Study of the post-combustion CO₂ capture applied to conventional and partial oxy-fuel cement plants

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Abstract

The present communication is focusing on the application of Carbon Capture and Re-Use (CCRU) in the cement industry, especially on the CO₂ capture step. Indeed, reducing carbon dioxide industrial emissions became one of the most relevant issues nowadays and it is necessary to optimize the application of CCRU to all the major CO₂-emitting industries.

The post-combustion CO₂ capture technology using amine-based chemical absorption is a mature and industrially developed technology which has been proved to be efficient even if the solvent regeneration step still requires a high-intensive energy consumption. On the other hand, oxy-fuel combustion requires a large amount of high purity oxygen conventionally supplied by cryogenic distillation, which is clearly the higher energy penalty of this technology.

An alternative solution for CO₂ capture is the post-combustion capture applied to kilns working under enriched O₂-combustion namely called a “partial oxy-fuel combustion” (see Fig. 1) which leads to a more CO₂-concentrated cement flue gas compared to the conventional one. It is an intermediate process between both technologies that proposes an optimized operation leading to further reductions of the overall energy consumption [1-3]. Indeed, thanks to a more CO₂-concentrated flue gas and the choice of an adequate solvent, this process allows a reduction of the regeneration energy in the amine plant and a reduction of the energy costs for the Air Separation Unit (ASU) in comparison with total oxy-fuel conditions due to the lower quantity of O₂ needed. This technology has been proved to be applicable for the power plant case [2] and thus, in order to evaluate its potential for the cement industry, the aim of this work is to focus on cement flue gases compositions for conventional kilns (y₃CO₂ from 15 to 30%) but also for partial oxy-fuel kiln conditions (y₃CO₂ up to 60%), which will bring new relevant results allowing to compare the different CO₂ capture technologies.

The research methodology followed in the present work (see Fig. 2) was composed of two parts. Firstly, the performances of several solvents were evaluated thanks to screening tests carried out both at lab (double-stirred cell, cables-bundle contactor, regeneration cell) and micro-pilot (absorption-regeneration micro-pilot unit) scales and considering high CO₂ contents (y₃CO₂.in = 20-60 vol.%). Quite conventional solvents were tested in such conditions, such as: primary alkanolamines (Monoethanolamine (MEA)), secondary alkanolamines (Diethanolamine (DEA) and
Methylmonoethanolamine (MMEA), cyclical di-amines (Piperazine (PZ)) and non-cyclical tetramines (Triethylenetetramine (TETRA)); but new solvents were also investigated and especially hybrid ones corresponding to a combination of a physical solvent (an acetal in the present case, namely TOU - 2,5,7,10 -Tetraoxaundecane) and a chemical solvent (e.g. MEA). Indeed, the use of an hybrid solvent such as MEA 30% + TOU35% seems competitive with activated solutions as it showed better absorption performances than MEA 30% or other conventional solvents. Moreover, a demixing phenomenon appeared in the solution once significantly loaded with CO₂. Therefore, as already highlighted with the DMX™ solvents developed by IFP Energies Nouvelles, it is possible to take advantage of this demixing phenomenon in order to regenerate only the CO₂-rich phase and to reduce the energy consumption of the process thanks to a lower liquid flow rate in the stripping column. Based on [5], the regeneration energy is reduced from 3.7 GJ/tCO₂ down to around 2.1 GJ/tCO₂ with the use of demixing solvents, which means a 40% decrease of the regeneration energy and justifying that such solvents were considered in our work. Based on all the experimental results, it was shown that in addition of the interesting potential of the studied hybrid solvents, the use of the activated solutions of AMP, DEA and MMEA 30 wt.% with PZ or TETRA 5 wt.% presented particularly high absorption performances both in conventional and high CO₂ contents conditions, the performances becoming even better than conventional solvents ones (such as MEA 30 wt.%) when yCO₂ was increased.

Secondly, Aspen Hysys™ simulations of the absorption-regeneration process were carried out considering different solvents and process configurations (see Fig. 2) in order to optimize the energy consumption of the process. In parallel, our simulation model was also used to highlight the interest of the partial oxy-fuel combustion in terms of regeneration energy. Considering the flue gas coming from the Norcem Brevik cement plant (Norway) as base case, the simulations were carried out with the design of a pilot unit used during a previous European project, namely the CASTOR/CESAR one (designed to handle a flow of 5000 Nm³/h, all the design and operating parameters being available) and the CO₂ content of the inlet flue gas was increased. Based on these simulation results (see Fig. 3), it was highlighted that an increase of yCO₂ from 20% to 44% leads to a decrease of 24% of the MEA 30 wt.% regeneration energy (from 3.4 to 2.6 GJ/tCO₂), which is clearly encouraging.

As perspectives, further works on this topic will include the continuation of the screening tests with different solvents and especially demixing ones. Combined absorption-regeneration tests with a micro-pilot unit (described in [6]) will be also scheduled in order to have a more global evaluation of the solvent performances under partial oxy-fuel conditions (high CO₂ contents). Regarding the simulations, the effect of increasing the CO₂ content of the gas to treat will be investigated for other solvents (especially PZ and aMDEA) and a global optimized process will be proposed including both alternative configurations and new solvents, but also the energy costs associated to the O₂ production (ASU) for the partial oxy-fuel conditions, allowing to reduce the cost (OPEX and CAPEX) of the post-combustion CO₂ capture process applied in the cement industry.

References
Figures

Fig.1. $O_2$-enriched air combustion combined with post-combustion CO$_2$ capture system (adapted from [1] to cement industry).

Fig.2. Research methodology allowing the optimization of the absorption-regeneration CO$_2$ capture process for the application to cement flue gases.

Fig.3. Example of Aspen Hysys$^{\text{TM}}$ simulation results with MEA 30 wt.% highlighting the decrease of the regeneration energy thanks to a higher CO$_2$ content in the gas to treat under partial oxy-fuel conditions (CO$_2$ captured amount of 1.5 t$_{CO2}$/h).