Raschig Super-Pak

A new packing structure with innovative advantages

(Engl. translation of: "Raschig Super-Pak – Eine neue Packungsstruktur mit innovativen Vorteilen im Vergleich", published in: Chemie Ingenieur Technik 2008, 80, No. 7)

Prof. Dr.-Ing. M. Schultes
Raschig GmbH, Mundenheimer Str. 100, 67061 Ludwigshafen, Germany,
e-mail: MSchultes@raschig.de

Abstract

The Raschig Super-Pak is a new geometric packing design which through an innovative structure, has three major advantages over other high-performance packing: lower pressure drop, higher capacities, and better separation efficiency. The performance data measured at the Separations Research Program (SRP) at the University of Texas at Austin are presented and evaluated in comparison to other high-performance and standard structured packing.

Introduction

Today, the use of structured packings for separation tasks in distillation, absorption, desorption, and extraction columns is the standard solution when it comes to realizing excellent separation performance with very low pressure drops.

Today's standard packings consist of a wave-shape profiled sheet, wherein the waves mostly run with an positioning angle of 45° or 60° to the horizontal, see Fig. 1. Studies relating to fluid dynamics in standard packings have shown that at the crossing points of the packing layers, an increased pressure drop comes about due to the abrupt redirection of the flow of gas. This in turn leads to localised retention of the liquid, followed by early flooding of the structure.

In the mid-90's, the high-performance packings that we know today came onto the market. This is characterised by a change in geometric design at the ends of the packing layers, see Fig. 1. Depending on the provider, three different designs are currently available. The thing that all designs have in common is the vertical position of the wave-like profiles in the zones at the ends of the packing. While Montz allows the transition to the 45° position to run well into the centre of the packing and only realizes this on the lower side of the packing, Sulzer makes the transition on both the upper and lower sides of the packing layer with a relatively short transition area. Koch-Glitsch is pursuing a similar concept as Sulzer; however, it realizes the transition with an abrupt change in the angle. The result of this change to the geometric design in the transition area of the packing layers resulted in substantial increases in capacity.

A new structure through innovative ideas: The Raschig Super-Pak

On the basis of years of experience with the application of standard structured packings, Raschig entered the scene some years ago with the development of a new, high-performance packing. The aim was to define an innovative and strong geometric design with the help of new ideas, detached from existing designs. By evaluating existing design concepts, the following questions formed the core issues, see Fig. 1:

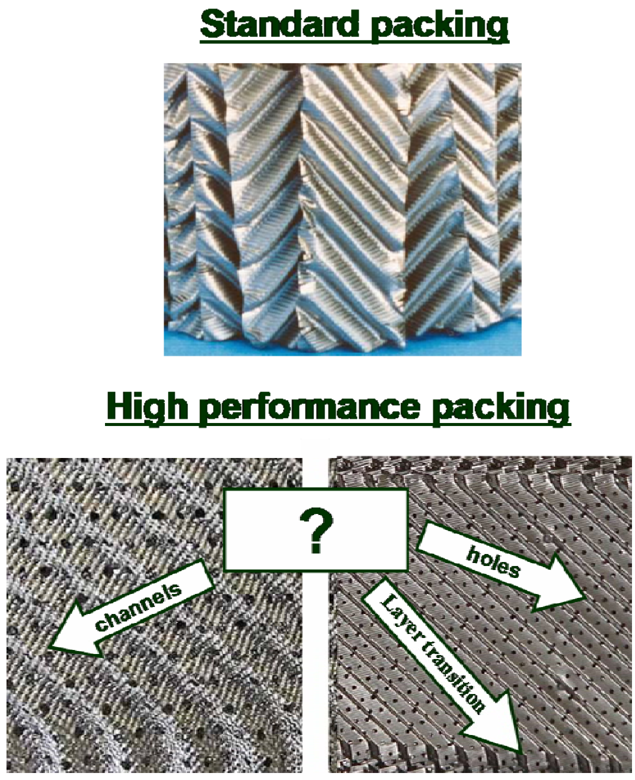


Fig. 1: The structures of various standard and high-performance packings

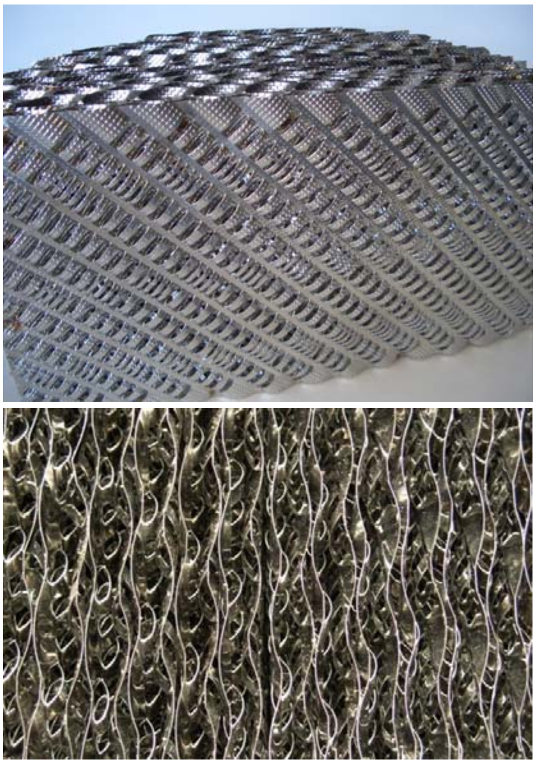
Question 1: Is the largely closed-channel structure in structural packing ideal for counter-flow processes?
In standard and high-performance structured packing, the vapour and liquid phase mostly moves within flow channels. These are set by the neighbouring structured sheets, see Fig. 1. Given that the wave-shaped and angularly-structured sheets are arranged so that they are turned in relation to each other, the sheets touch in a punctiform way so that the liquid and the gas can move between the sheets. A transgression of the two phases, from one flow channel to the adjacent flow channel is, if at all, only possible in perforated sheet structures. If flow bottlenecks arise through either the unequal distribution of the phases or deposits in the individual channels, early flooding can be expected within these zones.

Question 2: Do perforated channel structures have a positive effect on the performance of packing?
In an operational state, the liquid flows downwards in the form of a film over the packing structure, while the gas flows upwards in the volume created by the

remaining void fraction. Some packing manufacturers provide perforated plate sheets in order to give the phases the opportunity to exchange through the holes in the sheets.

On account of the bridging formations however, the liquid often covers the small holes in the sheet so that the flow phase exchange is restricted between two adjacent channels. In the case of foaming systems, it was found that the fluid dynamics of perforated packing structures has an adverse affect, as the passage of gas through the holes forms bubbles and as such, promotes the development of foam. In the case of packings with low specific surfaces (≤ 300 m^2/m^3), the holes were found to have no significant effect on the fluid dynamics of packing and its behaviour in relation to separation performance.

Question 3: Is the vertical profile position in the transition area of the packing layers in high-performance packing the most dynamically efficient design in relation to the fluid flow?
In the channel structures of standard packing, an increase in capacity results out of necessity on the vertical position of the flow channels in the transition areas of the packing layers. The question however is whether the phase transition between the layers can be facilitated by using an entirely different packing structure.



SHOW FIGURE 2

Fig. 2: The Raschig Super-Pak with its innovative lamellar structure (top) and view of a packing layer in the flow direction of the gas phase (bottom)

Fig. 2 (above) shows the structure that has resulted from the considerations described above and experiments into fluid dynamics. The structure of the Raschig Super-Pak is formed through narrow, wave-like loops, which alternately pass out of the packing sheet in an upward and downward motion. The loops run inclined to the horizontal and the sheets are turned in relation to each other by 180°. Due to the narrow alternating loops, the Raschig Super-Pak retains an extremely open structure which no longer exhibits flow channels. As such, localized bottlenecks relating to fluid flow and the phenomena of preflooding are ruled out. Fig. 2 (below) also shows a view of the new packing structure in the direction of the gas flow when entering a new packing layer. When transgressing into the next packing layer, the extremely open structure does not force the gas to change direction. The following chapters will show, that this innovative surface geometry allows especially high capacity levels and excellent results in terms of separation performance.

Comparison of the Raschig Super-Pak with standard and high-performance structured packing

In order to be able to evaluate the performance of the Raschig Super-Pak (RSP), tests were performed as part of the SRP at the University of Texas in Austin. The distillation mixture of cyclohexane / n-heptane was used as a test system at four different pressures. With this system, studies of standard performance and high-performance structured packings have been carried out both at the SRP and at FRI (Fractionation Research Inc.) in Stillwater, Oklahoma.

The newly developed Raschig Super-Pak 250 has an enhanced surface texture. In order to identify this surface, the packing will be referred to as Raschig Super-Pak 250 wSE (with surface enhancement). In an earlier article /1/ the Raschig Super-Pak 300 was introduced with a smooth surface. For comparison, the results of this packing will also be described (this packing is referred to as the Raschig Super-Pak 300 woSE (without surface enhancement).

Description of the test column

The SRP test column has an inside diameter of 429 mm and was filled with Raschig Super-Pak up to a packing height of 3124 mm. Detailed observations concerning the setup of the experiment and the experimental procedure can be found in publication /2/.
The SRP standard distributor with 145 drip points per m^2 column cross sectional area was used as the liquid distributor. Cyclohexane/n-heptane was selected as the distillation test system at pressures of 4.14 bar, 1.65 bar., 0.33 bar and 0.165 bar. The tests were carried out at an infinite reflux ratio (total reflux). The Montz B1-250 (standard packing) and Montz B1-250M (high-performance packing) were also tested at the SRP and analyzed under identical conditions.

Likewise, the performance figures of the Raschig Super-Pak are also compared below with the Sulzer packing M 250Y (standard packing) and M 252Y (high-performance packing) tested at the FRI in each case. The FRI test column has a diameter of 1219 mm and is equipped with a packing height of 3670 mm. The FRI standard pan type distributor (TDP type) was used as the liquid distributor for the M 250Y Sulzer packing. The M 252Y Sulzer high-performance packing was tested with Sulzer's VKG high-performance trough type distributor. Further experimental details can be found in publication /3/.

Evaluation of the separation performance and capacity of the Raschig Super-Pak at different column pressures

Fig. 3 shows the separation performance of the measured Raschig Super-Pak 250 at the four distillation pressures. The separation performance is shown in terms of the height of a theoretical plate (HETP-value) in m, over the specific liquid load u_L in m^3/m^2h.

At a pressure of 4.15 bar, the packing structure of the Raschig Super-Pak could not be flooded because the capacity of the evaporator and condenser was not sufficient.

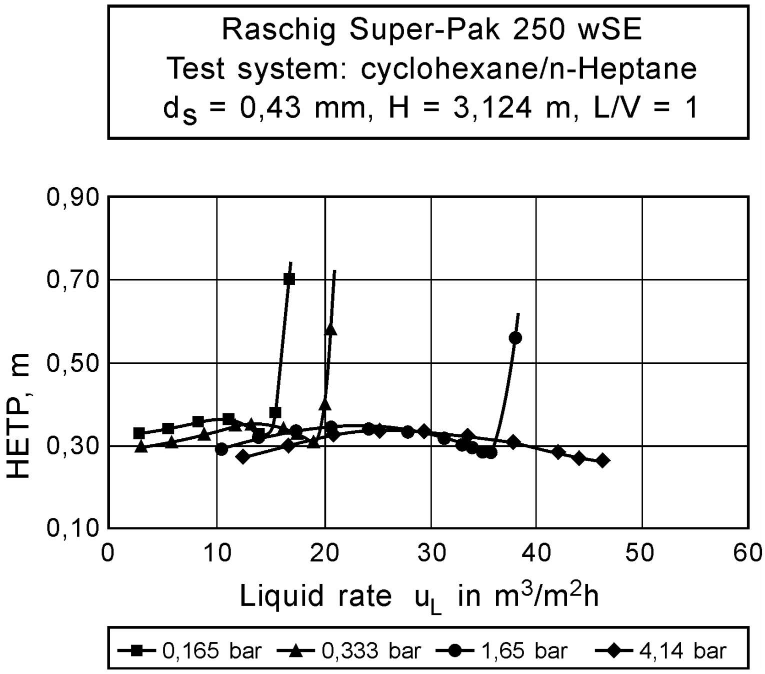


Fig. 3: Separation performance of the Raschig Super-Pak 250 wSE for rectification at different column pressures shown over the liquid load in the case of total reflux

Fig. 3 shows that the Raschig Super-Pak achieves consistently good separation efficiency over a wide liquid loading range. The limit for the lowest liquid load was determined by the lower limit capacity of the liquid distributor. The upper load range is limited by the flooding of the packing.

In the following, the measurements at 4.14 bar and 0.33 bar are looked at more closely. This is because these results offer particularly characteristic findings. The results can be transferred to other pressures in the same way.

Evaluation and comparison of the test results for the Raschig Super-Pak at p = 4.14 bar

Fig. 4 shows the separation performance results for the Raschig Super-Pak 250 wSE and Raschig Super-Pak 300 woSE at p = 4.14 bar for the cyclohexane/n-heptane test distillation system applied across the vapour capacity factor F_V in $\sqrt{Pa}$. The vapour capacity factor is calculated from the vapour velocity u_V in m/s related to the column cross section area multiplied by the square root of vapour density ρ_V in kg/m^3.

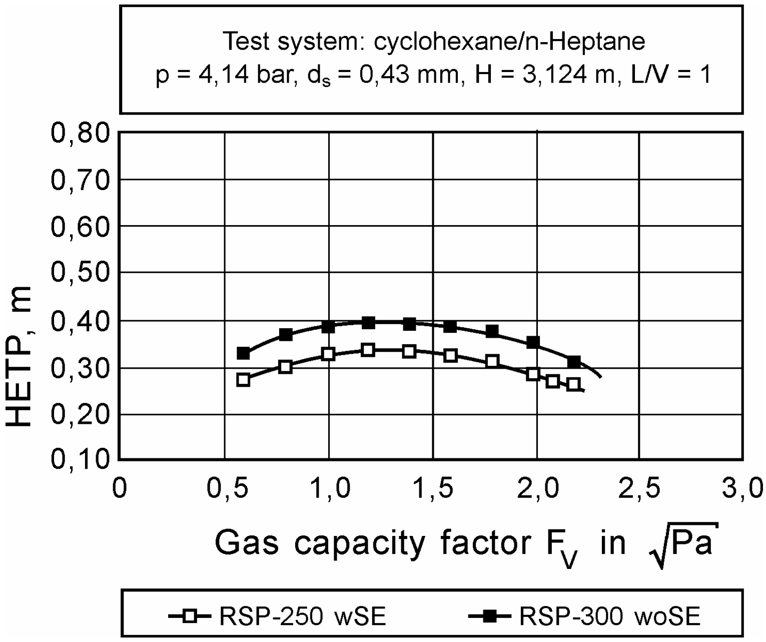


Fig. 4: Separation performance of the Raschig Super-Pak 250 wSE and the Raschig Super-Pak 300 woSE for rectification shown over the vapour capacity factor in the case of total reflux

Although the specific surface of the Raschig Super-Pak 250 wSE is 17% smaller than that of the Raschig Super-Pak 300 woSE, the surface enhancement has a very positive effect on the separation performance. Due to the rough surface, the fluid content increases in the column and the liquid film is more turbulent. Both these factors combined have the effect that the separation performance of the Raschig Super-Pak 250 wSE is about 15% better than that of the smooth Raschig Super-Pak 300 woSE.

Fig. 5 opposes the pressure drops of the Raschig Super-Pak 250 and 300 to those of the B1-250 and B1-250M Montz packing. The Montz packing was measured at the SRP with the same test column structure.

It is noticeable that the course of the pressure drop for the Raschig Super-Pak 250 wSE does not differ from that of Raschig Super-Pak 300 woSE. Obviously, with the increased fluid content of the Raschig Super-Pak 250 wSE, the rough surface over compensates the normally expected pressure drop reduction due to the lower specific surface area.

Compared to the Montz packings, both Raschig Super-Pak surfaces achieved a substantially smaller pressure drop and a much greater capacity limit. In comparison, the B1-250 Montz standard packing indicated the highest pressure drop. The B1-

250M Montz high-performance packing offers significantly lower pressure drop than the B1-250, but again, the Raschig Super-Pak 250 wSE is significantly below this.

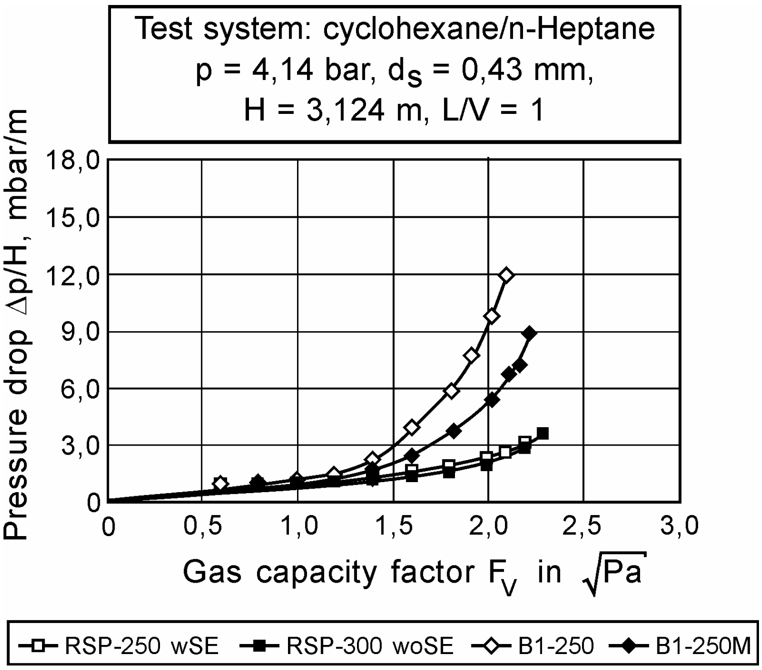


Fig. 5: The pressure drop of Raschig Super-Pak 250 wSE and the Raschig Super-Pak 300 woSE compared to the B1-250 and B1-250M Montz packing for rectification shown over the vapour capacity factor in the case of total reflux

The large differences in pressure drop and capacity characterize the fundamentally different fluid-dynamic properties of the Raschig Super-Pak. Through the perpendicular position of the lamellar packing structure, there is very little flow resistance for the gas. This also applies to the area between two packing layers, thus resulting in much greater capacities. The narrow lamellae further ensure that the packing sheet is coated by liquid from both sides, something which together with the surface corrugation leads to excellent mass transfer performance.

Evaluation and comparison of test results for the Raschig Super-Pak at p = 0.33 bar

Further comparisons are offered from distillation experiments at 0.33 bar. First, Fig. 6 (top) shows the comparison in separation performance of the Raschig Super-Pak 250 wSE in the form of the HETP value against the separation performance of the B1-250 and B1-250M Montz packing. With the B1-250M Montz high-performance packing~~,~~ separation performance is deteriorated when compared with the B1-250 standard packing. This is not seen with the Raschig Super-Pak. In fact, the HETP values of the Raschig Super-Pak 250 wSE are below those of the Montz 250 standard packing. Besides this, the Raschig Super-Pak 250 wSE is characterized by a much greater capacity than the two Montz packing types.

In Fig. 6 (btm) the Raschig Super-Pak 250 wSE is compared to the M250Y Sulzer standard packing and the M252Y Sulzer high-performance packing. This comparison also shows that the Raschig Super-Pak 250 wSE had the best separation performance and the greatest capacity.

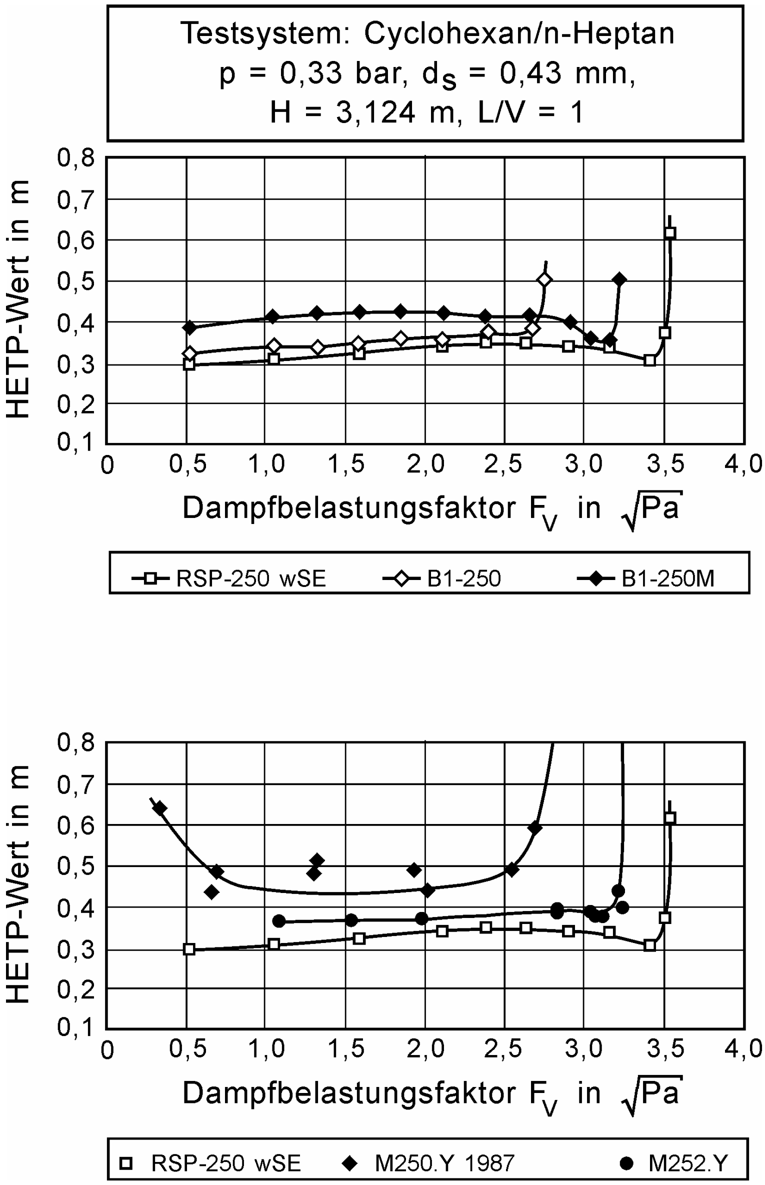
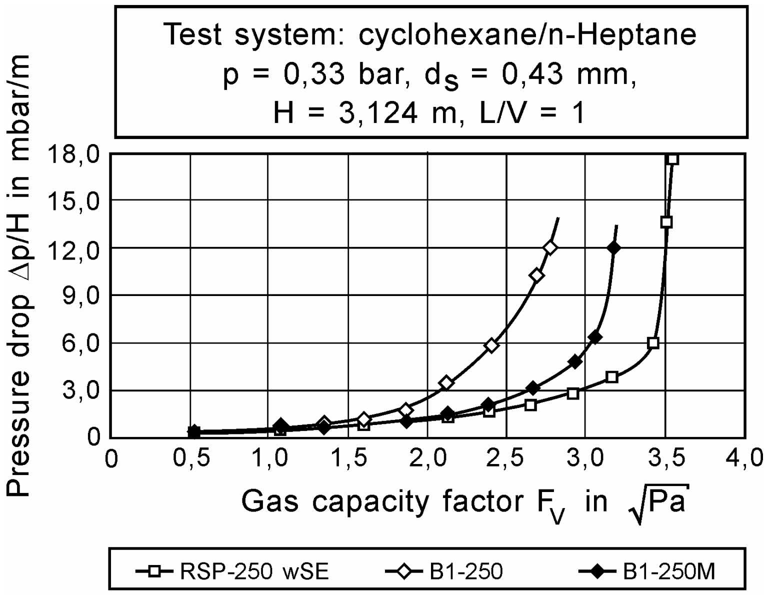


Fig. 6: Separation performance of the Raschig Super-Pak 250 wSE compared to the standard packing and high-performance packing of Montz and Sulzer for rectification shown over the vapour capacity factor in the case of total reflux. Sulzer packing is tested at FRI.

Fig. 7 shows the pressure drop comparisons between the Raschig Super-Pak and the Montz and/or Sulzer packing.

Again, compared to the Montz standard packing and the Montz high-performance packing, the Raschig Super-Pak's significantly smaller pressure drop and much greater capacity is evident. The same is true from the comparison made with the

Sulzer packing, where the course of the pressure drop of the M252Y Sulzer high-performance packing was just as low as the Raschig Super-Pak. The Raschig Super-Pak only achieved lower pressure drop than the M252Y Sulzer high-performance packing with high vapour capacity factors.



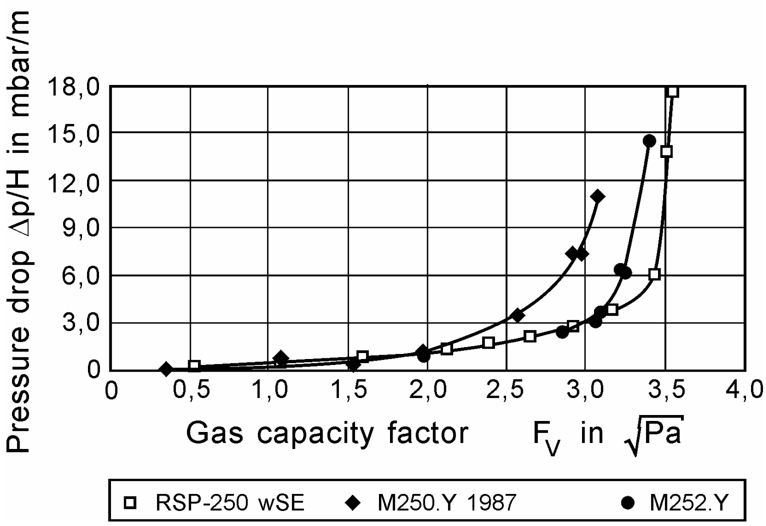


Fig. 7: Pressure drop of the Raschig Super-Pak 250 wSE compared to the standard packing and high-performance packing of Montz and Sulzer for rectification shown over the vapour capacity factor in the case of total reflux. Sulzer packing is tested at FRI.

When making a comparison with the Sulzer packing, it should be noted that the Sulzer packing was not ~~been~~ measured as part of the SRP but at FRI. FRI tests structured packing, while the same material system, but with a diameter of 1219 mm. This column is significantly larger than the one used in the SRP. In an earlier study, Olujic /4/ was able to show that the pressure loss of structured packing decreases with increasing column diameter. For this reason, with larger column diameters, the pressure drop of the Raschig Super-Pak could possibly turn out to be lower; however, this experiment has not yet been performed.

Figure 8 shows the comparison of the pressure drops per theoretical plate for the different packing structures. Particularly low pressure drops per theoretical stage are important for vacuum distillation. Again, the Raschig Super-Pak exhibits significant advantages over the Montz and Sulzer packings.

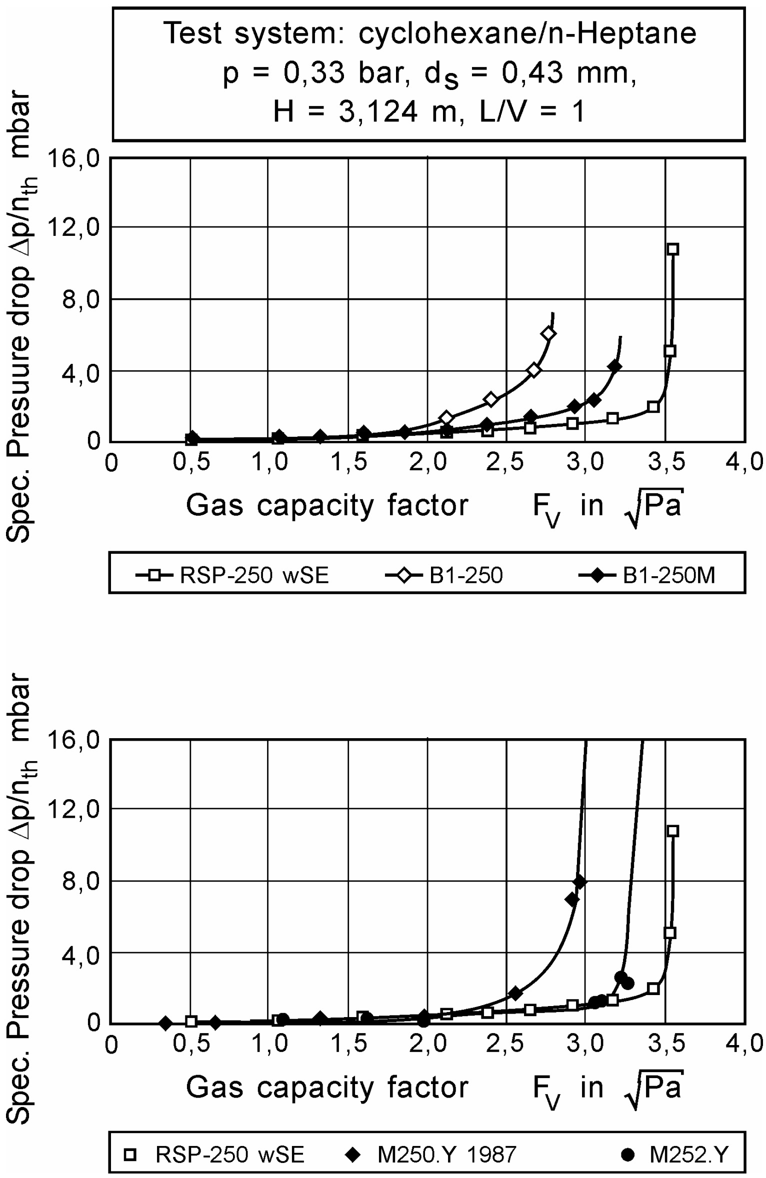


Fig. 8: Pressure drop per theoretical plate of the Raschig Super-Pak 250 wSE compared to the standard packing and high-performance packing of Montz and Sulzer for rectification shown over the vapour capacity factor in the case of total reflux. Sulzer packing is tested at FRI.

Assessing the capacity of structured packing at the design point

When making a comparison of capacities at the design point of mass transfer columns, one finds two fundamentally different approaches. Fig. 9 attempts to make this clear. Fig. 9 shows the separation performance and pressure drop of Montz packing compared to the Raschig Super-Pak.

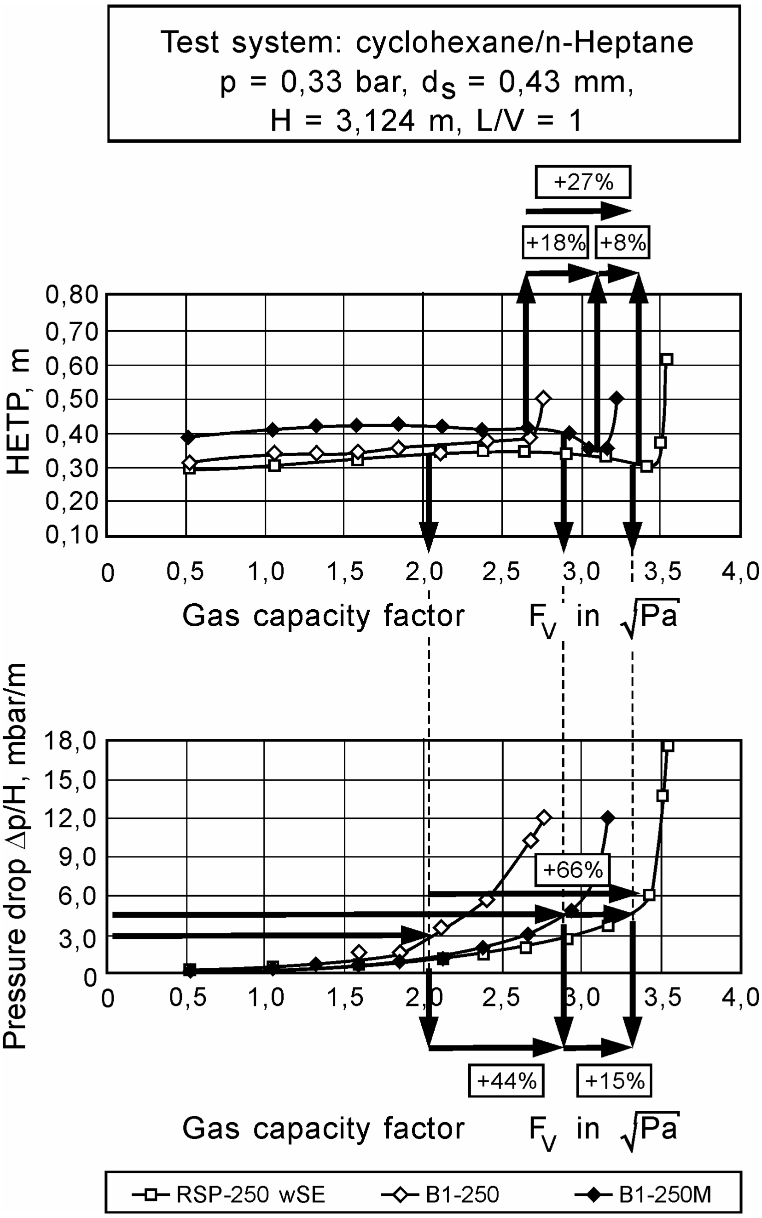


Fig. 9: Determination of the capacity limits of structured packings in a rectification process

1st approach: Standard packing such as the B1-250 Montz packing is often designed for a maximum pressure drop of 3 mbar/m, see Fig. 9 (btm). High-performance packings such as the B1-250M Montz packing is designed for greater permissible pressure drops, e.g, 5 mbar/m. A 44% capacity increase results. If one applies the same pressure drop criterion of 5 mbar/m for the Raschig Super-Pak 250 wSE, there is a capacity increase of 66% compared with the standard packing and a capacity increase of 15% compared to the Montz-type high-performance packing. The upper diagram shows the corresponding separation performance. It is clear to see that for this type of evaluation, the high-performance packing types move significantly closer to the flood limit, so that under certain circumstances, the column operation reacts more sensitively to load fluctuations.

2nd approach: A different kind of capacity comparison ~~of~~ is based on comparing the percent capacities on flood-point comparison of a packing structure (vertical rise of the function curves in the case of separation performance and pressure drop). Similar values for comparing capacities is offered by applying the last effective separation point on the separation performance diagram, see Fig. 9 (top). With these comparative criteria one obtains an 18% increase in capacity amongst high-performance packing compared to standard packing. In this comparison, the Raschig Super-Pak achieved an 8% increase in capacity compared to Montz high-performance packing and a 27% increase in capacity compared to the Montz standard packing.

The design of a distillation column takes place according to this observation: e.g., with a vapour load which corresponds to 75-80% of the flood point. Table 1 provides a summary of the capacity gains to be expected with the Montz and Sulzer high-performance packing compared to their standard products. As a basis for comparison, the last effective separation point of the products is used in accordance with Fig. 9 (top). The basis for comparison (100%) is represented by the capacity of the B1-250 Montz standard packing. The table also shows the capacity gains when using the Raschig Super-Pak.

Impressively, it is clear that in comparison with their standard products, the capacity gains of high-performance packings can sometimes be doubled if the Raschig Super-Pak is used. The fact that these gains in capacity are also accompanied by a separation performance gain of approximately 5-15% when compared to Montz or Sulzer high-performance packing is particularly impressive.

Summary

On the basis of the experiments presented it can be seen that the Raschig Super-Pak represents a fundamentally new design geometry for structured packing which leads to significant advantages in separation performance, capacity and pressure drops compared to standard packing and to other high-performance packing. It is astonishing that at the same time, the benefits show up which are due to the optimal fluid dynamics of the geometry. Apart from low levels of flow resistance inside the packing, there is in an unobstructed transgression of gas between the packing layers. In addition, the narrow lamellae of the Raschig Super-Pak ensure that the liquid has the tendency to wet the structure simultaneously from both sides.

Nomenclature

d	Diameter, m
F_V	Vapour or gas capacity factor $u_V \cdot \sqrt{\rho_V}$, $\sqrt{Pa}$
H	Height, m
L	Mole flow rate of the liquid, kmol/h $^{-1}$
n_{th}	Number of theoretical plates
p	Pressure, bar
u_L	Liquid velocity, related to the free column cross section, $m^3/m^{-2}h$

u_V	Vapour velocity, related to the free column cross section, m^3/m^2s
V	Mole flow rate of the gas, kmol/h
HETP	Height equivalent to the theoretical plate, m

Greek Symbols

ΔP	Pressure drop, mbar/m
ρ	Density, kg/m^3

Indices

L	Liquid
S	Column
V	Vapour or gas

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[4] Z. Olujic, *IChemE* **1999**, *77 (A)* 505-510

Tab. 1: Comparison of the capacities of different packings for various column pressures

	Standard packing		High-performance packing		
Product supplier	**B1-250 Montz**	**M250Y Sulzer**	**B1-250M Montz**	**M252Y Sulzer**	**RSP 250 Raschig**
p = 4.140 bar	100 %	--	110 %	--	122 %
p = 0.333 bar	100 %	95 %	118 %	120 %	127 %