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Performance characteristics of a new high capacity structured packing[☆]

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Abstract

Total reflux distillation results of a comprehensive experimental study are reported for a new generation of Montz high capacity structured packings. The major feature of the Montz B1-M® series is a smooth bend in the bottom third of the corrugation with continuously increasing corrugation base width. A comparison is made with the performance of conventional structured packing under the same test conditions. The relationships between specific surface area, pressure drop, capacity, and separation efficiency are discussed.

Keywords: Structured packings; High capacity; Pressure drop; Mass transfer efficiency

1. Introduction

In answer to the latest cry for more capacity at minimum investment, some packing manufacturers have managed to increase the capacity of their packings by adopting simple but effective modifications in the geometry of the top and/or bottom ends of the elements [1]. To maintain efficiency, a corrugation angle of 45° is used. Namely, as illustrated in a previous study by Olujic, Seibert and Fair [2], if the angle of corrugation is increased to 60°, the capacity increases significantly. However, the percentage increase appears to be roughly equal to the percentage decrease in mass transfer efficiency. As a result, it is not feasible to revamp existing columns equipped with 45° packing by simply increasing the corrugation angle.

The standard structured packing with a corrugation angle of 45° results in a 90° change in the gas flow direction at the transitions between packing elements (layers) which at higher gas loads causes pronounced liquid build-up. Thus, at high gas loads, drainage of liquid from packing elements is difficult. The accumulation of excess liquid within the element transitions appears to be the limiting factor for increasing capacity. Experimental evidence was reported by Suess and Speigel [3] and soon afterwards, the first packing modification was patented [4,5] and licensed under the trade name 'Flexipac®HC™' [6]. Sulzer Chemtech followed with an elegant and effective solution known as 'MELLAPAKPLUS' [7]. Characteristic features of Flexipac®HC™ and Mellapak Plus are described elsewhere [1,8].

During the ACHEMA Exhibition, held in May 2000 in Frankfurt, Germany, J. Montz introduced their version of high capacity packing. As shown in Fig. 1, the major feature of the Montz-pakM® series is a smooth bend of the bottom third of the corrugation with continuously increasing hydraulic diameter.

In recent years, another development that has profoundly altered the design of packing surface area is the reduction of metal thickness (down to 0.1 mm or even less).

This paper presents results of a recent comparative total reflux study carried out with new Montz packings

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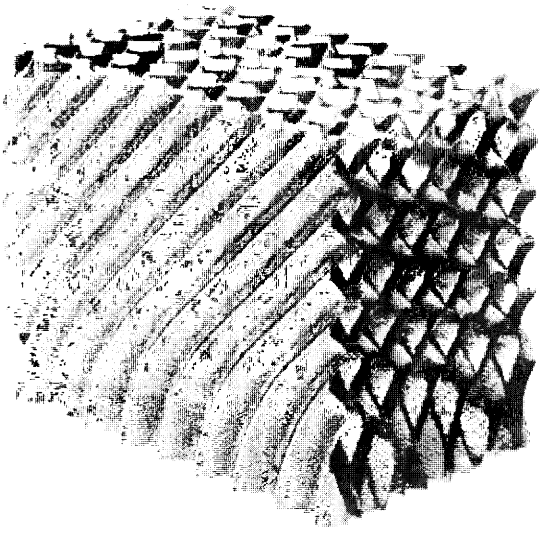

Fig. 1. Photograph of a segment of J. Montz high-capacity packing B1-250M.

evaluated at different operating conditions. A comparison is made with the performance of conventional structured packings under identical test conditions and an indication is given on the relationship between specific surface area, pressure drop, capacity, and separation efficiency.

2. Experimental

Total reflux distillation experiments were carried out at Separations Research Program (SRP) using a bed height of approximately 3.3 m. The standard cyclohexane/n-heptane test system was utilised. The effects of system properties were determined through operation at pressures of 0.17, 0.33, 1.03, and 4.14 bar. All comparative tests were carried-out using a wide range (5–50 m^3/m^2 h), narrow trough drip tube distributor (145 drip points per m^2) supplied by Montz. A thorough description of the experimental set up and procedures can be found elsewhere [2].

The major dimensions of the Montz-packings considered in this study are reported in Table 1. The B1-250NEW is common B1-250 packing manufactured with a thinner material (0.1 mm) relative to the standard wall thickness of 0.15–0.17 mm, called here B1-250OLD.

The hydraulic results in terms of pressure drop per unit height ($\Delta p/\Delta z$) and mass transfer efficiency represented as height equivalent to a theoretical plate (HETP) are plotted against the vapour load (F-factor). The F-factor is defined as the product of superficial vapour velocity and the square root of the vapour density, and is based on the column bottom conditions.

Since the cyclohexane/n-heptane system is essentially an ideal mixture, the number of equilibrium stages at total reflux may be calculated from the distillate and bottoms compositions using the Fenske equation and an average relative volatility. Values of pertinent physical property data are given in Table 2. The effects of chemical properties can be observed by operating at different pressures.

It should be noted that a number of significant operational improvements were made to the SRP total reflux distillation system a few years ago. A new, advanced process control and data acquisition system (Fisher-Rosemount Delta-V) was implemented along with new insulation of the column sump section. In addition, prior to 1997 flooding data were obtained during the initial wetting of the packing, i.e. as part of the start-up procedure. However, the time involved was too short for the column to reach thermal equilibrium, and this generally ensured accuracy within ±10% in flooding point data. With increased interest in capacity, the accuracy of 10% became inadequate, and a more stringent operational procedure was adopted. This procedure implies very careful approach to the flooding point, 24-h operation, and runs arranged in increasing pressure. As a result, tests of the B1-250 structured packing were re-run. While the repeated tests showed similar efficiencies, the capacity was observed to be approximately 10% less.

3. Results and discussion

The effects of operating pressure on pressure drop, capacity and the mass transfer efficiency of the standard corrugated sheet packing made of thinner sheets (B1-250NEW) are shown in Fig. 2. As expected, efficiency

Table 1
Characteristic dimensions of structured packings considered in this study

	a_p (m^2/m^3)	ε (−)	h_{pe} (m)	h (m)	b (m)
B1-250OLD	244	0.98	0.197	0.012	0.0224
B1-250NEW	247	0.985	0.197	0.012	0.022
B1-250M	250	0.98	0.205	0.0116	0.0200
B1-350	346	0.97	0.201	0.008	0.0167
B1-350M	350	0.97	0.208	0.008	0.0147

Table 2
Physical properties of the cyclohexane/n-heptane system (average at bottom conditions) at operating pressures employed in this study

Pressure (bar)	0.17	0.33	1.03	4.14
Property				
Average temperature (°C)	49	61	97	154
Liquid density (kg/m^3)	659	657	625	561
Liquid viscosity (Pa s)	4.67 E-4	4.31 $E-4$	2.97 $E-4$	1.61 $E-4$
Liquid diffusivity (m^2/s)	2.31 E-9	2.72 $E-9$	4.44 $E-9$	9.17 $E-9$
Vapour density (kg/m^3)	0.66	1.19	3.53	13.14
Vapour viscosity (Pa s)	6.67 $E-6$	6.94 $E-6$	7.78 $E-6$	9.17 $E-6$
Vapour diffusivity (m^2/s)	13.30 $E-6$	11.40 $E-6$	4.17 $E-6$	1.39 $E-6$
Surface tension (N/m)	0.018	0.017	0.014	0.008
Relative volatility	1.94	1.86	1.64	1.42
Slope of equilibrium line	1.54	1.50	1.35	1.32
Liquid load (m^3/m^2 h), at F-factor = 2 m/s (kg/m^3)$^{0.5}$	8.88	11.95	21.64	46.52

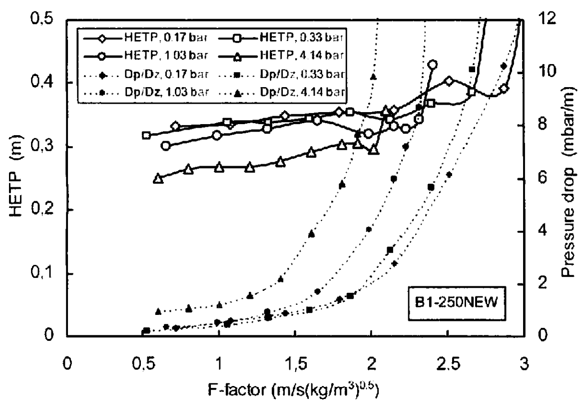

Fig. 2. Effect of the operating pressure on the hydraulic and mass-transfer performance of the thin wall B1-250 packing (total reflux, cyclohexane/n-heptane, $d = 0.43$ m, $h_{\mathrm{pb}} \approx 3.3$ m).

improves and capacity (maximum F-factor) decreases with an increase in operating pressure. Striking is the absence of a pronounced deteriorating trend in efficiency with increasing F-factor, as observed in the preloading range with the standard packings [2].

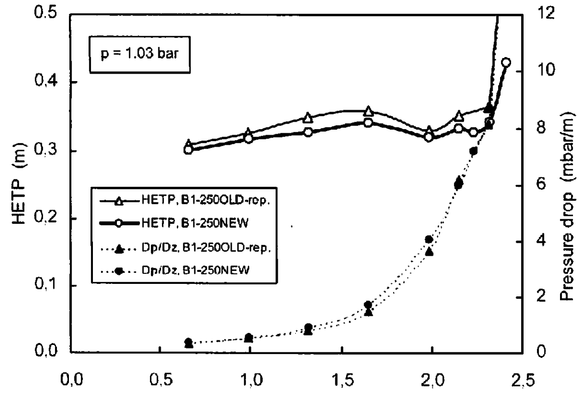

Fig. 3. Comparison of the total reflux distillation performances of standard (B1-250 OLD-rep) and thin sheet version (B1-250NEW) of this packing (cyclohexane/n-heptane, 1.03 bar, $d = 0.43$ m, $h \approx 3.3$ m, 'OLD-rep' refers to the test repeated with the same packing in 2000).

The repeated test results of the B1-250 at atmospheric pressure are compared with the new (thin sheet) B1-250 design in Fig. 3. The efficiency of new (B1-250NEW) packing is less sensitive to the increase in F-factor than that of the old one (B1-250OLD-repeated). The same trend is observed at other operating pressures. The pressure drop of the B1-250NEW is generally higher except at 4.14 bar where the curves overlap. A comparatively better efficiency of the new packing could be attributed to some extent to the increased pressure drop. Somewhat rougher packing, resulting from the thinner metal, may be responsible for the increased pressure drop.

The performance characteristics of the high capacity packing (B1-250M) made of standard thickness metal sheets are shown in Fig. 4. The packing behaves similarly to the standard packing with respect to the effect of the operating pressure. The more-rounded pressure drop curves indicate a rather smooth transition from the pre-loading into the loading range and subsequently a less pronounced point of onset of flooding. The good and stable performance of the standard packing is observed at all operating pressures with a

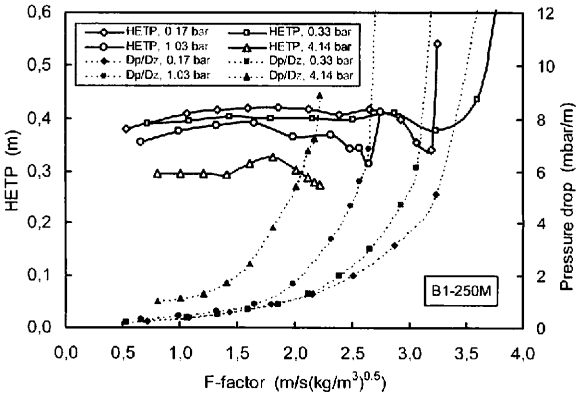

Fig. 4. Effect of the operating pressure on the hydraulic and mass-transfer performance of Montz-pak B1-250M (total reflux, cyclohexane/n-heptane, $d = 0.43$ m, $h_{\mathrm{pb}} \approx 3.3$ m).

pronounced improvement upon entering the loading range. There is a small deterioration in efficiency around the loading point at 4.14 bar which resembles the well known 'efficiency hump' effect observed in high-pressure distillations. It should be noted that both the surface tension (0.008 N/m) and the liquid load corresponding to higher F-factors at 4.14 bar (above 35 m^3/m^2 h) are in the range of that involved in typical high pressure distillations.

The extent of improved performance is striking in the loading range at high liquid loads and may be attributed to the beneficial effect of modified packing geometry (lower part of each element with 60 mm section with nearly vertical walls). In the straight section of the channel, the vapour does not hit any inclined surface and, thus, it is not forced to change the flow direction abruptly. This also allows liquid to be drained smoothly. The entrained liquid is fluidised to some extent because of the relatively large open space, particularly in the vertical direction. This allows creation of significant additional interfacial area, which in conjunction with strong mixing enhances mass transfer in the immediate vicinity of flooding point. The typical sudden drop in efficiency is not observed at 4.14 bar because the maximum reboiler capacity was reached before the flooding point condition.

Figs. 5 and 6 compare the performance of standard and modified, high capacity packings at operating pressures of 0.17, 0.33, 1.03 and 4.14 bar. The corresponding performance curves of the packing with larger specific surface area (350 m^2/m^3) are added for comparison purposes. A good and stable performance of the standard packing is observed at all operating pressures with only a slight deterioration with increasing F-factor at 4.14 bar. As expected, the mass transfer performance improves with increasing pressure. The same is true with the modified packing but with a certain degree of deterioration in the loading region. This is particularly the case at 4.14 bar operation where a pronounced 'efficiency hump' is visible.

Obviously, the packing with a bend in the lower part of each corrugated sheet can be operated at considerably higher F-factors than the standard packing. On average, using a pressure drop of 3 mbar/m as reference, the capacity gain in case of the B1-250M packing is around 23% and in the case of B1-350M packing around 30%. However, in both cases, the relative gain in capacity decreases gradually with increasing operating pressure, i.e. liquid load. However, the capacity gain is accompanied by some loss in efficiency, which is demonstrated in Fig. 7. The loss at 4.14 bar is less pronounced.

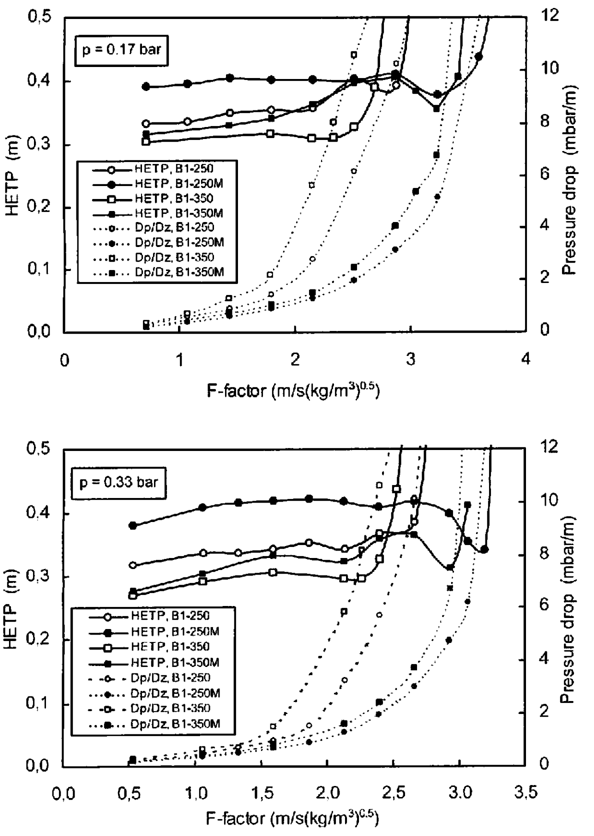

Fig. 5. Comparison of total reflux distillation performances of common and high-capacity 250 and 350 series packings at 0.17 and 0.33 bar (cyclohexane/n-heptane, $d = 0.43$ m, $h_{pb} \approx 3.3$ m).

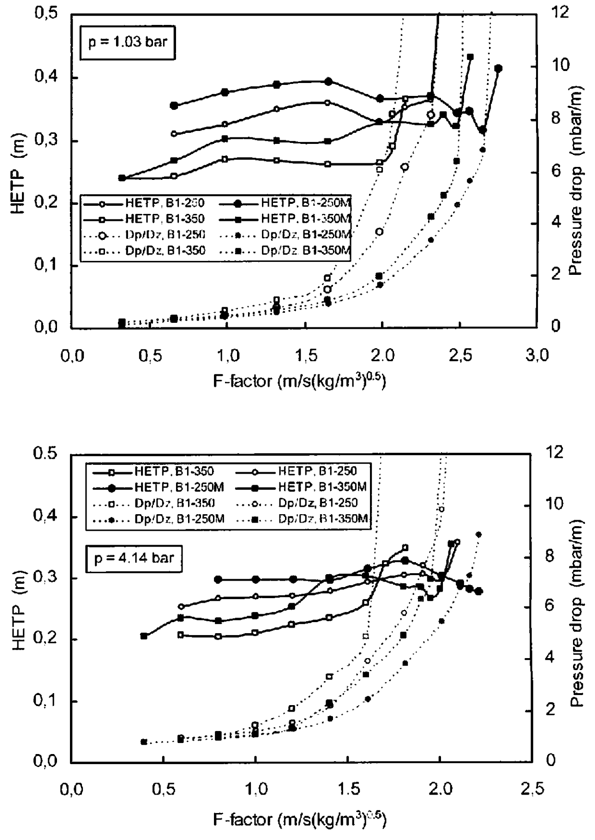

Fig. 6. Comparison of total reflux distillation performances of common and high-capacity 250 and 350 series packings at 1.03 and 4.14 bar (cyclohexane/n-heptane, $d = 0.43$ m, $h_{pb} \approx 3.3$ m).

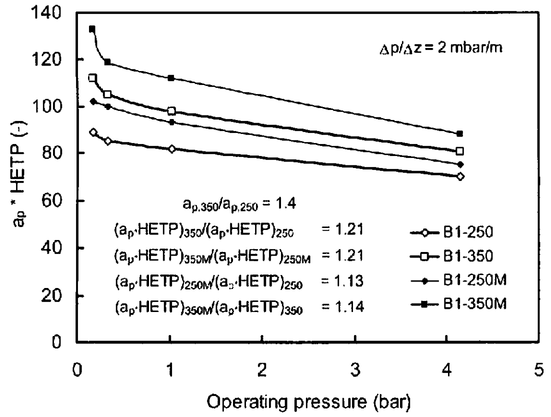

Fig. 7. Relative surface utilisation efficiency as a function of operating pressure (total reflux, cyclohexane/*n*-heptane, $d = 0.43$ m, $h_{pb} \approx 3.3$ m).

Namely, Fig. 7 shows the dimensionless product of the specific surface area and HETP as a function of the operating pressure for both packing sizes in the standard and high capacity design. The values correspond to a preloading region *F*-factor equivalent to a pressure drop of 2 mbar/m. The characteristic ratios indicate the relative performance. Clearly, the larger surface area packings appear to use their available surface less efficiently. The average performance enhancement in case of 350 series packings is 21% with respect to standard size, while the ratio of specific surface areas (1.4) suggests that lower HETP values could be expected. The corresponding ratios for the same size of the packing area indicate that the high capacity packings are roughly 14% less efficient in the pre-loading region than their standard counterparts. Possible reasons for this loss of efficiency are discussed elsewhere [1].

Certainly, the trend in efficiency is similar for both packing sizes in the pre-loading region. However, in the loading region, the effect of *F*-factor is significant. As previously mentioned, the efficiency of standard size (250 m^2/m^3) packing deteriorates rather slowly with increasing *F*-factor. Upon reaching the load point, the efficiency improves considerably and reaches the level of the efficiency of standard packing. The relatively high efficiency is maintained until the point of flooding is reached. Therefore, it may be expected that in the range of potential applications, the B1-250M packing will operate with similar efficiency as the original packing in its range of applications. In other words, columns previously equipped with B1-250 packing can be revamped with B1-250M packing. On the otherhand, the efficiency of B1-350M packing goes through a more pronounced deterioration just before the loading region, then improves as the *F*-factor approaches the flooding point. Hydraulically, there is no difference, i.e. the packing operates with a considerably lower pressure drop and behaves similar to the standard size packing. Nevertheless, the somewhat reduced free space (in all directions) in the curved bottom part of corrugations appears to provide to a less favourable mass transfer interaction of phases. As a result, one should expect an efficiency loss of 10–20% for the B1-350M packing relative to the standard packing (B1-350).

4. Conclusions

The new B1-250 packing, made of 0.1 mm thin metal sheets, provides more efficiency than the standard thickness one at practically the same capacity. The high-capacity version of this packing (B1-250M) enables efficient operation at substantially higher vapour loads.

In addition, the larger surface area packing, B1-350, performs well at all pressures. However, it achieves relatively less mass transfer efficiency from its installed surface area relative to the B1-250 packing. The impressive capacity gain of B1-350M is accompanied by an appreciable loss of efficiency which is more pronounced in the loading region.

With regard to the observed efficiency trends, future efforts may shed some light on the reason for the 'efficiency hump'.

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Appendix A: Nomenclature

a_p	specific surface area (m^2/m^3)
b	corrugation base length (m)
F-factor	$u_{Gs}\,(\rho_G)^{0.5}$ = vapour (gas) load factor (m/s) $(kg/m^3)^{0.5}$
HETP	height equivalent to a theoretical plate (m)
h	corrugation height (m)
h_{pe}	height of the packing element (m)
u_{Gs}	superficial vapour (gas) velocity (m/s)

Greek letters

$\Delta p/\Delta z$	pressure drop per unit length (mbar/m)
ε	packing void fraction (porosity) (m^3/m^3)
ρ_G	density of vapour (gas) (kg/m^3)

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