THE GEOMETRY OF PACKING

Ralph Weiland, Nathan Hatcher and G. Simon Weiland, Optimized Gas Treating Inc., detail the effects of packing characteristics on gas treating absorber performance.

In recent years in the gas treating world, much attention has been given to two application areas: deep carbon dioxide (CO_2) removal in LNG production, and selective hydrogen sulfide (H_2S) removal. Columns containing trays or packing have radically different mass transfer characteristics, and both are widely used. Reliably designing an acid gas removal column containing trays appears somewhat more straightforward than with packing, and the effect of parameters such as weir height, numbers of passes, etc. are fairly well documented.

In a packed tower, however, a discontinuous film flows over solid surfaces through a continuous gas, and mass transfer rates can be affected by packing size, packing geometry, and brand. With structured packing, even the surface treatment of the (usually) sheet metal used in fabrication can impact the column performance. The effects of liquid and vapour volume loading are not discussed in this article, as the focus is entirely on the powerful influence of packing geometry. Packing size almost directly correlates with the effective interfacial area.

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Packing geometry is unique to each packing brand of a given nominal size, although the dry surface area is still the primary controlling factor. Lowered confidence when designing for packing may in part be a consequence of such a plethora of sizes, shapes and physical structures that it can be difficult to assign even a meaningful size to a given packing, let alone quantify its mass transfer performance.

This article takes a close look at the performance differences between two structured packings supplied by different manufacturers as a function of crimp size, as well as between five different random packings, selected on the basis that each has a wide range of available sizes for comparison. Candidates that are representative of first, second, third and fourth generation metal random packings were selected for study. To avoid the implications of bias, none of the packings used are identified by brand or supplier. However, Generation 1 packings are typified by the classic Raschig Ring and most forms of saddles; Generation 2 by Pall Rings under various names; Generation 3 by what might be described as shortened Pall Rings; and Generation 4 by stamped and bent web-like packings. The hydraulic and mass transfer characteristics of each packing used are as specified by the manufacturer. Each succeeding generation is an improvement on the previous one, and each is intended to utilise the interior volume of the packing pieces more effectively; retain more uniform, stable, liquid distribution;

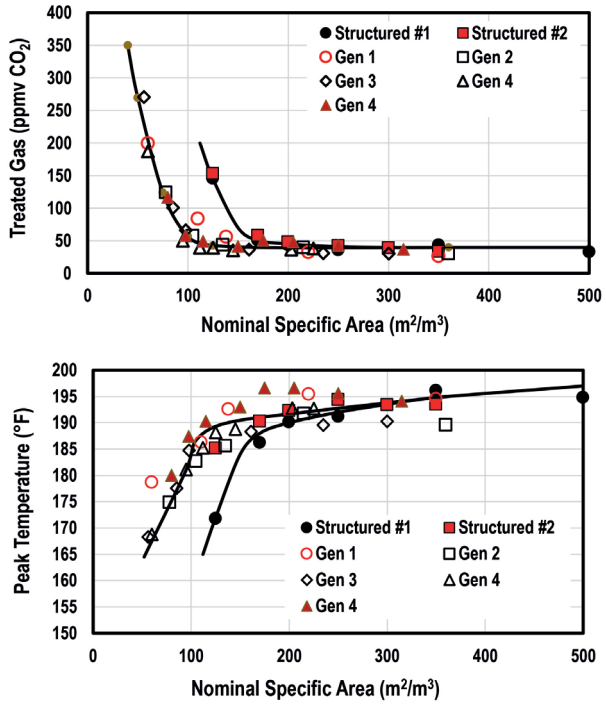

Figure 1. How packing type, style and size affect absorber performance in an LNG unit. Structured #1 and Structured #2 designate two different 45° crimp angle packings. Top: effect of specific area on CO_2 in treated gas. Bottom: effect of specific area on peak temperature.

and produce lower pressure drop or higher capacity. First-generation packings replaced the broken glass, glass spheres, and pieces of stone or coke used in the mid-to-late 19th Century, and which had unpredictable efficiency and hydraulic behaviour. The authors are aware of an absorber packed with broken beer bottles in natural gas service in New South Wales, Australia, in the 1980s – this packing was certainly inexpensive and readily available, albeit perhaps not of the highest engineering standards.

The first case study relating to the performance of a CO_2 removal unit in LNG production was carried out using a water-saturated feed gas containing 2% CO_2 balance methane, at 100°F, and treated with a solvent containing 7 wt% piperazine in 38 wt% MDEA at 120°F. Gas and solvent rates, tower diameter (48 in.), and packed depth (30 ft) were kept constant throughout. In the second selective removal study, the raw gas was water-saturated methane with 10% CO_2 and 2% H_2S at 100°F, treated using 50 wt% MDEA at 120°F. Again, gas and solvent rates were kept constant between cases, with a 48 in. tower diameter and 20 ft of packing in each case. A system or foam factor was not applied to any calculation.

Deep CO_2 removal: LNG production

The range of packings used commercially for CO_2 removal in LNG production encompasses the whole spectrum of random packings, mostly from Generations 3 and 4, as well as structured packings of modest crimp size. The absorber performance of four random packings and two structured packings were compared in terms of (a) the CO_2 level achieved in the treated gas, and (b) the magnitude of the temperature bulge within the columns.

The desired CO_2 level in the gas resulting from CO_2 removal absorbers is usually < 50 ppmv. To ensure that they can meet the treated gas specification, absorbers in this service almost invariably contain a greater depth of packing than necessary, so they tend to be lean-end pinched. This means that the treated gas CO_2 content is controlled by the lean solvent loading (moles of acid gas per mole of total amine). In recognition of this fact, the various cases were all run with the lean solvent CO_2 loading set to a value that would comfortably produce gas with less than 50 ppmv CO_2.

Acid gas removal using amines is quite exothermic, and usually generates high temperatures in the absorber. A rather large temperature bulge often forms. Its size and location are determined by the relative gas and liquid traffic in the column and, of course, by the exothermicity and rate of the chemical reaction between the acid gas and the amine(s). The magnitude of the bulge is an important parameter that must be controlled, because excessively high temperatures cause amine degradation, as well as corrosion of the tower shell and internals. The maximum recommended bulge temperature is usually approximately 185°F (85°C). Unfortunately, absorbers are rarely built with any provision for measuring temperatures anywhere inside the equipment, so often the best that can be done is to infer internal temperatures from simulation. A soundly-based simulator such as OGT | ProTreat® provides a highly-accurate assessment of

every detail of what is actually happening within the tower. This includes very accurate temperature profiles that can be used to ensure that solvent degradation and corrosion rates are known, and therefore kept within limits. The whole assessment can be fully automated when the simulator is connected to OGT | ProBot™.

Because packing shapes and structures vary so widely, packing size itself is such a nebulous, ill-defined quantity that it is unsuited for use as a basis for comparison between packings. What packings present to the gases and liquids flowing through and over them, however, is surface area. This seems like a much more promising parameter to use when making comparisons. Figure 1 compares packings on the basis of what is termed their specific area, which is the area of the dry packing per unit of packed volume. Specifically, Figure 1 (top) shows that, in terms of actual treating, the four generations of random packing all have much the same performance, even when the column is not pinched, i.e. when performance is mass transfer rate-controlled. Equivalent mass transfer performance is probably a result of these generations of packing all granting pretty much full gas-liquid access to the interior of the packing pieces, and not just their outer shell – as would be the case with Raschig Rings (first generation).

The better performance of some packings over others is mostly the result of greater surface area. When mass transfer is rate limiting (not equilibrium pinched), these results suggest that random packings are somewhat better performers than structured packing, possibly because of lower back mixing. As Figure 1 (bottom) shows, however, random and structured packings appear to display equivalent peak temperatures when the < 50 ppmv CO_2 treating goal is met.

What is potentially interesting is that the greater the specific area (faster absorption rates or more efficient packing), the hotter the temperature bulge. This is because small packings show lower axial dispersion (mixing) than large packings do. Practically, then, there is a lower limit to packing size just from a mass transfer performance point of view. Smaller, more efficient packings are likely to have higher temperature maxima, and solvent degradation and corrosion rates therefore tend to be more severe. Thus, when selecting packing, it might be better to do so on the basis of cost per unit of specific area, with enough area to achieve the treating goal but not so much as to cause excessive temperatures from the heat of absorption. Of course, this is predicated on achieving satisfactory hydraulic (flood and pressure drop) performance.

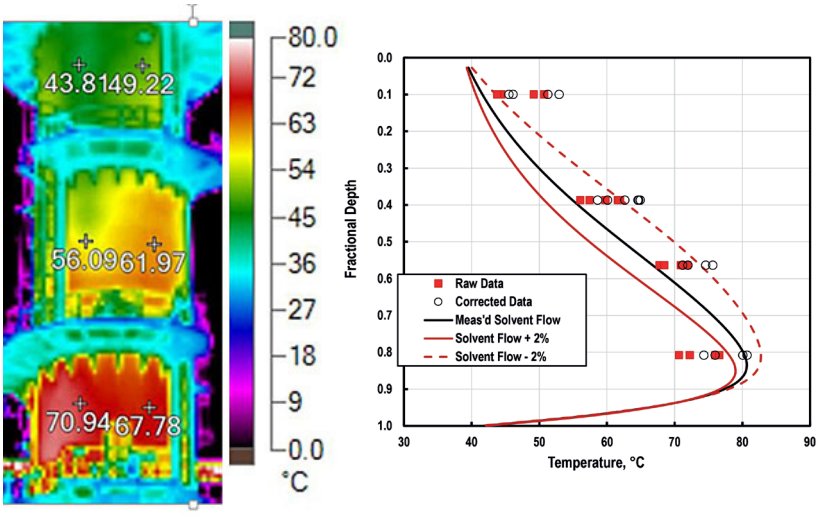

Figure 2. Thermal image and digitised data measured at various positions across the column diameter. Data is measured skin temperatures, and was corrected for radiative, conductive and convective heat loss. Simulations were also run at solvent flows 2% higher and lower than measured, showing sensitivity to solvent rate.

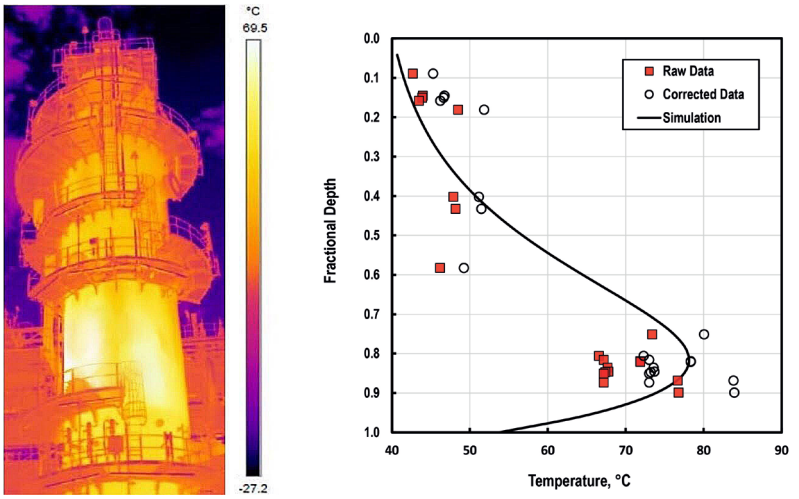

Figure 3. Thermal image and digitised data measured at various positions in the image. See Figure 2 for further detail.

Example

Figures 2 and 3 are temperature profiles measured in the CO_2 absorbers of two LNG trains. The absorber corresponding to Figure 2 contained 250-size structured packing, while Figure 3 refers to a nominally 2 in. random packing. The temperature profiles are as measured via thermal imaging. These results show a positive agreement between simulation and measured data. The figures indicate the extent to which the external skin temperature (measured by thermal imaging) needs to be adjusted to account for conductive, convective and radiative heat losses; and that

temperature profiles can be fairly sensitive to errors in measuring such parameters as solvent flow rates. All simulations were run using OGT | ProTreat.

Selective H_2S removal: natural and refinery gas

Selective treating presents a whole other set of circumstances. Unlike the deep CO_2 removal of LNG production, the objective here is to remove H_2S to (usually) < 4 ppmv, and to reject as much CO_2 as possible back into the treated gas, i.e. to maximise CO_2 slip. This is done using a solvent that is reactive towards H_2S, but not towards CO_2. Usually, MDEA is the solvent of choice. If one wishes to achieve a specified CO_2 target as well, a more reactive solvent can be mixed with the MDEA to provide a blend with tailored reactivity.

Figure 4 shows how the H_2S content of the treated gas, as well as the peak (bulge) temperature, depend on packing type and size. Figure 4 (top) shows that in terms of actual treating, the three generations of random packing all have much the same performance regardless of whether the column is pinched or not. Just as for CO_2 removal in LNG production, equivalent mass transfer performance is probably a result of these packings all granting pretty much full gas-liquid access to the inside of the packing pieces, and not just their outer shell. However, the better performance of some packings over others is mostly the result of greater surface area.

When the mass transfer itself is limiting (not equilibrium pinched) these results suggest that again random packings are somewhat better performers than their structured brethren. As Figure 4 (top) shows, at least for the conditions of the case study, structured packings with specific areas below about 200 m^2/m^3 start to show unsatisfactory performance (H_2S > 4 ppmv), whereas random packings do not start to show degraded functioning until the specific area falls below approximately 100 m^2/m^3. The difference is probably the result of higher levels of turbulence in the gas and liquid flows in random vs structured packing. However, higher turbulence comes with the price of higher pressure drop (or lower gas and liquid handling capacity).

From the perspective of H_2S removal, random packings show somewhat better performance for the same dry specific area. However, from the viewpoint of the temperature bulge (Figure 4 [bottom]), if a satisfactory H_2S content gas is being produced, the temperature bulge is independent of packing type (structured vs random), and responds mostly to size via axial dispersion and mixing.

Referring to Figure 5 (top), when the specific area of either structured packing is below 200 m^2/m^3, more than 55% of the CO_2 is slipped through the absorber, i.e. is not removed but remains in the treated gas. With a random packing of area < 100 m^2/m^3, more than 65% of the CO_2 remains in the treated gas. However, for the same specific area, structured packing slips more CO_2 than random. Flooding (Figure 5 [bottom]) appears to be a mostly linear function of specific area, although it is interesting to note that the second generation random packing shows reduced tower capacity (earlier approach to flood).

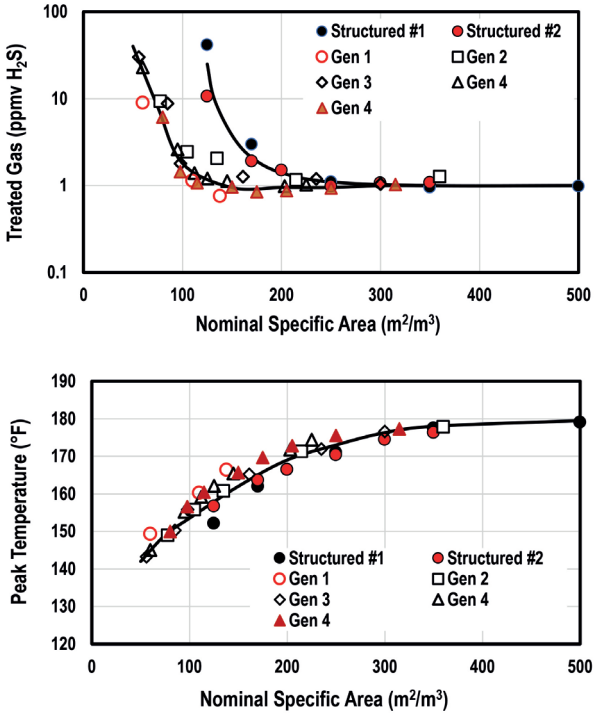

Figure 4. How packing type, style and size affect absorber performance in a selective treating unit. Structured #1 and Structured #2 designate two different 45° crimp packings. Top: effect of specific area on H_2S in treated gas. Bottom: effect of specific area on peak temperature.

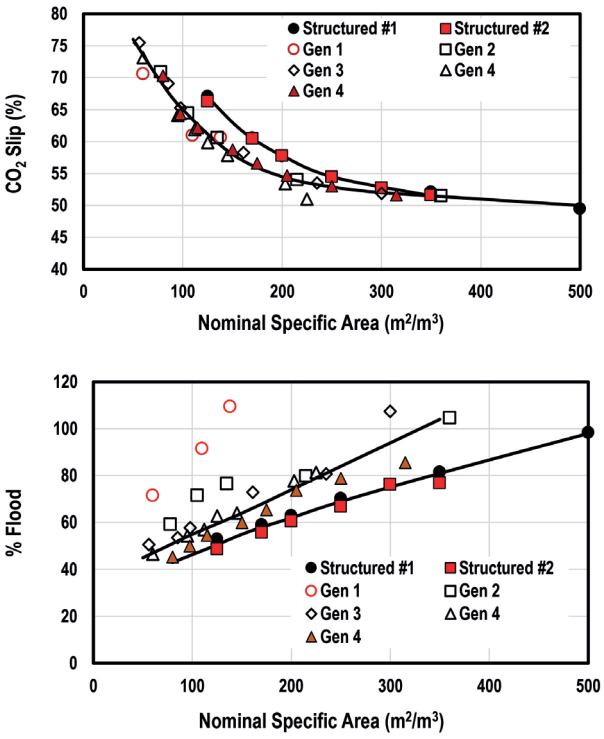

Figure 5. How packing type, style and size affect CO_2 slip and hydraulic performance in a selective treating unit. Structured #1 and Structured #2 denote two different 45° crimp packings. Top: effect of specific area on CO_2 slip. Bottom: effect of specific area on flooding performance.

Conclusion

These comparisons are as unbiased as possible because OGT | ProTreat only uses data that is supplied by the manufacturer of the individual packings. Mass transfer performance in LNG and selective treating applications does not seem to depend strongly on the generation of random packing so long as the outer walls of the packing pieces are sufficiently open for the interior of each piece to be as accessible to the liquid and gas flows as the exterior. In other words, third and fourth generations are roughly equivalent, and even first and second generation packings are not strikingly inferior (except in flood capacity and pressure drop).

The latter statement pertains to mass transfer performance in gas treating. It is predicated on using specific surface area as the comparison basis, because surface area provides a uniquely-quantifiable measure of mass transfer performance, especially in chemically-reactive absorption systems where surface area is the critical, deciding parameter. The theory of chemically-reactive mass transfer suggests that for liquid-phase, diffusion-controlled systems with fast chemical reaction, the absorption rate is a function almost solely of wetted interfacial area. This work bears that out. However, it should be noted that these results may not pertain to distillation or other non-reactive mass transfer separations because then there are no fast reactions, and the importance of interfacial area must be shared with mass transfer resistances in the vapour and liquid phases rather than being a function of interfacial area only.

The size of the temperature bulge in an absorber is an important parameter that must be controlled to ensure acceptably low amine degradation rates, and to ensure that corrosion rates are within reasonable corrosion allowances. The bulge temperature is rarely measured and even its location is hardly ever known. Thermal imaging is a practical way of providing an estimate of this information in the field. However, a high-precision, mass transfer rate-based simulation is an excellent means to expose this critical process data.

Packing performance should be conceptualised and assessed based on the dry specific area and not on packing size – which is an amorphous concept at best. Even packing brand is relatively unimportant to mass transfer, although it is crucially important in pressure drop, hydraulic capacity, and in very low pressure applications such as CO_2 capture or in vacuum service and, of course, it impacts costs. Dry specific area captures the overwhelming majority of the influence of packing parameters on mass transfer performance in most amine-based gas treating applications. For an unbiased and well-balanced decision, the OGT | ProTreat simulator can be used to provide guidance for treating performance predictions as well as the influence of packing type on the bulge temperature predictions for a specific treating service.