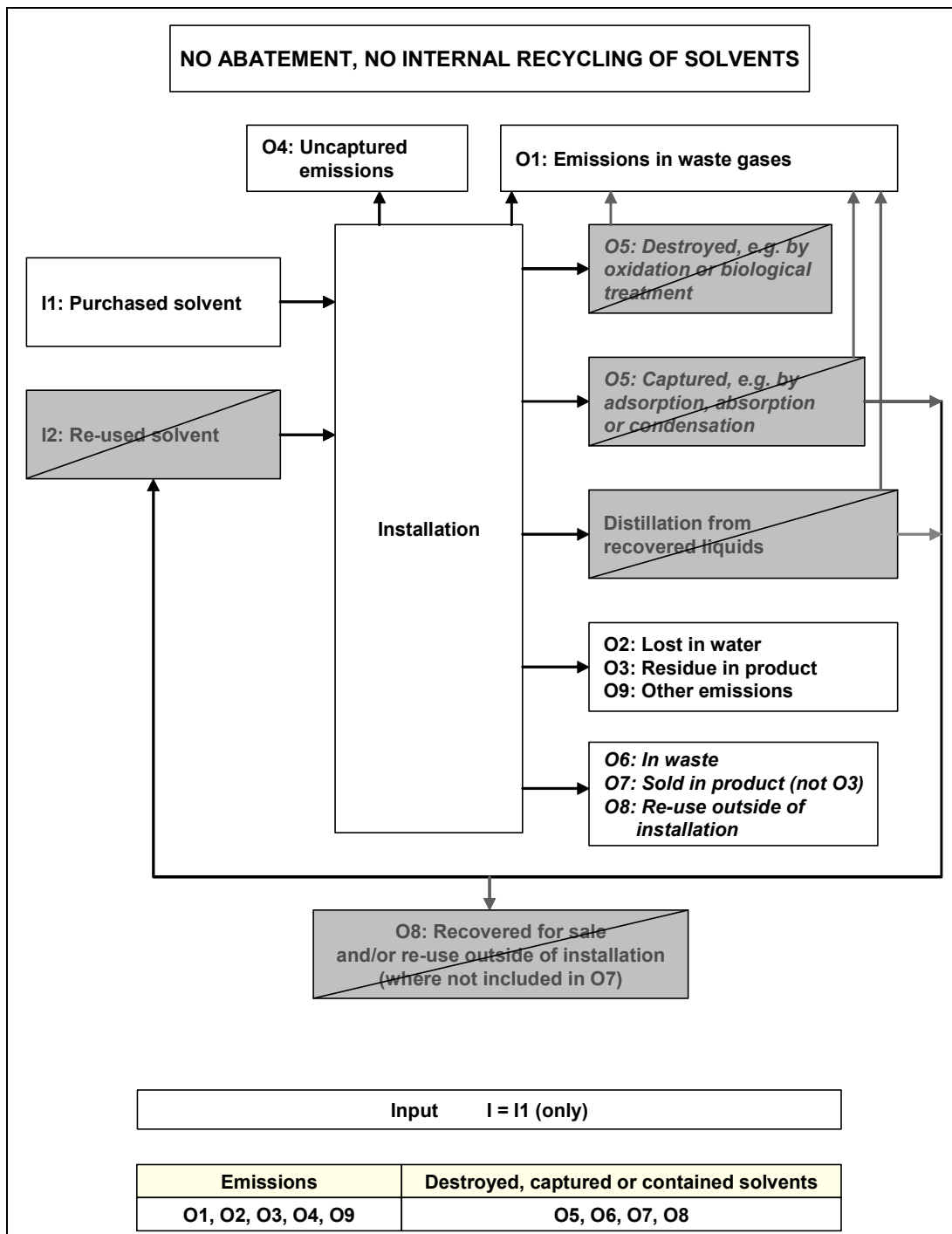


Figure 24.1: No end-of-pipe abatement, and no internal recycling

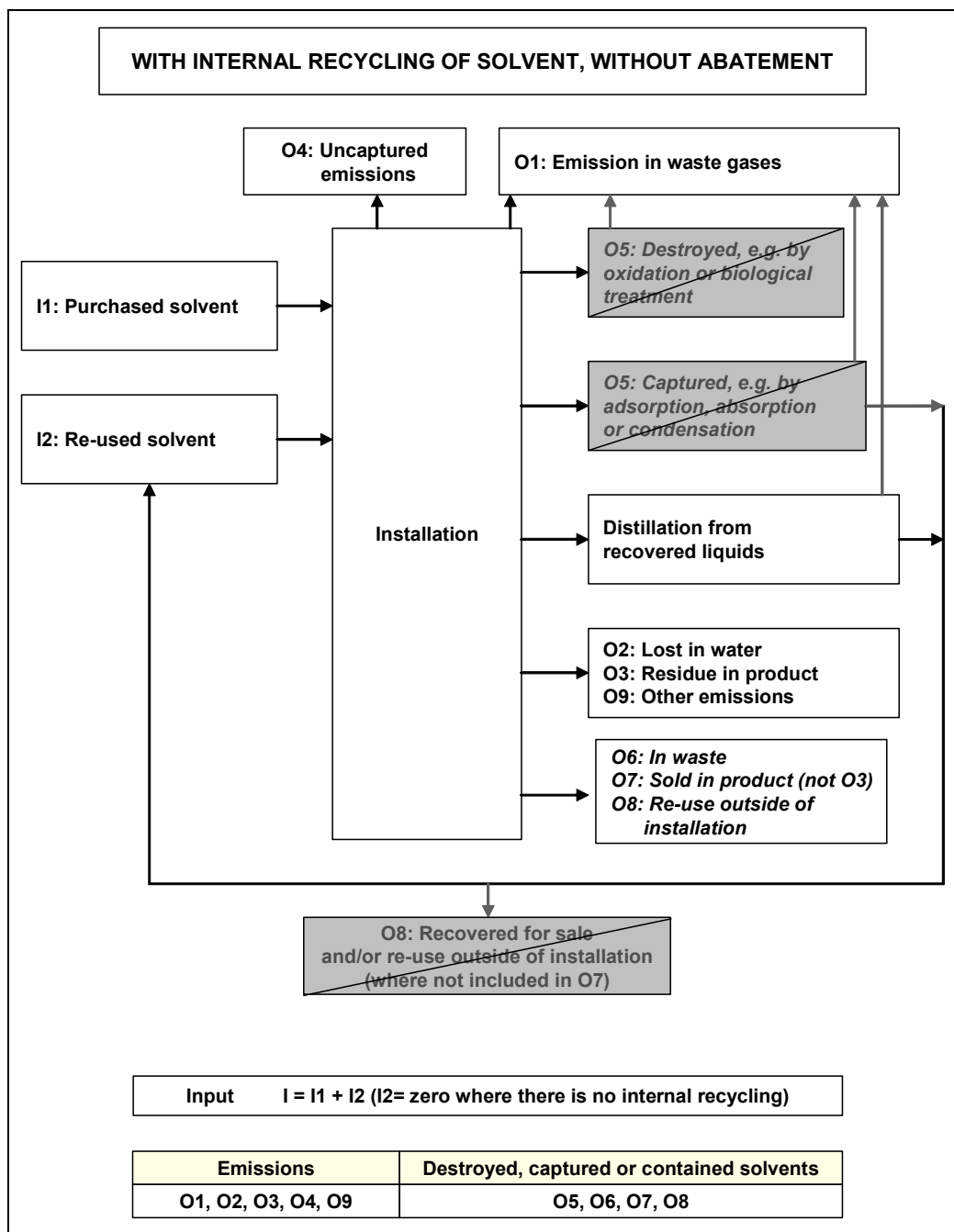


Figure 24.2: No end-of-pipe abatement, but with internal solvent recovery and re-use

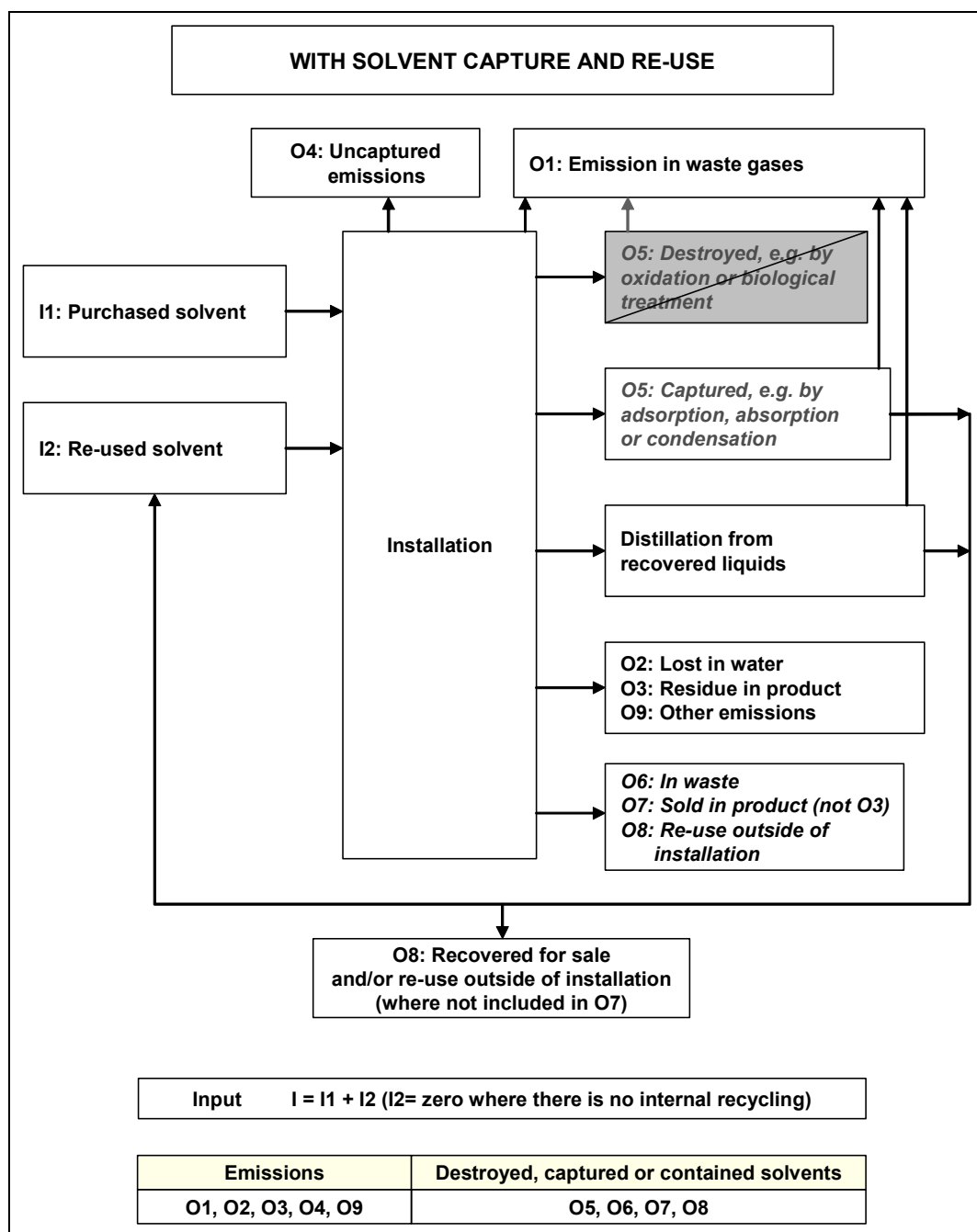


Figure 24.3: With solvent capture and re-use (internally and externally)

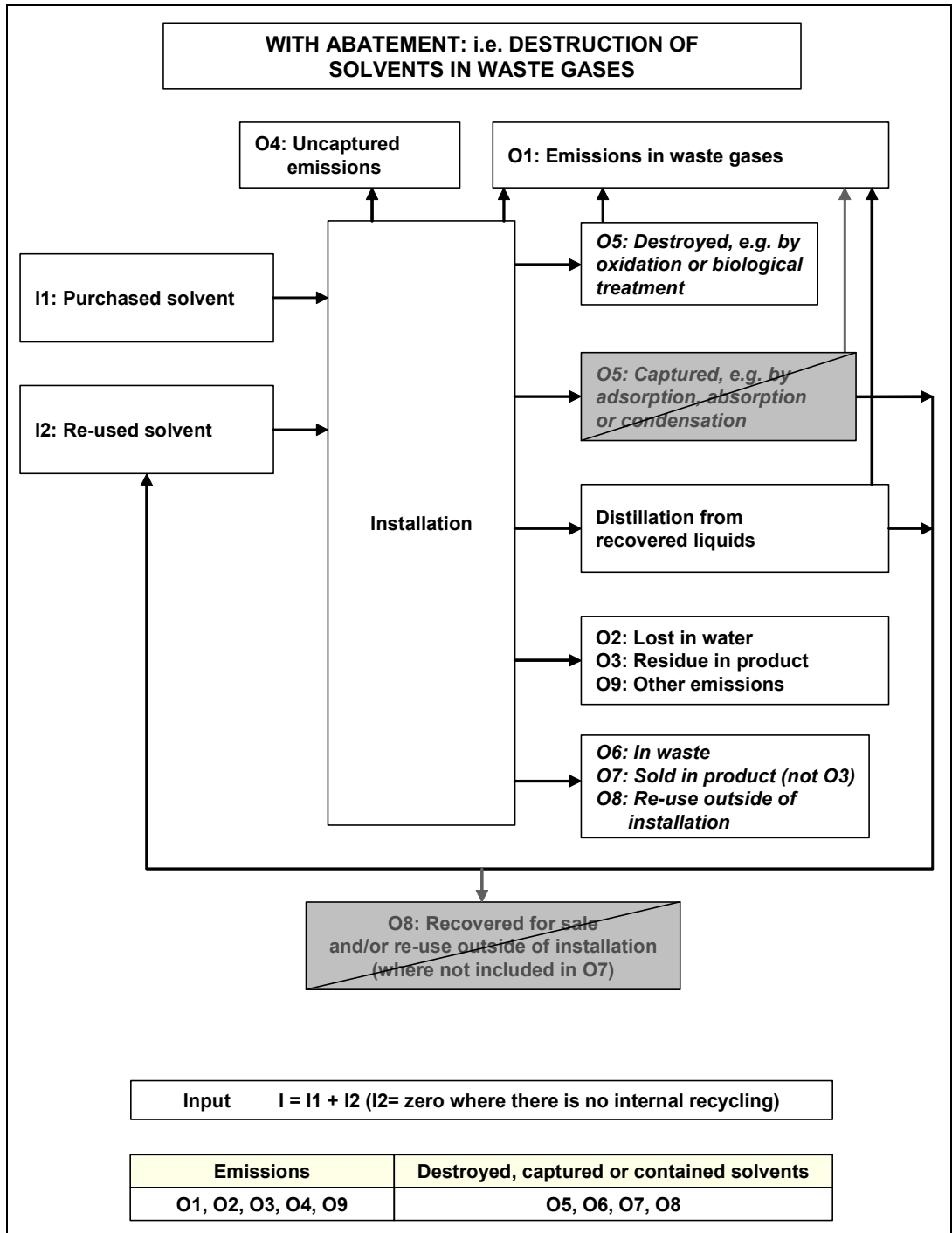


Figure 24.4: Destructive end-of-pipe abatement

24.5 Determination of VOC emissions from vehicle paint shops

[159, ACEA, 2006]

24.5.1 Basic principles/overview

1. Limit values of organic substances (LV_{VOC}) which are emitted from vehicle paintshops are defined as total emissions of volatile organic compounds – VOC (M_{VOC}) of the installation in relation to the surface of the painted vehicles (A_{veh}):

$$LV_{VOC} = \frac{m_{VOC}}{A_{veh}} \quad \left[\frac{\text{g VOC}}{\text{m}^2} \right]$$

Determination of these values means simultaneous determination of the emission mass flow from the paintshop and the surface area of the vehicles to be painted (see Sections and 2.2).

2. Determination of VOC emissions from paintshops by continuous end-of-pipe measurements is not sufficiently accurate, reliable or robust enough for regular monitoring purposes. It fails to take account of potentially significant fugitive emissions and gives poor cost-benefit considering the high capital and operating costs (see Section 24.5.2.1 and 24.5.2.2). The technique is not considered good practice.
3. For regular monitoring of VOC emissions, a mass balance method based on the scheme in the Solvent Emission Directive 1999/13/EC (SED) should be used. The required accuracy of the determination of different mass flows (see Figure 24.5 for the explanation of symbols, which equate to the SED scheme) should follow their relative contribution to the overall result (see Section 2.1.2):

- VOC input data (I1) must be determined with highest accuracy. This can be achieved by one of the following:
 - direct metering of the consumption of all compounds containing solvent (paint, thinner, etc.)
 - calculation of solvent input using procurement data bases.

If internal recycling of solvent is done, I2 must be determined.

- The amount of destroyed VOC (O5) can be calculated from measuring input and output mass flows of the waste gas treatment unit. From these measurements also:
 - the temperature dependency of the combustion efficiency is derived
 - the carryover factor f_c is determined. This coefficient describes the amount of VOC released in the spray booth and transferred into the drier oven with its waste gas treatment unit
 - these measurements must be done once for each spray booth or oven waste gas treatment system (WGT). The combustion efficiency and carryover coefficient must be recalculated only when the application process, the cabin design or the waste gas extraction and combustion system is changed.
- Performance of the waste gas unit can be monitored by continuous temperature measurement of the combustion. The efficiency of the WGT can be verified by this measurement.

- For given carryover factors f_c the amount of destroyed VOC can be monitored using consumption data of the spray booth:

$$O5 = (I1 + I2) \times f_c - O1.1$$

- All other mass flows are negligible or small. Single measurement or estimation of these values, to be repeated only after process or design change, is sufficient.

Total emissions into air (E) can be calculated using:

$$E = F + O1$$

where fugitive emissions

$$F = I1 + I2 - O1 - O5 - O6 - O7 - O8$$

$$E = I1 + I2 - O5 - O6 - O7 - O8$$

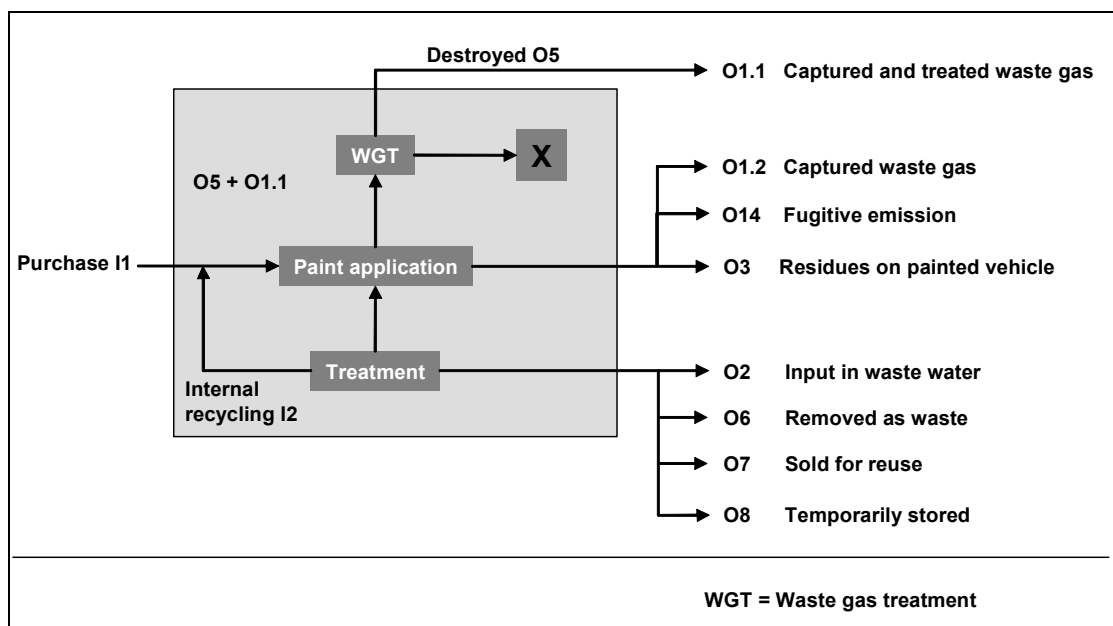


Figure 24.5: Basic input/output mass flows of solvents in a paint shop

- The surface area A_t of a body is calculated for each vehicle type t from:

$$A_t = \frac{2 \times m_t}{b_t \times d_t} \quad [m^2]$$

with

m_t = total weight of body in white shell

b_t = average thickness of metal sheet

d_t = density of metal sheet

Alternative methods (e.g. using CAD data) are also applicable.

- The total surface A_{veh} area is obtained from the number n of the cars which are transferred from the paintshop to the final assembly. This is in accordance with the 'product' definition in the SED.

$$A_{veh} = \sum_{t=1}^j A_t \times n_t \quad [m^2]$$

The number of vehicles needs to be determined for each type t.

6. Due to variations of the production process in time and production constraints (colour and vehicle change, cleaning, breaks...) the time scale for monitoring needs to be long enough. Representative values from mass balance calculations can be obtained only from averaging periods of at least one month. In accordance with the SED, Annex III, solvent management plans, limit values for VOC emissions from vehicle paintshops should be annual mean values.

24.5.2 Explanation

24.5.2.1 Monitoring of VOC emission mass flows

24.5.2.1.1 End-of-pipe measurements

a. Number and location of test points

Correct measurements need long undisturbed measuring sections, which are normally available only in high stacks. All other configurations need a net measurement with several test points in the duct cross-section to average flow- and concentration fluctuations.

Measurements of the cabin effluent stream have to be made in each single duct leaving the cabin. In some paintshops more than 50 stacks are used. If central waste gas ducts are used, these ducts have very large diameters and are heavily obstructed by other pipework and appliances. The installation of measuring points at the correct location is difficult or even impossible, especially if it has to be installed in existing paintshops. In nearly all cases, multiple points would have to be installed (see above).

The waste gas of the drier ovens is usually treated by some abatement technique. Emissions from waste gas treatment units (WGT) have to be measured in the hot clean air stream.

Depending on the technical design of the installation, fugitive emissions may be significant and have to be assessed to meet the requirements of the SED. By definition, end-of-pipe monitoring does not cover these sources. Direct monitoring of fugitive emissions is not possible or extremely expensive for complex installations such as vehicle manufacture.

Conclusion: *To collect emission data by end-of pipe measurements many test points must be installed. Fugitive emissions cannot realistically be measured directly.*

b. Measuring principle

Continuous and discontinuous measurements are usually done by the FID (flame ionisation detection) method. A small volume of the waste gas is continuously supplied to the equipment.

Organic compounds are burned in a hydrogen-air flame. The ionisation of organic compounds occurs, giving an electrical current which is measured and which is proportional to the mass flow of the organic compounds in the sample stream.

The output signal of the detector depends on the chemical nature of the compounds, but also on the geometry of the detector and the conditions under which the burner is operated. Regular calibration of the whole system is necessary. The calibration function constitutes a relation between detector signal strength and concentration of propane in the reference gas. The results are given in ppm or ppb equivalent to CH₄.

Due to its principle, the method continuously determines an index value that responds mainly to the number of C-H bonds in the sample gas volume. The response factor is not constant for all organic compounds but is a unique property of each substance. Therefore only after a second calibration which establishes a correlation between the detector signal (shown in ppm CH₄) and the concentration of organic compounds in the sample, meaningful concentration values in g VOC/m³ can be given.

The calibration process has to be repeated in regular intervals.

Compounds with lower volatility may condense in the line of sampling or in the systems of the analyser. It is thus necessary to heat the relevant parts of the system to a temperature of at least 150 °C. This precaution is vital for analysing the waste gases of curing ovens.

Conclusion: *The analytical set-up is very demanding and technically difficult for the situations described in Section 24.5.2.1.1(a). Repeated calibration is necessary to adjust the detector signal to the real concentration of VOC in the effluent gas.*

c. Representativeness of on-line FID systems

Even though this method can easily be chosen and applied in the case of one organic compound, it becomes extremely difficult and delicate in the case of the car painting processes. Automotive paint systems are very complex formulations with many volatile organic substances. More than 20, very often up to 50 different volatile organic compounds can be found in the effluent air. Moreover, the composition is not constant with time and depends on:

- colour mix in the application cabin (each colour differs in its solvent composition)
- amount of solvent used for cleaning (colour change, etc.)
- kinetics of evaporation from the vehicle surface
- re-evaporation of solvent from water in the venturi scrubber system.

Conclusion: *Practically, it is not possible to calibrate an on-line FID monitoring system in such a way that the detector signal gives real values for the actual VOC concentration*

d. Cost

The operating expense for continuous measurements is very high. It would be necessary to equip each exhaust stack with an FID analyser, usually with multiple sampling points and therefore sophisticated sampling control and recording. Due to the dimensions of the paintshop, heated sampling lines of up to 20 m length must be installed for each sample point. Each FID analyser must be fed with hydrogen gas, synthetic air and calibration gas. In addition to the VOC measurement O₂ concentration, temperature, humidity and gas velocity must be determined. The equipment also needs daily maintenance to avoid blocking of the air inlet tubes by paint particles. For calibration purposes discontinuous compliance measurements with approved reference methods must be made by verified expert organisations, usually external independent institutions.

Conclusion: *The cost for the monitoring of VOC emissions with the end-of-line method is extremely high.*

e. General conclusion

The principal drawback for monitoring of VOC emissions with the end-of-line method is that only the emissions from stacks can be measured. The expense is extremely high for this type of industry. Diffuse emissions cannot be measured directly within reasonable means. This type of emission monitoring should be applied only when special operating conditions of an installation, which cannot be covered by calculations, need to be monitored or if other reasons justify intensive monitoring. In the car painting industry, these conditions do not occur.

24.5.2.1.2 Calculation of solvent mass balances

Basic principle

The Solvent Emission Directive 1999/13/EC (SED) prescribes a general method for solvent emission monitoring using a solvent mass balance (solvent management plan). This method can be applied with small adjustments for vehicle paintshops as well.

In Figure 24.5, the general scheme of a solvent mass balance is shown. The numbering of the input and output flows is taken from the SED and extended for the purpose of differentiating between waste gas from paint cabins (O1.2) and curing ovens with waste gas treatment (O1.1).

No.	Mass flow	Relevance	Comment
I1	Input of organic solvents	High	= 100 % (in general) VOC in paints, thinners and spray gun rinsing solvents and general purpose cleaning material
I2	Input of organic solvents from internal recycling	No	= 0 % (in general) In some cases solvents are re-used after internal purification. If solvent is recycled by external operators, it should be registered under I1
O1	Emissions in waste gases	High	= 60 – 95 % Emissions from: <ul style="list-style-type: none"> • application cabins (O1.2) without treatment • residual emissions after waste gas treatment (O1.1) (usually waste gas from curing ovens, sometimes from paint cabins)
O2	Solvents carried out with waste water	Low	≤ 5 % Depends on amount of waste water and solubility of VOC in water
O3	Solvent residues in painted surface of vehicles	No	= 0 %
O4	Fugitive emissions	No	≡ 0 % Since fugitive emissions cannot be monitored, this mass flow is treated as part of O1.2
O5	Solvents which are captured and destroyed in waste gas treatment systems	High	= 10 – 40 % Generally thermal incineration of drier oven waste gas, sometimes from cabin waste gas as well.
O6	Output of solvent as waste	Yes	= 5 – 10 % <ul style="list-style-type: none"> • as mixture of paint and thinner • as residue in paint sludge
O7	Sold as product	No	= 0 %
O8	Solvents recovered for re-use or temporarily stored	Low	≈ 0 % (usually) (Solvents, paints, which are already counted as input but not used during the reporting period)
O9	Any other output	No	= 0 %

Table 24.9: Input/output flows in vehicle paintshops (according to SED 1999/13/EC)

Total emissions into air (E) can be calculated for paintshops using the indirect method of the SED (1999/13/EC)

$$E = F + O1$$

with

$$F = I1 + I2 - O1 - O5 - O6 - O7 - O8 \text{ (fugitive emission)}$$

$$E = I1 + I2 - O5 - O6 - O7 - O8$$

Under normal operating conditions, this equation simplifies to:

$$E = I1 - O5 - O6$$

The advantage of the indirect method is that direct monitoring of O1 (emissions in waste gases) and O4 (fugitive emissions) is not necessary. Since O1 is the largest flow of all output flows, any measurement uncertainties of O1 have a very large impact on the overall monitoring accuracy. Generally, the direct method is only applicable if fugitive emissions (O4) can be definitely excluded.

***Conclusion:** The mass balance method is the most appropriate way for monitoring VOC emissions into air. It takes account of any fugitive emissions, as required by the SED. Expensive and unreliable direct end-of-pipe measurements are substituted by a set of measurements and calculations of the residual mass flows. The result is comprehensive, robust, sufficiently precise and is obtained with less expense.*

24.5.2.1.3 Methods for the determination of specific mass flows

I1 Solvent input

(a) Direct metering of the consumption of all compounds containing solvent (paint thinner, etc.).

(b) Calculation of solvent input using procurement databases. The amount of rejected material must be identified and considered.

For method (a), control devices to monitor the filling status of the storage tanks must be installed and online data processing of the signals is recommended. Consumption data can be integrated into the existing production management IT systems and are also available for performance optimisation activities. For method (b), data from financial data bases can be used.

In both cases knowledge about the solvent content in the paints and other material is crucial and must be requested from the supplier.

O2 Solvent carried out with waste water

Not only paint particles but also volatile organic compounds are dissolved in the water reservoir of the venturi scrubber. Waste water is discharged from this system with solvent concentrations up to the solubility equilibrium. The solvent management plan of the SED 1999/13/EC presumes that this solvent will be completely emitted from the sewerage system or the waste water treatment installation. Since O2 is a rather small mass flow compared to O1 or O5, it is sufficient to treat it as a constant or a function of the waste water volume.

O5 Solvent captured and destroyed by waste gas treatment

The mass flow O5 is the residue of the solvent which is emitted from any sort of waste gas treatment into the air (O1.1, VOC in captured and treated waste gas) and the input of solvent within the raw gas flow (O5_{in}) into this equipment.

$$O5 = O5_{in} - O1.1$$

Volatile organic compounds in the waste gas flow of waste gas treatment installations (O1.1) can be measured by continuous or discontinuous methods. According to SED 1999/13/EC a limit values of 50 mg C_{tot}/m³ must be regarded for these emissions after air treatment installations¹³.

Air treatment systems efficiency is controlled via temperature monitoring. The combustion temperature, which guarantees observance of the limit values under all operational conditions, is determined by calibration measurements.

The mass flow of VOCs from each application zone to the emission abatement equipment is proportional to the solvent consumption of the painting process in the cabin. Therefore (if I2≠ 0)

$$O5_{in} = I1 * f_c$$

The carryover factor f_c describes the ratio of solvent consumption in the application zone to the VOC input into the waste gas treatment equipment of the drier oven. It is constant within the range of solvent consumption for a given paint application process and cabin geometry. This factor should be recalculated only when the application process, material technology or the cabin design (or related extraction system, etc.) is changed.

O6: Organic solvents disposed of as waste

The largest mass flow in this category are separately captured solvents from purging and cleaning processes (colour change, purging of the ring pipe system, general cleaning). Monitoring is done by measuring the flow volume in the tank inlets or from extracting data from transport documents. Generally, recovered solvents contain considerable amounts of paint, therefore determination of the VOC concentration may be necessary.

Solvents are also carried out with paint sludge. Concentrations of VOC in paint sludge should be established and verified as necessary.

***Conclusion:** Most of the mass flow data that need to be established are constant or depend on material consumption and other easily accessible parameters.*

24.5.2.2 Determination of the surface area throughput

24.5.2.2.1 Vehicle surface area

According to SED 99/13/EC, the surface area dealt with is defined as follows: ‘the surface area calculated from the total electrophoretic coating area, and the surface area of any parts that might be added in successive phases of the coating process which are coated with the same coatings as those used for the product in question, or the total surface area of the product coated in the installation.’

The surface of the electrophoretic (e-coat) coating area is calculated using the formula:

$$A_t = \frac{2 \times m_t}{b_t \times d_t} \quad [m^2]$$

with

m_t = total weight of body in white shell
 b_t = average thickness of metal sheet
 d_t = density of metal sheet

¹³ A limit value of 50 mg C_{tot}/m³ corresponds to approximately 70 mg VOC/m³.

This method shall also be applied for other coated parts. Alternative methods (e.g. using CAD data) are also applicable.

The index t indicates that different types of bodies have different surface areas:

$$A_{veh} = \sum_{t=1}^j A_t \times n_t \quad [m^2]$$

Conclusion: *The correct determination of the e-coat area for each car model is very important. The procedure should be documented and operators must be aware that all relevant data might be checked by the competent authority.*

24.5.2.2.2 Number of vehicles per time period

The mass balance method – on which VOC emissions monitoring in the automotive industry is based, according to the Solvent Emission Directive 99/13/CE – requires the calculation of the total area of bodies painted. The number of cars that are taken into account are the number of cars coated in the paintshop and delivered (as ‘product’ of the paint process) to the final assembly line.

Therefore vehicles that must be painted a second time (re-runs) are not counted twice and the additional solvent emissions caused by the repainting are assigned to the number of the original vehicles. Likewise bodies which are scrapped are not counted.

Conclusion: *Vehicle production data as described above are available from production control systems, therefore no additional expense is incurred by the emission control requirements.*

24.5.2.3 Time scale for mass balance representativeness

24.5.2.3.1 Limit values based on small averaging periods

It should be kept in mind that for technical as well as for practical reasons, there is always a time gap between measurement or calculation of solvent emissions and determination of the number of vehicles as a prerequisite for the calculation of the reference surface area. Therefore, a limit value with low averaging time cannot be adequately monitored.

All paintshops are operated with venturi systems to remove paint particles from the effluent air. Solvents are dissolved in the water (especially with waterborne paints) and repeatedly pumped through the system. These dissolved solvents lead to residual VOC emissions even if no vehicle is painted and only the clean air from the cabin conditioning system is blown through the venturi system.

Long periods exist where emissions take place but no or only a limited number of vehicles are painted. This is because of production breaks, periodic cleaning of cabins and application equipment or start of production after weekend time outs. The emission value, defined as ratio of emission to the surface area goes up to high or even infinite values, even if the absolute amount of solvent emissions is rather small.

A definition of the emission limit value as hourly, daily or shift mean would lead to strongly fluctuating values because of these effects. Emission values will very often formally exceed limit values even if the mass flow of solvent in terms of grams is very small (as the m² value is low or zero). The calculation of solvent emission data in g/m² for time scales smaller than one month would not give representative values.

Conclusion: *Emission limit values, based on short averaging periods cannot be adequately monitored. As the emission values are a ratio of mass flow of VOC to the production rate, large fluctuations may be recorded which do not give meaningful information about the environmental impact.*

24.5.2.3.2 Limit value based on annual mean value

A reference period of one year corresponds very well with the character of this limit value as a parameter which defines the environmental quality of the paint process. In fact, the solvent balance of the Solvent Emissions Directive requires data on an annual mean level. All typical production situations are averaged out and the overall performance of the paintshop is monitored.

There are no toxicological reasons to limit, and therefore monitor, short time fluctuations of the VOC emission.

Conclusion: *The annual mean as the reference period for the emission limit of vehicle paintshops is appropriate.*

24.6 Some Solvent Emission Directive limit values

Because of the complexity of the Solvent Emissions Directive [123, EC, 1999], and ascertaining that activities in this Directive apply to industries in this reference document, some data for some of the industries are given below:

SED Activity 7, Coil coating:

The SED limit values are:

- reducing VOC emissions to 50 mgC/m³ for waste gas emissions or 150 mgC/m³ where solvents are recovered from waste gases and:
 - for new plants - 5 % for diffuse emissions
 - for existing plants - 10 % for diffuse emissions
- if using the reduction scheme, diminishing the overall emissions:
 - for new plants - to 0.3 kg VOC per kg consumption of non-volatiles
 - for existing plants - to 0.45kg VOC per kg solids.

SED Activity 8, Other coating including metal, plastic, textile, etc.

The SED limit values are:

- reducing VOC emissions to 50 mgC/m³ for drying and 75 mgC/m³ for coating application in waste gases and to 20 % of solvent consumption for diffuse emissions, or
- if using the reduction scheme, diminishing the overall emissions to 0.375 kg VOC per kg consumption of non-volatiles.

Metal packaging (also Activity 8):

In the SED, two compliance routes are available: emission limit values and solvent reduction schemes. Draw and wall iron cans (DWI) processes are capable of using replacement materials substitution to achieve compliance via solvent reduction schemes [76, TWG, 2004].

The SED limit values are:

- reducing VOC emissions to 50 mgC/m³ for drying and 75 mgC/m³ for coating application in waste gases and to 20 % of solvent consumption for diffuse emissions, or
- if using the reduction scheme,:
 - for non-food applications, diminishing the overall emissions to 0.375 kg VOC per kg consumption of non-volatiles
 - for coatings in contact with food, diminishing the overall emissions to 1.165 kg VOC/kg solids.

SED Activity 10, Wood coating

The SED limit values are:

- reducing VOC emissions to 50 mgC/m³ for drying and 75 mgC/m³ for coating application in waste gases and to 20 % of solvent consumption for diffuse emissions, or
- if using the reduction scheme, diminishing the overall emissions to 1.0 kg VOC per kg consumption of non-volatiles.

SED Activity 12, Wood preservation

The SED limit values are:

- reducing VOC emissions to 100 mgC/m³ in waste gases (not with creosote) and to 45 % of solvent consumption for diffuse emissions, or
- 11 kg/m³ for total VOC emissions
- if using the reduction scheme, diminishing the overall emissions to 0.75kg VOC per kg consumption of non-volatiles.

24.7 Calculation of effective POCP

See Section 20.10.2.

References: Swan Eco-label (the Swan Eco label: labelling of car and boat care products, www.Svanen.nu,) [169, Lemoine, 2006] [170, Tempany and Lemoine, 2006].

The POCP concept (or other reactivity scales, such as MIR) is based on the assumption that 100 per cent of the solvent evaporates directly on exposure to air. This does not hold for several chemical substances because the rate of evaporation varies between different substances. In order to be able to assess the ozone creation of the actual quantity that ends up in the atmosphere (within a reasonable time), the POCP of a substance should be weighted against its relative rate of evaporation (RA). RA is based on the substance's vapour pressure and diffusion in air, and is calculated by dividing the rate of evaporation for the substance in question by the rate of evaporation for a reference substance. Butyl acetate is used as the reference substance.

However, the calculation is long and for several substances in a mixture in differing conditions, can be tedious (see calculation, below)

An approximate surrogate is to use vapour pressure multiplied by the POCP (or other reactivity scale). To differentiate from the effective ozone creation potential (APOCP_e, see below) call this the POFP, the Photochemical Ozone-Forming Product where OFP is the Photochemical Ozone Forming Potential, usually POCP:

$$\text{POFP} = (\text{Vapour pressure}) \times (\text{OFP})$$

and

$$\sum_1^n [\text{POFP}_{\text{total}}]_{\text{total}} = \sum [\text{POFP}_1]_1 + [\text{POFP}_2]_2 + \dots [\text{POFP}_n]_n$$

where:

$[\text{POFP}_1]_1$ is the concentration (or mass or percentage) of Substance 1 with a Photochemical Ozone-Forming Ratio 1 = Concentration₁ x (Vapour pressure)₁ x (OFP)₁, etc.

$[\text{POFP}_{\text{total}}]_{\text{total}}$ is the total Photochemical Ozone-Forming Product for n substances in given mixture (or single substance where n = 1)

Where the concentration is expressed as wt-%, POFP_{total} must be multiplied by 100. To arrive at a suitable scale for comparisons, the parameters are best expressed as:

- vapour pressure (VP) in kPa (range approximately 0.001 to 50 kPa). The VPs for more than one solvent should all be expressed at the same temperature
- concentration as a percentage (range 0 – 100)
- if POCP is the unit, use a scale of ethylene = 100, then the range is about 10 to 140.

Examples of calculations:

Formulation 1				
	* Xi (%)	VP (KPa)**	POCP	POFP value
Xylene	40	0.87	110	3828
POFP _{total}				3828
* (Xi) concentration of the substance in the formulation)				
** At 20 °C				

Table 24.10: Example 1 of an effective POCP calculation

Formulation 2				
	* Xi (%)	VP (KPa)**	POCP	POFP value
n-butyl acetate	20	1.529	27	826
Dearomatised white spirit	20	0.46	41	377
[POFP _{total}] _{total}				1203
* (Xi) concentration of the substance in the formulation				
** At 20 °C				

Table 24.11: Example 2 of an effective POCP calculation

Calculation of relative rate of evaporation (RA) and APOCP_e
(from the Swan Eco label: labelling of car and boat care products):

The rate of evaporation (F) of a substance can be calculated according to Fick's 1st law:

$$F = D \times (dC/dZ) \quad (I)$$

where:

- D is the diffusion constant of the substance in air
- dC/dZ is the concentration gradient from an area where the substance exists to free air, and can be calculated using the general gas law as follows:

$$dC/dZ = (P \times Mw)/(RT \times 10^6) \quad (II)$$

where:

- R = 8.32 J K⁻¹ mol⁻¹
- T = absolute temperature
- dZ = 1 cm

If the diffusion constant is given in cm² s⁻¹, F may be expressed as g cm⁻² s⁻¹.

$$RA_i = F_i/F_{\text{butyl acetate}}$$

According to equations I and II, butyl acetate has a rate of evaporation (F) of 4 x 10⁻⁶ g cm⁻² s⁻¹ at 20 °C.

Substance	RA
2-propylene glycol-1-methyl ether	0.84
Isopropanol	2.5
Butyl acetate (reference)	1.0

Table 24.12: Examples of relative rates of evaporation (RA) for a selection of VOCs

Multiplying the absolute ozone creation potential of a substance by its relative rate of evaporation (RA) produces a measure of the effective ozone creation potential, APOCP_e:

$$APOCP_{e,i} = APOCP_i \times RA_i$$

Example calculation. Determination of APOCP_{e, isopropanol} in environment A

$$APOCP_{e, isopropanol} = 0.06 \times 2.5 = 0.15$$

Substance	A	B	C	D	E
2-propylene glycol-1-methyl ether	0.08	0.18	0.12	0.18	0.52
Isopropanol	0.15	0.38	0.25	0.4	1.2
VOC reference	0.11	0.27	0.17	0.27	0.84

Table 24.13: Examples of APOCP_e for a selection of VOCs and a reference VOC in the five different environments A, B, C, D and E

APOCP is the same number as POCP in the previous calculation.

24.8 Marginal social costs of climate change

A recent report [116, AEA, et al., 2005] reviews current thinking on the social costs of climate change expressed as EUR/t CO₂. A recent review is quoted giving a mean of EUR 25/t CO₂ with a 95 %ile of 96/t CO₂. Other workers are citing figures in the area EUR <12 to <20/t CO₂. The report shows that these figures are based on data for market effects and ignore wider social implications and catastrophic effects from higher climate temperature increases: these are harder to define and agree costs.

Different stabilisation scenarios have differing costs:

- low rate of increase of climate temperature: EUR <15/t CO₂
- high rate of increase of climate temperature: EUR 30 – 140/t CO₂.

However, the report [116, AEA, et al., 2005] looked at these areas and estimated figures for 2002 of:

- a lower bound of EUR 15/t CO₂
- a central illustrative estimate of EUR 20 – 25/t CO₂, rising to EUR 30/t CO₂ by 2020
- upper central estimate of EUR 80/t CO₂.

From these, a central working estimate of EUR 30/t CO₂ has been derived for this document, to compare with marginal damages for VOC per tonne emission from the cost benefit assessment for CAFE (see the ECM REF [97, EIPPCB, 2005]).

This is an area of major political interest and continuing development of the economics. For example, see Stern Review of Environmental Economics, [176, Stern, 2006]. From this interest, the tendency may be towards including the wider social implications and catastrophic effects that are associated with climate change, but not with other environmental impacts (such as those associated with VOC, where the marginal social costs fully include key impacts, mainly health). These factors significantly increase the social costs per t CO₂.

24.9 Removal efficiency of waste gas treatment techniques

[148, TWG, 2006] [183, Verspoor and TWG, 2006]

End-of-pipe techniques: Descriptions and considerations for applicability

The descriptions and considerations for applicability below are intended as an overview only. See the relevant sections in Chapter 20 of this document for additional information. The information in this annex on its own cannot serve as the basis for the selection of a suitable abatement technique.

End-of-pipe technique and description	Conditions for applicability	Applicable:
<p>Thermal oxidation Waste gases are heated by burning natural gas. There is no attempt at heat recovery for a reduction of energy consumption</p>	<p>The simplest oxidation technique with the lowest capital investment Autothermic operation only at concentration levels over 25% LEL. Lowest electrical energy consumption for the main fan. Highest gas relative consumption. As the simplest technique, has relatively the lowest maintenance and least downtime. Rapid start up (0.5 – 1 h), but requires a stable operating temperature. Non-organic dust needs to be removed (to <3 mg/m³) before the oxidation unit, although this technique is more tolerant of dust than others</p>	<p>For intermittent use (a few days a week; very variable airflows; one shift system, etc.) Where the capital costs are much more relevant than operational costs or in combination with other abatement technologies for multi-purpose units or for air volumes <2000 m³/h For concentration ranges between 5 and 16 g/m³, high inlet temperatures of the waste gas and in situations where gas flow and solvent concentrations are relatively constant. Operation at concentration levels above LEL is also possible</p>
<p>Recuperative oxidation Similar to thermal oxidation but with a heat exchanger that preheats the incoming waste gases with the heat of the exhaust gases. Reduces gas consumption, but the heat exchanger requires a higher investment</p>	<p>With a heat exchanger of maximum efficiency (about 76 %), autothermic operations are possible at solvent concentrations approaching 10 g/m³ (ethyl acetate or ethanol) or more. Autothermic concentration depends on the caloric value of the solvent. Electrical energy consumption for the main fan is higher than in the case of thermal oxidation. Gas consumption is lower. A simple oxidation technique, but with a relatively high investment due to the large steel content. Almost immediate start up (0.5 – 1 h). Removal efficiency is restricted by the maximum operating temperature which is determined by the mechanical integrity of the heat exchanger. The heat exchanger has a limited lifetime and requires substantial maintenance due to corrosion and thermal stress. Heat exchangers may easily be blocked by accumulation of dust in the tubes, and efficiency will be reduced due to the partial fouling, increasing investment and running costs. However, the technique is more tolerant of dust than others, and there are techniques for clearing blockages (air blow, chain cleaning, ball drop, etc.).</p>	<p>For intermittent use (one or two shift systems), but where the reduction of gas consumption warrants additional capital cost and electrical energy. Where autothermic operation is possible, but excess energy cannot be used in the installation as an alternative for regenerative oxidation</p>

End-of-pipe technique and description	Conditions for applicability	Applicable:
<p>Catalytic oxidation Oxidation temperatures are lower, at some 280 – 450 °C (instead of some 800 °C) Often equipped with a heat exchanger. Reduces gas consumption, but catalysts and heat exchangers lead to a higher investment. Catalyst may need maintenance and occasional replacement which add to the operational cost and downtime.</p>	<p>When equipped with an efficient heat exchanger (maximum possible some 87 %), autothermic operations are possible at solvent concentrations of some 5 g/m³ or over (depending on the calorific value of the solvent). The maximum possible temperature of the catalyst limits the inlet concentration to some 8 g/m³ Electrical energy consumption for the main fan is higher than in the case of thermal oxidation. With solvent concentrations below 25 % LEL, the gas consumption will be lower than in the case of recuperative oxidation. The catalyst makes this a less simple oxidation technique, but still with a relatively low investment. Almost immediate start up (1 h to preheat the catalyst), but shutting down too frequently may damage the catalyst carrier. Catalyst adds to the need for maintenance and increases downtime. Some solvents or dust particles poison the catalyst and lead to early replacement of the expensive catalyst. Catalyst and carrier need to be adapted to waste gas composition, required temperature and expected removal efficiency. A used catalyst may need to be disposed of as hazardous waste, although the catalyst material can often be recycled. Very sensitive to the presence of dust and droplets in the waste gases. Sensitive to changes in the inlet concentration</p>	<p>Used only where all solvents that are to be oxidised are known not to poison the catalyst and where the inlet temperature is not too high for the catalyst. Where autothermic operation is possible, but excess energy cannot be used in the installation as an alternative for regenerative oxidation.</p>

End-of-pipe technique and description	Conditions for applicability	Applicable:
<p>Regenerative oxidation: 2 beds The oxidising chamber is situated between two ceramic beds. The waste gas passes through one bed before entering the oxidising chamber and leaves through the other. The direction of waste gas flow is alternated every 1 to 5 minutes. One bed preheats the waste gases; the other accumulates the heat from the exhaust. During the changeover solvent-laden waste gases are emitted for a few seconds. Reduces fuel consumption drastically. Increases the need for electrical energy due to the higher air resistance in the ceramic beds</p>	<p>With a high heat exchanger efficiency (maximum possible 96 %), autothermic operations are possible from solvent concentrations of 2 g/m³ and over (depending on the calorific value of the solvent, e.g. ethyl acetate 2.2 g/m³). Preheating after periods of standstill may, however, account for considerable gas consumption. Electrical energy consumption for the main fan is higher than in the case of other oxidisers because of the high pressure drop in the ceramic beds. Where the solvent concentration in waste gases is higher than the autothermic concentration, excess heat is produced. This may be recovered. Where excess heat is not permanently recovered and the concentrations are variable, the efficiency of the heat exchanger may need to be reduced to prevent overheating of the ceramic beds when high concentrations occur. This leads to a higher autothermic concentration and the need for adding natural gas in periods of low solvent concentrations. The complicated sensors and large valves necessary to repeatedly change the direction of the airflow mean complex equipment and the need for skilled personnel. Higher maintenance costs and more downtime than other oxidation techniques. Every one or two years there is a need for 2 to 3 days downtime for maintenance. Needs preheating before start up since the ceramic beds cool down during standstill. (After 36 hours of standstill, 1 to 2 hours are needed for preheating) Removal efficiency is a few per cent lower than that of the 3 bed system (see below) due to emissions during changeover of the direction of the waste gas stream. Where EoP emission limits expressed in mgC/m³ averaged over a short period of time apply, the emissions during changeover of the direction of the waste gas stream may lead to an average outlet concentration that exceeds the limit values if the inlet concentration is higher than about 3g/m³. The regenerator blocks rapidly with dust. It is possible to run with some low dust concentrations, but the regenerative beds need a different structure (structured packing (honeycomb instead of saddles) with different cost and efficiency</p>	<p>Specifically suitable in continuous or near continuous operations where most of the time the solvent concentrations in the waste gases are over the autothermic concentration and the solvent concentrations do not vary significantly</p>
<p>Regenerative oxidation: 3 beds In principle the same as the 2 bed system. The third bed serves to avoid the emission of solvent laden air during the change of the direction of the waste gas flow</p>	<p>(Relative to the 2 bed system). Investment some 25 % higher than a 2 bed system. Lower emissions. Higher preheating cost. Some 10 % higher electricity consumption due to larger fan for purging purposes Removal efficiency a few per cent higher than that of the 2 bed system due to the prevention of emissions during changeover of the direction of the waste gas stream. Online burnout possible for removing sticky particles</p>	<p>(Relative to the 2 bed system) Most suitable for concentrations from 1 – 12g/m³, especially if there is a variation in the concentration over the production time. Most suitable in large continuous operations with solvent concentrations in waste gases well above autothermic concentration. Where the resulting emission reduction warrants the additional investment and operational cost</p>
<p>Other oxidation techniques (Not included in calculations of removal efficiency)</p>		
<p>Process heater The waste gases to be treated are sent to an existing heater (e.g. boiler) as combustion air and complementary fuel</p>	<p>A suitable heater must be available and must be operating and able to receive all the waste gases at times when they are produced</p>	

Annexes

End-of-pipe technique and description	Conditions for applicability	Applicable:
Flameless oxidiser Packed bed oxidiser in which the front of combustion is kept at a predetermined position in the ceramic packing	Intermediate system between thermal and regenerative oxidiser. Low fuel requirements when idle. Combustion temperature relatively low (800 – 850 °C). Sensitive to the presence of dust	
One bed regenerative oxidisers Direction of the waste gas flow alternates over one bed instead of two or three	Generally low capacity systems	
Adsorption (to a solid)		

End-of-pipe technique and description	Conditions for applicability	Applicable:
<p>Regenerative carbon adsorption The low temperature waste gases are led through a bed of activated carbon. The solvent adsorbs to the activated carbon. When the carbon is saturated the waste gas flow is switched to a second carbon bed. The saturated bed is desorbed through heating. The heat releases the solvents from the carbon in such a high concentration that it allows condensation of these solvents</p>	<p>Desorption must be done in an atmosphere with little or no oxygen. Steam, nitrogen or oxygen-free hot air may be used. After condensation of the solvent, complex techniques may be necessary to make the recovered solvents ready for re-use. These techniques depend on the solvent recovered. Some examples: In the case of toluene and xylene, desorption is done with steam and simple condensation will suffice. In the case of ethyl acetate, desorption is done with nitrogen. Dewatering with molecular sieves and several subsequent distillation steps are necessary to remove side products and secondary solvents such as acetic acid, traces of ethanol and low volatility solvents. Since the adsorption characteristics of solvents differ enormously, the size of the adsorbers (and therefore not only the investment but also the energy and inert gas consumption) is very much determined by the kind of solvent. (Examples: Toluene and xylene need relatively 'small' adsorbers. Ethanol needs a 25 % larger adsorber than ethyl acetate) Some solvents may react with the activated carbon and cause fire. MEK is one of these, but techniques exist to prevent these reactions and recover MEK safely. Some low volatility solvents may adhere to the activated carbon permanently and quickly reduce the adsorption capacity with early replacement of the activated carbon as a result. Activated carbon also adsorbs water effectively. Waste gas streams with a high moisture content are therefore not suitable. Investment and operational cost are considerably higher than in the case of oxidation. This is more evident where the solvent loads are below 1000 tonnes per year. Alternatives with moving carbon beds exist, but are not commonly used. Electrical energy consumption for the main fan is higher than in the case of oxidisers because of the higher resistance of the beds of activated carbon. High displacement with low airspeeds necessary to prevent blowing out of the activated carbon. The complex equipment requires specifically trained technical personnel. Very reliable operations and very little downtime are the norm. The high cost in comparison to oxidation and with the low market value of recovered solvents necessitates the re-use of the solvents in the same installation in order to make solvent recovery a viable option. Breakeven point between oxidation and recovery evidently depends on the price of the solvent recovered and the techniques necessary. For toluene and xylene, recovery may be cheaper than oxidation starting at a solvent consumption of 100 t/yr. For ethyl acetate, MEK and ethanol, breakeven with oxidation was calculated to be possible starting at approximately 500 to 1000 tonnes per year. Does not work with high inorganic dust concentrations</p>	<p>Only to be considered when the recovered solvent can be re-used in the installation or be sold against the market value of 'fresh' solvents. (The sale of recovered solvent brings no more than 50 % of its original price). Where several hundred tonnes of toluene or xylene are used as the only solvent this technique can always be seriously considered. With other solvents higher annual quantities are necessary to make this a viable option. Especially where there are mixtures of several different solvents, numerous complications may need to be solved before this technique can be used successfully. However, technical solutions exist for most of these practical problems. The end result may be too complicated and expensive</p>

End-of-pipe technique and description	Conditions for applicability	Applicable:
<p>Polymer adsorption The low temperature waste gases are lead through a moving bed of grains of a special polymer. The solvent adsorbs to the polymer. The saturated polymer is desorbed through heating. The heat releases the solvents from the polymer in such a high concentration that it allows condensation of these solvents</p>	<p>Desorption is done with hot air. The concentrations are above the higher explosion limit in order to prevent accidents. After condensation of the solvent, complex techniques may be necessary to make the recovered solvents ready for re-use. These techniques depend on the solvent recovered. Since the adsorption characteristics of solvents differ enormously, the amount of polymer necessary is very much determined by the kind of solvent. Since the polymer is the most costly part of the equipment (10 to 20 times the cost of activated carbon). this technique is known to be suitable for only very few solvents. Since the polymers do not adsorb water, the system can be used for waste gases with high moisture content. Also no dehydration of the recovered solvent is necessary. The equipment is very simple. High displacement fans with low airspeeds are necessary to prevent blowing out the polymer. Very reliable operations and very little downtime are possible Does not work with high inorganic dust concentrations</p>	<p>No examples of successful application in industries in the scope of this document are known</p>
<p>Other adsorption techniques (Not included in calculations of removal efficiency)</p>		
<p>Oil scrubbing VOC removal efficiency generally relatively low. Mainly used for abating emissions of inorganics or odours</p>		
<p>Coolsorption Scrubbing with a refrigerated absorbent. Combines absorption with condensation</p>		
<p>Water scrubbing Several types exist. Waste gases are led through a curtain of water or water mist. Particularly suited for the removal of droplets and dust. Waste water treatment is necessary</p>		<p>Water soluble VOCs</p>
<p>Condensation Condensation at ambient temperature, no inert gas drier (Not included in calculations of removal efficiency) Waste gases are cooled down to a temperature above freezing point. Low volatility solvents condense. High volatility solvents, however, are not condensed effectively</p>	<p>The equipment is very simple and not expensive. No information about operating costs</p>	<p>No examples of successful application in industries in the scope of this document are known</p>

End-of-pipe technique and description	Conditions for applicability	Applicable:
<p>Condensation with inert gas drier In an enclosed drying system containing an inert gas (mostly nitrogen) the solvent concentration is allowed to rise to several hundred grams per m³. The inert gas is led through a condenser where a part of the solvents are condensed at approximately room temperature. The inert gas with a reduced solvent content is returned to the drier. The condenser is often cooled with the liquid nitrogen that is also needed for topping up the drier system</p>	<p>The driers are obviously more expensive than traditional driers. The operational costs depend to a large extent on the amount of nitrogen used. Nitrogen is used mainly when the drier needs to be opened, for instance in the case of job changes. Where mixtures of solvent are used, complex techniques may be necessary to make the recovered solvents ready for re-use. Since the drier needs to be as closed as possible, the technique can only be used for drying thin even substrates that can be led through the drier without serious leaks at the entry and exit</p>	<p>The technique is only applicable where there is no need to open the drier for several days in a row</p>
<p>Other condensation techniques (Not included in calculations of removal efficiency)</p>		
<p>Refrigerated condensation: The waste gas is cooled to a temperature below 0 °C. Icing occurs and regular de-icing is necessary. For that purpose there are usually two condensers. A condensation step above 0 °C upstream reduces the water content of the waste gas.</p>	<p>The running costs are high and increase if a lower condensation temperature is necessary</p>	<p>Mostly for the recycling of higher cost solvents. Low airflows with high concentrations</p>
<p>Cryogenic condensation: Condensation at very low temperature usually with liquid nitrogen</p>		<p>Mostly for the recycling of higher cost solvents. Low airflows with high concentrations</p>
<p>Biological</p>		
<p>Biological treatment (Not included in calculations of removal efficiency) The waste gas is blown through a bed of organic material in which the VOCs are adsorbed and destroyed (metabolised) by bacteria</p>	<p>The equipment is simple and not expensive, but needs a lot of space in the case of large airflow. Bacteria are easily killed by changing the composition of the waste gas or by lack of feed in the holiday season. This affects the filter efficiency. No information about operating cost</p>	<p>Waste gas stream with low concentration. Biodegradable and preferably water soluble components. Odour problems</p>

Table 24.14: Waste gas abatement techniques

Removal efficiencies

Table 24.16 and Table 24.17 below give the removal efficiency of oxidation techniques and solvent recovery with activated carbon. For other techniques, insufficient data were available to produce similar tables.

Removal efficiency depends on:

- the carbon content of the solvent molecule
- the average inlet concentration
- the average outlet concentration
- operating temperature (see technical note below).

The shaded bands in the tables give the range of removal efficiency that can be expected from either oxidation or solvent recovery.

The lower parts of the band correspond to the lower inlet concentrations.

The attainable solvent concentrations in the waste gases for solvent recovery are somewhat higher than in the case of oxidation. The removal efficiencies are therefore somewhat lower.

The effectiveness of the oxidation

The effectiveness of the oxidation of VOC is dependent on three parameters:

- a) Turbulence: A complete movement and mixture of the waste gases in the burner chamber.
- b) Time: Minimum residence time of the waste gases in the burner chamber (typically 1 second).
- c) Temperature: The burner chamber operating temperature (typically in the range of 720 to 850 °C).

Points (a) and (b) are design parameters set by the manufacturer. Point (c) (temperature of the burner) is the only parameter available for adjustment by the operator. It must be noted, however, that high energy demands and increased NO_x levels will result from elevated running temperatures when attempting to increase VOC removal efficiency.

Inorganic dust

The techniques are sensitive to inorganic dust to varying degrees. Some are very sensitive, others less so, or they can be adapted. Inorganic dust is likely to affect the efficiency of the technique and/or gas throughput (higher airflow resistance) and the amount of maintenance required. Adapting to waste gases with inorganic dusts can therefore have an impact on capital and running costs.

Calculations

The removal efficiency equals 100 % minus the percentage of remaining carbon after the abatement equipment. The percentage of carbon remaining is calculated by dividing the 24 hour average outlet concentration by the 24 hour average inlet concentration. For this calculation, the inlet concentration is expressed in g/m³ solvent, multiplied with the percentage carbon content of the solvent. The outlet concentration is expressed in mg carbon per m³.

The 24 hour average outlet concentrations are based on experience in installations that today are subject to EoP emission limit values. It must be noted that, in order to be certain of compliance, the actual 24 hour average outlet concentrations are always lower than these EoP emission limit values.

It must also be noted that the actual EoP concentration may vary widely over the day, depending on the production circumstances in the installation.

Carbon content

The carbon content of a solvent can be determined on the basis of a chemical formula. For reasons of simplicity, four categories are given in Table 24.15 for use in Table 24.16 and Table 24.17.

Solvent group	Average carbon content (%)	Chemical groups of solvents
Group 1	55.0 %	Alcohols, glycol ethers, glycol, ether esters
Group 2	65.0 %	Esters, ethers, ketones
Group 3	85 %	Hydrocarbons
Group 4. Exceptionally low carbon content compared to other chemicals in their group	37.5 %	Methanol
	48.6 %	Methyl acetate

Table 24.15: Chemical groups of common solvents and their carbon content

Removal efficiency and BAT

Table 24.16 and Table 24.17 provide information about the range of removal efficiencies associated with oxidation and solvent recovery (activated carbon adsorption). These tables do NOT imply that compliance with every single value in the ranges can be considered BAT.

The emission ranges attainable by the application of BAT are given in the industry specific parts of Chapter 21 in this document. These emission ranges associated with BAT always apply to the total of both end-of-pipe emissions and fugitive emissions.

Where the emission range associated with BAT is, for instance, 10 % of solvent consumption, and the fugitive emissions account for 5 % of solvent consumption, the removal efficiency of the abatement equipment must be over 95 %.

The abatement equipment must obviously be chosen in such a way that it will reduce emissions sufficiently to attain the emission range associated with BAT and still leave room for unavoidable fugitive emissions.

Removal efficiency and end-of-pipe emission limit values

The Solvent Emissions Directive and similar national legislation may prescribe end-of-pipe (EoP) emission limit values. These values may be different for different industries. Attainment of the lower parts of the removal efficiencies ranges given in Table 24.16 and Table 24.17 may not lead to compliance with these emission limit values (ELVs). Indeed compliance with some especially low emission limit values may require removal efficiencies higher than the highest value given in the tables. This may, for instance, be the case where solvents are used such as mentioned in Art 5.6 of the Solvent Emissions Directive (carcinogens, mutagens or toxic to reproduction).

Oxidation	Removal efficiency	75.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Group 1 solvents	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										
Oxidation	Removal efficiency	75.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Group 2 solvents	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										
Oxidation	Removal efficiency	75.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Group 3 solvents	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										
Oxidation	Removal efficiency	75.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Methanol	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										
Oxidation	Removal efficiency	75.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Methyl acetate	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										

Table 24.16: Removal efficiency of oxidation techniques

Activated carbon recovery	Removal efficiency	75.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Group 1 solvents	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										
Activated carbon recovery	Removal efficiency	75.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Group 2 solvents	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										
Activated carbon recovery	Removal efficiency	75.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Group 3 solvents	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										
Activated carbon recovery	Removal efficiency	60.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Methanol	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										
Activated carbon recovery	Removal efficiency	60.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Methyl acetate	0.5 - 1.0 g solvent/m ³										
Inlet concentration	1.0 - 2.0										
	2.0 - 6.0										
	6.0 - 12.0										

Table 24.17: Removal efficiency solvent recovery for activated carbon