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Simulations of various configurations of the post-combustion CO_2 capture process applied to a cement plant flue gas: parametric study with different solvents

Lionel Dubois* and Diane Thomas

Chemical and Biochemical Engineering Department, Faculty of Engineering, University of Mons,
20 Place du Parc, 7000 Mons, Belgium - *Contact person: lionel.dubois@umons.ac.be

Abstract

Even if Carbon Capture Storage and Utilization (CCSU) has gained widespread attention as an option for reducing greenhouse gas emissions from power plants, specific developments are still needed for the application to other industries, specifically for the cement industry where the flue gas has a higher CO_2 content in comparison with power plants ones. More precisely, the post-combustion CO_2 capture process by absorption-regeneration using amine based solvents is the more mature technology for the application in the cement industry but it is still needed to reduce its energetic costs.

The present study is focusing on the simulation of different CO_2 capture process configurations [1] (namely “Rich Solvent Recycle” (RSR), “Solvent Split Flow” (SSF), “Lean/Rich Vapor Compression” (L/RVC)) applied to the flue gas coming from the Norcem Brevik cement plant (Norway) where different post-combustion CO_2 capture technologies are tested [2] and especially the absorption-regeneration process (Aker Solutions technology) in a conventional configuration. For each configuration considered in our study, in addition to the $(L/G)_{vol.}$ ratio (optimized for all the configurations), a parametric study was carried out in order to identify the specific operating conditions (split fraction, injection stage in the columns, flash pressure drop, etc.) minimizing the solvent regeneration energy (E_{regen}) and allowing to highlight the interest of using alternative process configurations in order to reduce the energy consumption of the process. The simulations were carried out considering a pilot unit used during a previous European project, namely the CASTOR/CESAR one [3] (designed to handle a flow of 5000 Nm^3/h, all the design and operating parameters being available). In a first step, these simulations were performed considering the benchmark monoethanolamine (MEA) 30 wt.% as solvent but in a second step, other solvents (piperazine (PZ) and activated methyldiethanolamine (aMDEA)) are considered. The modeling was developed in Aspen Hysys^{TM} v.8.6 software using the acid gas package and the conventional “efficiency mode”. The CO_2 recovered purity was fixed at 98 mol.% and the absorption ratio was equal to 90 mol.%.

Among the different process configurations simulated with MEA 30 wt.% as solvent (see results example on Fig. 2) and considering the optimum operating parameters ($(L/G)_{vol.}$ ratio in the range 5.3 to 7.3 10^{-3}), it was shown that the heat pump modifications (namely LVC (see Fig.1) and RVC process modifications) give the best regeneration energy savings (around 14%) leading to E_{regen} lower than 3 GJ/t_{CO2} (namely 2.9 GJ/t_{CO2}, see Fig. 3). Regarding the two other categories, namely absorption enhancement (RSR) and the exergetic integration (SSF), smaller energy savings were obtained

(between 4 and 8 %) which can be justified by the fact that even with the conventional process configuration, the rich CO_2 loading of the MEA 30 wt.% was close to its equilibrium value, thus the potential for increasing this loading is very limited (which is normally the purpose of RSR configuration for example). Concerning the SSF one, the major advantage identified was linked to the decrease of the condenser cooling energy (which is also clearly decreased thanks to the LVC configuration). Finally, even if not negligible, the pumping and LVC/RVC compressor energy consumptions have an order of magnitude clearly lower than the regeneration energy.

Regarding the simulations with PZ 40 wt.%, simulations were performed with a reboiler pressure of 200 kPa (same value as for MEA 30 wt.%) at the bottom of the stripping column and of 600 kPa (allowing to reach conventional regeneration temperature for this solvent, namely around 150°C), the optimum $(L/G)_{vol.}$ ratio being identified in the range 3.1 to 6.6 10^{-3} depending on the pressure and configuration considered. The LVC modification gave the higher energy savings in both cases (around 18% energy savings), leading to E_{regen} equal to 2.57 GJ/t_{CO2} in the case with the higher pressure.

As perspectives, these simulations are still under progress with aMDEA. Other configurations will be also investigated such as the combination of two configurations (for example RSR and RVC). Finally, in addition to the interest in terms of OPEX, the consequence in terms of CAPEX will have to be estimated for a more precise evaluation of the global economic interest of using alternative process configurations, especially for the application to cement plant flue gases.

References

[1] Le Moullec Y. et al., *Int. J. Greenhouse Gas Control*, 31, 96, 2014.
[2] Bjerge L.-M. and Brevik P., *Energy Procedia*, 63, 6455, 2014.
[3] Knudsen J.N. et al., *Energy Procedia*, 1, 783, 2009.

Figures

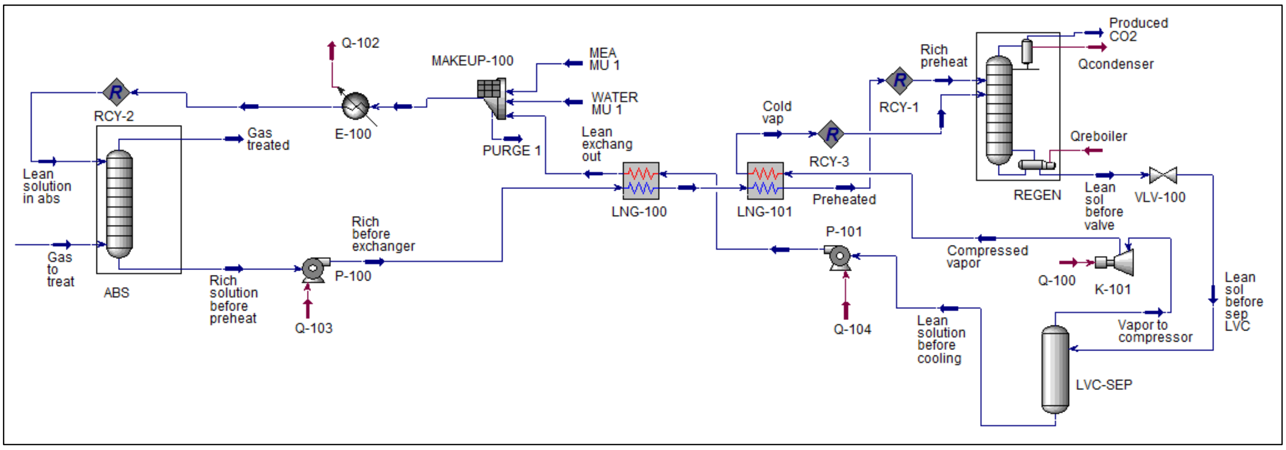

Fig. 1. Aspen Hysys^{TM} flow sheet for the Lean Vapor Compression (LVC) process configuration (MEA 30 wt.%)

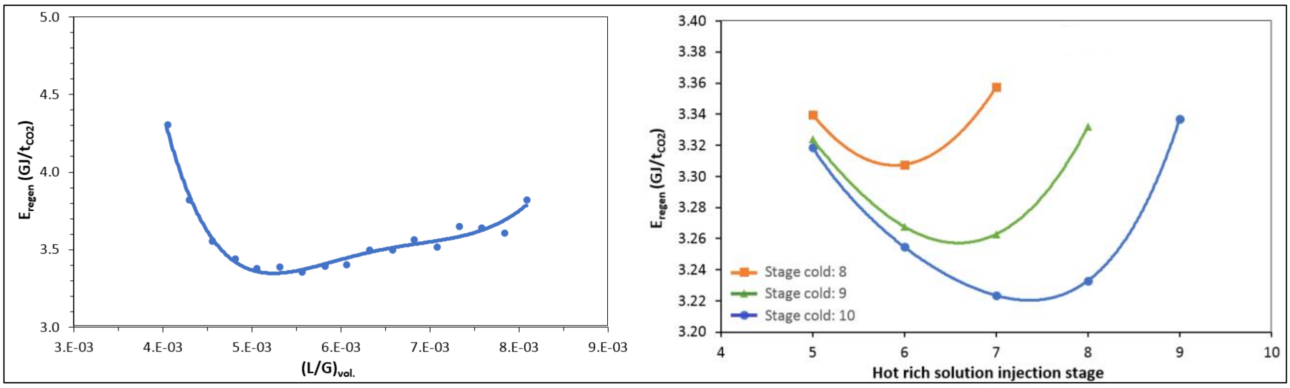

Fig. 2. Results example with MEA 30 wt.%: E_{regen} as a function of the $(L/G)_{vol.}$ ratio for the conventional configuration (left) and E_{regen} as a function of the injection stage of the hot solution into the stripper for different injection stages of the cold solution considering optimum operating parameters for the SSF configuration (right)

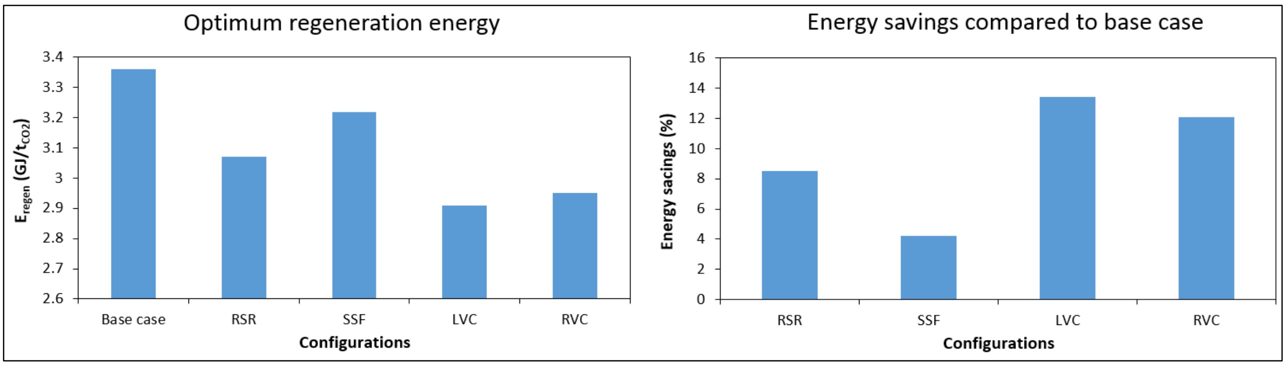

Fig. 3. Optimum regeneration energy for each process configurations (left) and energy savings linked to the use of alternative configurations in comparison with the base case (right) (MEA 30 wt.%)