The CONTACTOR™

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CO_2 Capture – 90% Recovery, or Higher?

Amine-based technology is still benchmark for post-combustion CO_2 capture (PCCC). A conventional PCCC process operates in an absorption-desorption loop using packed towers. The gas stream enters at the bottom of the absorber while the CO_2-lean solvent enters at the top. The packing provides the necessary contact area for the transfer of CO_2 from the gas to the liquid phase, where it reacts with the amine. The gas, depleted in CO_2, leaves the top of the absorber and is water washed before the gas is emitted to the atmosphere. The washing recovers volatile amine, controlling the emissions, and condenses part of the water enabling the plant's water balanced to be more easily closed. The CO_2-rich solvent leaves the bottom of the absorber and is sent to the top of the solvent regeneration column after first passing through a cross exchanger to heat recovery. In the stripper, the solvent is thermally regenerated with the CO_2 being produced from the top of the stripper with composition higher than 99.9% (dry basis). Before the regenerated lean solvent returns to the top of the absorber, it passes through a cooler to adjust the temperature to the desired inlet conditions. The clean gas leaves at the top of the absorber and is water washed to recover most of the volatilized solvent.

This process is often designed to remove just 90% of the inlet CO_2 as is the case for two large-scale operating PCCC plants in North America: Boundary Dam (SaskPower, Estevan, Saskatchewan, Canada) and Petra Nova (NRG Energy, Thompsons, Texas, USA). This recovery level is easily achieved with minimal reboiler energy consumption, this being the main energy consumer in PCCC. However, higher capture rates can be achieved with greater energy consumption using essentially the same size equipment. With many countries committed to the Paris agreement targets, especially net zero targets, CO_2 emissions should not only be reduced, but completely avoided. If a process is unable to remove all the CO_2, it will be required to compensate using more costly negative emission technologies such as direct air capture (DAC). Therefore, capture rates higher than the default design value of 90% can represent major savings for more complete decarbonization of industrial processes.

Case Study

To illustrate the effect of higher capture rates on energy requirements, a process to capture CO_2 from a flue gas from a hypothetical waste-to-energy plant is studied. The solvent used in the simulations is 30 wt% monoethanolamine (MEA). The gas enters the absorber at 1.04 bara and 40˚C. It contains 10.8%vol. CO_2 with a flow rate of 140 kNm^3/h, and it is water saturated. Figure 1 shows a highly simplified process flow diagram. For ease of understanding, the water wash section was not simulated; instead, a Control Block is used to enforce both water and amine component balances.

The study uses the OGT | ProTreat® simulator to evaluate the thermal requirements for capturing CO_2 at three capture levels: 90%, 95% and 98%. The premise of the study is that the CO_2 capture plant already exists and was designed originally for 90% capture. With the same equipment sizes (diameter and packing heights of the columns, heat exchanger areas, etc.), 95% and 98% capture are achieved by varying the solvent flowrate and the reboiler duty. Because CAPEX for an already-built unit is fixed, the evaluation focuses on the OPEX variations. For PCCC, the main OPEX item is the steam demand for solvent regeneration. Thus, we focus on evaluating the reboiler duty for different capture rates.

For the simulations, the outlet temperatures of the stripper condenser and the lean cooler were set to

40˚C. The molar boil-up ratio was then varied and the solvent flow was automatically adjusted by a Solver Block to meet the specified capture target.

Figure 2 shows the results of simulations as represented by the specific reboiler duty (SRD) (left axis, solid lines) and the absolute reboiler duty (right axis, dashed lines). The SRD is calculated by dividing the absolute reboiler duty by the flow of CO_2 captured.

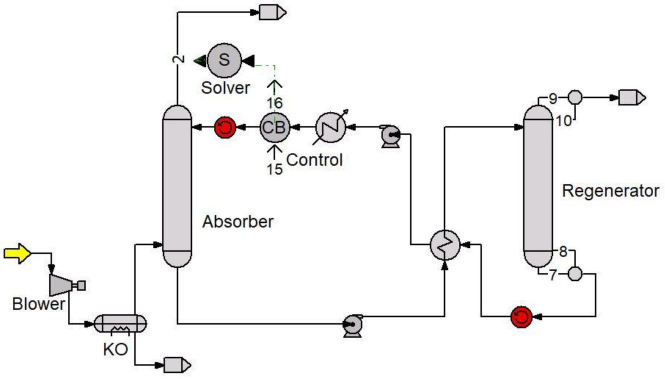

Figure 1: CO_2 capture process flow diagram

The reboiler duty required for CO_2 capture is the sum of three main contributions: the heat required to reverse the reaction of CO_2 with the amine (Q_1, absorption heat); the heat required to heat the solvent entering the stripper (Q_2, sensible heat); and the heat required to vaporize the solvent (Q_3, latent heat).

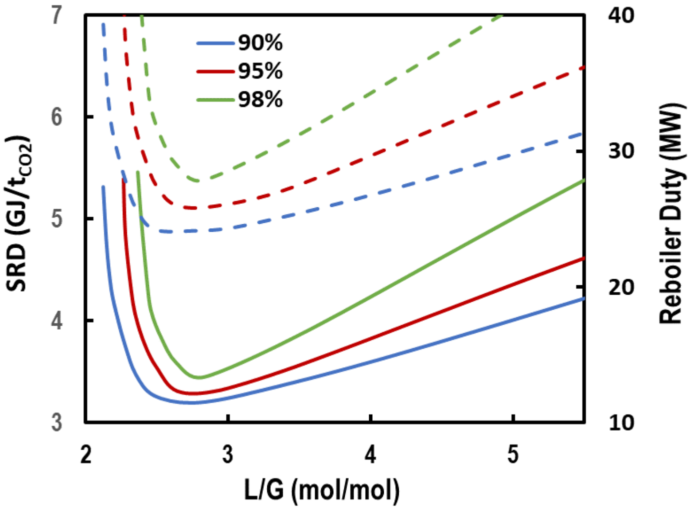

Figure 2: Heat duty variation with liquid flow for 90, 95 and 98% capture. Solid lines represent the SRD, dashed lines are absolute reboiler duty.

The changes in these 3 terms define the shape of the curves in Figure 2. Q_1 is fairly constant for a fixed capture rate, but as the liquid flow rate increases, Q_2 increases while Q_3 decreases. The trade-off between these effects leads to the U-shaped curves. At low liquid flowrates, the solvent needs to be much leaner to achieve the target capture rate, and this requires higher energy consumption. Conversely, at higher liquid flows, sensible heating of the solvent (Q_2) dominates, consuming a larger fraction of the reboiler duty.

Such opposing trends of Q_2 and Q_3 with the variation of the liquid flowrate lead one to expect a maximum or minimum in such a plot (in this case a minimum) superimposed on the constant contribution of Q_1. Thus, a minimum in both the specific and absolute reboiler duties results, as seen in Figure 2.

As expected, the absolute reboiler duty increases with an increase in the fraction captured. For this case, the minimum reboiler duty is 24.2, 26.0 and 27.9 MW for capture rates of 90, 95 and 98%, respectively. When analyzing the SRD, the minimum energy requirement for a 95% capture rate increases by only 0.06 GJ/t_{CO2} compared to the 90% case while 98% capture increased the specific reboiler duty by 0.20 GJ/t_{CO2}.

This indicates that for the same plant (same CAPEX) it is possible to operate at up to 98% capture rate, greatly reducing the requirements for CO_2 emissions compensation. Currently, there are not many options available for emissions compensation. In the future, when DAC technologies are implemented, the optimal capture rate could be calculated from an economic perspective, taking the emissions off-setting costs into account.

OGT | ProTreat® with its rigorous rate-based models can accurately represent the PCCC process to identify optimal designs and operating conditions for a cost-efficient process.

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