A Yokogawa Company

CARBON CAPTURE STUDY INTRODUCING THREE DIFFERENT AMINE-BASED SOLVENTS

JIANYUAN PANG, Ph.D., P.Eng and RODOLFO TELLEZ-SCHMILL, Ph.D., P.Eng.

All about EXCELLENCE

Managing CO_2 Emissions for Sustainability

According to US EPA (2022), carbon dioxide (CO_2) accounts for around 80% of atmospheric greenhouse gases. It is the most significant of all greenhouse gases emitted because it traps heat in the atmosphere that can negatively affect air quality and human health. For efficient climate control, CO_2 emissions should be managed for sustainable development including environmental, social, and financial impact. Amine solvents are one of the most accepted technologies used worldwide for capturing CO_2. Selecting the appropriate solvent depends on many factors including the chemical composition of the gases containing CO_2, the availability of the amines in a specific region, and always, cost.

Digital twins have proven to be the ideal tool to solve problems facing the oil and gas industry. One key operational and business objective achieved through successful deployment of a digital twin involves continuous process monitoring to meet and enhance unit production targets. Digital twins can also be applied to carbon capturing systems. This paper discusses the analysis of carbon capturing technologies, specifically CO_2 capturing from flue gases using different amine solvent formulations (IECM 2019). Selecting the right and optimum solvent will benefit the final set up of a digital twin.

Mono-ethanolamine (MEA) has been extensively used as the preferred solvent for CO_2 capture from flue gases (Luis 2016). Multiple research efforts have centered on minimizing energy consumption on the regeneration of rich MEA (MacDowell et al. 2010). It is well known and proven that the energy regeneration requirements are higher compared to other alternative amine solvents such as Diethanolamine (DEA), Methyl-diethanolamine (MDEA), MDEA+Piperazine and others (Hasan et al. 2021). Recently, the use of amine solutions with Sulfolane have gained attention. They are being considered as an advanced solvent alternative over the traditional MEA by improving the absorption rate while lowering the regeneration heat duty (Dash et al. 2015).

This paper presents case study results from a typical CO_2 capturing system using three different amine solvents: 1) MEA (30 wt%), 2) MDEA+Piperazine (33wt% MDEA + 7wt% Piperazine), and 3) MDEA+Sulfolane (20 wt% MDEA + 30wt% Sulfolane). MDEAPiperazine (solvent 2) is also referred to as activated MDEA solutions in the industry (Closman et al. 2009). These solvents will capture CO_2 from flue gases deriving from the same source.

Model development and Process Description

According to *Hydrocarbon Processing,* Petro-SIM® software is considered the best process simulator to build digital twins. It provides operators with a single source of truth for driving decisions within the plant at an asset level in the oil and gas industry. Additionally, Petro-SIM simulator has the AMSIM module integrated as part of its thermodynamic packages. AMSIM[1] is a specialized thermodynamic package designed to simulate the absorption process for natural gas and liquefied petroleum gas (LPG) sweetening and carbon dioxide capture using alkanolamine and/or physical solvent, in which the acid gases such as hydrogen sulphide (H2S), CO_2 and other impurities (carbonyl sulphide, carbon disulphide and mercaptans) are removed. AMSIM uses a rigorous non-equilibrium stage model for plate columns and the rate-based model for packing columns, as well as the Peng-Robinson equation of state to simulate the performance of contactors and regenerators.

1. AMSIM is maintained and developed by DBR, now D&I GeoUnit of Schlumberger Canada and is backed by DBR 30+ years' expertise including in-house experimental facilities and the numerous measurement data.

The process configuration in the digital twin model is shown in Figure 1. This process consists of an absorption column, a lean/rich amine heat exchanger, a regeneration column, a circulation pump, and a lean amine cooler. The flue gases are produced from burning 24 tonnes/day of fuel gas with 15% excess air. Traces of nitrogen oxides (NOx) and carbon monoxide (CO) are present in the flue gas with concentrations within acceptable environmental limits. The flue gases are cooled to 37oC before feeding them to the absorption column.

The make-up stream provides pure water which is lost in the regenerator's vent stream (Am 5). This stream can be connected to a compression system for transporting the recovered CO2 before storage.

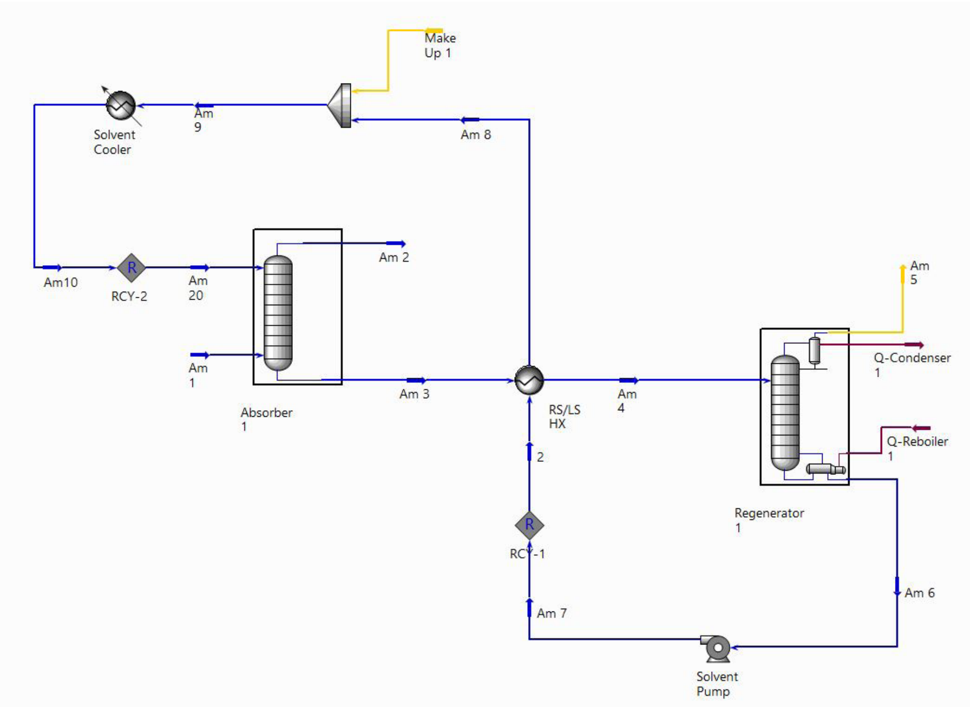

Figure 1: CO_2 capturing PFD

The absorption and regeneration towers are assumed to have the same number of stages, and both work at pressures very close to atmospheric pressure.

Simulation results

Table 1 summarizes the simulation results. The required column diameters for each type of solvent were estimated using commercially available tray sizing software (i.e. SULCOL 3.4.4[2]). A low-cost substance, MEA is the most commonly used amine for carbon capturing. Most importantly, it has the largest CO_2 absorption capacity compared to activated MDEA and, therefore, requires low solvent recirculation rate demand (Hasan et al. 2021). These last statements are consistent with the simulation results shown in Table 1. The solvent recirculation rate for the MDEA+Sulfolane solvent is more than three times the requirement for MEA. The MDEA+Piperazine solvent requires 40% more solvent recirculation flow rate to achieve the same CO_2 removal percentage as MEA. However, its regeneration energy requirement is 20% smaller.

A low solvent recirculation rate doesn't necessarily imply a low capital cost, the vapor traffic in the absorber determines the column diameter. The absorber diameter required for MEA is 10% larger compared to the diameter required for the other two MDEA solvents. Figure 2 shows the vapor traffic in the absorber for the three solvents. The regeneration of MEA also requires high vapor traffic in the regenerator compared to the required vapor traffic for the MDEA solvent cases. Figure 3 shows a comparison of the vapor traffic in the regenerator for each solvent. The use of MDEA solvents requires low regeneration heat requirements, being this characteristic a major advantage over the use of MEA.

		Solvent		
Process variables		MEA	MDEA + Piperazine	MDEA + Sulfolane
Flow Rate	act-m^3/h	25.5	36.6	75.1
CO_2 removal	%	99.91	99.91	97.53
Rich amine loading	mol CO_2/mol Solvent	0.5875	0.5229	0.1784
Lean amine loading	mol CO_2/mol Solvent	0.0384	0.0118	0.0001
Regenerator reboiler duty	MW	15.0	12.0	10.0
	GJ/Ton CO_2	20.3	16.2	13.9
Regen condenser duty	MW	12.7	9.9	7.8
	GJ/Ton CO_2	17.2	13.4	10.8
Rec. pump duty	kW	1.786	3.070	6.356
Estimated equipment dimensions				
Absorber ID	mm	1524	1372	1372
Regenerator ID	mm	2134	1981	1829

Table 1: Simulation results

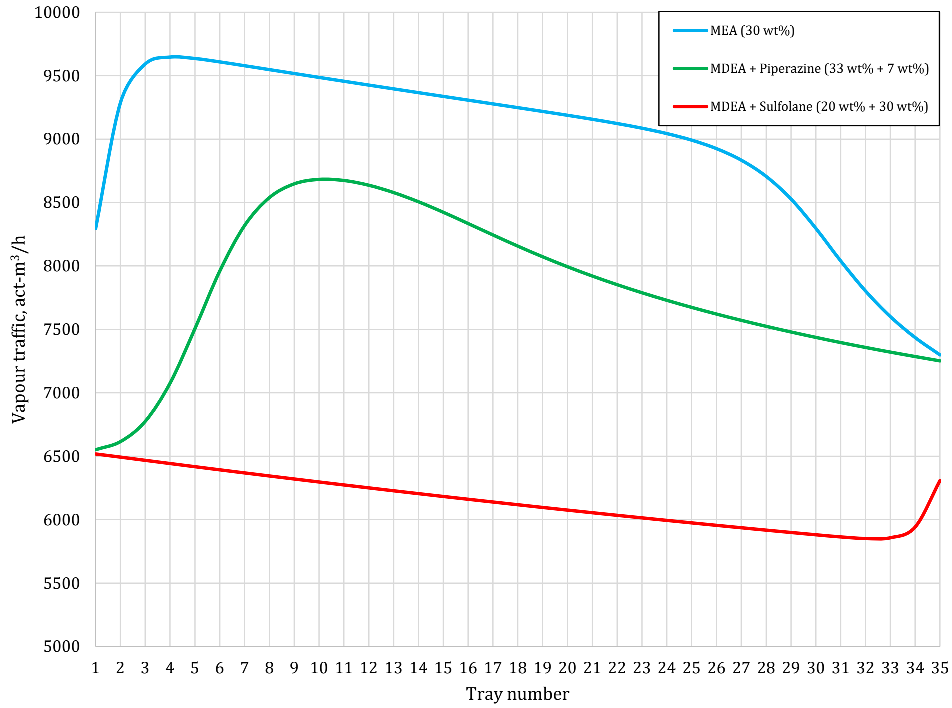

Figure 2: Vapor traffic in absorber

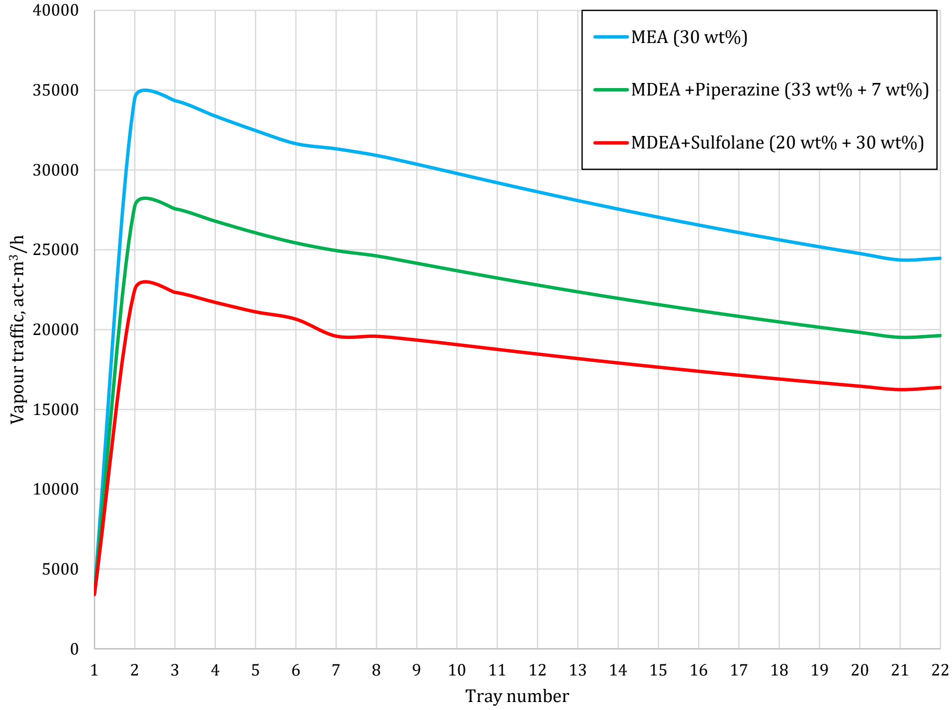

Figure 3: Vapor traffic in the regenerator

In Figure 4, a comparison of the CO_2 concentration in vapor shows the performance of each solvent in the absorber. MEA solvent absorbs CO_2 more efficiently with the lowest solvent recirculation rate. The MDEA+Sulfolane solvent exhibits a reduced capacity to absorb CO_2 (Qian and Mather 1995), this is the reason for requiring a very large solvent recirculation flow rate. Figure 5 shows the comparison of the CO_2 concentration profile in the liquid inside the regenerator. The results in Figure 5 show that the regeneration of the MDEA+Sulfolane solvent is stripped with minimal energy requirements to regenerate.

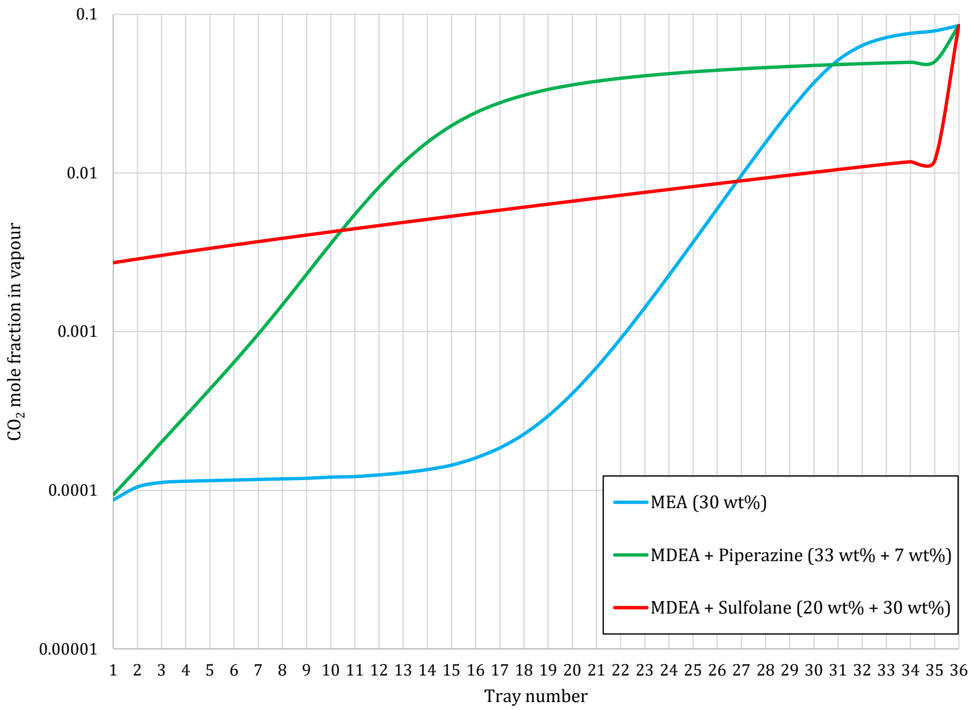

Figure 4: CO_2 mole fraction in vapor inside the absorber

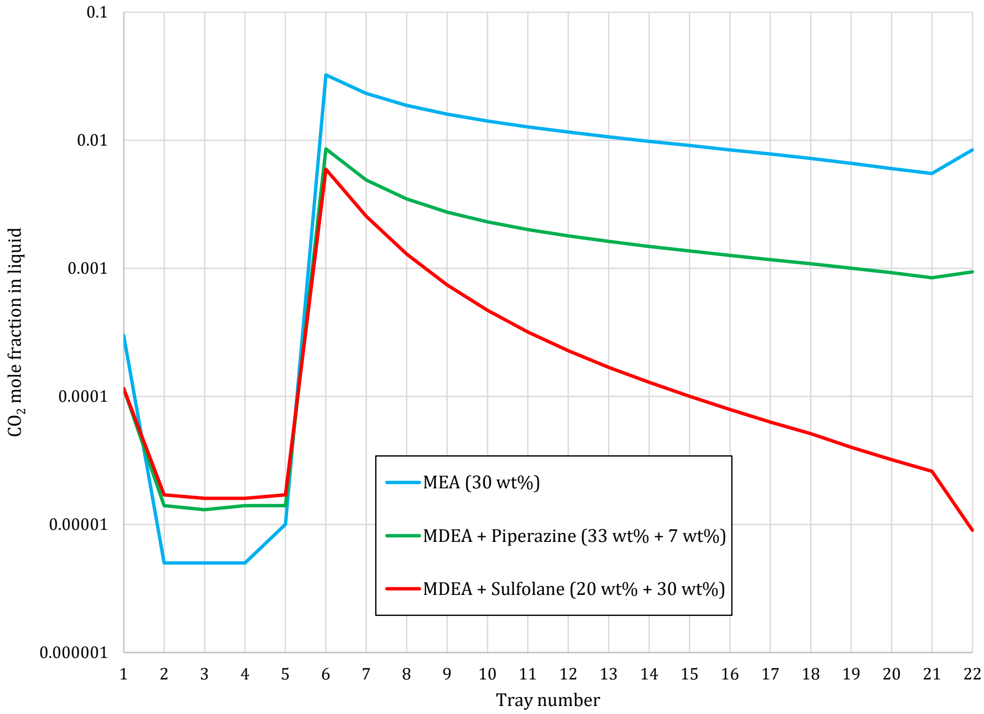

Figure 5: CO_2 mole fraction in liquid inside the reformer

2. SULCOL 3.4.4 is a hydraulic rating software developed by Sulzer that analyzes trayed and packed columns.

Conclusion

Simulation results are consistent with and support the relevant published literature. MDEA containing solvents require less energy for regenerator compared to MEA. However, the solvent recirculation flow rate is significantly larger. Vapor traffic using activated MDEA are smaller than the use of MEA. In turn, this will imply smaller columns and lower capital cost expenditure.

Author Biographies

Jianyuan (Jane) Pang

Jianyuan (Jane) Pang holds Ph.D. degree in Chemical Engineering from the University of Saskatchewan, Canada and served as Technical Principal at Schlumberger. She has 30+ years' academia and industry experience in chemical and reservoir engineering. Her primary expertise lies in gas/NGL treating and CO2 capture process simulation, fluid properties and phase behavior for conventional and heavy oil, EoS modeling, flow assurance, PVT analysis and predictions and HAPs/VOCs/hydrocarbon emission predictions. She is a member of Association of Professional Engineers and Geoscientists of Alberta (APEGA) and technical reviewer of Journal of Chemical Engineering Data, Journal of Natural Gas Chemistry.

Rodolfo Tellez-Schmill

Rodolfo Tellez-Schmill is Product Champion - Process Simulation with KBC (A Yokogawa Company). He has over 20 years of experience in chemical engineering activities including process engineering, quality control, project management, research and development, technical support, and training, with a strong background in process simulation, control, optimisation, and design. He is currently Petro-SIM Product Manager with KBC Advanced Technologies, holds a Ph.D. in chemical engineering from the University of Calgary, and is a Professional Engineer registered in the Province of Alberta, Canada.

References

Closmann, F., Nguyen, T., and Rochelle, G.T. (2009). *"MDEA/Piperazine as a Solvent for CO_2 Capture"*; Energy Procedia, Vol. 1, pp. 1351-1357.

Dash, S.K., Mondal, B.K., Samanta, A.N. et al. (2015). *"Post-Combustion CO_2 Capture with Sulfolane Based Activated Alkanolamine Solvent,"* Computer Aided Chemical Engineering, Vol. 37, pp. 521-526.

Hasan, S., Abbas, A.J., and Nasr, G.G. (2021). *"Improving the Carbon Capture Efficiency for Gas Power Plants through Amine-Based Absorbents,"* Sustainability, Vol. 13,72.

IECM (2019). *"Amine-based Post-combustion CO_2 Capture,"* Integrated Environmental Control Model Technical Documentation.

Luis, P. (2016). *"Use of Monoethanolamine (MEA) for CO_2 Capture in a Global Scenario: Consequences and Alternatives,"* Desalination, Vol. 380, pp. 93-99.

Mac Dowell, N., Florin, N., Buchard, A. et al. (2010). *"An Overview of CO_2 Capture Technologies,"* Energy Environ. Sci., Vol. 3, pp. 1645-1669.

Qian, W., Li, Y., and Mather, A.E. (1995). *"Correlation and Prediction of the Solubility of CO_2 and H2S in an Aqueous Solution of Methyldiethanolamine and Sulfolane,"* Ind. Eng. Chem. Res., Vol. 34, pp. 2545-2550.

US EPA (2022). *"Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019,"* https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

AMERICAS
15021 Katy Freeway
Suite 600
Houston, TX 77094
USA

T: +1 281 293 8200

EUROPE
42-50 Hersham Road
Walton on Thames
Surrey KT12 1RZ
UK

T: +44 (0) 1932 242 424

ASIA PACIFIC
5 Bedok South Road
Singapore 469270
T: +65 6735 5488

MIDDLE EAST
Level 17, The Offices World
Trade Center, Central
Market, Al Markaziya
P.O. Box 3876
Abu Dhabi, United Arab
Emirates

T: +971 2 508 7300

E: info@kbc.global | **www.kbc.global**

0183-PetroSIM-AMSIM-WHT-US-42022