MEA-Propanol-based demixing solvent investigation for the absorption-regeneration CO_2 capture process

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Topic(s): Pre- and post-combustion capture – Absorption/adsorption

Keywords: *Post-combustion CO_2 capture; Absorption; Demixing solvents; Experiments; Simulations*

ABSTRACT

The implementation of CCUS (Carbon Capture Utilization and/or Storage) in different industrial sectors (e.g. steel, cement, lime, glass, etc.) is still facing a number of challenges. Regarding specifically the post-combustion absorption-regeneration technology, one of the biggest challenges is still its high thermal energy demand (typically higher than 3 GJ/t_{CO2} (IEAGHG, 2019)). This is particularly impacting on the economic viability of the process when large amounts of heat (especially as steam) are not available on-site. Among the different solutions to reduce the thermal energy demand of that technology, the development of new solvents is still a hot topic. One of the most promising solutions is the use of a demixing (liquid-liquid) solvent. Indeed, in such a process (see Figure 1), once the CO_2 is absorbed by the solvent, a biphasic phenomenon occurs by the formation of two liquid phases in the CO_2-loaded solvent at the outlet of the absorption column. Carbon dioxide is distributed heterogeneously between the two phases, CO_2 being present almost exclusively in the CO_2-rich phase that is carried to the regeneration column. Therefore, a lower solvent mass flow is brought to the regeneration column, together with a higher CO_2-concentration of this flow compared to the one observed with a non-demixing solvent. These two elements lead to a significant reduction of the specific solvent regeneration energy. For example, the interest of this process has been shown through pilot tests performed in the framework of the 3D project (3D project, 2025) using DMX™ solvent developed by IFPEN. The chemical composition of such kind of blend being not "open access", the purpose of the present study is to investigate other potential demixing solvents, allowing to reduce the CO_2 capture process energy consumption while using quite "well known" chemical compounds.

The work methodology followed in the present work is presented on Figure 2 (left). In a first step, a detailed bibliographic review and a methodological selection have been performed in order to select potential candidates. The selection methodology is completely described in (Verdonck et al., 2024). Based on this methodology, 30 aqueous amine(s)-based blends have been identified (see Figure 2 (right)), including a blend composed of the well-known MEA (monoethanolamine) 30 wt.% and PROP (propanol) 40 wt.% as phase-splitting agent. The second step of the works included physicochemical, equilibrium and kinetic data acquisition. For example, density (Figure

3 (left)) and viscosity (Figure 3 (right)) of MEA+PROP solvent have been measured. It can be seen that despite these properties values increase due to the demixing phenomenon (for the rich-phase), they are still in an acceptable range for process application. The absorption (see Figure 4 (left) and Figure 5 (left)) and regeneration (see Figure 4 (right) and Figure 5 (right)) performances of this solvent were also measured using lab-scale experimental devices. It can be noticed that MEA+PROP blends keep good absorption performances (compared to MEA alone) for different CO_2 contents in the gas to treat, while the demixing blend exhibit a much higher regeneration efficiency (higher desorbed CO_2 flow on Figure 5 (right)) thanks to a more CO_2-rich solution (both considering the same liquid volume or the total MEA 30 wt.% one for the non-demixing solution).

As presented in Figure 6, an Aspen Plus® V14 simulation modeling of the MEA 30 wt.% + PROP 40 wt.% demixing system has been developed in order to estimate the energy savings with this solution in comparison with a conventional MEA 30 wt.% system. This comparison was performed for a flue gas coming from a lime kiln (y_{CO2} = 24%), considering a capture rate of 90%. e-NRTL-RK model (Electrolyte Non-Random Two Liquids with the Redlich-Kwong equation of state (Wang et al., 2019)) was considered, including the Helgeson model (Tanger & Helgeson, 1988) to calculate the standard thermodynamic properties, especially efficient for the decanter part. After finding the liquid-to-gas flow rates ratio minimizing the solvent regeneration energy (E_{regen}), it was shown that the E_{regen} of the MEA+PROP solvent is ~20% lower (2.68 GJ/t_{CO2}) compared to the MEA 30 wt.% one (3.32 GJ/t_{CO2}).

In future works, tests will be performed with a new micro-pilot unit developed at the University of Mons (see Figure 2 (left)), both with MEA-PROP blend, but also with other blends that present a high score in the methodological selection (Verdonck et al., 2024).

ACKNOWLEDGEMENTS

Damien Verdonck is a Research Fellow of the Fonds de la Recherche Scientifique – FNRS (Belgium). The authors would like also to express their gratitude to the SPF Economie (Belgium) for funding the DRIVER project in the framework of the Energy Transition Fund program.

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FIGURES

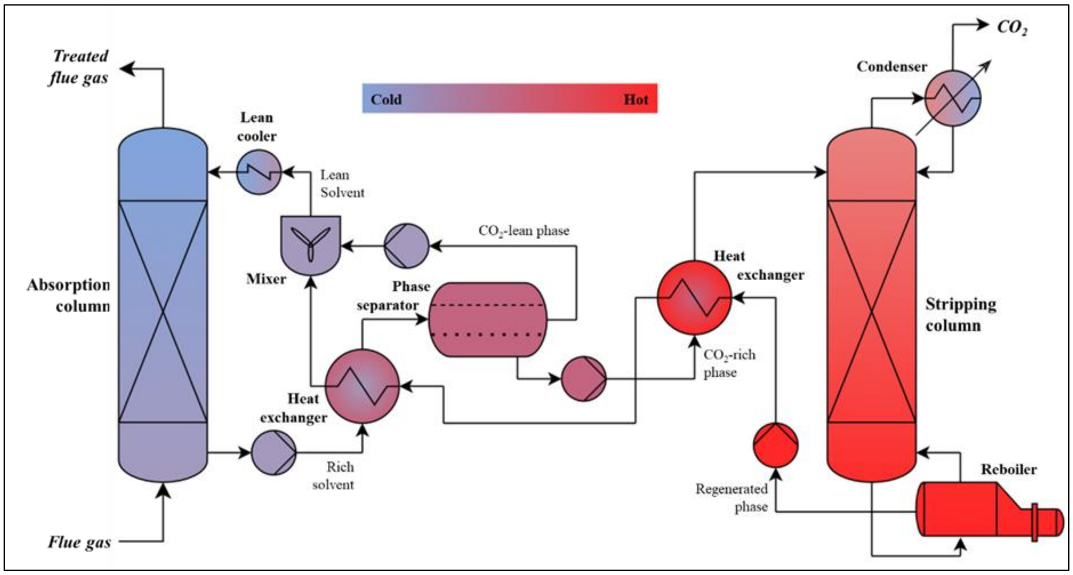

Figure 1. Typical flowsheet of an absorption-regeneration process using liquid-liquid biphasic solvent.

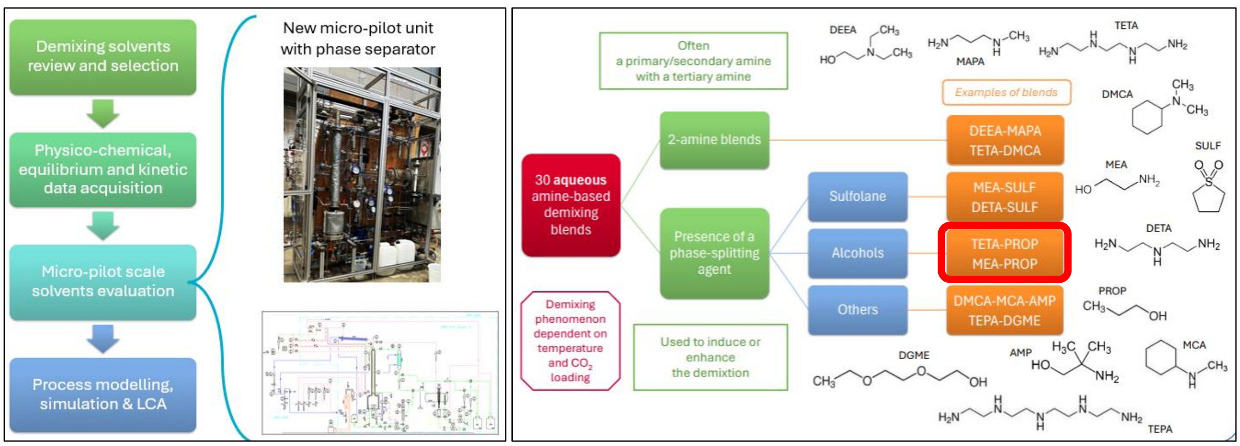

Figure 2. Demixing solvents evaluation methodology (left) and selection (right).

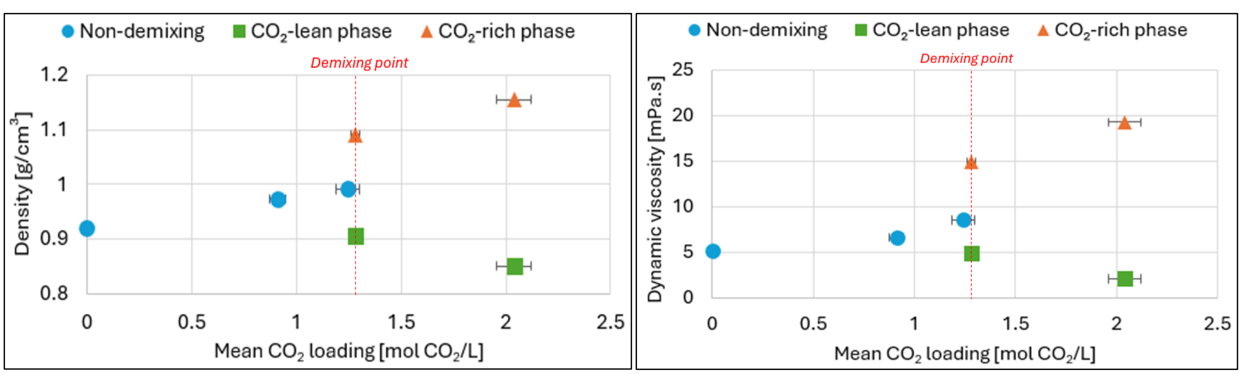

Figure 3. Density (left) and dynamic viscosity (right) measurements for MEA (30 wt.%) + PROP (40 wt.%) solvent.

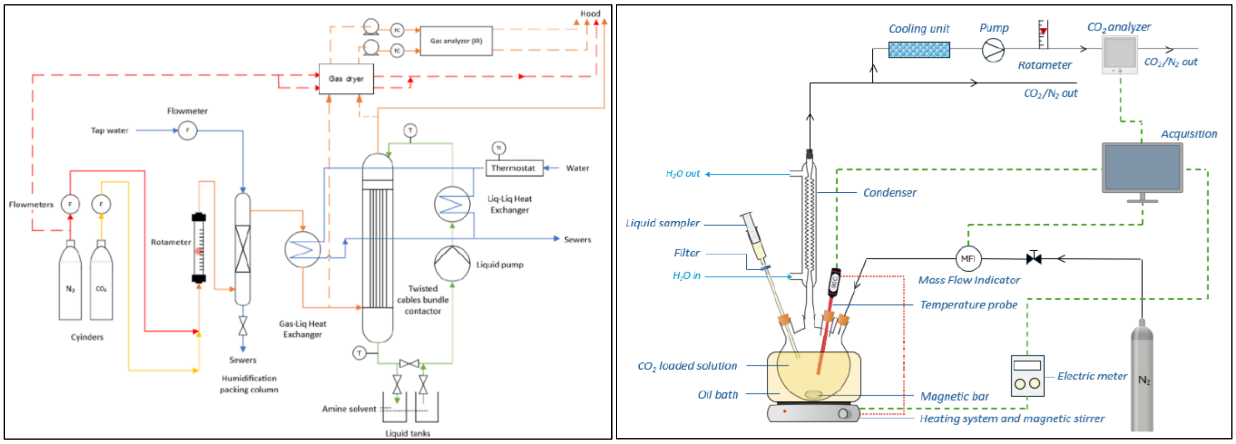

Figure 4. Flowsheet of the experimental setups used for CO_2 absorption (left) and regeneration (right) experiments.

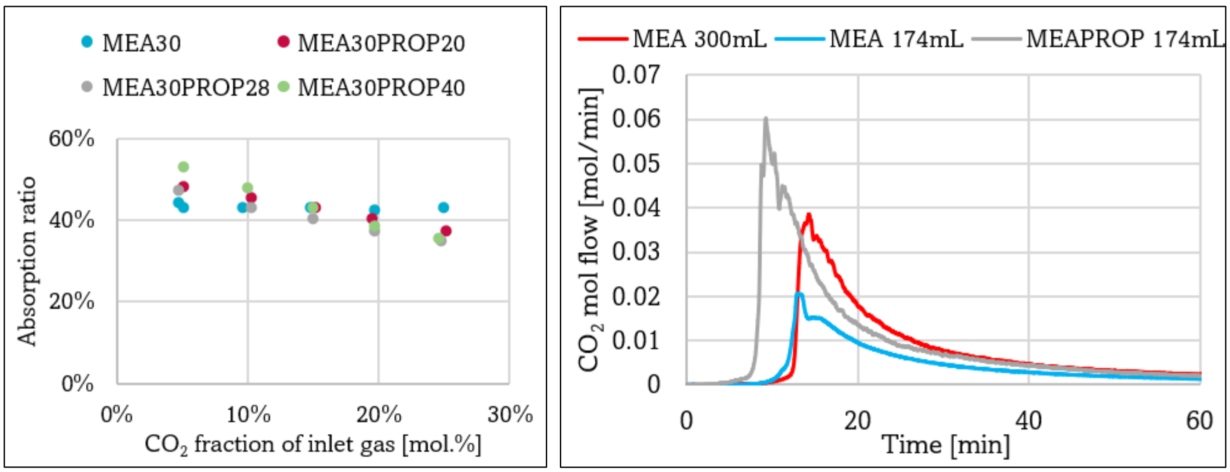

Figure 5. Absorption ratios measurements (left) and CO_2 flows produced during the regeneration tests (right).

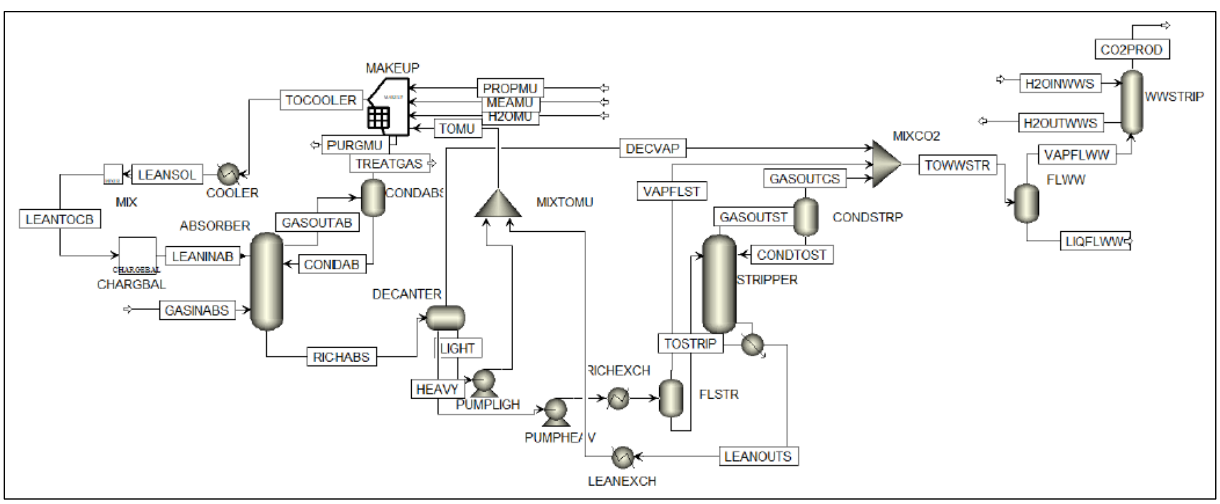

Figure 6. Aspen Plus process flowsheet for the demixing aqueous solvent MEA (30 wt.%) - PROP (40 wt.%).