



The CONTACTOR™

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Tray and Packing Hydraulics: Things to Know

Generally, most process simulation tools aren't much more than automated heat and material balancers. Unlike the ProTreat® simulator, they have little or no predictive power because for distillation and absorption towers their basis is the ideality of equilibrium stages. Mass transfer rate-based simulation, on the other hand, is rooted in mechanistic models of the processes actually taking place on real tower internals. Provided they make no reference to tray efficiencies whether calculated, estimated, or guesstimated, such models have inherent predictive power. However, unless the user is aware of how tower internals affect mass transfer rates, it's all too easy to apply simulation to completely inappropriate process conditions. Mass transfer rate-based simulation models of towers are concerned with a lot more than tray and packing hydraulics—the effect of hydraulics on mass transfer is even more important.

Trays

At the high traffic end of the spectrum, the hydraulic and mass transfer performance of trays are constrained by entrainment flooding, downcomer backup limitations and downcomer choke flooding. Turn-down is limited by dumping, weeping, possibly spray vs. froth regime operation, and bypassing of gas up downcomers rather than through tray decks. These limits bracket turn-down and turn-up operation. In addition, different types of trays have different operating ranges and limits.

Conventional valve-type crossflow trays are the industry standard and are the benchmark. There is a whole range of more modern so-called high-performance trays, some using special valves to reduce entrainment or to mitigate against fouling, others with special downcomer treatments to allow more of the tower cross-section to be used as active tray area. For example by truncating the downcomer above the tray it feeds, liquid is deposited through perforations directly onto a now larger tray active area. Other types of trays include downcomerless varieties such as disc-and-donut and Dual Flow trays. Trays without downcomers are rarely if ever used in gas treating. At the other end of the spectrum there are ultra-high performance trays that rely on complex (and more costly) constructions to provide centrifugal flow devices within the columns to greatly enhance hydraulic capacity.

It is probably accurate to state that the development of new trays and packings has been driven almost exclusively by the goal of higher hydraulic capacity, i.e., increased throughput,

with little consideration given even to efficiency, let alone improving mass transfer characteristics (beyond increasing the surface area of random packings).

As a strictly mass transfer rate-based simulator, ProTreat® provides accurate correlations for the hydraulics and mass transfer characteristics of conventional bubble cap, sieve, and valve-type crossflow trays in both the spray and froth operating regimes. Hydraulic calculations are based on public domain correlations and on proprietary correlations supplied by certain vendors. Correlations for mass transfer coefficients and gas-liquid areas on operating trays were originally based on open literature data but over the years they have been almost completely supplanted by correlations derived in-house from analyzing a large amount of data collected from operating gas plants around the world. The ProTreat® simulator's tray characterization represents trays as they actually perform in operating columns, from a cartridge tray in a 1-ft diameter column to 6-pass trays in a 12-m diameter absorber and at pressures from atmospheric to over 100 barg.

Hydraulic performance calculations specifically for high capacity trays can be done using software available from the tray vendors. Measured mass transfer performance information based on fundamentals (not just efficiencies in hydrocarbon distillation), however, is another matter altogether and is completely lacking, possibly being unknown even to the suppliers of the internals. But, all is not lost! High capacity valve-type trays certainly outperform conventional valve trays hydraulically by perhaps 10–15%. But in terms of fluid flow, gas enters tangentially into the liquid on a valve tray and once it leaves the escape area under the valve, the gas has no memory of the details of its introduction. In other words, the mass transfer performance is largely independent of valve and downcomer types so ProTreat simulation is just as valid for high capacity trays as for conventional ones. Only the hydraulic capacity is higher.

Downcomer sealing is an important aspect of tray design. The modern approach is to seal downcomers dynamically by restricting the distance between the bottom of the downcomer apron and the tray it feeds (called the downcomer clearance) so the liquid velocity under the downcomer is high enough to prevent gas entry into the downcomer bottom. One of the dangers of using a tray in a high liquid downturn situation is that the downcomer may become subject to unsealing. Once a downcomer is unsealed, vapor bypassing tends to persist.

Choke flooding of downcomers is another poorly understood phenomenon, but is well illustrated by an example. The student winners of beer chugging contests in engineering school tend to be those with the widest gullets who can also control their swallow reflex. The chug rate is limited by the capacity of the gullet, not by the countercurrent passage of gas. In tray design the limit to liquid handling capacity is measured by the flowrate over the weir (measured in gallons per foot of weir length, or equivalent). Conventional trays are limited to a nominal 180 USgpm/ft while high capacity crossflow trays are limited to about 225 USgpm/ft. If your simulation is being used to determine the tower diameter and tray active area, and you find the weir load exceeds these values, increase the number of tray passes. Note however: the number of tray passes affects tray mass transfer performance.

On the other hand, once the weir load starts to fall below about 60–80 USgpm/ft, one starts to enter the spray regime where the liquid flow slowly begins to morph from continuous to dispersed and the gas slowly changes from dispersed to continuous (see *The Contactor*, Vol 3, No 2). The mass transfer characteristics of sprays are radically different from froths, and tray performance changes drastically. The further into the spray regime one goes, the better H₂S absorption and the greater CO₂ slip become. In other words, the greater the selectivity. Careful analysis of numerous sets of low-weir-load commercial operating data in H₂S-selective applications enables ProTreat to accurately account for the effect of flow regime on selectivity. In fact, decreasing weir load by using multipass trays can be an effective way to greatly improve selectivity for H₂S, *even when single-pass hydraulics are satisfactory*.

Increasing weir height increases the volume of froth on a tray, and therefore the interfacial area for mass transfer; however, doubling the weir height does not double the interfacial area. The total height of froth on a tray is in part attributable to weir height and in part due to the required height over the weir needed to drive the flow (according to the Francis weir formula, for example). In fact, trays do not have to have weirs at all to function properly (!) and when weir height is zero (no weirs) the froth height is certainly far from zero. On properly designed trays the space between trays should be almost but not quite filled with froth. If a tray with a 2-inch weir already has 20 inches of froth, doubling the weir height to 4 inches may increase froth height to 22 inches but it may not affect the separation much. So don't look to weir height as a parameter with a strong effect on treating in a commercial column—it usually doesn't.

Liquid holdup volume or residence time on a tray is an important parameter in column *dynamics*, but it has no bearing on treating *per se*. The important parameter is the gas-liquid interfacial area for mass transfer which depends on tray type (sieve vs. valve type, for example) and physical properties such as surface tension and foaming tendency. Mass transfer rate calculations depend on the interfacial area for mass transfer, not the tray residence time. And the effect on mass transfer of slow reactions such as CO₂ hydrolysis when MDEA is the solvent cannot be logically accounted for by applying a stirred-tank reactor model to an ideal stage (see *The Contactor*, Vol 4 No 3).

Packing

The two main types of packing are random and structured. The earliest random packings were broken ceramics and glass containers. An extreme example: when one small absorber was opened in Queensland, Australia in the 1970s the packing was found to be broken beer bottles, an item in plentiful supply.

Random Packings

Manufactured random packings range from simple Raschig Rings to so-called fourth generation packings developed for low pressure drop and high throughput. Random packings are widely used in non-fouling gas treatment applications (e.g., CO₂ removal in LNG production and ammonia syngas treating). The most commonly used sizes are nominally 1 to 2 inches diameter. In quench towers and other primarily heat transfer applications much larger packings can be effectively used. Metal is the most used although from time to time plastics are seen, especially in ambient temperature applications. ProTreat contains a very wide selection of random packings.

Structured Packings

Structured packings have very low pressure drop and very high capacity. They are often used in sour water strippers and allow smaller diameter towers to be used than do trays. Structured packing is fabricated (punched and crimped) from either sheet metal or woven wire screen (rarely used in gas treating, mostly used in low volume production of fine chemicals).

The formed packing may be conventional, or curved by forming at the ends of the sheets to reduce pressure drop and increase capacity by directing a more gradual directional change in the gas flow at the joints between layers. There are very few gas treating applications in which the added cost of the high capacity version of structured packing is justified.

Suppliers generally recommend packed beds be limited to about 20 feet (6 meters) in depth with liquid redistribution between beds. In ProTreat simulation the packed depth is immaterial to the simulation because ProTreat® assumes excellent liquid (and gas) distribution throughout the column.

There are many nuances to column internals selection, and their behavior as mass transfer devices. But ProTreat deals with their mass transfer in the scientifically most appropriate way so you will have surety that simulated performance closely reflects commercial reality without having to provide performance guesses or estimates. The answer you get may not be the one you want—but it will always be *the right answer*.

To learn more about this and other aspects of gas treating, plan to attend one of our training seminars. Visit www.pro-treat.com/seminars for details.

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