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Post-combustion CO\(_2\) 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

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**Abstract**

The cement industry corresponds to around 20% of the total industrial processes CO\(_2\) emissions. Moreover, almost 66% of a cement plant CO\(_2\) emissions are considered as unavoidable as they are linked to the limestone decarbonation. The only way to significantly reduce the CO\(_2\) emissions from the cement industry is therefore to implement CCUS (Carbon Capture Utilization and/or Storage). Focusing on the CO\(_2\) capture step, two possibilities exist for the cement industry:

- oxy-fuel combustion: requiring large amounts of pure oxygen for performing the combustion, the need for kiln and burners adaptations, such as the implementation of a CPU (CO\(_2\) Purification Unit);

- and the post-combustion CO\(_2\) capture process: as end-of-pipe system, this is the most developed technology which does not require to adapt the industrial process upstream, but which is still very expensive, especially in terms of thermal energy consumption for the solvent regeneration. The present work is focusing on this technology.

More precisely, two innovative post-combustion CO\(_2\) capture processes by absorption-regeneration using amines-based solvents were investigated, and compared on techno-economic aspects, for reducing the solvent regeneration energy, namely: (i) the implementation of an advanced process configuration (Rich Vapor Compression (RVC) with Inter-Cooled Absorber (ICA)) including Water-Wash (WW) sections and Rich Solvent Splitting and Preheating (RSSP), implementing a methyldeethanolamine (MDEA) – piperazine (PZ) blend (see [1-3] for more information regarding the best process configurations to be applied for a cement plant application); and (ii) the use of a demixing process (diethylethanolamine (DEEA) + methyl-amino-propylamine (MAPA) blend [4] was considered as case study) allowing, thanks to the separation of the two phases formed after the CO\(_2\) absorption, to regenerate a lower solvent flow rate with a higher CO\(_2\) loading.

These two solutions were compared to a reference case (conventional process configuration using monoethanolamine (MEA) 30 wt.%) both in terms of operating (OPEX) and capital (CAPEX) costs. These different configurations, implemented in Aspen Plus\textsuperscript{TM} software, are presented on Fig. 1, 2 and 3. The implementation of the DEEA+MAPA demixing system is based on [4] for the thermodynamic modeling and also includes the implementation of Fortran sub-routines allowing a dedicated kinetic modeling using literature data.
As case study, a BAT (Best Available Technology) cement plant producing 3000 tons of clinker per day was considered, leading to the emission of 2475 tons of CO₂ per day, the cement plant generating 249 300 m³/h of flue gas containing 20 mol.% of CO₂. A CO₂ absorption rate of 90% is considered, the recovered CO₂ being compressed to 110 bar at 40°C in view of its transport. In both simulated configurations, a Direct Contact Cooler (DCC) is implemented in order to reduce the flue gas temperature to 50°C and to saturate it in water prior to the absorption step performed at atmospheric pressure and 40°C in all cases. Regarding the regeneration step, it is performed at 2 bar for the conventional configuration, at 6 bar for the advanced configuration and at 4 bar for the demixing system. Therefore, the CO₂ compression chain is adapted consequently: a 4-stages compression train being required for the conventional and demixing systems, while a 3-stages one is enough for the advanced configuration. These different configurations were simulated considering the same software, the same calculation hypotheses and the same study boundaries, allowing to perform a relevant comparison.

Some techno-economic results for the three processes investigated are given in Tab. 1. It can be seen that the advanced process configuration leads to the minimum in terms of regeneration energy (1.97 GJ/tCO₂) corresponding to 41.4% savings in comparison with the conventional process (3.36 GJ/tCO₂). The demixing technology leads to a quite similar regeneration energy (2 GJ/CO₂, 40.5% savings in comparison with the conventional process) as with the advanced process. The steam cost contributes to 80% in the OPEX for the conventional configuration, while it represents respectively 71% and 74% of the OPEX for the advanced process and demixing system. In terms of CAPEX, it can be seen from Tab. 1 that the equipment costs are increased by 8.8% and 1.6% for the advanced configuration and demixing process in comparison with the reference system. Indeed, while the addition of a decanter in the demixing system does not impact too much these costs, the advanced process implies the addition of a compressor (for the RVC) and of two heat exchangers (for the RVC and RSSP), even if the compression train can work with only 3 stages instead of 4 with the other configurations. For all cases, it is worth mentioning that Direct Contact Cooler (DCC) and blower costs contribute respectively to 15% and 9% to the total equipment costs.

Globally, it can be pointed out in Tab. 1 that the implementation of an advanced process configuration (49.17 €/tCO₂) or a demixing system (47.53 €/tCO₂) leads respectively to a decrease of 23.6% and 26.1% of the total CO₂ capture costs in comparison with the conventional process (64.33 €/tCO₂) using MEA as solvent. The two solutions investigated in the present work represent therefore interesting options to be considered to significantly reduce the cost of the post-combustion CO₂ capture process applied to cement plant flue gases even if the implementation of a demixing system is possible with a lower CAPEX investment than with the advanced configuration investigated.

References


Keywords: Post-combustion CO₂ capture; Absorption-regeneration process; Aspen Plus™ simulation; Demixing solvent; Advanced process configuration
Fig. 1. Aspen Plus™ flow sheet of the conventional CO₂ capture process (MEA as solvent)

Fig. 2. Aspen Plus™ flow sheet of the advanced CO₂ capture process configuration (MDEA+PZ as solvent)

Fig. 3. Aspen Plus™ flow sheet of the demixing CO₂ capture process (DEEA+MAPA as solvent)

Table 1. Techno-economic results for the three processes investigated

<table>
<thead>
<tr>
<th></th>
<th>Conventional process</th>
<th>Advanced process configuration</th>
<th>Demixing process</th>
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<tbody>
<tr>
<td>$E_{regen}$ (GJ/tCO₂)</td>
<td>3.36</td>
<td>1.97</td>
<td>2.00</td>
</tr>
<tr>
<td>/Conventional process</td>
<td></td>
<td>-41.4%</td>
<td>-40.5%</td>
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<tr>
<td>Equipment costs (M€)</td>
<td>30.74</td>
<td>33.43</td>
<td>31.23</td>
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<td>/Conventional process</td>
<td></td>
<td>+8.8%</td>
<td>+1.6%</td>
</tr>
<tr>
<td>Total CO₂ capture costs (€/tCO₂)</td>
<td>64.33</td>
<td>49.17</td>
<td>47.53</td>
</tr>
<tr>
<td>/Conventional process</td>
<td></td>
<td>-23.6%</td>
<td>-26.1%</td>
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