CO_2 capture applied in the cement industry: reducing the energy consumption of the post-combustion absorption-regeneration process

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The 2019's IPCC (Intergovernmental Panel on Climate Change) report clearly showed that Carbon Capture Utilization and Storage (CCUS) must be envisaged in order to keep the world temperature increase at around 1.5°C thanks to a significant reduction of the CO_2 emissions. Focusing on the industrial sector, the cement industry itself contributes globally to around 30% of the total CO_2 emissions. It is therefore a necessity to investigate the implementation of CCUS solutions specifically for this industry where the CO_2 content in the flue gas ($y_{CO2,in}$) is higher (17 vol.% < $y_{CO2,in}$ < 35 vol.%) than in the case of power plants ($y_{CO2,in}$ < 15 vol.%). Moreover, even if the post-combustion CO_2 capture by absorption-regeneration using amine(s)-based solvents is the most mature technology, reducing its energy consumption and more globally its cost is still a challenge needing process improvements and optimization.

In addition to new equipment (e.g. new gas-liquid contactors), the implementation of alternative process configurations and the development of novel solvents are two efficient ways to reduce the CO_2 capture costs through the decrease of the solvent regeneration energy. Based on these statements, the present work, carried out in the framework of the ECRA (European Cement Research Academy) Academic Chair at UMONS, focused on these two solutions through Aspen Software^{TM} simulations, supported by micro-pilot tests for validation purposes.

Concerning the first solution, considering a cement plant flue gas ($y_{CO2,in}$ = 20 vol.%), several CO_2 capture process configurations were simulated with different solvents (namely monoethanolamine (MEA), piperazine (PZ) and methyldiethanolamine (MDEA) activated by PZ). Based on previous results [1-2] showing the configurations with the highest potential, the present work focused on the Rich Vapor Compression (RVC) configuration. This configuration included Water-Wash sections (WW) and was combined with an InterCooled Absorber (ICA). More precisely, in combination to this RVC+ICA configuration, the present study investigated the implementation of Rich Solvent Splitting and Preheating (RSSP) loops, leading to the flowsheet on Fig. 1 (left). The principle of RVC configuration is to produce a gaseous stream (mainly composed of CO_2 and H_2O) thanks to the flashing of the rich solvent. This stream is compressed and sent back to the regeneration column in order to reduce the steam demand at the reboiler. Concerning ICA, its principle is to withdraw the solvent flowing in the absorber, to cool it down and to send it back in the column in order to optimize its temperature profile. Regarding RSSP loops, it allows to recover some energy which is generally lost at the stripper's condenser as, before entering the internal heat exchanger, a part of the rich solution is preheated by the hot vapor going out at the stripper's top. The preheating of the entire rich solvent flow (Rich Solvent Preheating – RSP) after the RVC unit was also investigated. This operation leads to a better preheating of the rich solution and therefore reduces the reboiler energy demand.

The simulations were developed in Aspen Hysys^{TM} software using the Acid Gas package, considering an absorption ratio of 90 mol.%. The design and dimensioning of the CO_2 capture installation considered was based on CASTOR/CESAR European Projects for comparison purposes with previous works. Considering the optimized parameters, the RVC+ICA+RSSP process configuration leads to the highest energy savings with MDEA+PZ solvent (see Fig. 1 (right)) as in such case, E_{regen} was decreased to 1.97 GJ/t_{CO2} corresponding to 41% energy savings in comparison with the base case (MEA 30 wt.% with conventional process configuration).

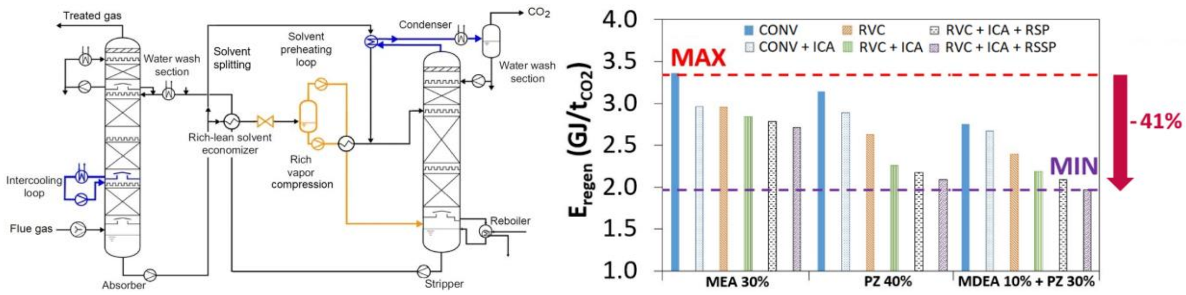

Fig. 1. RVC process configuration combined with ICA, WW sections and RSSP (left), and summary of the simulation results for different process configurations and solvents (right)

Regarding the second solution to reduce the solvent regeneration energy, the works focused on an aqueous blend composed of the tertiary amine diethylethanolamine (DEEA) and the diamine N-Methyl-1,3-Propanediamine (MAPA). In addition to the interesting absorption properties characterizing this blend, the CO_2 loaded solution can split into two liquid phases, one lean and one rich in CO_2. Consequently, the two phases can be separated based on density differences and only the CO_2-rich phase sent to the regeneration column. Hence, significantly less energy is needed thanks to the reduction of the amount of the regenerated solution and to the high CO_2 content of the loaded amine solution. A complete modeling of the absorption-regeneration process using DEEA-MAPA mixture was developed and implemented in Aspen Plus^{TM} software (see Fig. 2 (left)). The methodology was based on determining the model's parameters for the two subsystems first (DEEA-based and MAPA-based systems) and then for the global system DEEA-MAPA-H2O-CO_2. Electrolyte NRTL thermodynamic model has been successfully developed. Density and viscosity models were also presented together with the reactions occurring in the system and their corresponding characteristics. The developed model was firstly validated trough UMONS micro-pilot tests, and secondly, a process simulation at industrial scale (still considering a cement plant flue gas and an upscaled installation) was performed for a MEA reference case and for DEEA-MAPA demixing mixture.

Thanks to the process optimization, a regeneration energy gain of more than 40% compared to MEA reference process was shown. Moreover, a techno-economic assessment of the global process was performed through CAPEX and OPEX evaluations. The resulting global cost of CO_2 capture using DEEA-MAPA demixing mixture was shown to be 36% lower than the reference case (see Fig. 2 (right)), the importance of the steam cost being also pointed out.

Therefore, it could be concluded that implementing the combination of RVC+ICA+RSSP configurations, and also the use of DEEA-MAPA demixing mixture, represent very encouraging options to be considered to significantly reduce the energy consumption and the cost of the CO_2 capture process applied to cement plant flue gases.

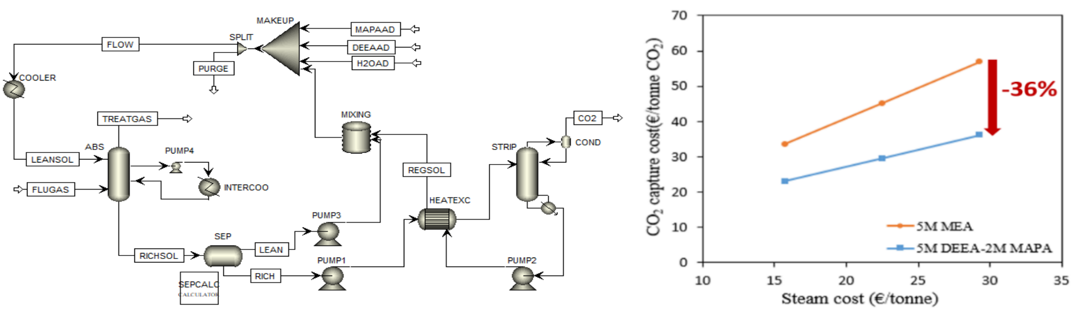

Fig. 2: 5M DEEA-2M MAPA demixing solvent simulation flowsheet in Aspen Plus^{TM} with CO_2 rich phase separation (left), and CO_2 capture costs comparison as function of the steam cost (right)

References:

[1] Dubois L. and Thomas D. Int. J. Greenhouse Gas Control 69, 20–35, 2018.

[2] Dubois L. and Thomas D. GHGT-14 Conference Paper, SSRN, 3365618, 2019.