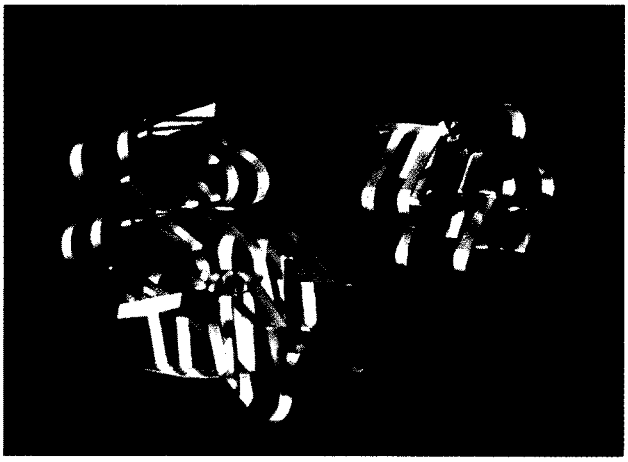
Researching rings

Michael Schultes, Raschig GmbH, Germany, presents the new generation of random packing, and highlights its advantages over previous packing methods.



The Raschig Super-Ring No. 2.

When developing dumped type packing geometries in the past, one generally pursued the ultimate goal of producing low pressure drops for the gas flow by keeping the spatial geometry as open as possible. The flow characteristics of the liquid phase usually had no influence on shape. In the design of the Raschig Super-Ring, however, consideration has been given to the liquid flow behaviour, as a result of fluid dynamics studies in experimental and industrial columns and, therefore, a concept has been pursued that is fundamentally different.

Whereas in the design of earlier geometries the liquid droplet formation rather than the liquid flow was deliberately promoted; with the Raschig Super-Ring attention was focused on producing liquid films as much as possible, as is the case with structured packing. It had been obvious for years that structured packing has a lower pressure drop and higher capacities than random packing. In addition to the geometry of structured packing, with only a few deflections for the gas flow, the low pressure drop and high capacity is also based on the film flow that is dominant in this type of packing.

The Raschig Super-Ring, therefore, has no drop promoting edges or tabs in its geometry. Furthermore, for the first time, the ring achieves an even distribution of material in the packed bed, which in addition to short diffusion pass between the gas and the liquid flow, also leads to a highly homogeneous distribution of gas and liquid over the column cross section[1].

Hydraulic and mass transfer studies in rectification columns

In Oklahoma, USA, Fractionation Research Inc. (FRI) operates one of the world's largest test plants for the determination of pressure drops, capacity limits and mass transfer efficiencies of trays, structured packings and dumped packings. At the end of 1998, the metal Raschig Super-Ring No.

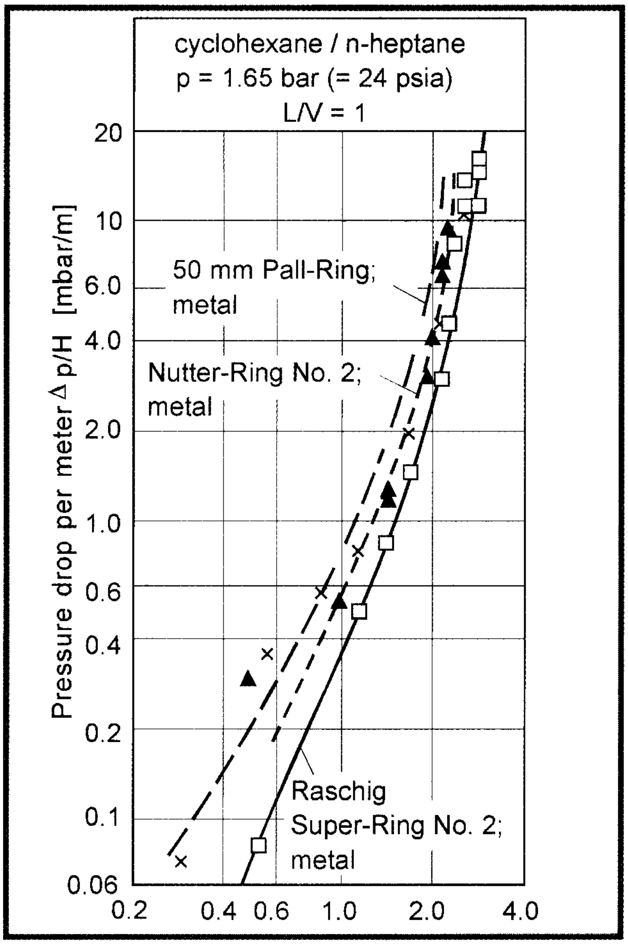


Figure 1. Comparison of pressure drop for Raschig Super-Ring No. 2, 50 mm Pall-Ring and Nutter-Ring No. 2.

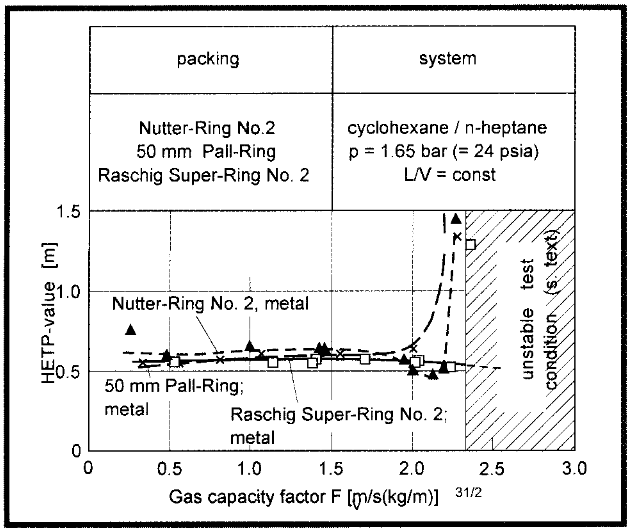


Figure 2. Comparison of mass transfer efficiency for Super-Ring No. 2, 50 mm Pall-Ring and Nutter-Ring No.2.

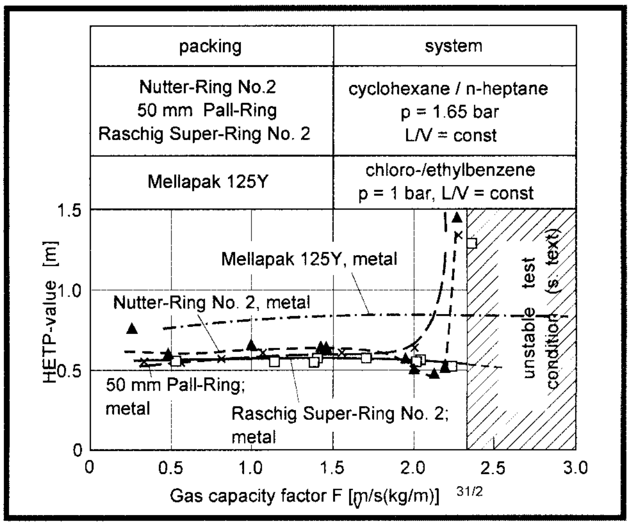


Figure 3. Comparison of mass transfer efficiency for Raschig Super-Ring No. 2, 50 mm Pall-Ring, Nutter-Ring No. 2 and the structured packing Mellapak 125Y.

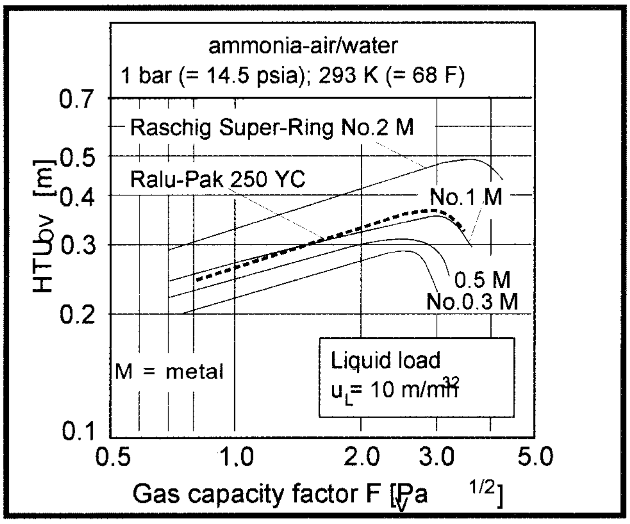


Figure 4. Comparison of the height of overall mass transfer unit between various sizes of Raschig Super-Rings and the structured packing Ralu-Pak 250 YC.

2 was tested at 1.65 bar (24 psia) with the system cyclohexane/ n-heptane, and at 6.9 bar and 11.4 bar (100 and 165 psia), with the system iso-butane/n-butane in the high pressure rectification column.

Figures 1 and 2 show the pressure drops measured and the mass transfer efficiencies of the ring at 1.65 bar (24 psia) for the system cyclohexane/ n-heptane. The Figures also show the curves for 50 mm Pall-Rings and the metal No. 2 Nutter-Ring obtained in earlier tests in the same test facility[2]. The comparison clearly shows that the Raschig Super-Ring not only displays a considerably lower pressure drop than the Pall-Ring, but also lower values than the No. 2 Nutter-Ring. The latter is already related to high capacity dumped packings. Figure 1 also shows a considerably greater capacity for the Super-Ring.

The mass transfer efficiencies of the Super-Ring No. 2, the 50 mm Pall-Rings and the No. 2 Nutter-Rings depicted in Figure 2 show that the Super-Ring displays comparable and, at higher loads, 5% better mass transfer efficiencies than the Pall-Ring, and achieved 5 - 15 % lower HETP values than the Nutter-Ring in the main load range. It was above the loading point of the Nutter-Ring that the HETP values approximate those of the Super-Ring or Pall-Ring, and even fall below briefly before the flooding point of the Nutter-Ring occurs.

Before the loading point of the Super-Ring was achieved, the HETP measured suddenly rose at a gas capacity factor of:

$$F_V = 2.3\sqrt{Pa} \quad (1.89\ ft/s\ (lb/ft^3)^{0.5}$$

as can be seen from Figure 2. This was not expected, based on the air/water tests or industrial experience. During studies for the Super-Ring, the fluid dynamic behaviour of the bed could be observed through an inspection glass immediately above the bed of dumped packings and below the liquid distributor. Above the gas capacity factor of:

$$F_V = 2.3\sqrt{Pa} \quad (1.89\ ft/s\ (lb/ft^3)^{0.5}$$

a marked condensation of the vapour phase was suddenly observed in the gas passing the gas risers of the liquid distributor, and in the ring shaped gap between the distributor and the column wall. This was as a result of the following: the large cold reflux quantities subcooled the liquid distributor heavily, which owing to its design, had a large liquid holdup. As the column load continued to increase, the liquid distributor flooded. Both these circumstances caused condensation of rising gas, which shifted downwards into the packed bed periodically and created backmixing effects of the phases, the early rise in the pressure drop and a premature drop in mass transfer efficiency.

Random vs structured packings

Figures 3 and 4 show a comparison of the mass transfer efficiencies between random and structured packings for various rectification systems.

Figure 3 shows that the mass transfer efficiency of structured packings is not as good as that of random packings if the same surface area is used as the basis for comparison[3,4].

Whereas the Nutter-Ring has a surface area of 95 m^2/m^3, the Pall-Ring of 105 m^2/m^3 and Super-Ring of 98 m^2/m^3, the surface area of Mellapak 125Y meets 125 m^2/m^3. These measurements verify that the structured packing, with a 25% greater geometric surface area, has approximately 35% poorer mass transfer efficiency than the 50 mm random packings[5,6]. The reason for this is that the higher turbulence in the countercurrent gas flow for random packings results in higher mass transfer coefficients in the gas phase. Of course, this also results in a higher pressure drop of random packings, which can be referred to as a 'useful pressure drop for mass transfer' if the pressure drop is of less importance, as is the case in normal or pressure distillation, for example.

To verify the comparison bases between random and structured packings, Figure 4 shows the mass transfer efficiencies relating to the height of transfer units for ammonia air/water and selected Super-Rings, plus the values for the structured packing Ralu-Pak 250 YC[7].

It can be seen that the efficiency of Ralu-Pak 250 YC coincides with those of Raschig Super-Ring No. 1. Again, the higher pressure drop of Super-Ring No. 1 compared to the structured packing results in higher gas turbulences and gas side mass transfer coefficients though the surface area is less. Figure 4 also shows that the maximum capacity of Ralu-Pak 250 YC is equivalent to that of Raschig Super-Ring No. 1.

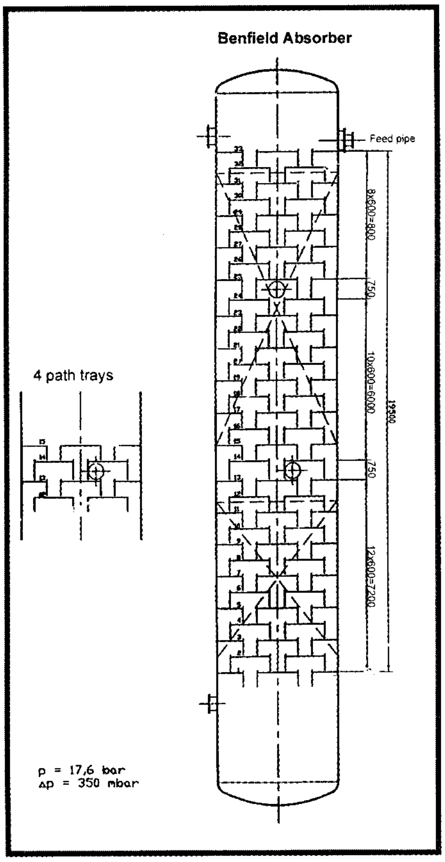
Industrial applications

The previously described properties of the Super-Ring are also noticeable in industrial plants. However, the large dimensions of industrial mass transfer columns demand further innovations from modern packings. The size prevents the measurement of properties in small test facilities.

The ratio of column diameter to nominal packing diameter is often much larger than in experimental plants, raising the question of the influence on mass transfer efficiency. In the past, it was reported on repeated occasions that, with a diameter ratio of column shell to nominal packing size larger than 20, a drop in mass transfer efficiency is to be expected[8]. According to earlier studies, the same occurs if packed beds assume great heights[9,10]. One sees that the cause for this is a maldistribution of the liquid or gas phase, which may be caused by an uneven distribution of the phases over the column cross section, or by the fact that the liquid tends to flow towards the column wall as the column length increases[11]. If the liquid reaches the wall, it remains there and trickles downwards in an accelerated manner, with the result that the mass transfer efficiency deteriorates.

The industrial use of the Super-Ring shows that its geometry largely avoids these effects. The liquid film usually trickles down through the open geometry. Furthermore, the homogeneous distribution of material of only one Super-Ring element results in a highly homogeneous packed bed, with the effect that the liquid is much more evenly distributed over the column cross section than with earlier random packings. From various applications, it was seen that the ring can be dumped much higher than other random packings without a loss of mass transfer efficiency occurring. For instance, dumping heights of 10 - 11 m (33 - 36 ft) have already been achieved, independent of absorption, desorption or rectification application. The very even distribution of material and liquid also makes it possible for very large ratios of column diameter to nominal packing diameter to be achieved. Despite a ratio of over 200, no loss of mass transfer efficiency is observed with Super-Rings in industrial plants. Of course, care has to be taken in the distributor design to ensure a uniform liquid distribution over the column cross section.

Figures 5 and 6 show a typical revamp application of the rings. An existing column was built with 33 4-pass trays to absorb CO$_2$ in a caustic solution. The Benfield process operated in an ethylenoxide unit under a top pressure of 17.6 bar (255 psia), with a total pressure drop of 350 mbar (5.1 psia). The purpose of the revamp was to minimise the pressure drop and to keep extra capacity available for future operation conditions. The revamp study verified that the Super-Ring No. 2 would fit the future operation condition, as well as the maximum pressure drop criteria. Furthermore, it was decided to install a packed bed of over 10 m (33 ft) at the top of the column, and a second bed of approximately 6 m (19.7 ft) at the bottom. A further advantage of the ring was that all support rings and downcomer bars of the existing 4-pass tray column were left inside so that the shutdown time was minimised. Between the beds, a liquid collector was installed to mix the liquid from the top bed before it was redistributed into the second bed. Special care was taken in the design of the liquid distributor at the top and the liquid redistributor between the beds to ensure a homogenous liquid distribution over the packing. Below the bed, a gas distributor was installed to also ensure a homogenous gas distribution over the column cross section. After starting up the column, the pressure drop decreased tremendously in comparison to the tray solution. Presently, the column operates with a pressure drop below the accuracy of the measurement device, which starts to show the pressure drop at 10 mbar (0.15 psia) total pressure drop.



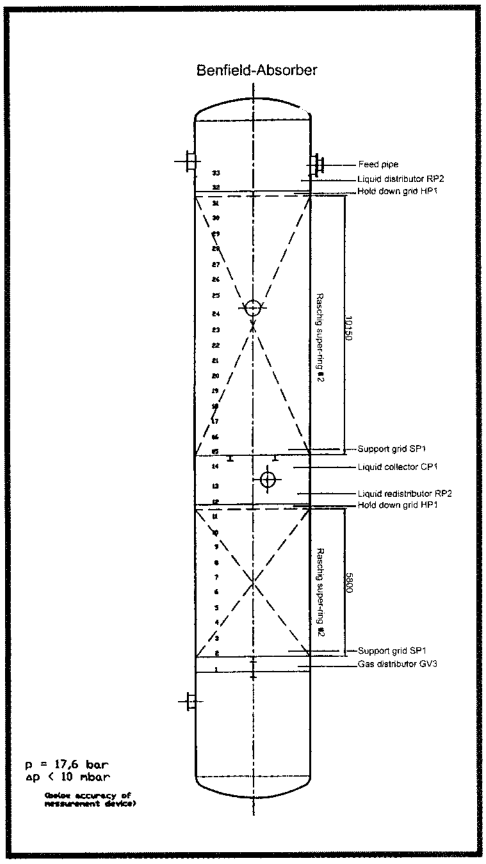


Figure 5 (left). Benfield absorber with 4-path trays before revamp.
Figure 6 (right). Benfield absorber with Raschig Super-Ring No. 2 after revamp.

Figure 7 shows a further revamp application of Super-Rings. The column operates as a propane/propene splitter with a top

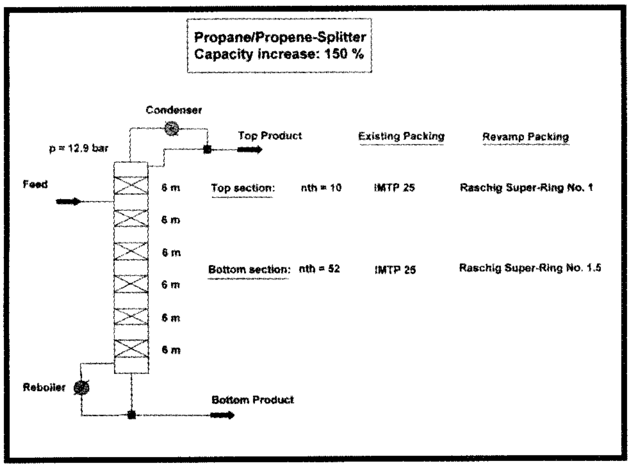


Figure 7. Revamp of a C3-splitter from IMTP 25 to Raschig Super-Ring No. 1 and No. 1.5.

pressure of 12.9 bar (187 psia) and was equipped with 25 mm IMTP-Rings. It was designed with a 6 m (19.7 ft) bed at the top of the column, and a further five beds, each of 6 m (19.7 ft), below the feed. The purpose of the revamp was a capacity increase by 150%, but without any loss in the separation efficiency so that the top and bottom specification of the product quality could be held constant. The process study verified that the Super-Ring equivalent to IMTP 25 was not able to handle a capacity increase of 150 % because the IMTP 25 packing was already operating at capacity limit. The first larger size of Super-Ring that could handle the capacity increase was ring No. 1 at the top and ring No. 1.5 at the bottom. Furthermore, the efficiency study verified that the HETP of the existing packing IMTP 25 was higher than expected, and could also be guaranteed by the selected Super-Rings at the top and bottom of the column. The study of the column internals shows that the liquid redistributors used in the existing column were not able to equalise any liquid maldistribution in the packed beds. With the new liquid redistributors, special care was taken in the design to have the liquid homogeneously distributed over the column cross section at each intersection of the packed beds. After startup of the C3-splitter, the new capacity and product specification were reached in just a few hours.

Table 1. Selection of applicants for Raschig Super-Rings

Natural gas plant	Methanol plant
Caprolactam plant	N-methylpyrolidone plant
Refinery plant	Synthesis gas plant
Fatty acid plant	Effluent water treatment
Effluent gas plant	Ethylene plant
Ammonia plant	Sulfur plant
Ethanol plant	TDI plant
Formaldehyde plant	Ethylenoxid plant

Table 2. Equivalence of metal Raschig Super-Rings to metal Pall-Rings for various sizes

Pall-Ring		Raschig Super-Ring	
Size	a (m^2/m^3)	Size	a (m^2/m^3)
15	360	0.3	315
-	-	0.5	250
25	215	0.7	180
-	-	1.0	150
38	135	1.5	120
50	105	2.0	100
80	78	3	80

Table 1 shows a selection of applications in which the Super-Rings have been used. Table 2 explains the equivalence of Super-Rings to Pall-Rings.

Conclusion

The fundamental new idea in the shape of the Super-Ring has proven itself both in test columns and in industrial application.

In the test facility, the Fractionation Research Incorporation (FRI), the Super-Ring shows a large reduction in the pressure drop and a much higher available capacity. This is when compared to Pall-Rings and also other high capacity random packings. This article has discussed tests carried out under rectification conditions. With the low pressure drop of Super-Rings and available capacities, they came very close to structured packings. The industrial application described earlier underlines the notable performance characteristics of the Super-Ring: the first type of fourth generation random packing.

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Enquiry no: 27