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MAXIMIZING THE PERFORMANCE OF CORRUGATED SHEET STRUCTURED PACKINGS

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Abstract
Total reflux distillation experiments carried out using state of the art test facilities at Bayer TS with newest generation of J. Montz structured packings indicate that by combining appropriately the dimensions and design of corrugations and the corrugation inclination angle, i.e. by affecting the pressure drop accordingly, either efficiency or capacity, or even both can be enhanced significantly, depending on the type of the packing. This allows leaner columns in new designs and more capacity and other benefits in retrofit situations. Delft model, with appropriate geometry modifications, proved capable of predicting the observed trends. The estimates of the pressure drop seem to be consistently lower than measured and the deviation from experiments tends to increase with increasing specific geometric area of the packing, while the predicted points of onset of loading are close to observed ones. On the efficiency side, the predictions appeared to be conservative; however a fairly good agreement with experiment is obtained if installed specific geometric area is used as effective area.

Keywords: Distillation, structured packings, total reflux, high performance packings

1. Introduction

As observed during hydraulic tests performed with air/water system with a prototype of B1-250M packing, a long smooth bend on bottom side of corrugations proved to be a simple but highly effective geometry modification that enabled significant capacity increase with respect to conventional Montz B1-250[1]. Indeed enabling a smooth transition of both the ascending vapour and more importantly for the descending liquid, which tends to accumulate at transition of packing element or layers at sufficiently high vapour load[2], was the key to success in this case. Subsequently the prototypes of B1-250M and B1-350M have undergone total reflux distillation tests, which were performed at the Separations Research Programme (SRP) of the University of Texas at Austin in a column with the internal diameter of 0.43 m. The total reflux distillation tests were carried out with cyclohexane/n-heptane (CH/nH) at pressures of 0.17, 0.33, 1.03, and 4.14 bar, respectively[3].

These tests confirmed that the M-series packings can be operated within the extended loading region at the same efficiency as conventional counterparts. In the meantime, a comparison of liquid distribution characteristics of B1-250 and B1-250M was carried out using TU Delft 1.4 m diameter air/water column hydraulics simulator. The large scale liquid distribution and mixing, which occurs at transitions between packing elements, appeared to be consistently good, and, in this respect, the performance of B1-250M was even better[4]. Interestingly, this packing exhibited a more pronounced wall flow, which however is avoided in practice by installing properly working wall wipers. In the meantime both packing sizes have been installed in numerous columns and proved to work accordingly in both new designs and revamps.

However the total reflux distillation tests performed at SRP indicated a certain loss of efficiency in preloading range, where M-packings operate at a relatively lower pressure drop. Main part of the reduction in overall pressure drop comes from avoiding sharp bends at transitions of packing elements or layers. Another significant contribution in this respect results from the fact that a long bend reduces strongly the number of crossings of gas flow channels, which is reflected in a less pronounced pressure drop due to interaction of crossing vapour flows. The latter is generally considered to be more useful because it is associated with mixing of crossing gas flows (maintenance of concentration gradient within a packing element) and superimposition of swirling flow pattern on gas flowing through triangular flow channels that enhances interaction of two phases at the interface.

Since capacity and efficiency are generally interdependent, and capacity more affected by the liquid handling than by the pressure drop associated with transitions between subsequent packing elements, it was conjectured that reducing the length of a bend, i.e. increasing the number of gas/liquid interactions per flow channel length could be beneficial for efficiency. Similar effect could be expected from a reduction in the corrugation inclination angle, i.e. going below common 45 degrees, which however, as suggested by Delft model[5], strongly influences the pressure loss. So the challenge was to arrive at a favourable corrugation geometry i.e. that maximizing the desired gain in efficiency with an acceptable penalty on pressure drop side, and vice versa, including standard sheet metal and expanded metal packings with a large specific geometric area. Figure 1 shows schematically the original structure and geometry parameters manipulated. Since the imperforated surface of large specific geometric area B1-series packings proved to be sensitive to upsets in efficiency at column loads associated with those achievable with high-capacity packings, these packings have been provided with a regular pattern of holes (see Fig. 2).

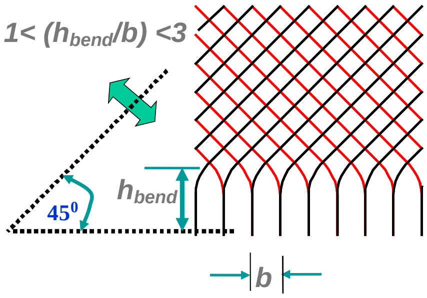

Figure 1. Schematic illustration of the structure of "M" series packings, indicating manipulated geometry parameters

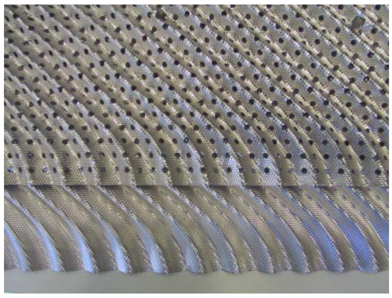

Figure 2. Corrugated sheets of B1-MN type packing, with and without perforations

Upon completing a series of screening tests at TU Delft, packing geometry adjustments (perforations, corrugation bend length and inclination angle balanced) have been implemented and representatives of different types and sizes of new packings thoroughly tested using total reflux distillation facilities available at Bayer Technology Services in Leverkusen, Germany. These data have been used to validate Delft model.

2. Experimental

The packing tested were three common sizes of sheet metal B1-MN series packings, with specific geometric of 250, 350, and 500 m^2/m^3, respectively. Also a representative of new generation of extended metal packings, i.e. BS-500MN, was tested on this occasion. Since these packings differ from the first generation of high capacity packings denoted as "M", the second generation, more appropriately called high performance packing, is denoted as "MN". In general, these packings are characterized by a shorter bend and a lower corrugation inclination angle, with respect to that of M series, with specific values correlating with corrugation dimensions.

A flowsheet of the state of the art total reflux installation available at Bayer Technical Services (BTS) in Leverkusen, Germany, used in this study, can be found elsewhere[6], together with the detailed description of the experimental procedure and a table containing representative values of physical properties. The heart of this installation is a 0.588 m internal diameter column that can accommodate beds up to 4 m height. The test system was the ideal, close boiling mixture of chlorobenzene/ethylbenzene (CB/EB), which is also the standard system adopted long ago at Sulzer[6], and the operating pressures were 100 and 1000 mbar, respectively. To ensure the proper initial liquid distribution, for each of two operating pressures a separate narrow trough liquid distributor was used. One should note that irrigation density based on the number of equidistantly placed drip tubes was that corresponding to requirements, however in some cases it was maximized by adding Montz proprietary devices (Type S), which ensure proper wetting of packing surface even at such low specific liquid loads as encountered with CB/EB system at 0.1 bar. Packings have been delivered in single elements, and installed in heights either of 2 m (10 elements or layers) or 3.4 m (17 elements), each element rotated to previous one by 90 degrees.

Relevant properties of the mixture, i.e. densities, viscosities, specific heat capacity, enthalpy of evaporation, and vapour pressure were determined on additive basis for top and bottom conditions. Geometric average was used for column relative volatility, which together with measured top and bottom conditions was used in conjunction with Fenske equation to determine the number of theoretical plates, N, contained in the bed. Both, efficiency expressed as the bed height equivalent to a theoretical plate (HETP = h_{bed}/(N-1) and measured bed pressure drop were plotted as a function of the average F-factor. The latter is an arithmetic average of top and bottom values.

3. Results and Discussion

Figure 3 shows performances of B1-250MN, B1-350MN, and B1-500MN packings as observed at 0.1 bar, including for comparison the data for B1-500MN obtained at the pressure of 1 bar. As expected both the efficiency and pressure drop increase with increasing specific geometric area. One should note that the observed efficiency for this close boiling system is high, generally higher than that observed with cyclohexane/n-heptane(CH/nH) system at the similar conditions[7]. However, the trends, i.e. the extent of deterioration in the efficiency with increasing F-factor, depending on packing specific area, is similar to that observed with CH/nH system. The efficiency of 250 m^2/m^3 packing tends to decrease with increasing F-factor, i.e. vapour and liquid load. In case of 350 m^2/m^3 packing, the slope of HETP curve is less pronounced and the 500 m^2/m^3 packing seems to be insensitive in this respect. Striking is the performance of B1-350MN, suggesting that this fully optimized packing can operate smoothly at very high capacity, similar to that of B1-250MN, which reaches the maximum efficient capacity at a pressure drop of around 9 mbar/m, and performs still well under hydraulic flood conditions. Indeed the performance of B1-350MN is strikingly good; it approaches the larger specific area packing in efficiency and smaller specific area packing in capacity.

Interestingly, at the lowest F-factor the efficiencies of three packings are close to each other, and with increasing F-factor tend to diverge, approaching at the high end the values corresponding to the ratios of specific geometric areas. This indicates indirectly that low area packing uses much more effectively the installed area than the packing with largest specific geometric area.

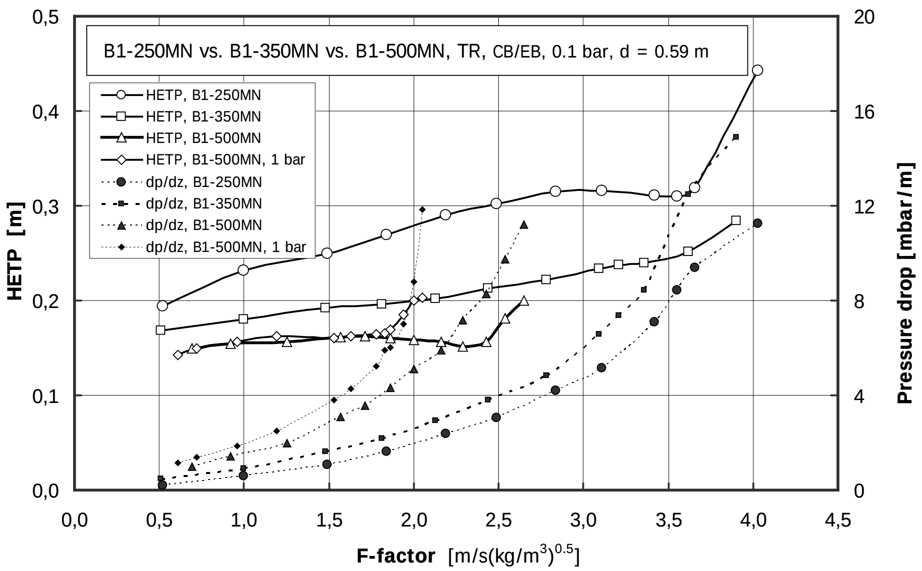

Figure 3. Effect of specific geometry area and operating pressure on efficiency, pressure drop and capacity of high performance structured packings

This is clearly illustrated in Fig. 4, which shows the relative surface utilisation efficiency, expressed by dimensionless product of specific geometric area and corresponding HETP values, as a function of F-factor. The lower the value of the product of the specific geometric area (a_p) and the HETP the better is the packing performance. Clearly the best utilisation of the installed area is evident in case of B1-250MN, and this is most pronounced at lowest F-factors, where this packing exhibited approximately 1.6 times better efficiency than at the loading point. This indicates that the effective area was at its maximum, relative to installed area. Since the highest efficiency of B1-250 MN packing at lowest F-factor, expressed as ratio of (a_p * HETP) values, appeared to be approximately 62 per cent of that achieved with B1-500 MN packing, the wetting of the latter may be considered as being much less effective under same operating conditions. This is in accordance with earlier experiences gained with conventional B1-series packings, indicating that the relative effective area tends to decrease with increasing specific geometric area. This is something inherent to the geometry of shallow embossed surface corrugated sheets where the radius of the crimp angle tends to decrease with increasing specific geometric area, i.e. decreasing dimensions of corrugations. Namely, a factor 2 difference in the specific geometric area implies the same difference in the number of parallel flow channels. Doubling the number of flow channels in conjunction with sharper corrugation ridges means a reduced capability of the liquid to go over the corrugation ridges to neighbouring channels, thus less effective wetting of the installed surface area.

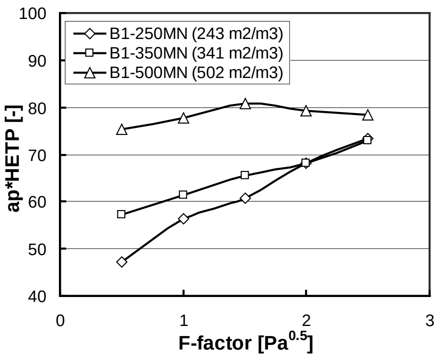

Figure 4. Relative packing utilisation efficiency as a function of F-factor

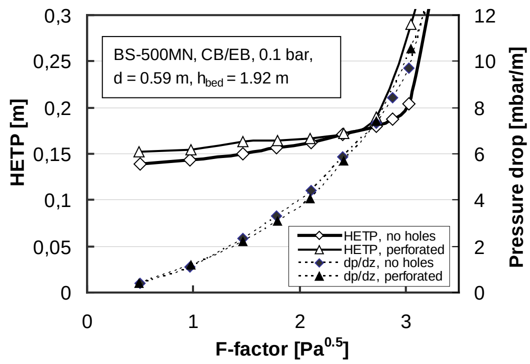

Figure 5. Effect of perforations on performance of expanded metal structured packing

Increased liquid load should be beneficial in this respect. However, as illustrated in Fig. 3, the efficiency of B1-500MN exhibits the same trend and same values at 0.1 and 1 bar operating pressure, while in the latter case the specific liquid load is approximately three times larger. Identical behaviour has been observed with Sulzer packings tested with the same system at similar operating pressures[7]. As expected, on hydraulics' side this leads to an increased pressure drop and correspondingly reduced packing capacity. Similar behaviour was observed in the tests carried out with CH/nH system[3], but in that case B1-series packings have shown some improvement in efficiency with increasing operating pressure. The B1-series packings compared in Fig. 3 were provided with perforations, i.e. a regular pattern of 4 mm holes. These appeared to be essential for B1-500MN packings to perform accordingly in loading region. However, the expanded metal packing with the same specific area and corrugation design does not require perforations to perform well over the whole range of operating conditions. According to the Fig. 5, unperforated BS-500MN packing exhibits a smooth and stable performance up to the point of onset of flooding, which is some 15 per cent beyond that of perforated counterpart as well as B1-500MN. Somewhat lower but very stable efficiency in the loading region is mainly due to the absorbing effect of expanded material which allows the liquid to be pushed through to the other side of the sheet to allow pressure equalization of neighbouring channels. A considerably higher price of the material makes expanded metal packings less interesting economically, however the beneficial pressure drop could make it to be an interesting alternative for B1-series packings in pressure sensitive applications.

On the other hand, as known from earlier evaluations, B1-250MN performs practically equally with and without perforations. According to Fig. 5, it appears that efficiency of BS-500MN in the loading region is not affected by perforations. However, in preloading region the perforated packing, with a regular pattern of 4 mm holes, which effectively reduce the installed area up to 10 per cent, exhibits nearly equivalent loss of efficiency. This should be kept in mind, because if a reduction of specific geometric area by 10 per cent is accounted for in the Delft model[5] this will reduce efficiency accordingly, which is not justified in present case. Moreover, a rather high efficiency achieved with lower specific area packings in conjunction with rather low specific liquid load (1 - 3 m^3/m^2h), as encountered with CB/EB system at 0.1 bar, at F-factors below 1 $Pa^{0.5}$, suggests that the degree of deterioration in wetting with increasing specific area and decreasing liquid load, as predicted correctly for CH/nH system by extended Onda correlation[5] does not hold quantitatively in present case. This appeared to be truth in present case.

Figure 6 shows the efficiencies and pressure drop of three packings as predicted by Delft model, assuming that effective (interfacial) area is equal to specific geometric area. The predicted trends in both efficiency and pressure drop agree fairly well with observed ones. Quantitatively, the predicted efficiency is in case of B1-250 MN and B1-350 MN on safe side, the latter quite close to observed one, while the pressure drop prediction in both cases is on the optimistic side.

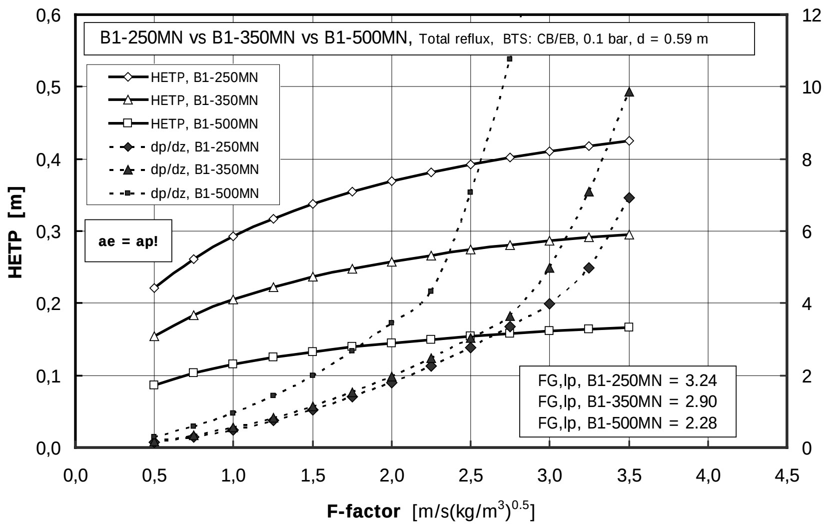

Figure 6. Predicted performance of the packings with different geometric specific areas

Figure 7 shows a direct comparison of measured and predicted values in the case of B1-500MN. Predictions are based on assumption of full wetting of installed packing area. At 0.1 bar, predicted efficiency is highest at lowest F-factor, and tends to decrease with increasing F-factor, matching the measured one in the loading region. Interestingly, in case of 1 bar operation the predicted efficiency shows the same trend but it is consistently lower than the measured one. Striking here is the discrepancy between theory and experiment regarding the pressure effect. Namely both BTS and Sulzer experiments show absence of any pressure related effect, while the predictions indicate much higher efficiency in 0.1 bar case. This is attributed to the fact that for the same effective area the model fully reflects the factor five difference in the value of diffusion coefficient of the vapour. Since the contribution of liquid side resistance is minor in present case, it may be assumed that the efficiency loss/gain due to a factor five variation in the vapour diffusion coefficient is compensated by an equivalent increase/decrease of effective area, caused by a factor three difference in the specific liquid load. Predicted pressure drop trends resemble the measured ones, however difference for 0.1 and 1 bar operation in preloading region is much less pronounced than in the experiment. Unfortunately, in both cases the pressure drop is under-predicted, and a relatively much larger discrepancy is observed at 1 bar. One should note that the pressure drop measured with the same system but in a larger diameter column was predicted well by Delft model[7], which may mean that in present case relatively higher values have been consistently measured.

Although Delft model predicts well the trends associated with changes in packing geometry and in operating conditions, reflected through changes in relevant physical properties, its accuracy is limited, due to insufficiency with respect to predicting the actual active wetting pattern, which seems to deteriorate with increasing geometric area in a way that depends on changes in micro geometry of corrugations, e.g. the radius of the crimp angle, imposed by the manufacturing process. This is difficult to account for properly in a general model and therefore the Delft model is recommended for structured packing performance screening purposes only.

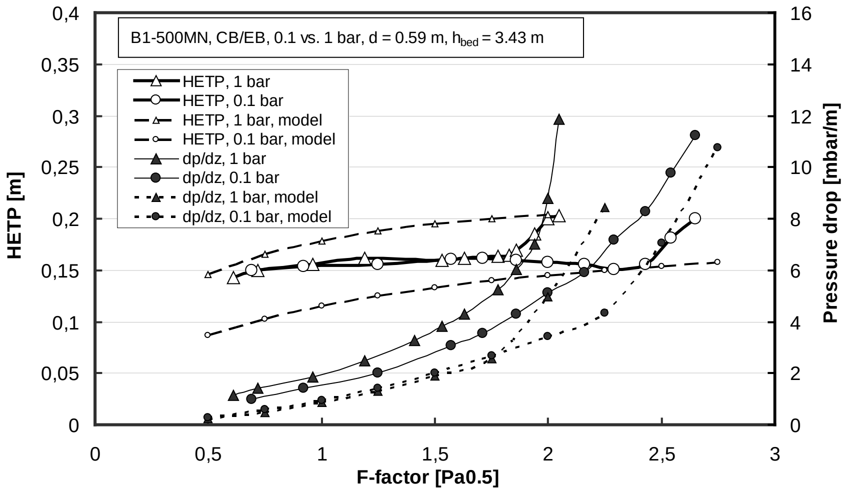

Figure 7. Effect of the pressure on performance of B1-500MN: model vs. experiment

4. Conclusions

The test results indicate that dimensions and design of corrugations and the corrugation inclination angle can be arranged to affect the pressure drop in a way that will favour either efficiency or capacity, or even both, as it appeared to be the case with B1-350MN that exhibited best overall performance characteristics. The strikingly good efficiency of B1-250MN exhibited at low vapour and liquid loads tends to deteriorate with increasing F-factor, while the efficiency of sheet metal and expanded metal packings is only slightly affected by changes in F-factor. B1-500MN requires a perforated area to perform accordingly and its efficiency appeared to be the same at 0.1 and 1 bar, while the imperforated BS-500MN packing exhibited at same efficiency a significantly larger capacity than its perforated counterpart. This indicates that perforations in the surface (roughly 10 per cent less installed area) do not affect the effective area adversely within the range of normal operation. Hydraulically, all packings exhibited expected performance.

Delft model appeared to be capable of predicting observed trends correctly, however exhibited a consistent under-prediction of observed pressure drop which tends to increase with increasing specific geometric area of the packing. Predictions of efficiency agree well with observation only if total installed area is used as effective area, and indicate that this may be close to actual situation with the system CB/EB as well as that the area utilisation efficiency under vacuum conditions tends to decrease with increasing specific geometric area.

References

1. Ž. Olujić, H. Jansen, B. Kaibel, T. Rietfort, E. Zich, *Ind. Eng. Chem. Res.* 40 (2001) 6172-6180.
2. Ph. Suess, L. Spiegel, *Chem. Eng. Proces.* 31 (1992) 119-124.
3. Ž. Olujić, et.al. *Chem. Eng. Proces.* 42 (2003) 55-60.
4. Ž. Olujić et al, *Chem. Eng. Res. Des.*, 84 (2006) A10, 867-874.
5. Ž. Olujić, M. Behrens, L. Colli, A. Paglianti, *Chem. Biochem. Eng. Q*. 18 (2004) 89 – 96.
6. Ž. Olujić, T. Rietfort, H. Jansen, B. Kaibel, E. Zich, G. Ruffert, T. Zielke, Topical Distillation Conference Proceedings (Editors: H.Z. Kister and M.D. Pritchett), AIChE Spring National Meeting, April 22-26, 2007, Houston, Texas, pp. 435-444.
7. Ž. Olujić, M. Behrens, L. Spiegel, *Ind. Eng. Chem. Res.* 46 (2007) 883-893.
8. M. Pilling, L. Spiegel, Separations Technology Topical Symposium, AIChE Annual Meeting, Reno, NV, USA, November 4-9, 2001, Vol. 1, pp. 64-69.