Why Not Structured Packings In High Pressure Distillation?

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Abstract. In the chemical processing industries (CPI), structured packings are widely used for distillation and absorption columns. However, the HETP 'hump', or deterioration of the mass transfer performance at about 65-85% of flood, made the structured packing not suitable for high-pressure distillation applications. It is very crucial to understand why the structured packing is not trusted in the high-pressure distillation applications. In this paper, the hump phenomenon and observations are described. The previous studies on the HETP hump are reviewed. The possible explanations of the hump mechanisms are discussed. Based on this study, the likely reasons that may cause the HETP hump are proposed, and a guideline about the structured packing application is provided. Future studies on HETP hump are discussed to further under the hump phenomenon.

Keywords Distillation, HETP hump, Structured packing

Introduction

The use of structured packings revolutionized distillation technology starting in the early 1970's. They are based on a geometry that combines high surface area per unit volume as well as an aerodynamic design that significantly reduces bluff body friction. The result is a very volumetrically efficient device with low pressure drop and high hydraulic flood capacity as shown Figure 1. The test results in the figure 1 are one of the many test results collected by Fractionation Research, Inc in a commercial size 1.2 m diameter distillation column (1).

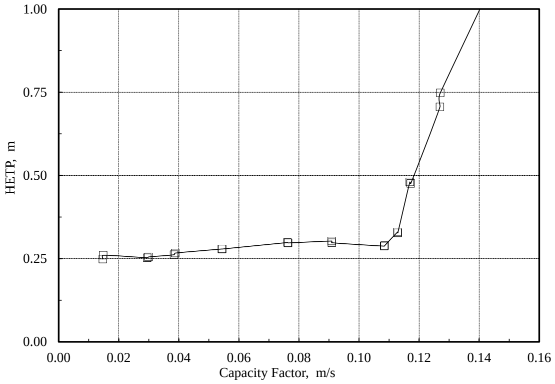

Figure 1. HETP vs Capacity Factor of Mellapak 250Y with o/p xylene system at 0.1 bara

This clearly offered retrofit and new construction advantages to distillation and absorption columns and industry embraced the technology quickly and widely. These days structured packings remain the technology of choice for vacuum distillation. On the other hand, structured packings present some limitations as well. Their use is not advisable in fouling services; they can be more expensive than random packings or trays; their efficiency is limited when plastic packing is required; they can be easily damaged during installation or removal, and last but not least, they are extremely sensitive to liquid distribution and redistribution.

Nevertheless, the potential advantages of high efficiency, low pressure drop, and high hydraulic capacity make them an alternative to be considered in most distillation applications at pressures below say 7 bara. But the realm of high pressure distillation has not been one for structured packings even though high pressure absorption (for example glycol dehydration of gas) is clearly an application amenable to them. Why is this?

It is noteworthy at this point that applications of random packings in high pressure distillation are successfully implemented. A clear case example of this is the extensive use of random packings in the top of de-methanizers in gas processing where pressures are very high.

The “Hump”

Experimental data collected and published by fractionation Research, Inc (FRI) before (1, 2) clearly show that the efficiency behavior of structured packings in hydrocarbon distillation is affected by system pressure. The mass transfer performance of Mellapak 250.Y was measured under total reflux conditions for the butane system at 11.4 bara pressure. The measured HETP is shown in Figure 1 together with previously measured data for the same packing and same system but a longer 3.78 m bed for comparison. It can be seen that the efficiency “hump” still exists for the 1.69 m bed, which is similar to that found for the 3.78 m bed. However, as shown in Figure 2, the overall HETP for the short bed is lower than that for the 3.78 m bed. This result can be attributed to the bed length effect on HETP.

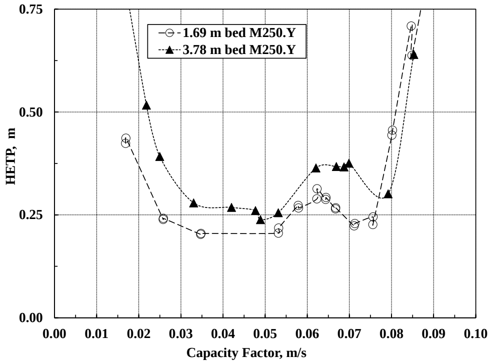

Figure 2. HETP vs Capacity Factor of Mellapak 250Y with iC4/nC4 system at 11.4 bara

Part of the difference in the baseline efficiency is caused by the deceasing relative volatility as pressure increases. Another part is caused by increasing liquid flow rate. The capacities are also affected due to the afore mentioned liquid flows as well as the lower gas buoyancy when pressure increases. But it can also be noted that the efficiency curves present an anomaly in the middle of the curves that becomes more noticeable as pressure increases. This anomaly has been called the “Hump” in distillation communities. Interestingly, this efficiency anomaly is not seen in random packings and in trays at the same conditions. Figures 3 and 4 are the efficiency data of the sieve tray (3) and random packings (4) tested by FRI, respectively.

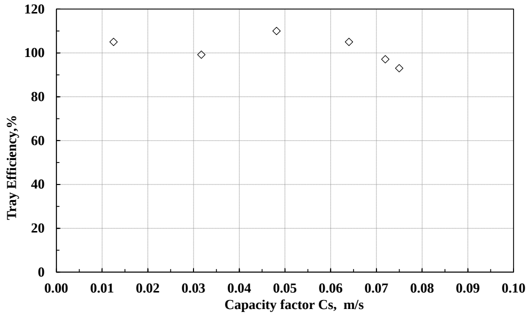

Figure 3. Sieve Tray Efficiency vs Capacity Factor with iC4/nC4 system at 11.4 bara

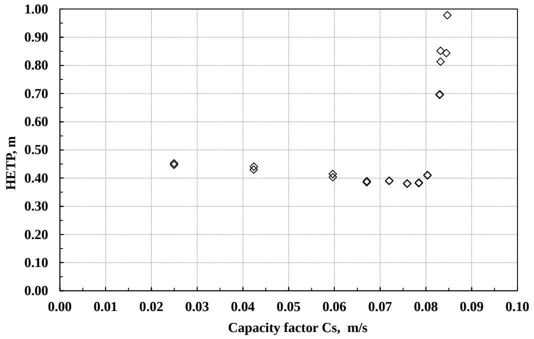

Figure 4. HETP vs Capacity Factor of Rasching Super-Ring Random Packing No. 2 with iC4/nC4 system at 11.4 bara

What Can Cause the "Hump"

Several theories have been postulated by experts to explain the appearance of the "Hump" in structured packing data. Clearly, any explanation has to dovetail with the fact that the phenomenon is not seen in random packings.

The performance of the liquid distributor suffers at high pressure. This would explain why structured packings, which are more sensitive to liquid distribution exhibit poor efficiencies in the middle of the range since gravity distributors need to accommodate small density difference between gas and liquid. The improvement at high rates, near flood can be explained by entrance of the system into the loading region which would aid in overall liquid distribution caused by the gas flow.

Axial back-mixing of gas and/or liquid would produce low efficiency. The departure from plug flow of either phase will cause an efficiency drop. As load increases, the drag between the phases increases as well, potentially leading to axial back-mixing. As the majority of this drag in structured packings is caused by the interface and not by the bluff body effect, back mixing would be more prevalent in structured packings than random packings

Experimental or measurement errors can be eliminated since the tests outlined above showed excellent repeatability and consistency, typical of FRI experimental work.

Performance of liquid distributor

Uniform liquid distribution on the top of the packed bed is crucial for the mass transfer performance of the structured packing. Billingham and Lockett (5) studied the sensitivity of packed distillation columns to liquid maldistribution. The distributors of choice for structured packings are gravity, multiple point distributors of the type shown in Figure 5. Since they operate by gravity inside the column, they are susceptible to changes in the density differences between the gas and liquid phases. As this difference gets smaller at high pressures, the level in the distributors needs to increase. So the capacity of the liquid distributor to keep the liquid within it without overflowing depends on the density difference, the pressure loss across the distributor, and the height of the distributor. At high loads it is possible to assume that even a small pressure loss in the gas phase within the distributor can be such that the distributor overflows or floods.

All these factors combined make distributor design tricky in high pressure applications. They need to have enough open area for gas flow, enough height for turndown with low density difference, and of course, enough well-located drip points to wet the entire packing surface area.

Tests in the FRI column indicate that the distributors used in the cases where the "Hump" was observed were not overflowing and thus causing maldistribution.

Figure 5. FRI VKG Trough Type Liquid Distributor

Axial Back- Mixing in Structured and Random Packings

The fact that axial mixing of either phase in a mass transfer application is deleterious to efficiency due to diminished concentration gradients is widely accepted. The most efficient conditions are those that can assure countercurrent plug flow of both gas and liquid phases. Deviations from plug flow in either phase are equivalent to maldistribution. On the other hand, we also know that if a column were to be totally mixed, its efficiency would be limited to one stage regardless of height. This is also applicable to heat transfer where plug flow is used to maximize temperature differences and heat transfer efficiency.

Seminal work by Jacques and Vermuelen (6) elucidates how axial mixing and back-mixing affect mass transfer in packed columns and that geometric variables and single phase friction factors play a very large role. This work can point to theoretical explanations as to why mixing behavior in random and structured packings can be so different.

An interesting fact is that the pressure drop in a distillation column has the dual effect of acting against mixing of the vapor flow but in favor of mixing of the liquid flow. So as pressure drop increases in a packed column, the liquid backmixing (axial mixing) can eventually affect mass transfer efficiency more quickly than any gas side effects.

As the loads increase the liquid tends to backmix. When random packings are used, there is a natural opposing resistance to the liquid backmixing presented by the bluff body effect of a random packing. Whereas in the case of structured packings, where the bluff body effect is significantly reduced, there is no opposing effect to the liquid back mixing through increasing packing depths, thus exhibiting a loss in efficiency.

At low loads the efficiencies are fine because of the absence of liquid backmixing, as loads increase the mixing increases, but at the loading point, when liquid holdup is affected by gas velocity, the liquid holdup itself tempers the backmixing until the flood point is reached and even the liquid holdup is overwhelmed.

Effect of Packing Geometries, Liquid Loading and Physical Proprieties

Liquid backmixing depends on the vapor upwards velocities and packing geometries. Higher vertical vapor velocities may cause more liquid backmixing. For structured packings, the buck of the vapor flows in the channels between the sheets with crimps. The higher surface area packings that have smaller crimp heights will resulted in higher vertical vapor velocities and more liquid backmixing. The HETP "Hump" was first found by FRI with the Mellapak 250Y structured packing with the iC4/nC4 system at 11.4 bara system pressure. For structured packings with larger surface areas than Mellapak 250Y, the ‘Hump’ may occur at lower system pressure because smaller flow channels yield higher vapor velocities. On the other hand, a lower surface area packing may not have HETP ‘Hump’ at a higher distillation pressure.

Based on experimental data of the structured packings collected by FRI, the physical properties of the liquid and vapor greatly affect the mass transfer efficiency. The HETP ‘Hump’ may occur for high pressure distillation system, especially for the system with low surface tension. The size of the liquid droplets is related to the liquid surface tension. For a distillation system, a higher distillation pressure usually means a lower surface tension, which will result in the smaller droplets that may be easier to be entrained upwards by the vapor or so called liquid backmixing. However, for a high pressure absorption, the structured packing still performs well without HETP ‘Hump’. The main difference between high pressure distillation and absorption systems is liquid surface tension. For similar pressure, the absorption system generally has a high surface tension than the distillation system. So the surface tension is an important physical property to determine if the structured packing is suitable for the distillation application.

Analogy to Liquid-Liquid Extraction

In many ways, the hydraulic behavior of high pressure hydrocarbon distillation systems is similar to those found in Liquid-Liquid Extraction and Supercritical Extraction systems. These types of systems have been amply studied and the effects of axial mixing of the phases is frequently a topic for discussion. Very interesting work by Seibert and Fair (7) indicated that one of the main effects of column internals (trays or packings) is to reduce backmixing. Their work demonstrated how these devices compare to empty columns.

These are systems with low density differences akin to those found in high pressure distillation and their learnings transfer very well.

Guidelines of Structured Packing Applications

The extensive research by FRI and academics and industrial application confirmed that the structured packing performs very well for the low pressure and low liquid load services with high capacity, low pressure drop and good separation efficiency. However, the structured packing is not recommended for high pressure distillation system due to the HETP ‘Hump’. Though the root cause of HETP ‘Hump’ is not well understood yet, theoretical studies and experimental data showed that the ‘Hump’ is likely caused by the liquid backmixing. Distillation applications with low surface tension and high flow parameter tend to have poor separation efficiency due to the liquid backmixing.

Figure 6 shows the ratios of the HETP at around 80% of the flood capacity to the baseline HETP for wide range of the liquid surface tension from 1 to 25 dyne/cm. Figure 7 shows the ratios of the HETP at around 80% of the flood capacity to the baseline HETP for various flow parameters,

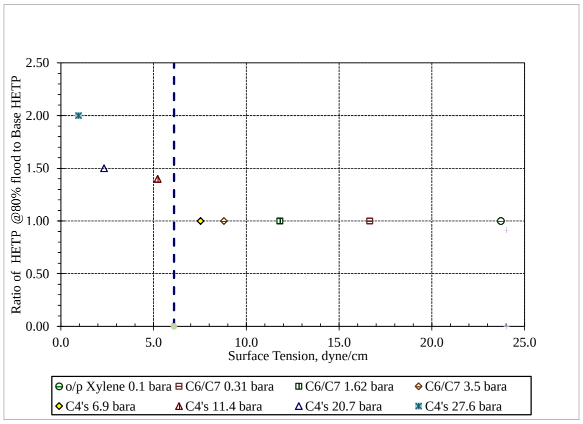

Figure 6. Ratio of HETP at 80% Flood Capacity to the Baseline HETP vs Surface Tensions

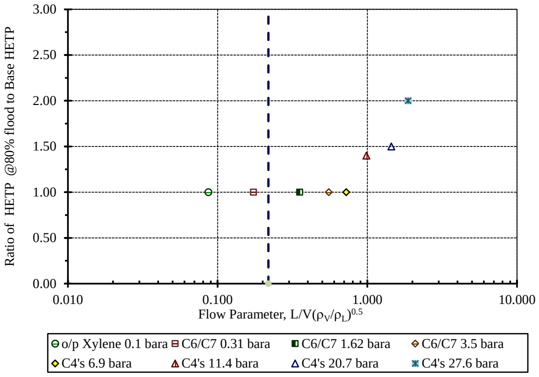

Figure 7. Ratio of HETP at 80% Flood Capacity to the Baseline HETP vs Flow Parameters

As shown in Figure 6, when the liquid surface tension is below 5 dyne/cm, the HETP of the structured packing at typical design/operating conditions may be significantly higher than the baseline HETP so the mass transfer efficiency may suffer greatly. The test results shown in Figure 7 confirm that the structured packing works very well for the applications with low flow parameters, or low pressure and low liquid rate applications. If the flow parameters is close to 1, caution needs to be exercised to employ structured packing.

Conclusion

The use of structured packings in high pressure distillation systems is not advisable. Experimental and field data indicate that there are efficiency anomalies that present themselves more pronouncedly as the density difference between the phases diminishes. It appears that these anomalies are caused by increased axial backmixing of the liquid phase under these conditions. System properties and liquid vapor loadings are better indicator to determine if the structured packing should be selected for distillation applications. For applications with low liquid surface tension and high flow parameter, structured packing is not recommended. Trays and random packings help ameliorate the onset of backmixing in the liquid phase by presenting a larger bluff body effect. It is also necessary to remind the reader that the design of liquid distributors always must account for the effects of density difference and pressure drop across the distributor itself, regardless of operating pressure

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