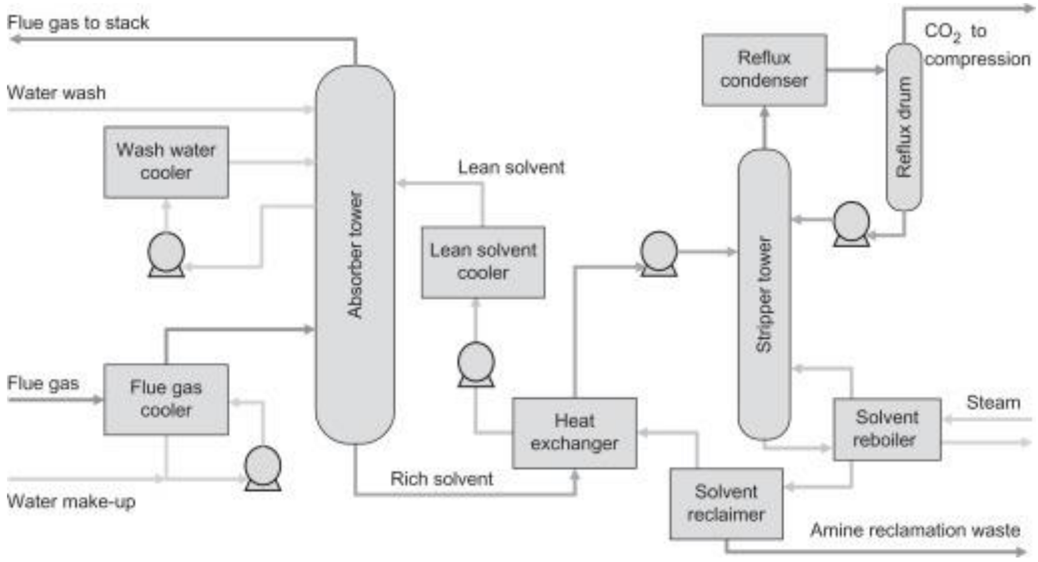
CHEMICAL ABSORPTION by AMINES/BLENDS

map-it CCU

This infosheet contains information on chemical absorption technology employing all the amines other than the MEA solvent (see dedicated infosheet on MEA-based technologies). The other amines include secondary and tertiary amines, their blends, and mixtures including different additives. More information on various amines is given in this review paper.[1] The information provided here is for the amine-based solvents, which are publicly available or from the main technology providers. The process is similar to that of MEA-based technology as shown in the Figure below. The flue gas is sent to the absorber column, where it flows upward and comes into contact with the down-flowing aqueous amine solution. The CO_2 in the feed gas reacts with the amine to form a CO_2-rich solution. This solution is then heated in a regeneration column to release a pure CO_2 stream and regenerate the amine for reuse. For amine-based technology, there are various influencing factors towards specific energy consumption, namely CO_2 partial pressure with respect to the type of applications, type of amine used, specific heat integration concept, etc.



Amine based scrubbing technology

TECHNICAL ASPECTS (all % are volume-based)

Point sources: Power generation, cement/lime production, petrochemical & refineries, iron and steel, hydrogen generation, waste to power facilities.[2]

CO_2 concentration range: 2-30%[2] (typical), 0.1-70% (OASE)[2]

CO_2 capture efficiency: >99%[2]

CO_2 purity: >95%[3]

Min. feed gas pressure: 1.0 bar[4]

Max. feed gas temperature: 60 °C[5]

Typical scale:

Large (1 MtCO_2/yr for ADIP Ultra by Shell)[2]

Medium to large (75 ktCO_2/yr – 6 MtCO_2/yr for CANSOLV by Shell)[2]

Small to large (3 ktCO_2/yr – 3 MtCO_2/yr for OASE® Blue by BASF)[2]

**Calculated based on 300 operational days per year.*

Primary energy source: Thermal (steam)

Impurity tolerance: NOx = 20 ppm, SOx = 10 ppm, O_2 = minimum possible or use of O_2 inhibitors.[6] (assumed same as for MEA)

Cansolv: SO_2 - 15-60 ppmv[7]; PM - <20 mg/Nm[3]; prescrubber removes 90% of SO_2 and NO_2[8]; Remaining SO_2 in feed gas is converted to sulfite in CO_2 absorber.[7]

FUNCTION IN CCU VALUE CHAIN

- Capture CO_2 from flue gases.
- Some solvents may be highly affected by flue gas impurities, requiring several pre-treatment steps depending on the impurity.
- **Cansolv** also removes other gases, such as SO_2, if present in small quantities.[7]

LIMITATIONS

- Tertiary amines have slower reaction kinetics compared to primary and secondary amine processes, often requiring larger absorption columns.
- Although tertiary amines require less energy for regeneration than primary or secondary amines due to their lower heat of absorption, the overall energy consumption is still significant.

- Aqueous amines can corrode equipment, especially with flue gas impurities like SOx, NOx, and O_2.

ENERGY

- Thermal (steam) is used for the regeneration of the solvent.
- Electricity is used for operating pumps, blowers, and control systems.

CONSUMABLES

- The solvent is used as a medium to capture CO_2. Some solvents may be lost and need make-up.
- Water is used in the process as a solvent diluent for the amine solution.

Energy and Consumables

Parameter	Value
Heat (GJ/tCO_2)	OASE® Blue – 2.5[9]-2.7[10] ACC™ S21 & S26[11] – 3.4 MDEA (10%) + PZ (30%)[12] – 1.9 Cansolv DC-103[8] – 2.92 Cansolv DC-201[8] – 2.33 Piperazine – 2.99 – 3.04 – 2.72 – 2.85[13] MHI KS-1™ - 2.15[3,14]
Electricity (kWh/tCO_2)	OASE® Blue – 135[10] MDEA (10%) + PZ (30%)[12] – 224 Cansolv[15] – 107.6 (69% compression) Piperazine – 107 – 81 – 74 – 71[13] MHI KS-1™ – 186[3,14]
Solvent makeup (kg/tCO_2)	Cansolv DC-103[7] – <10%/yr ACC™ S21[11] – 0.5-0.6 ACC™ S26[11] – 0.2-0.3 MDEA (10%) + PZ (30%)[12] – 0.92
Cooling water (t/tCO_2)	OASE® Blue – 1.63[10] (makeup) Cansolv DC-103[8] – 44.4 Cansolv DC-201[8] – 32.3 MHI KS-1™ - 2.6[3,14] (makeup) MDEA (10%) + PZ (30%)[12] – 5.3 (makeup)

[10]OASE blue technology; CO_2 conc. 21.3%; CO_2 purity >99.9%; capture capacity – 1.4 $MtCO_2$/yr; capture efficiency - 95%; electricity includes CO_2 compression to 158.5 bar.
[11] Aker solutions ACC™ advanced solvents S21 and S26 solvents; CO_2 conc. 3.4% and 4%, respectively; without heat integration; 87% capture.
[12]CO_2 conc. – 20.4%; CO_2 capacity – 2227.5 tCO_2/day; electricity includes compression to 110 bar.
[8]Shell Cansolv; CO_2 capacity – 132 tCO_2/hr; uses mechanical vapor recompression
[13]Piperazine solvent; increasing CO_2 concentration 4% - 12% - 20% - 33%; electricity includes CO_2 liquefaction at 20 bar and -20 °C.
[3,14]Coal power plant; CO_2 conc. – 12.3%; 90% capture efficiency; MHI KM-CR Process® with KS-1™ solvent; Heat is calculated from steam consumption (5.9 bar and 160 °C); electricity includes compression power, about 33.3%.

COSTS

CAPEX:
OASE® Blue: 21.5 €/tCO_2[10]
Cansolv: 32.5 €/tCO_2[16]
MDEA (10%) + PZ (30%): 10.1 €/tCO_2[12]
Piperazine: 13.5 – 7.6 – 6.6 – 5.6 €/tCO_2[13]
MHI KS-1: 25.2 €/tCO_2[3,14]
Main CAPEX: absorption column, stripping column, and main heat exchanger.

OPEX:
OASE® Blue: 33.4 €/tCO_2[10]
Cansolv: 17.4 €/tCO_2[16]
MDEA (10%) + PZ (30%): 38.7 €/tCO_2[12]
Piperazine: 16 – 13.7 – 11.8 – 12 €/tCO_2[13]
MHI KS-1: 17.9 €/tCO_2[3,14]
Main OPEX: steam, electricity, cooling water, and amine make-up.

CO_2 capture cost:
OASE® Blue: ~55 €/tCO_2[10]
Cansolv: ~50 €/tCO_2[16]
MDEA (10%) + PZ (30%): 48.7 €/tCO_2[12]
Piperazine: 29.5 – 21.3 – 18.4 – 17.6 €/tCO_2[13]
MHI KS-1: 43 €/tCO_2[3,14]

CO_2 avoidance cost:
Cansolv[16]: 64.4 €/tCO_2
Piperazine[13]: 85 – 69 – 63 – 60 €/tCO_2 (estimated)

[10]OASE blue technology; Steam-methane reforming plant; CO_2 conc. 21.3%; CO_2 purity >99.9%; capture capacity – 1.4 $MtCO_2$/yr; capture efficiency - 95%; electricity includes CO_2 compression to 158.5 bar; electricity price – 65 €/MWh; lifetime – 30 yrs.

[16]Cansolv solvent; Coal power plant; CO_2 conc. – 13.3%; 90% capture efficiency; lifetime – 30 yrs; 3.58 $MtCO_2$/yr; 2015 euros; discount rate – 12%; operating hours – 7446 hr/yr; includes compression up to 110 bar; excludes transportation costs.

[12]MDEA (10%) + PZ (30%) solvent mixture; CO_2 conc. – 20.4%; CO_2 capacity – 2227.5 tCO_2/d; capture efficiency – 90%; CO_2 purity – 98%; includes CO_2 compression to 110 bar; electricity price – 58.1 €/MWh; steam price – 22.5 €/t; 90% capture efficiency; 2019 euros; plant lifetime – 25 yrs; interest rate – 15%; CRF – 0.154.

[13]Piperazine solvent; values for CO_2 conc. – 4%, 12%, 20%, and 33%; CO_2 capacity – 0.168, 0.446, 0.709, 1.12 tCO_2/yr; piperazine concentration – ~8 mol-PZ/kgH_2O; excluding CO_2 liquefaction (20 bar and -20°C); including flue gas pretreatment; operating hours – 8000 hr/yr; electricity price – 64 €/MWh; steam price – 5.5 €/t; 90% capture efficiency; 2020 euros; plant lifetime – 20 yrs; interest rate – 6%.

[14] MHI KM-CR Process® with KS-1™ solvent; coal power plant; CO_2 conc. – 12.3%; 90% capture efficiency; CO_2 purity – >95%; 2.99 $MtCO_2$/yr; 2017 euros; CRF – 0.1243; operating hours – 6745 hr/yr; includes compression up to 152.7 bar and 35 °C; process steam at 5.9 bar and 160 °C; excludes transportation costs.

ENVIRONMENTAL

CO_2 footprint: Not available. Can be considered same as the MEA-based chemical absorption technology (see infosheet).

Spatial footprint:

Amine scrubbing: 37,500 m^2 (250x150) for 2.56 $MtCO_2$/yr, which also includes compression system[17] (assuming it to be the same as MEA-based process).

Cansolv DC-103 solvent: 465 m^2 for 100 tCO_2/day [7]

MHI KS-1™ solvent: 19,166 m^2 (550x370) for 2.99 $MtCO_2$/yr (including capture island, compression system, cooling tower, and wastewater treatment)[14]

Environmental issues: solvent emissions, heat stable salts waste, water usage, and wastewater management.

ENGINEERING

Maturity: Commercial (TRL 9)[2]

Large-scale commercial plants are operational for various solvents.

Retrofittability: Moderate

It can be integrated into existing industrial facilities without substantial modifications to the main process. The heat and electricity sources, and waste removal are required.

Scalability: High

Suitable for both medium and large-scale CO_2 capture operations (modular system). [2]

Process type: Liquid solvent based with chemical reactions.

Deployment model: Centralized or Decentralized.

Decentralized CO_2 absorption at point sources with centralized desorption.

Technology flexibility: Hybridization with other capture technologies is feasible. Other technologies can be used to increase CO_2 concentration.

TECHNOLOGY PROVIDERS

- CANSOLV by **Shell**, United Kingdom
- ADIP Ultra by **Shell**, United Kingdom *(MDEA as the main reactant and piperazine as the accelerator)*
- OASE® Blue by **BASF**, Germany
- ASCC by **Honeywell**, United States
- SUSTENOL™ by **Susteon**, United States *(mixed-amine solvent, regeneration energy = 2.01 GJ/t CO_2, capture efficiency = 96.2%, capture cost = €45/t CO_2)*
- ION solvent by **ION Clean Energy**, United States *(99% capture efficiency; greater stability; low emissions; faster kinetics; low energy requirements)*
- CycloneCC™ by **Carbon Clean**, United Kingdom *(uses rotating packed beds and amine-based proprietary APBS-CDRMax solvent; lowers energy demand by 10-25%, reduces corrosion by a factor of 20, decreases degradation by a factor of 10, and has a lifespan that is five times longer than conventional solvents)*
- KM CDR Process® by **Mitsubishi**, Japan
- Just Catch™ and Big Catch™ by **SLB Capturi**, Norway (formerly Aker Carbon Capture)
- Lummus CO_2 recovery by **Lummus Technology**, United States (up to 97% CO_2 recovery)
- GEA CEBO® Carbon Capture by **GEA**, Germany *(Suitable for cement, iron and steel, bioenergy, glass, chemical and waste-to-energy point source; modular, compact and cost-effective; 15 to 600+ t/day CO_2 capture capacities; high carbon capture efficiency of >90% with low energy consumption optimized by heat integration; CO_2 purity 97% at 2 bara and 40 °C; spatial footprint – 140 m^2 for 15 tpd and 600 m^2 for 300 tpd.)*

INNOVATIONS (examples)

- **Piperazine-activated amine blends**: Blending tertiary amines like methyl diethanolamine (MDEA) with piperazine (PZ) has been found to enhance CO_2 absorption rates and thermal stability.[18]
- **Amine-based solvents and additives**: Enhancing CO_2 capture efficiency, reducing energy requirements, minimizing solvent degradation, and mitigating equipment corrosion.[19]

CONTACT INFO

Mohammed Khan (mohammednazeer.khan@vito.be)
Miet Van Dael (miet.vandael@vito.be)

ACKNOWLEDGEMENT

This infosheet was prepared as part of the MAP-IT CCU project funded by VLAIO (grant no. HBC.2023.0544).

REFERENCES

1. Bernhardsen IM, Knuutila HK. A review of potential amine solvents for CO2 absorption process: Absorption capacity, cyclic capacity and pKa. *Int J Greenh Gas Control*. 2017;61:27-48.
2. Barlow H, Shahi SSM. *State of the Art: CCS Technologies 2024*.; 2024.
3. Panja P, McPherson B, Deo M. Techno-Economic Analysis of Amine-based CO2 Capture Technology: Hunter Plant Case Study. *Carbon Capture Sci Technol*. 2022;3(December 2021):100041.
4. Al-Juaied M. *Amine Scrubbing for CO2 Capture*.; 2021.
5. Jiang K, Li K. Harvesting CO2 reaction enthalpy from amine scrubbing. *Energy*. 2023;284(October):129268.
6. Adams D. *Flue Gas Treatment for CO2 Capture*. IEA Clean Coal Centre; 2010.
7. Shaw D. Cansolv CO2 capture: The value of integration. *Energy Procedia*. 2009;1(1):237-246.
8. Paul-Emmanuel Just. *Testing of CANSOLV DC-201 CO2 Capture System at the National Carbon Capture Center*.; 2017.
9. Linde/BASF. *Carbon Capture, Storage and Utilisation*.; 2024.
10. Shah M. *Engineering Design of a Linde-BASF Advanced PostCombustion CO2 Capture Technology at a Linde Steam Methane Reforming H2 Plant*.; 2022.
11. Gorset O, Knudsen JN, Bade OM, Askestad I. Results from Testing of Aker Solutions Advanced Amine Solvents at CO2 Technology Centre Mongstad. *Energy Procedia*. 2014;63:6267-6280.
12. Dubois L, Costa A, Mouhoubi S, De Weireld G, Thomas D. Postcombustion CO2 capture process by absorption-regeneration applied to cement plant flue gases: techno-economic comparison between the use of a demixing solvent technology and an advanced process configuration. *SSRN Electron J*. 2022;32(October).
13. Pérez-Calvo JF, Mazzotti M. Techno-economic assessment of postcombustion CO2 capture using aqueous piperazine at different flue gas compositions and flowrates via a general optimization methodology. *Int J Greenh Gas Control*. 2022;114:103587.
14. McPherson B. *CARBONSAFE ROCKY MOUNTAIN PHASE I: ENSURING SAFE SUBSURFACE STORAGE OF CARBON DIOXIDE IN THE INTERMOUNTAIN WEST*.; 2018.
15. Fout T, Zoelle A, Keairns D, et al. *Cost and Performance Baseline for Fossil Energy Plants Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity Revision 3*. Vol 1a.; 2015.
16. Yun S, Oh SY, Kim JK. Techno-economic assessment of absorption-based CO2 capture process based on novel solvent for coal-fired power plant. *Appl Energy*. 2020;268(November 2019):114933.
17. IEA. *Retrofit of CO2 Capture to Natural Gas Combined Cycle Power Plants*.; 2005.
18. Li L, Voice AK, Li H, et al. Amine blends using concentrated piperazine. *Energy Procedia*. 2013;37:353-369.
19. Loachamin D, Casierra J, Calva V, Palma-Cando A, Ávila EE, Ricaurte M. Amine-Based Solvents and Additives to Improve the CO2 Capture Processes: A Review. *ChemEngineering*. 2024;8(6):129.

PARTNERS

DISCLAIMER