ENGINEERING FEATURE

PRACTICAL TIPS ON TOWER PACKING

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In revamped distillation columns, trays are frequently being replaced with packing. This article discloses what designers and operators need to be aware of to achieve successful installation and performance.

If cost per theoretical stage were the only criterion in selecting internals for distillation columns, the packed tower for any service other than a corrosive system (which requires ceramic or plastic packing) would have disappeared about 40 years ago. For example, a manufacturer of both trays and packing quotes a price factor of two to three times as much for packing as for conventional trays [*1*].

Instead of disappearing, however, the packed column has become the object of renewed interest, both for its traditional services and for new ones. One reason for this is the current low level of new construction coupled with the need to get maximum service from existing equipment.

Increased capacity for a particular separation, with all process conditions the same, is infrequently achieved in a conversion from trays to packing. Normal tray spacing divided by stage efficiency is frequently approximately equal to, or slightly greater than, the height equivalent to a theoretical plate (HETP) of packing having the same capacity. Thus, with nothing else changed, a trayed tower will have about the same capacity as a packed one, with perhaps a few more stages when packed.

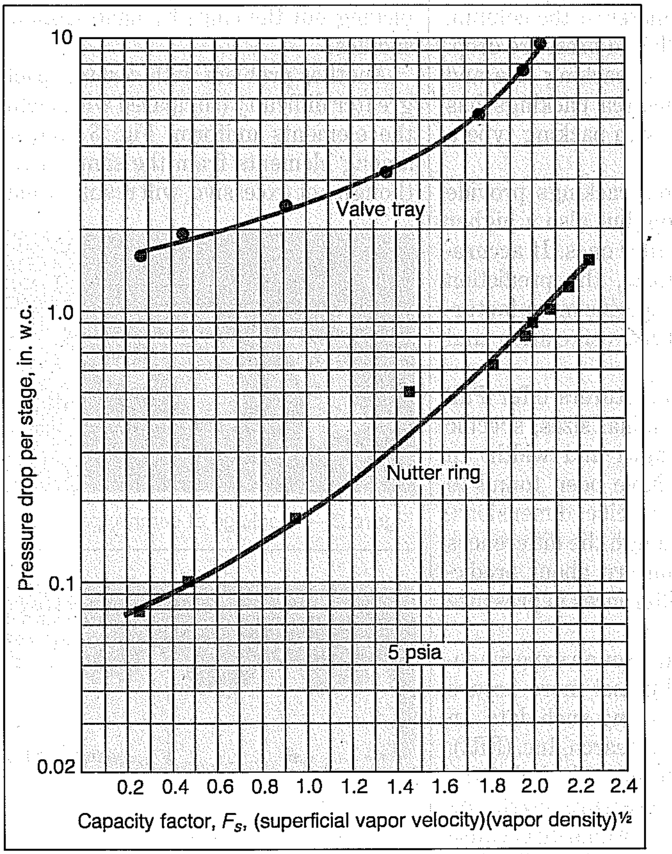


Figure 1 — Packing reduces pressure drop by order of magnitude

Replacing trays with packing makes economic sense when something will be gained from reducing pressure drop. This is apparent from Fig. 1, in which pressure drop per theoretical stage for a valve-type tray is compared to that of packing having about the same capacity [*3,4*]. The order-of-magnitude advantage in pressure drop makes packing a potential candidate for a number of applications:

1. In the distillation of a thermally sensitive material. Reflux may have been excessive because a pressure-drop (or temperature-rise) limitation restricted the number of trays. If packing having a lower HETP than the existing tray spacing, but a pressure drop within the current limitation, were to be installed, the large reduction in reflux

would result in significant savings from lower cooling-water circulation and steam consumption. Most frequently cited as an example of such a result is the separation of styrene from ethylbenzene.

2. In a trayed column using carrier steam. Steam is injected into some low-pressure columns as a partial-pressure depressant to reduce the bottom temperature. A low-pressure-drop packing could eliminate the need for the steam, thereby cutting utility cost and boosting capacity.

3. In almost any trayed column designed to a pressure-drop limitation. Such a column can be operated at higher throughput with packing. This might permit shutting down one train of a multitrain operation.

4. In trayed towers designed at about 75% of flooding, as was traditionally done. Such towers typically run out of reboiler or condenser capacity before flooding. An increase in the mean temperature difference resulting from lower pressure drop, together with a gain in the number of stages, could result in higher capacity.

5. In towers where a reduction in bottoms temperature would make it possible to use a more-economical source of heat. Conversely, holding the bottoms temperature and raising the overhead temperature could reduce cooling costs.

Having concluded that packing may make economic sense, the engineer will face an array of packing choices and bewildering claims and counterclaims for them.

Choosing packing size

When replacing trays with packing, process requirements, combined with the fixed length and diameter of the column, dictate the needed combination of HETP and pressure drop. This is a major factor in the selection of packing size and type. Research with modern, high-open-area packings has shown size to be the primary variable, with packing type a secondary one.

It is a safe generalization that larger packings provide greater capacity, and less pressure drop, but also a higher HETP (thus, lower efficiency), than smaller ones. If accuracy of pressure-drop prediction is critical, the prediction should be based on current data from a specific manufacturer, rather than derived via a generalized correlation and published data.

For example, although several manufacturers offer Pall rings or Pall-type rings in the same nominal sizes, specific dimensions differ, particularly slot length and width. In addition, Pall rings made in the U.S. have been found to differ from those made in Japan in specific dimensions, although of the same nominal size. Although the differences are not significant enough to cause concern about predictions of HETP, they could well cause differences in pressure drop.

Quotations of HETP are based on models or on experimental data. Although one would generally feel more secure with data, caution must be observed in using such data. In experimental work at the Fractionation Research, Inc. (FRI), some parameters found to affect efficiency include: the system, concentration range, absolute-pressure level, column diameter and bed length (the last two primarily because of the way they interact with small amounts of maldistribution). Therefore, one must be careful in accepting an efficiency prediction based on tests that are "close" to the operation for which the prediction is being adopted.

Selecting packing material

Random packings are mostly made of three materials: ceramic, plastic and metal. When selecting a material, one should consider not only normal process conditions but also commissioning, startup, shutdown, upset, and any special conditions.

The first packings specifically manufactured for towers were made of ceramic. References to jack chain, broken stone and clay spheres, as well as porcelain Raschig rings and Berl saddles, can be found in early articles [*5*]. Porcelain Raschig rings and Berl saddles are still used, but almost exclusively in services that are so corrosive that anything else would be dissolved.

Ceramic packing has lost favor not because of its behavior as tower packing but primarily because of its brittleness. Breakage as high as 40% in shipment has been frequently reported (some breaking is unavoidable in shipping under the best of conditions). As Fig. 2 shows, the breakage consists mostly of chips off corners. The large pieces can be used, of course, but the chips can be a problem if loaded into the column. They have been known to migrate to the bottom of the bed, work their way into the vapor holes of the support plate, and cause premature flooding. If, after inspection, one decides to screen a shipment before loading it into the column, care must be taken because screening can make chips as fast as it eliminates them. We once resorted to picking out the chips by hand from over 144 ft^3 of ceramic saddles.

Another problem with ceramic packing is the apparently greater difficulty (compared with metal or plastic) of making the elements uniform. Fig. 3 shows the typical variation among elements from the same box. Such variations, even though not excessive, will result in slightly more uncertainty

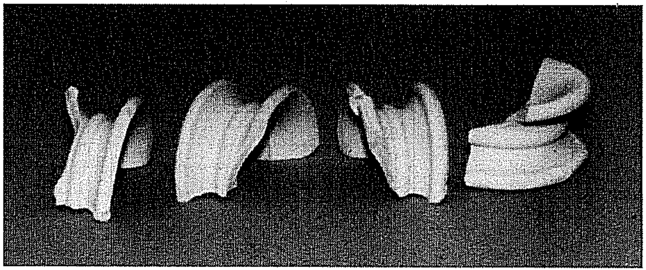


Figure 2 — Breakage of ceramic packing is unavoidable

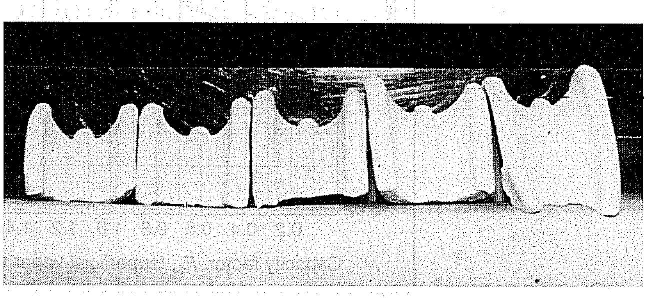


Figure 3 — Ceramic packing is less uniform than metal or plastic ones

in pressure-drop prediction than when using more-uniform packing.

Plastic packing in modest temperature service often offers a low-cost alternative to ceramics or exotic-alloy packing. The most common packing material is reinforced polypropylene. It is ideal for such services as caustic-washing and CO_2-removal systems, which operate well below the plastic's melting point of about 330°F.

However, with plastic packing, startup and shutdown procedures must be carefully drawn up. Instances of an entire bed of packing being fused as a result of the column being steamed out are common, and at least one column has the words "do not steam out" stencilled in large letters around its circumference so that the message can be seen from any direction.

Manufacturers also caution against the dry dumping of plastic packing at temperatures near freezing, at which point the packing loses impact strength. Additionally, it has been reported that it can take close to a week for a plastic packing to become thoroughly wetted, during which time its performance changes to some degree [*6*].

Packings are most commonly made of metal. Although they can be of almost any alloy, packings of carbon steel and Type 304 stainless steel predominate. Here again, operating conditions other than normal must be taken into account when selecting a metal. The standard wall thickness for a stainless steel Pall ring is thinner than that for a carbon steel one of the same size. This does not affect performance, but does affect shipping and handling. Metal packing must be handled with care, because manufacturers make it of the lightest gage consistent with shipping requirements and the need to achieve reasonable bed lengths. This leaves little room for abuse.

Aluminum is sometimes an alternative to stainless steel. Again, abnormal operating conditions need to be considered. In one case, high temperature during startup caused aluminum packing to lose strength and become compressed, making it impossible to attain the design pressure drop.

Defining loading and flooding

The terms loading and flooding have never been defined precisely. Sherwood and Pigford list three definitions of flooding [*7*]:

1. A liquid layer on top of packing.
2. The second breakpoint on a log-log plot of pressure drop vs. gas velocity.
3. The point at which measured liquid holdup increases abruptly.

They point out that the data of Sarchet [*8*] indicate that the visual flooding point is usually slightly less than that obtained from pressure-drop measurements. Silvey and Keller [*9*], who later tabulated nine different definitions of flooding, noted that developers of generalized correlations frequently combine "flooding" data from a variety of sources without regard for differences in definitions.

Flooding is an inherently unstable condition. An observer using a single definition consistently may report different results for two experimental runs because of variations in such factors as an increase in boilup rate and the stability of pressure control.

The definition of loading also presents a problem. The sharp upturn in the plot of pressure drop vs. gas velocity reported by the early experimenters, who used air and water in glass columns, has never been observed in distillation systems at FRI, although a change in the slope of the pressure-drop curve has been seen. However, it is debatable whether a smooth function or two curves that intersect at a unique point is a better way to represent the data.

Additionally, with low-pressure-drop packings, the unavoidable scatter in pressure-drop data makes pressure drop an unsatisfactory criterion for defining capacity. This concurs with the early work of Bain and Hougen [*10*], who reported that they did not always observe a distinct loading region.

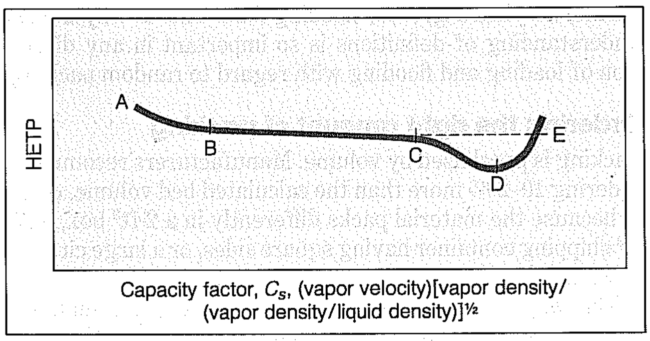


Figure 4 — Packing efficiency improves, then declines [*12*]

Relating capacity to efficiency

Because observations made at FRI coincided with those of Hengstebeck [*11*] that there is a relationship between efficiency and loading, an efficiency definition has been used in the correlation for the loading point at FRI for over twenty years.

Originally, the loading point was defined as the point of

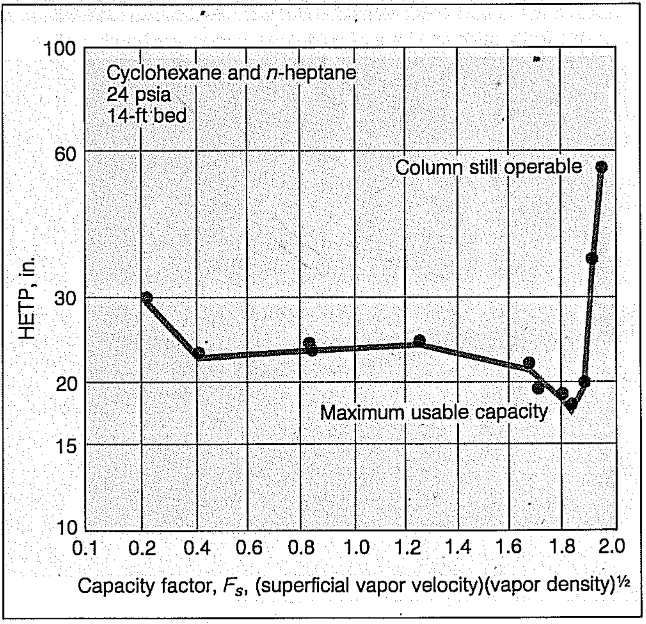
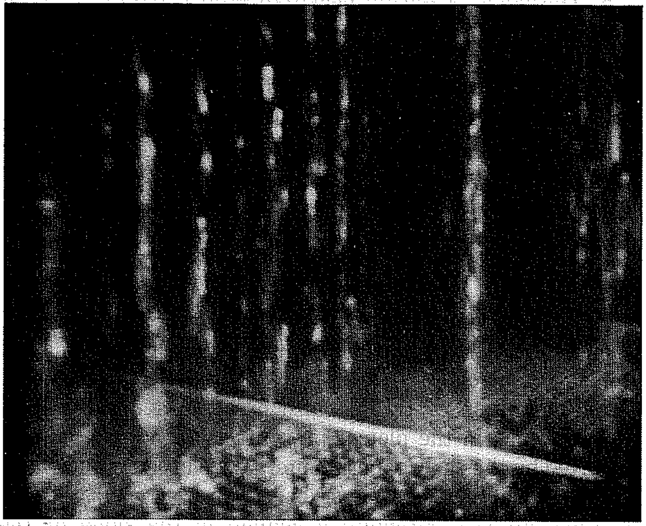
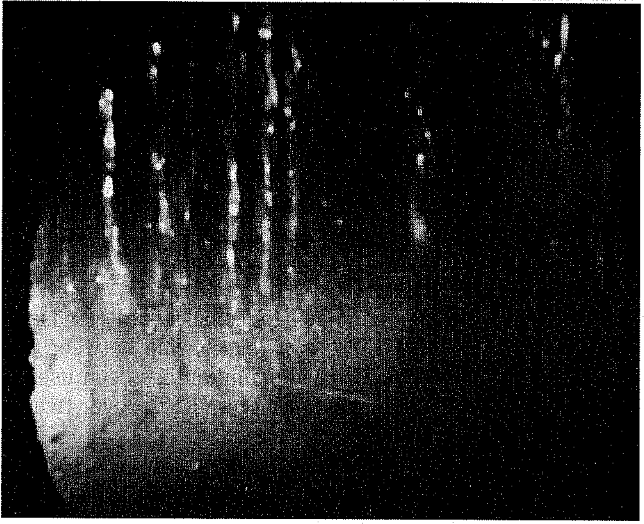


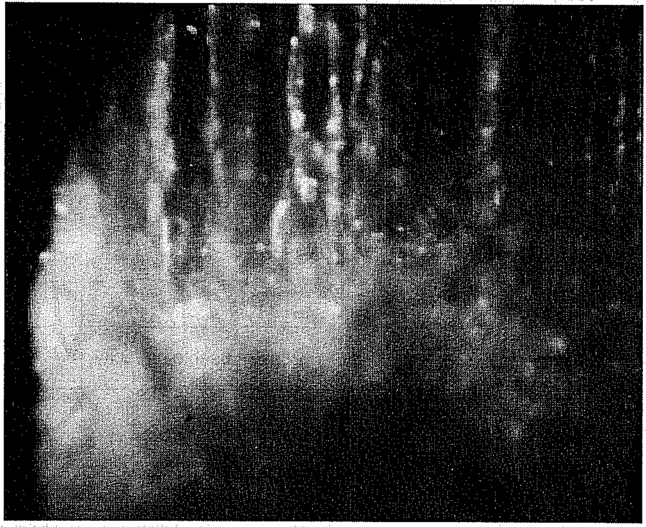
Figure 5 — Loading point may be regarded as "maximum capacity"



a. View immediately prior to appearance of froth



b. Stable froth; stiffening bars of hold-down screen are barely visible



c. Stable froth halfway to bottom of distributor

Figure 6 — Froth occurs at top of bed at maximum column capacity

maximum efficiency. Recently, it has been found that defining this point as one beyond which a very small increase in boilup results in a rapid deterioration in efficiency yields a more consistent and reproducible correlating parameter. The two points generally coincide, but sometimes do not.

We are not alone in using an efficiency definition when discussing capacity. Fig. 4 is redrawn from a plot by Strigle [12], who defines a constant efficiency range (Points B to C), a load point (C) as the point where efficiency begins to increase, a point of maximum efficiency (D), and a point of maximum operational capacity (E) beyond which design efficiency cannot be maintained.

Although we agree with this in general, some of our observations and definitions differ. For instance, we have not found a loading region of increased efficiency for all packings and at all conditions. In general, when we have observed a region of increased efficiency, we have found it to be more pronounced and to represent a greater percentage of total capacity for larger packings and lower absolute pressures.

Another definition of flooding

We define loading point as "maximum usable capacity." Fig. 5, which presents data from a recent proprietary packing test [4], shows that, beyond this point, a hike in boilup rate of about 5% resulted in about a threefold increase in HETP. Admittedly, at the highest reported value, the pressure drop was fluctuating and the reboiler level was surging — which could not be called good operation. Nevertheless, the column was still operating.

This operating region is characterized by a layer of froth (not clear liquid) on top of the bed. The Fig. 6 photographs, taken through the window of a 4-ft column, show this phenomenon. Although the photographs show flooding of ceramic saddles, rather than the metal rings used to obtain the data in Fig. 5, the behavior was the same. For this reason, we are reluctant to discuss efficiency in terms of percent of flooding.

This frothing behavior represents yet another reason why there is so much scatter in reported flooding data. A pan-type reflux distributor was installed about 1½ ft above the top of the bed for the run during which the photographs were taken. The loading that resulted in a froth level about midway between the top of the bed and the distributor was called flooding. A smaller space would have resulted in a lower flooding load, and the boilup could have been increased further to yield a greater flooding load. This is why a clear understanding of definitions is so important in any discussion of loading and flooding with regard to random packing.

Ordering the right amount of packing

Packing is purchased by volume. Manufacturers recommend ordering 10–20% more than the calculated bed volume, chiefly because the material packs differently in a 2-ft^3 box, a 25-ft^3 shipping container having square sides, or a large circular column.

The way in which the column is packed also makes a difference — particularly regarding whether a column is packed dry or wet. In the latter, the packing is floated down through the column of water. This method originated when

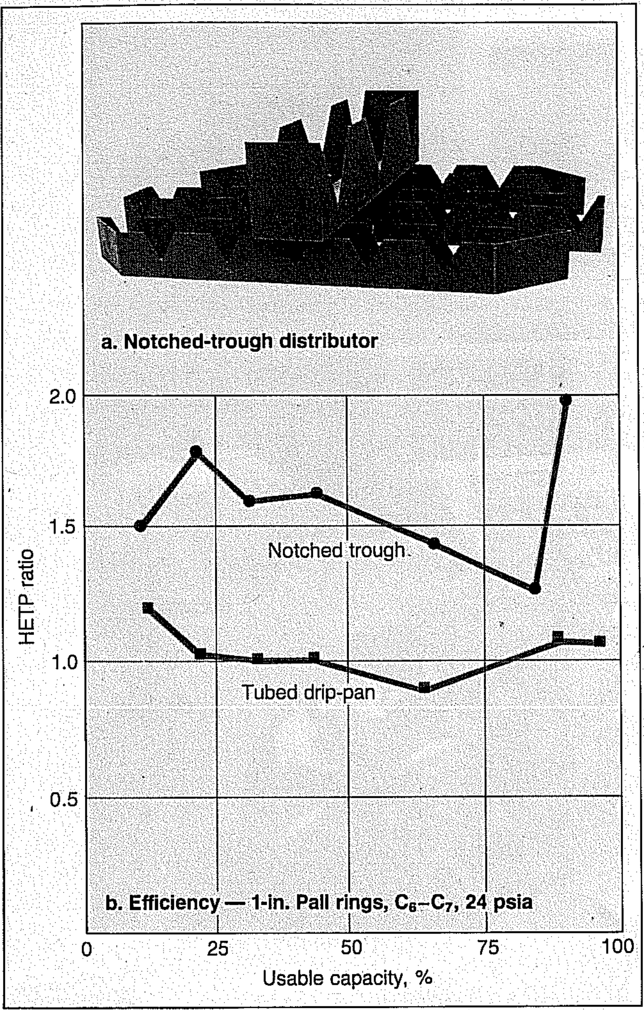


Figure 7 — Notched trough distributes flow better than tubed drip-pan

packings were primarily ceramic, to minimize breakage. Through custom, metal Pall rings were wet packed when first tested at FRI. When we realized that this was not necessary and packed them dry, we obtained a different pressure drop. We also found that more packing was loaded in the same length of bed.

Billet reported the same thing [*13*]. Four different procedures for loading 35-mm Pall rings into a 500-mm by 2-m bed resulted in the following loading densities: dry packing with planing — 19,260 pieces/m^3; random dumping — 18,460 pieces/m^3; dry packing dumped over a central cone — 18,500 pieces/m^3; and wet packing — 17,500 pieces/m^3.

Subsequent tests involving distilling methanol and ethanol at atmospheric pressure revealed that the four differently packed beds behaved virtually identically over the lower half of the capacity range. From beyond the midpoint, the pressure drops began to differ, with the spread becoming significant as the loading region was approached. Thus, there was little effect on efficiency until the loading point was reached.

Column auxiliaries

Poor liquid distribution is behind many cases of packed-column failures. For many years, the standard FRI distributor has been the notched trough (Fig. 7a). The apparent overall HETP using the distributor and a carefully designed and installed drip pan are compared in Fig. 7b. The 50% decrease in efficiency can explain to a considerable extent some failures in scaling up from laboratory to large commercial columns.

A liquid predistributor should be installed ahead of a gravity-flow orifice-type distributor to prevent wave action and splashing. The combination of the lowest anticipated liquid flowrate and the installation level-tolerance should be checked to eliminate the likelihood of a section becoming dry.

Studies have shown that small packings are more sensitive to maldistribution than larger ones, and zonal flows and discontinuities are more harmful than continuous variation (such as a slight tilt). There is no substitute for good initial distribution. Although redistributors can compensate somewhat, inadequate ones can do more harm than good. Based on the results of FRI's controlled maldistribution studies [*14*], a model has been proposed that shows promise of being able to predict quantitatively the scaleup effects of a good (but not quite perfect) distributor [*15*].

Packing supports are not critical if they have enough open area. The packing itself is the best vapor distributor as long as most of the pressure drop occurs in the bed.

***J. Matley,** Editor*

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