The CONTACTOR™

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Lean-, Rich-, and Bulge-Pinches in Carbon Capture

In previous issues of The Contactor™ we discussed operational instabilities and unexpected forms of performance behavior resulting from the very fast CO_2 kinetics of MDEA blends with piperazine, paying particular attention to operational cliffs. In this issue, we look at the effect of the MEA solvent rate on performance of a carbon capture (CC) plant. The interest stems from the facts that in conventional gas treating, fairly high solvent rates are used, whereas; in CC the solvent rate is minimized consistent with absorbing enough CO_2 to achieve only 85–90% removal. In the region between these extremes, some curious behavior can be found.

Figure 1 shows the processing scheme for this case study. The plan was to remove 90% of the CO_2 from the entering flue gas and the engineers were interested in exploring the extent to which reboiler duty (regeneration energy) depends on solvent circulation rate. The absorber contained 10 m of structured packing with specific surface area roughly 250 m^2/m^3. The cross exchanger was to operate with a 10°F temperature approach. When a series of simulations was run over the solvent flow range from 1,800 to 6,000 USgpm and the reboiler duty was adjusted on each one to achieve 90% removal, the rather unusual looking curve shown in Figure 2 was obtained. There are two minima, a maximum, and two asymptotes at the far left- and right-hand sides. The engineers conducting the study initially believed that the ProTreat® simulator predictions were in gross error. They expected to see a single minimum in the reboiler duty followed by a steady increase in required energy input based upon results from an equilibrium stage, efficiency-based simulator.

The reason for this seemingly strange behavior is that the absorber moves from a rich-end pinch condition at the far left of Figure 2, which is the desired mode of operation for carbon capture,

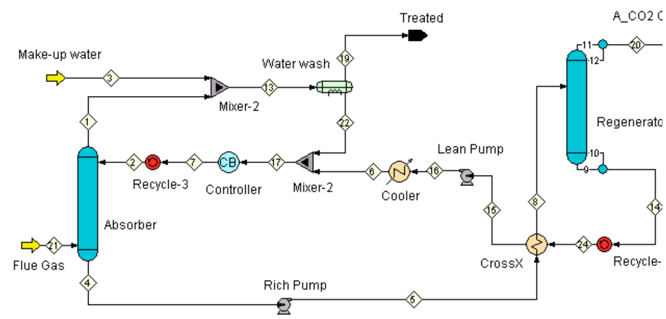


Figure 1 PFD of Carbon Capture Plant

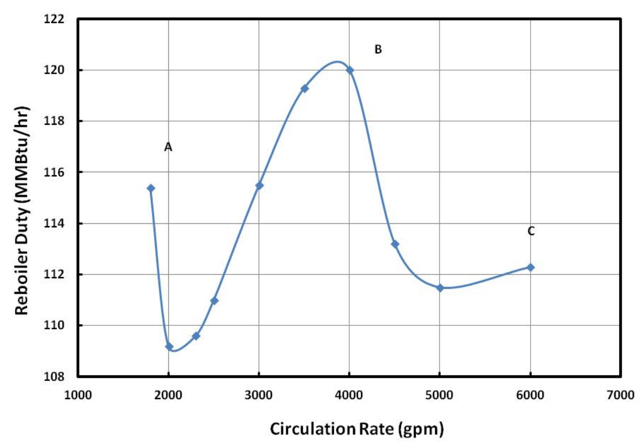
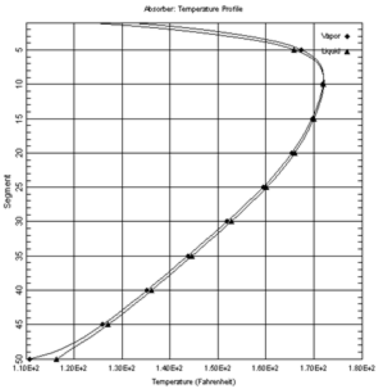


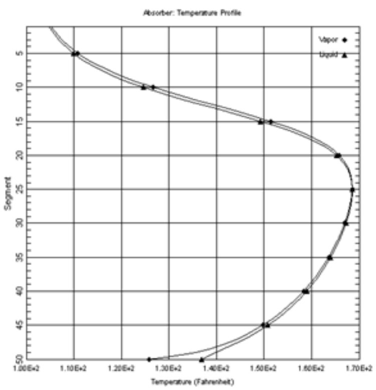
Figure 2 How Reboiler Duty and Solvent Flow Rate Interact to Achieve 90% CO_2 Removal in Carbon-Capture Unit

to a lean end pinch at the right. At the right hand side, far too much solvent is being used for only 90% CO_2 removal: this is more typical of a conventional MEA column used to treat to low CO_2 levels, except that here the reboiler duty is much reduced so that the equilibrium partial pressure of CO_2 over the lean solvent is close to what is needed to remove only 90% of the CO_2.

The regions marked A, B, and C in the figure signify areas where it might be worthwhile to look at temperature profiles for clues[1]. Figure 3 shows profiles corresponding to these regions.



(a) Rich Pinch



(b) Bulge Pinch

(c) Lean Pinch

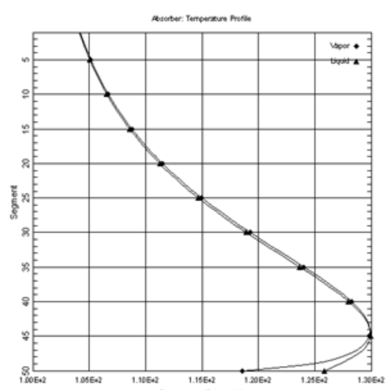


Figure 3 Absorber with (a) Rich, (b) Bulge, and (c) Lean-end Pinch Conditions

That the combination of low reboiler duty and low solvent rate is an efficient way to remove 90% of the CO_2 is no surprise—the rich end pinch produced by low solvent flow is used to limit and control CO_2 absorption. However, why does a higher solvent flow eventually require *more* reboiler energy to be expended? The answer is, that as solvent flow increases, the temperature bulge spreads to much of the interior of the column making the center region so hot it can do less absorbing. This leaves more CO_2 in the gas, unless, that is, the solvent gets stripped cleaner by more reboiler steam. At point B, the bulge temperature is nearly 170°F (approaching stripping temperatures), and only the ends of the column are effective in removing CO_2. As the solvent rate goes beyond the peak at 4,000 USgpm, the bulge continues to move down the column and treating becomes more lean-end pinched. Under lean-end pinch conditions, solvent lean loading controls the outlet CO_2 concentration, and higher and higher lean loadings are adequate for treating to 90% CO_2 removal. Despite the fact that the solvent flow is higher and more reboiler energy goes into heating the rich feed to its bubble point on the feed tray, less stripping still requires less energy and the curve falls through another minimum. To the left of the first minimum, a further decrease in solvent rate will require a substantial decrease in lean loading, hence higher reboiler duty, and to the right of the second minimum a higher solvent flow will require a gradually increasing reboiler duty to heat the solvent to the feed tray temperature (the solvent lean loading is fairly constant beyond 6,000 USgpm).

Maxima and minima are always caused by opposing factors. The factors here are (1) lean-end versus rich-end pinch, and (2) solvent net loading capacity versus the solvent flow rate—two pairs of factors! The complexity has been alleviated by considering CC (left-hand side) and high-purity treating (right-hand side) separately.

The performance curve is for 30% MEA, a fairly reactive solvent. The two regions of lowest energy treating are caused by lean-end versus rich-end pinching in the absorber. To appreciate this, one must be able to look not just at the absorber, but at the *whole* treating plant, and to look closely at how temperature profiles respond to changing solvent rates and reboiler duties. Understanding pinch conditions is critical.

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[1] It's amazing just how much information can be gleaned from a seemingly simple temperature profile. Accurate temperature (and composition) profiles are the purview solely of a genuine mass transfer rate model, and they indicate quite accurately just how a give column is operating and where improvements, including other treating strategies such as solvent additives, might be worthwhile.