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Effect of a Tower Swage on Packing Performance

Estimating the transfer unit height (HTU) or the height equivalent of a theoretical plate (HETP) can be exceedingly difficult in many applications, but none more so than in gas treating with amines. Values for HTUs and HETPs in gas treating have complex dependency not just on hydraulic conditions and the specifics of the packing itself, but also on local temperatures and compositions which vary quite widely within the packed bed.

When a tower has a mid-column feed or draw, it is sometimes economically attractive to swage the tower diameter around the mid-tower feed point. Technically, this change in column diameter is suggested entirely by hydraulic considerations, and economically by the lowered cost of a high pressure tower shell and the reduced volume of packing required. However, such a swage of diameter can result in radically different mass transfer behaviour on opposite sides of the swage.

Case Study: Swaged Absorber Section

This case arose out of a design study for a new LNG plant by a major engineering firm. The gas was 17.5% CO_2, 80% methane, and 2.5% ethane flowing at about 28000 Nm^3/h. The gas temperature and pressure were 70°C and 31 barg, respectively. The solvent contained 45 wt% of an MDEA-based amine especially formulated for deep CO_2 removal in LNG applications. The absorber had two 9.1-m deep beds of No. 2 Raschig Super-Rings® with solvent feed nozzles at the top of the upper and lower beds. Fully lean solvent having 0.005 mol/mol CO_2 loading entered the top of the upper bed at 450 m^3/h. Semi-lean solvent with 0.38 mol loading flowed at 2725 m^3/h.

Simulations were done using the ProTreat® simulator, and the first case was with the absorber of a uniform diameter calculated to achieve 80% of flood at the most flood-prone point in the tower. The simulator predicted that 26 ppmv CO_2 would be achieved in the treated gas and that the upper half of the column would be nearly lean-end pinched. In other words, the treating level would closely correlate with the loading in the fully-lean solvent. The tower diameter was calculated to be slightly less than 4.5 m; this diameter was set by the much larger total solvent flow through the lower packed bed (3175 m^3/h vs. 450 m^3/h). At 4.5-m diameter, the upper half of the tower was obviously grossly oversized for its 450 m^3/h solvent flow. This was an opportunity to save possibly considerably on shell cost and total required packing volume by swaging down the column diameter between the two packed beds. The absorber was re-simulated, this time for 80% flood in *each* of the two beds with a diameter change between them. The tower diameter needed for the upper one-half of the column was reduced to only 2.6 metres, translating into a potential 67% savings in packing volume (from 145 m^3 to only 48 m^3) for the upper bed (the lower bed remains unchanged). However, simulation of the swaged absorber also saw the predicted treating level go from 26 to nearly 200 ppmv CO_2, away off specification!

The blue and red curves in Figure 1 show the carbon dioxide profiles in the two 9.1-m deep beds of the absorber for the cases of uniform and swaged diameter, respectively. Apparently a deeper packed bed will be needed in the upper section for the swaged tower to reach the same 26 ppmv CO_2 level achieved by the uniformly-sized column; however, the reason for the perhaps surprising disparity remains to be explained. In terms of ideal stages, the HETP or HTU in the upper bed has nearly doubled despite the better coverage of packing with liquid at the higher liquid loading. Practitioners accustomed to dealing with ideal stages and HETPs or HTUs may well be astounded that such a simple reduction in column diameter could require a much deeper bed of packing. The reason lies in the dry packing surface area in the swaged upper bed. It has only 1/3rd of the area as the large-diameter bed. Table 1 shows the packing wetted area per unit volume of packing and the liquid-side mass transfer coefficient for the uniform diameter and swaged diameter cases.

Table 1 Parameters for Mass Transfer

	Single Diameter	Swaged Sections
Wetted Area, a (m^2/m^3)	83	92
Total Area in Section (m^2)	12000	4400
Liquid Film Coefficient, k_L m/s)	0.001	0.002
k_LA (m^3/s), refers to Entire Tower Section	12.0	8.8

Carbon dioxide absorption rates are directly proportional to the total wetted area of the packing. Although with uniform diameter the wetted area *per unit of packed volume* is lower in the large diameter upper bed (implying the absorption rate should be lower and treating worse) there is also three times the packed volume there; hence, the total wetted area is about 12000 m^2 in the full diameter section vs. only 4400 m^2 in the swaged down section. The liquid-film coefficient also plays a role, giving less than direct proportionality and preventing wetted area from being used as a simple scaling factor.

It is unlikely that a design based on an ideal stage simulation and estimated HETP values would have succeeded at all had the upper packed bed been in a swaged down shell. Of course, one would inevitably apply safety factors but the question remains as to whether the safety factors would be generous enough to salvage the design.

The savings in packing volume and the cost of the tower shell have come with a price of their own. Further simulation showed that to reach the same 26 ppmv CO_2 as achieved without swaging, an additional 6.1 metres of packing would be required in the same 2.6-m diameter shell. The required packing volume needed to achieve the same treating as the uniformly sized shell is about 80 m^3—still less than in the original uniformly sized shell, but not as great a savings as anticipated. The dashed line in Figure 2 shows that the corresponding composition profile for the now 15.2-m deep upper bed also tapers off to a value of about 25 ppmv, determined primarily by solvent lean loading. In operation, the 15.2-m deep upper bed would be lean end pinched.

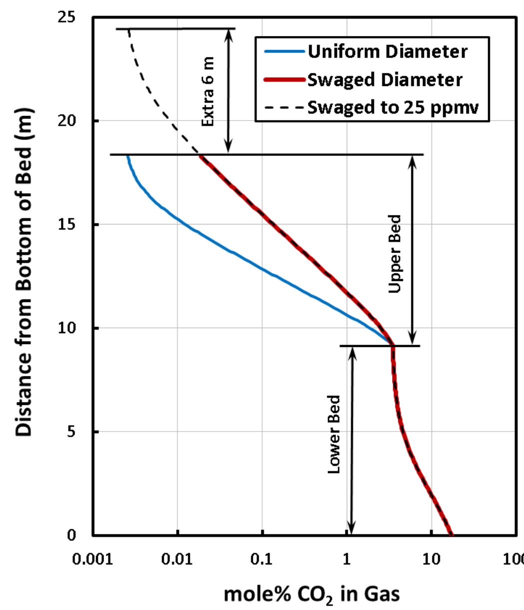

Figure 1 Concentration Profiles when Absorber is of Uniform Diameter (Blue), Swaged Diameter with 9.1-m Upper Bed (Red), and Swage with 15.2-m Upper Bed (--- Black)

The first lesson worth remembering is that regardless of the potential capital cost savings that might result from swaging tower diameters, there may be a column height penalty that, if not recognised, could result in a completely failed design. In fact, swaging the tower shell can spell disaster if one is unaware (as most are) of the effect on mass transfer performance that results. Another is the great difficulty in avoiding this situation when using ideal stages and HETPs—there are simply not enough data, and what little data there are lack sensitivity to operating parameters in amine systems where chemical reactions play such an important role.

In these kinds of situations (and probably in all situations involving packing in amine treating) the only rational, safe, and reliable way forward is simulation that makes exclusive use of a true mass transfer rate-based approach. Anything less introduces needless uncertainty and results in expensive overdesign.

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