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Making Sense of Absorber Temperature Profiles

Conventional wisdom seems to be that in amine absorbers the temperature bulge should always be near the bottom of the column—if it's not, something is wrong and the design may not a good one. In this issue of The Contactor we point out that such a blanket statement is quite misleading. The temperature bulge may be unavoidably at the bottom, the top, or the middle of the column even in an excellent design. Where it ends up is driven by treating objectives and depends on the physical properties, the relative gas and liquid rates, the acid gas concentrations in the feed gas, and the reactivity of the amine with CO_2.

The impetus for this study is a question that arose during the design of an absorber to remove low concentrations of acid gas using diglycol amine (DGA®). The design was for treating just over 60 MMscfd of gas at 700 psig containing 0.9 mol% CO_2 and about 20 ppmv H_2S. Carbon dioxide is so aggressively absorbed by DGA that the rich solvent CO_2 loading could be kept below its recommended maximum only by using a lot more solvent than strictly needed for CO_2 absorption. Figure 1 shows how the solvent temperature is simulated to change across the absorber using the ProTreat® simulator. Figure 2 shows the CO_2 loading profile.

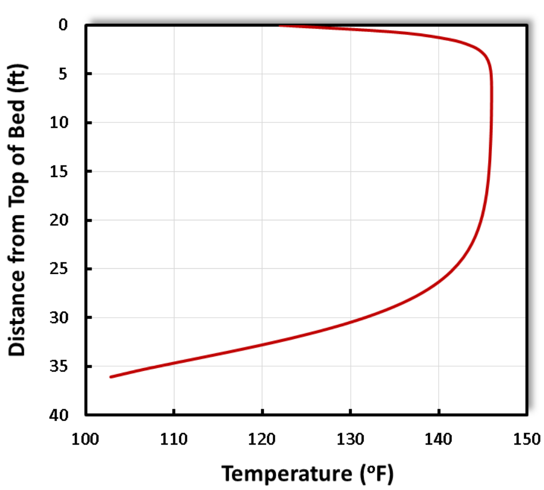

Figure 1 Absorber Solvent Temperature

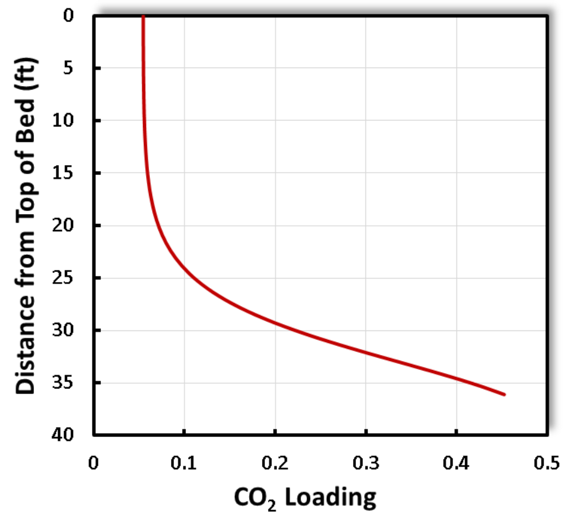

Figure 2 CO_2 Loading Profile across Absorber

Clearly, most of the CO_2 is absorbed in the bottom half of the contactor, implying most of the heat is generated there, too. So why isn't the lower half hot and the top half cold? To answer this, we need to look at the mass flow rates of the gas and liquid, and their heat capacities. In this particular case, the liquid and gas heat capacities differ by only 30–40%. But the gas to liquid mass flow ratio is nearly four to one. This means that for a given temperature change, the gas can carry four times as much heat upward as the liquid carries downward. Thus, most of the heat of absorption is carried up the column, making temperatures quite high beyond the location where most of the absorption and heat release take place.

The location of a temperature bulge and the shape of temperature profiles is an interesting function of the L/G ratio in the absorber. To examine this further, we will use the nonproprietary solvent MEA at 30 wt% as the simulation basis. As before, the absorber is packed with #1.5 Nutter Rings. The CO_2 concentration was varied but the total molar flow rate of CO_2 (heat released) was kept constant by adjusting the total gas flow rate. In all cases, the absorber was simulated at 70% flood.

Figure 3 shows how the solvent temperature profile changes with the Heat Transport Capacity Ratio, $HTCR = c_p^{(L)} L / c_p^{(V)} V$, of the two phases' ability to transport heat through the column. Here c_p is heat capacity and L and V are mass flow rates of the liquid and vapor phases, respectively.

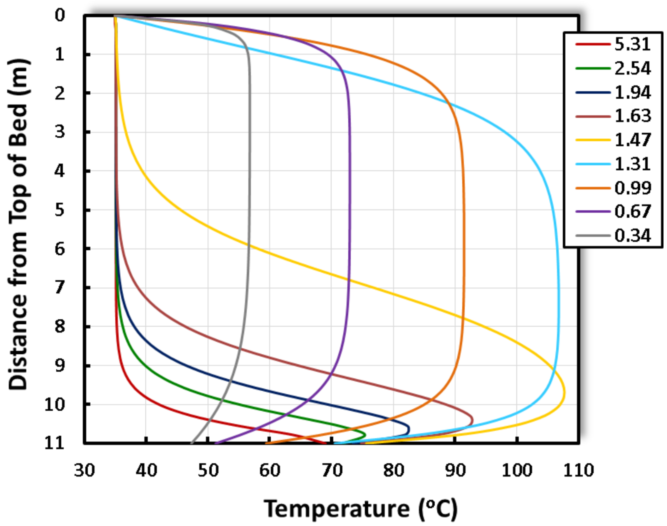

Figure 3 How Absorber Temperature Profiles Change with Ratio of Liquid-to-Vapor Heat Transport Capacity

When the HTCR is much above unity, the operation can be considered a high liquid rate one, in which case liquid flow rate dominates and the bulk of the heat of absorption is carried quite quickly out the bottom of the column. For example, at a value of 5.31 the temperature bulge is sharp, steep, and pushed right against the tower bottom. The temperature rise is also limited to about 67°C. As the vapor rate is increased, the temperature bulge climbs in both position and magnitude. It also broadens. Although the liquid is still carrying all the heat out the tower bottom, the heat flow is being countered by the vapor carrying heat upwards. Heat carried by the vapor gets released back into the liquid before being carried out the bottom.

Further increases in vapor rate result in still higher temperatures covering more and more of the lower part of the tower. At a value of 1.31 the bulge is very hot indeed, and it's occupying the lower 2/3rds of the packed bed. When the ratio reaches a value of roughly **unity**, the profile is fairly symmetrical about the mid-level of the column. Here the vapor and liquid remove a roughly equal portion of the heat of reaction from the column.

Regardless of the value of the HTCR, all the absorption occurs in the lower half of the packed bed. However, as gas rate increases the temperatures first become very hot because the rising vapor in the top of the column transfers a lot of its heat to the cool descending liquid. At the same time, the hot falling liquid gives up a lot of its heat to the cold rising vapor in the bottom. Each phase carries roughly an equal amount of heat back and forth, up and down the column. The heat of absorption gets trapped in the central region; hence, temperatures there can become extremely high.

As gas rate continues into the region where HTCR < 1 the temperature profile starts to cool significantly because the vapor is now carrying more and more heat out the top of the column. With its high flow rate, the gas doesn't have to become nearly as hot to remove generated heat.

At high vapor rates, the sharply bulged temperatures characteristic of high liquid rate operation do not appear here at the top of the column. Instead, temperatures plunge dramatically at the top and rise more gently at the bottom. All the heat is still generated in the lower part of the bed, but the absorption zone is more spread out, and it now covers the whole bottom half.

At high vapor rates, the temperature profiles become less symmetric about the mid-height level. Although the bulges are not as dramatic here as they are at high liquid rates, we can still identify a top-end temperature bulge. The transition from bottom to top bulges occurs at the point of symmetry, i.e., when the HTCR is about unity.

The exact shape of the temperature profile, as well as the bulge position and its value depend on the chemical system and the operating conditions of the absorber. Sometimes even a rather sharp upper-end bulge is evident. The purpose of this writing is to point out that seeing "unusual" temperature profiles is quite normal during simulation, and they all have rational explanations. There are also ways to move temperature profiles and bulges around by judiciously selecting the right operating conditions (and as will be shown in an upcoming issue, by properly selecting the tower internals). But correctly handling such issues requires the full mass transfer rate basis of ProTreat®.

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