14th International Conference on Greenhouse Gas Control Technologies, GHGT-14

21st -25th October 2018, Melbourne, Australia

Optimization of the post-combustion CO_2 capture applied to cement plant flue gases: parametric study with different solvents and configurations combined with intercooling

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Extended Abstract

Keywords: Post-combustion CO_2 capture; Absorption-regeneration process configurations; Solvents comparison; Aspen Hysys$^{\text{TM}}$ simulation; Intercooling; Cement plant flue gases.

1. Introduction

In order to significantly reduce the anthropogenic carbon dioxide emissions, the implementation of Carbon Capture Utilization and Storage (CCUS) is a necessity at world scale and not only for reducing the CO_2 emissions from power plants (flue gas CO_2 content (y_{CO2}) in the range 5-15 vol.%), but also from other industries such as cement plants (y_{CO2} from 17 to 35 vol.%). Even if the post-combustion CO_2 capture process by absorption-regeneration using amine based solvents is the most mature technology for the application in the cement industry, it is still needed to optimize the process specifically for this industry and especially to reduce its operating costs.

In addition to new solvents and equipment developments, implementing alternative CO_2 capture process configurations is an efficient way to reduce the CO_2 capture costs thanks to the decrease of the solvent regeneration energy. As direct continuation of a previous work [1], the present study is focusing on the Aspen Hysys$^{\text{TM}}$ simulation of different CO_2 capture process configurations, namely "Lean/Rich Vapor Compression" (L/RVC), and the combination of these configurations with an intercooled absorber (ICA). The Norcem Brevik cement plant (Norway) was taken as reference for the flue gas composition ($y_{CO2} \approx 20$ vol.%). Regarding the CO_2 capture installation considered for the simulations, it was based on a pilot unit used during the CASTOR/CESAR European projects (designed to handle a flow of 5000 Nm^3/h, all the design and operating parameters being available, [2]), and the simulations were performed with three solvents: monoethanolamine (MEA) as benchmark, piperazine (PZ) and activated methyldiethanolamine (aMDEA). For each configuration combined with intercooling (Inter-Cooled Absorber – ICA), a parametric study was carried out in order to identify the operating conditions (liquid to gas flow

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rates and all the parameters specifically related to intercooling) minimizing the solvent regeneration energy (E_{regen}) and allowing to highlight the interest of using alternative process configurations combined with intercooling in order to reduce the energy consumption of the process. Moreover, the previous simulation flow sheet presented in [1] was also updated with the addition of water-wash sections, as illustrated on Fig.1.

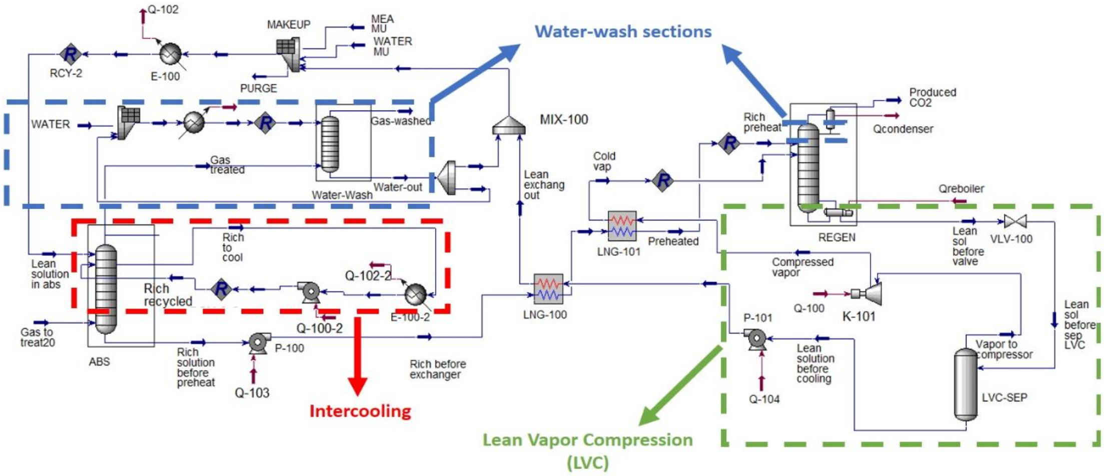

Fig. 1. Aspen Hysys^{TM} flow sheet for LVC configuration combined with ICA and water-wash (illustration for MEA)

The comparisons between the different solvents and configurations were not only based on E_{regen}, but also on other energy consumptions (e.g. compression electrical consumptions for LVC/RVC configurations), on equivalent work (using same method as in [1]) and on utilities costs (using Aspen Economics module in Aspen Hysys).

2. Results summary

The simulation results are globally summarized in Tab. 1 and a focus on E_{regen} comparison is given in Fig. 2. In comparison with the results without ICA (see [1]) it can be seen that even if implementing LVC and RVC configurations (without ICA) leads to supplementary electrical consumption and thus higher equivalent work values, thanks to intercooling W_{equ} are reduced (almost 15% decrease in the case of MEA 30 wt.% used in the base case configuration). In terms of utilities costs ($C_{utilities}$) significant savings are possible compared to the base case configuration using MEA 30 wt.%. For example, 24.5% of $C_{utilities}$ savings were obtained for MDEA 10 wt.% + PZ 30 wt.% implementing RVC + ICA configuration. Analyzing more specifically the effect of the addition of ICA itself, $C_{utilities}$ can be sometimes reduced or increased depending on the solvent and configuration.

Table 1. Simulation results with ICA for the different configurations with the three solvents considered (optimum operating conditions)

		Conv. config.	Conventional configuration + ICA			LVC configuration + ICA			RVC configuration + ICA		
		MEA	MEA	PZ	MDEA+PZ	MEA	PZ	MDEA+PZ	MEA	PZ	MDEA+PZ
Operating conditions											
$(L/G)_{vol,opt}$	(m³/m³)	$5.09\ 10^{-3}$	$5.02\ 10^{-3}$	$4.56\ 10^{-3}$	$4.57\ 10^{-3}$	$5.48\ 10^{-3}$	$4.57\ 10^{-3}$	$3.20\ 10^{-3}$	$7.31\ 10^{-3}$	$4.56\ 10^{-3}$	$4.57\ 10^{-3}$
L_{opt}	(m³/h)	22.49	22.21	20.15	20.20	24.23	20.20	14.14	32.29	20.15	20.20
Intercooling temp.	(°C)	-	40	40	40	40	40	40	40	40	40
Intercooling stage	(N°)	-	8	8	8	8	8	8	8	8	8
Flash Δp	(kPa)	-	-	-	-	100	500	500	100	500	500
$\alpha_{CO2,rich}$	(mol/mol)	0.51	0.53	0.80	0.72	0.52	0.75	0.73	0.51	0.80	0.72
$\alpha_{CO2,lean}$	(mol/mol)	0.21	0.24	0.47	0.36	0.25	0.41	0.46	0.42	0.47	0.36
Energy consumptions											
E_{pump}	(GJ/t_{CO2})	$1.61\ 10^{-3}$	$1.59\ 10^{-3}$	$8.66\ 10^{-3}$	$5.60\ 10^{-3}$	$3.99\ 10^{-3}$	$1.78\ 10^{-2}$	$1.20\ 10^{-2}$	$5.26\ 10^{-3}$	$1.75\ 10^{-2}$	$1.77\ 10^{-2}$
E_{cooler}	$(-GJ/t_{CO2})$	1.51	1.12	0.92	0.94	0.87	0.96	0.76	1.19	0.86	0.95
$E_{cooling\ ICA}$	$(-GJ/t_{CO2})$	-	0.96	0.85	0.77	1.12	0.62	0.82	0.92	0.86	0.78
$E_{condenser}$	$(-GJ/t_{CO2})$	1.94	1.89	0.65	0.63	0.69	0.69	0.62	0.88	0.55	0.51
$E_{LVC/RVC,compressor}$	(GJ/t_{CO2})	-	-	-	-	$8.59\ 10^{-2}$	$52.9\ 10^{-2}$	$38\ 10^{-2}$	$11.1\ 10^{-2}$	$41.5\ 10^{-2}$	$40.5\ 10^{-2}$
E_{regen}	(GJ/t_{CO2})	3.36	2.96	2.89	2.67	2.74	2.50	2.31	2.82	2.26	2.19
W_{equ}	(GJ/t_{CO2})	0.59	0.50	0.64	0.58	0.55	1.22	0.87	0.62	1.16	0.77
$C_{utilities}$	$^*(€/t_{CO2})$	31.54	29.89	29.00	27.38	27.10	25.82	24.59	30.84	24.47	23.81

*Currency conversion in October 2017: 1 US $ is equal to 0.8505 €.

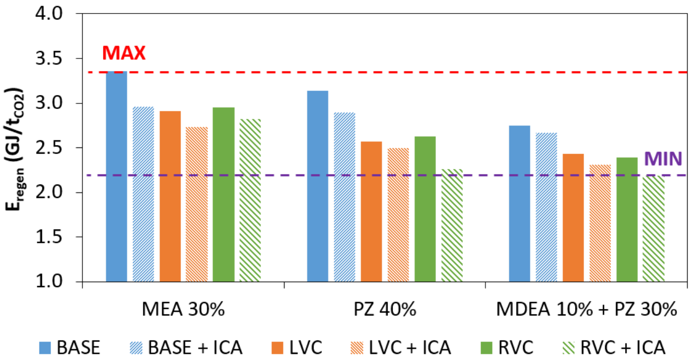

Fig. 2. Optimum value of E_{regen} as a function of the configuration for the three solvents considered

Finally, comparing the regeneration energy values, it is shown that for all the solvents and configurations, intercooling leads to energy savings in comparison with the same configuration without having implemented ICA. Moreover, even with LVC and RVC configurations (leading to significant energy savings even without ICA, see [1] for more details), supplementary E_{regen} savings are observed thanks to ICA. The best result (namely lowest E_{regen} value) was obtained with MDEA 10 wt.% + PZ 30 wt.% with RVC+ICA configuration, E_{regen} being reduced to 2.19 GJ/t_{CO2} which corresponds to 35% energy savings in comparison with MEA 30 wt.% used in the conventional process configuration. RVC + ICA configuration for PZ 40 wt.% (E_{regen} = 2.26 GJ/t_{CO2}) and LVC + ICA configuration for MDEA 10 wt.% + PZ 30 wt.% (E_{regen} = 2.31 GJ/t_{CO2}) gave also very interesting results. In terms of specific savings linked to the implementation of ICA, the highest effect was shown for RVC configuration with PZ 40 wt.% as solvent (almost 14% energy savings linked to ICA implementation).

3. Conclusions and perspectives

As direct continuation of [1], the purpose of the present study was to quantify the interest of implementing ICA for different configurations and solvents thanks to Aspen Hysys^{TM} simulations. The simulation models were also improved by the addition of water-wash sections in the absorber and stripper which allows to reduce the residual amine(s) emissions to the atmosphere. It could be highlighted that implementing ICA leads to supplementary energy savings in comparison with the alternative configurations (LVC or RVC) alone. The MDEA+PZ blend with RVC+ICA configuration leads to E_{regen} of 2.19 GJ/t_{CO2}, meaning 35% energy savings in comparison with MEA 30% conventional configuration. The low E_{regen} values obtained in the present work (including MEA 30 wt.% ones), are partially linked to the fact that the flue gas considered (coming from a cement plant) contains more CO_2 (y_{CO2} equal to 20 vol.%) than for a power plant (y_{CO2} from 5 vol.% to 15 vol.%) considered in most of other studies.

As perspectives, the promising DEA + PZ blend will be investigated with the same approach and configurations (LVC or RVC + ICA) as in the present work. Life Cycle Assessment (LCA) of the different simulated cases will be also envisaged in order to precisely quantify the environmental interest of the technical solutions investigated.

Acknowledgements

The authors would like to acknowledge the European Cement Research Academy (ECRA) and HeidelbergCement Company for their technical and financial support accorded to the ECRA Academic Chair at the University of Mons.

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