MASS TRANSFER AND HYDRAULIC DETAILS ON INTALOX® PhD™ PACKING

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ABSTRACT

Intalox® PhD™ packing is a new, random, mass transfer packing being introduced in 2002 by Saint-Gobain NorPro™ Corporation. The mass transfer efficiency of Intalox PhD packing is substantially greater than the most popular modern random packing with the same hydraulic capacity. The unique polyhedron shape of Intalox Intalox PhD packing makes optimal use of its material. Comparisons to other packings are done with performance data that was all taken in the same pilot plant test equipment.

Computational Fluid Dynamics (CFD) modeling was used to improve the design of the initial packing shape. NorPro's 0.406 m outside diameter distillation towers were used to confirm that the shape improvements suggested by the CFD analysis actually improved the packing mass transfer performance.

Keywords: Packing, random, distillation, absorption

INTRODUCTION

For the last four years Saint-Gobain NorPro, formerly Norton Chemical Process Products, has been working on developing Intalox PhD Packing, Figure 1. The goal of the R/D project was to develop a random mass transfer packing that was at least ten percent more efficient than Intalox® Metal Tower Packing (IMTP® Packing), Figure 2, introduced in 1979 [1,2] without capacity loss. The project goal was reached and in some cases exceeded. This was not an easy task considering the excellent performance characteristics of IMTP combined with the manufacturing constraints. More than ten different shapes were considered of which five were prototyped and evaluated in NorPro's pilot plant distillation tower with the iso-octane / toluene test system under vacuum, atmospheric conditions, and at pressure conditions with the cyclohexane / n-heptane system. The carbon steel pilot plant tower and test system used was the same one used during the development of IMTP packing thus assuring that test results of Intalox PhD packing were comparable to the Intalox IMTP packing data.

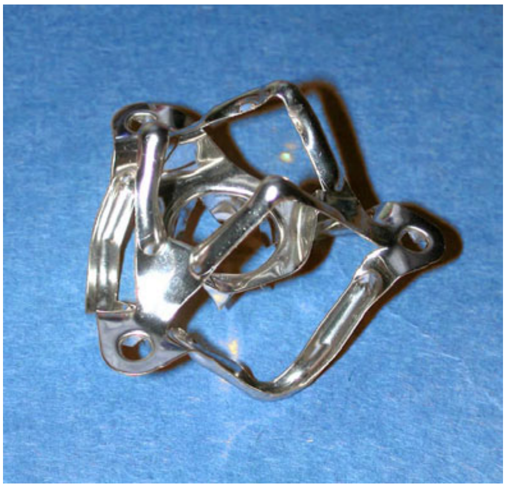

Figure 1 – Intalox® PhD™ Packing

Figure 2 – IMTP® Packing

Table 1 Distillation Tests Performed

Test Tower / System	Distillation			
	Iso Octane / Toluene		Cyclohexane / n Heptane	
	0.133 bar	0.987 bar	1.655 bar	4.137 bar
Carbon Steel, 0.406 m OD	X	X		
Stainless Steel, 0.406 m OD			X	X

Table 2Intalox PhD Packing Comparisons to IMTP Packing
Iso Octane / Toluene, 0.987 bar

	Efficiency Difference, %	Capacity Difference, %
Intalox PhD 25 VS #25 IMTP	+9.02	+2.77
Intalox PhD 60 VS #50 IMTP	-0.48	+6.86
Intalox PhD 60 VS #60IMTP	+15.24	-0.65

Table 3 Intalox PhD Packing Performance and Comparisons

	System	No. 25		No. 50	No. 60	
		Intalox PhD	IMTP	IMTP	Intalox PhD	IMTP
HETP, mm						
0.133 bar	Iso Octane / Tol.	350			579	701
0.987 bar	Iso Octane / Tol.	363	399	620	623	735
1.655 bar	C6 /C7			656	665	
4.137 bar	C6 /C7			527	528	
MEC - Cs, m/sec						
0.133 bar	Iso Octane / Tol.	0.0914			0.1251	0.1311
0.987 bar	Iso Octane / Tol.	0.0852	0.0829	0.1006	0.1075	0.1082
1.655 bar	C6 /C7			0.0939	0.0973	
4.137 bar	C6 /C7			0.0872	0.0915	

BACKGROUND

Distillation Test Method

The distillation performance parameters characterizing Intalox PhD packing such as Height Equivalent to a Theoretical Plate (HETP), pressure drop, and Maximum Efficient Capacity (MEC) [1,2,3] were measured in NorPro's pilot plant distillation towers, see Table 3. The iso-octane/toluene distillation tests were performed in the carbon steel tower at 0.133 bar and 0.987 bar in the same manner that the original IMTP packing was evaluated. The cyclohexane/n-heptane distillation tests were performed in the stainless steel tower at 1.655 bar and 4.137 bar. This is the same test system and conditions use by Fractionation Research, Inc. (FRI) [6]. Figure 3 presents a schematic of these towers. Both towers have an inside diameter of 0.387 m. Although each distillation column is capable of holding up to a 6.1 m deep bed of packing, the distillation tests described here were performed with a nominal 3.0 m deep bed to be consistent with the nominal bed depth used in the IMTP packing test work. The distillation tests in both towers were run at total reflux. The overhead vapor was totally condensed and returned to the tower via a reflux pump. The reflux liquid was reheated to within 5 ^{o}K of the overhead vapor temperature before it was return to the tower.

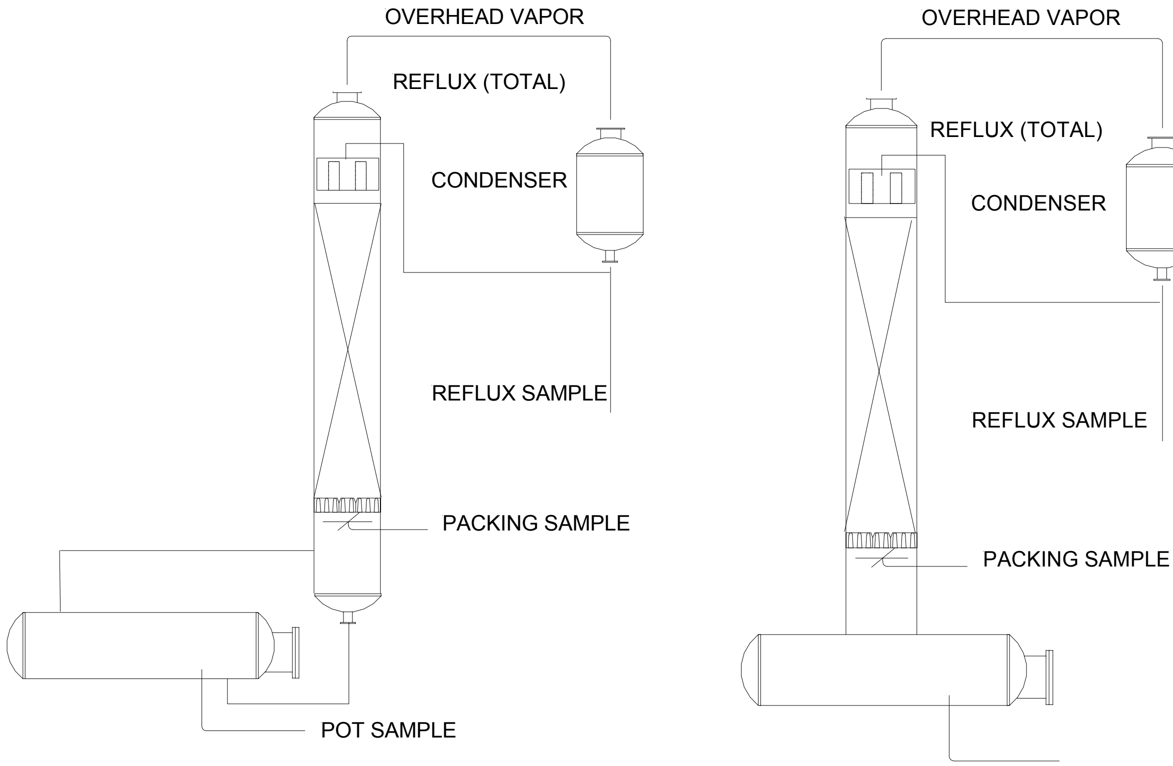

Figure 3 - Tower Sketches

The difference between the towers is the material of construction, carbon steel (CS) vs. stainless steel (SS), rated operating pressure and vapor inlet arrangement. The CS tower has the capability to operate from full vacuum to one bar and, the SS tower can operate from full vacuum to 26.6 bar. The carbon steel tower sets directly on the reboiler thus the vapor enters the tower vertically from the reboiler where as the stainless steel tower is not mounted on the reboiler and the vapor enters the tower through a 0.203 m nozzle radial nozzle.

Distillation Equipment

Multiple, pan type, gravity head, reflux distributors with seven (7) liquid pour points (59.5 points/m^3) and having a distribution quality number of 89% were used in order to cover the entire capacity range of the packing being tested under the range of the various test conditions. Each distributor had two vapor risers and an annular vapor passage between the distributor wall and the tower wall giving a total vapor passage area of 54% of the tower area. Figure 4 is a picture of one of the reflux distributors used. The distributor quality number is defined per the method given in reference [4,5]. This method divides the superficial tower cross sectional area into concentric circles. The diameter of the circle is determined by dividing the tower cross sectional area by the number of liquid pour points and then calculating the diameter of a circle that encompasses that area. Each circle is then laid out on the tower cross sectional area with its center located at the point at which the liquid stream leaving the distributor enters the bed. For simplicity, it is assumed that the liquid steam enters the bed directly below the liquid orifice in the distributor pan. Visual observations made during the tests confirms this to be a reasonable assumption. The ideal orifice pattern minimizes the amount of circle overlap and uncovered areas. Figures 5 & 6 give a visual representation of a poor quality (54%) and high quality (90%) liquid distributor pattern respectively.

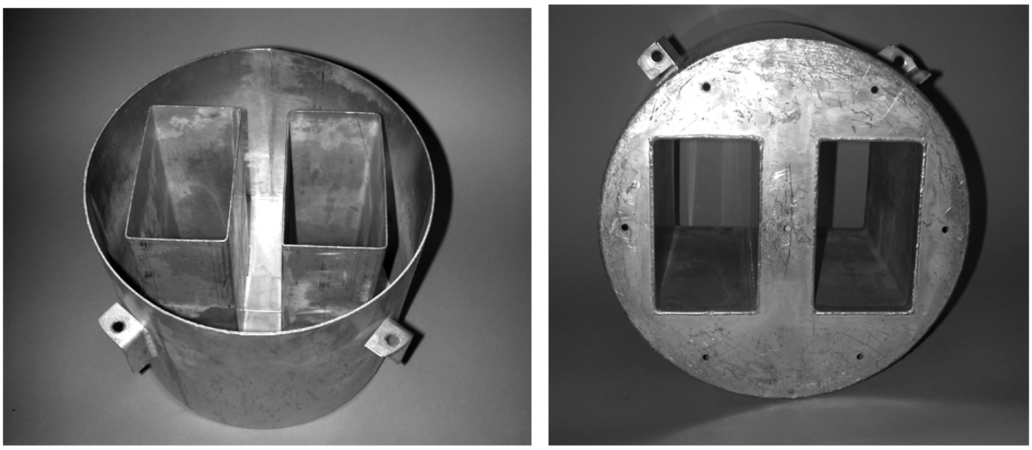

Figure 4 - Photograph of Reflux Distributor

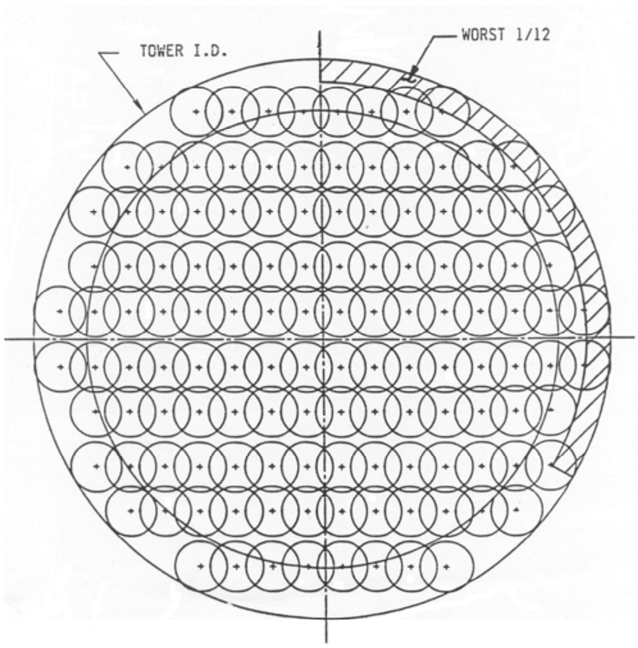

Figure 5

54% Distribution Quality

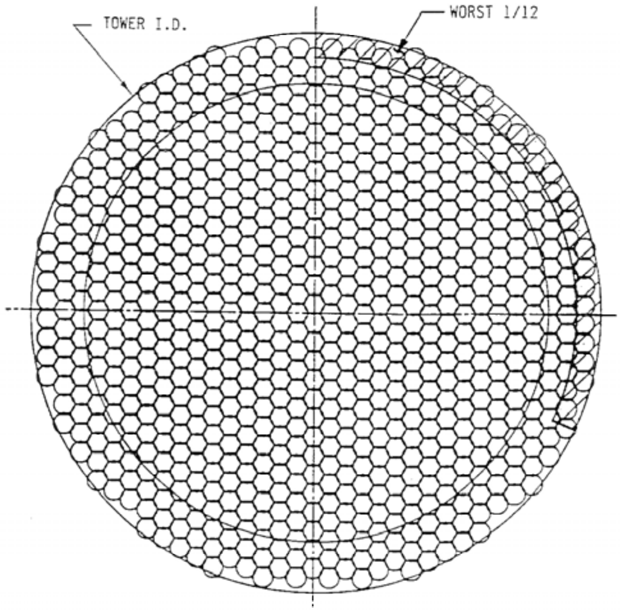

Figure 6

90% Distribution Quality

The reboiler liquid was steam heated by a U-tube heat exchanger. The reboiler liquid was continuously mixed by a reboiler circulation pump.

Three liquid samples were taken, one from the discharge of the reflux pump before the pre-heater, a second from a collector located directly below the packing support plate, and a third from the discharge of the reboiler recirculating pump. The liquid samples were analyzed by gas chromatography.

The HETP of the packing was determined by calculating the number of theoretical plates required to make the measured separation between the reflux sample and the bed collector sample and then dividing the packing bed depth by the number of theoretical stages calculated.

The maximum efficient capacity point was determined five ways: 1) by visual observation of flooding on the top of the packing; 2) by the packing pressure drop; 3) by the heat balance; 4) by the rapid lowering of the liquid level in the reboiler due to increasing hold up in the packing; 5) by the decline of packing efficiency.

CFD Application on New Product Development

During the process of developing the new packing, an extensive Computational Fluid Dynamic (CFD) analysis was applied. The CFD package utilized for this study was Fluent. Saint-Gobain NorPro has been using this software package for more than eight years for various applications including new product development of random and structured packing.

In the packing development project, the CFD package was not utilized as a tool for inventing the shape idea, rather it was very helpful for modification analysis of the given idea to optimize the original geometry to achieve better performance. The effect of changing various aspects of the packing geometry, in this case, the size of the center hole, addition of the corner holes, and the changing of the width of the upper or lower loops was scrutinized in the virtual wind tunnel of the CFD program. Figure 1 is the final CFD optimized version.

Using the CFD software, a simulated test zone was set up to include several pieces of the new packing within a 6” diameter tube. The inlet and outlet process conditions of the tube were set thus defining the virtual test zone computational domain for analyzing the gas or liquid interactions with the new packing located in this test tube. By fixing the inlet and outlet conditions of the test tube, the effect of the gas flow on various changes to the geometry of the new packing was analyzed and this process was iterated until a satisfactory result was achieved.

The main focus of the CFD analysis was on the flow behavior around the packing for different orientations and the effect of packing geometry change on the pressure drop. Surface area utilization for a given number of packing pieces was also considered. Figure 7 and Figure 8 present two of the many simulations that were performed during the optimization of the new packing in parallel with physical distillation test results in our 409 mm distillation column. Figure 7 and Figure 8 present the flow behavior in terms of the gas velocity vectors for the original and the final version of the Intalox PhD packing, respectively. Figure 8 (the final version of the Intalox Intalox PhD packing) shows more rigorous interaction between the gas and the surface of the packing compared to the original packing shape. It was assumed, that the more rigorous interaction between the gas and the surface of the packing would result in better efficiency. Also, from Figure 8 it is quite obvious that the more open the packing, especially at the corners and the center hole, the resistance to gas flow and therefore pressure drop would be lower.

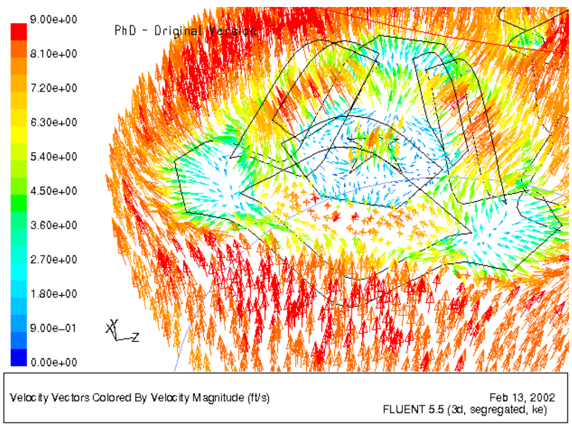

Figure 7
CFD Analysis of Original Packing Shape

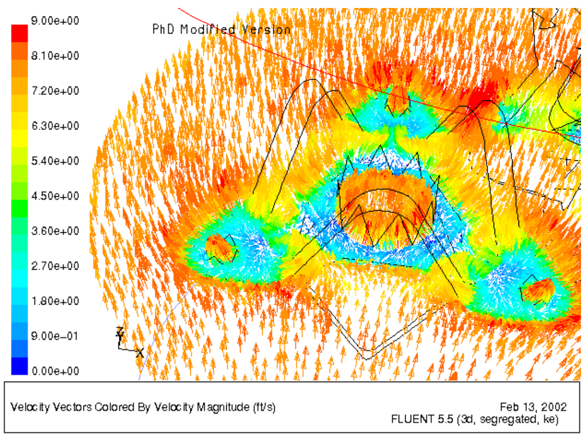

Figure 8
CFD Analysis of Modified Shape

Discussion of HETP VS Capacity Curves

The packing performance is expressed as HETP (lower value is better) and the capacity is expressed as the vapro capacity factor, C_S (larger value is better):

$$C_S = V\sqrt{\rho_G/(\rho_L - \rho_G)} \qquad (1)$$

where: C_S = capacity factor, m/s: V = vapor velocity, m/s: ρ_G = vapor density, kg/m^3: ρ_L = liquid density, kg/m^3. The packing performance is shown as a plot of HETP vs.Capacity.

Some of the IMTP packing was retested because of distributor differences between the original IMTP packing work and the present work. Figure 9, “Intalox PhD 25 Packing vs. #25 IMTP Packing With Different Distribution Quality Liquid Distributors” shows the effect of liquid distributor quality on the HETP vs. Capacity curve of #25 IMTP. The 7P2 liquid distributor is the pan type discussed above with 7 liquid pour points and a liquid distribution quality number of 89%. The NorPro test distributor known as Distributor C is a pipe type distributor with 12 liquid pour points and a liquid distribution quality number of 76%. The higher liquid quality rated distributor improved the HETP of #25 IMTP packing to 399 mm from 427 mm while employing fewer liquid pour points. The MEC remained unchanged. Having measured the performance of the two packings on the same basis assures that the efficiency improvements measured on Intalox PhD packing were not caused by differences in the test hardware.

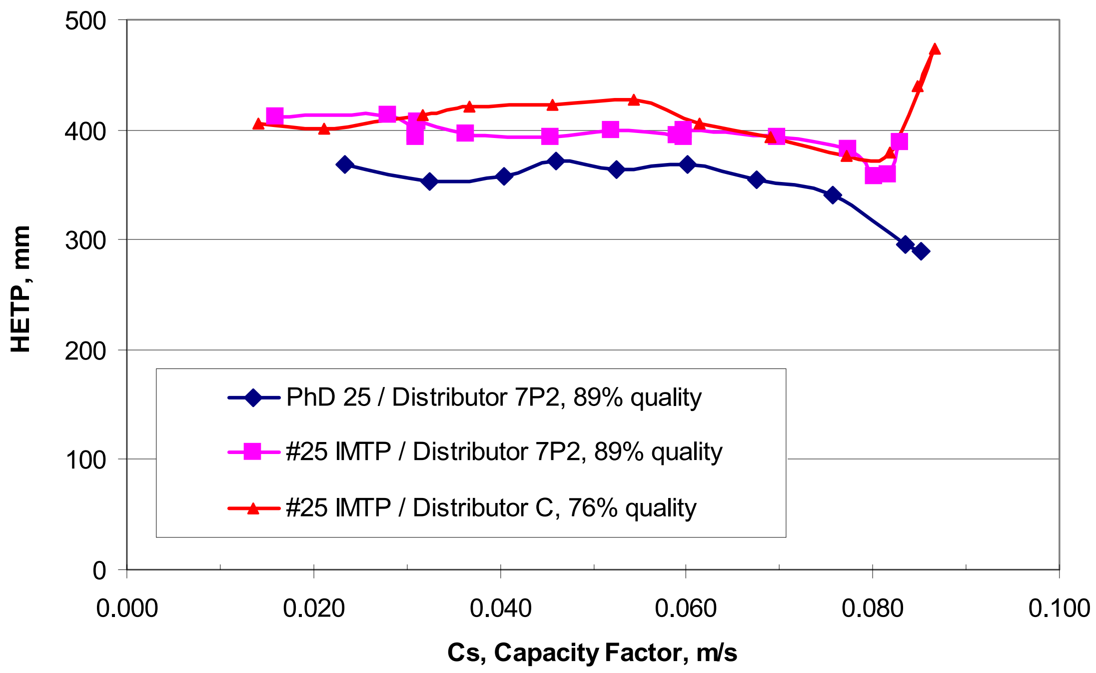

Figure 9
Intalox® PhD 25 Packing vs. #25 IMTP® Packing
Iso-Octane/Toluene, 0.987 bar

Figure 10, “Intalox PhD 25 Packing vs.. #25 IMTP Packing - Iso-Octane/Toluene, 0.987 bar”, gives the comparison of Intalox PhD 25 packing to #25 IMTP packing. The figure shows that the HETP of Intalox PhD 25 is 9.0% better than #25 IMTP packing and has 2.8% greater capacity, see Table 3. This indicates that Intalox PhD 25 packing is ideal to improve the performance of an existing tower packed with #25 IMTP packing.

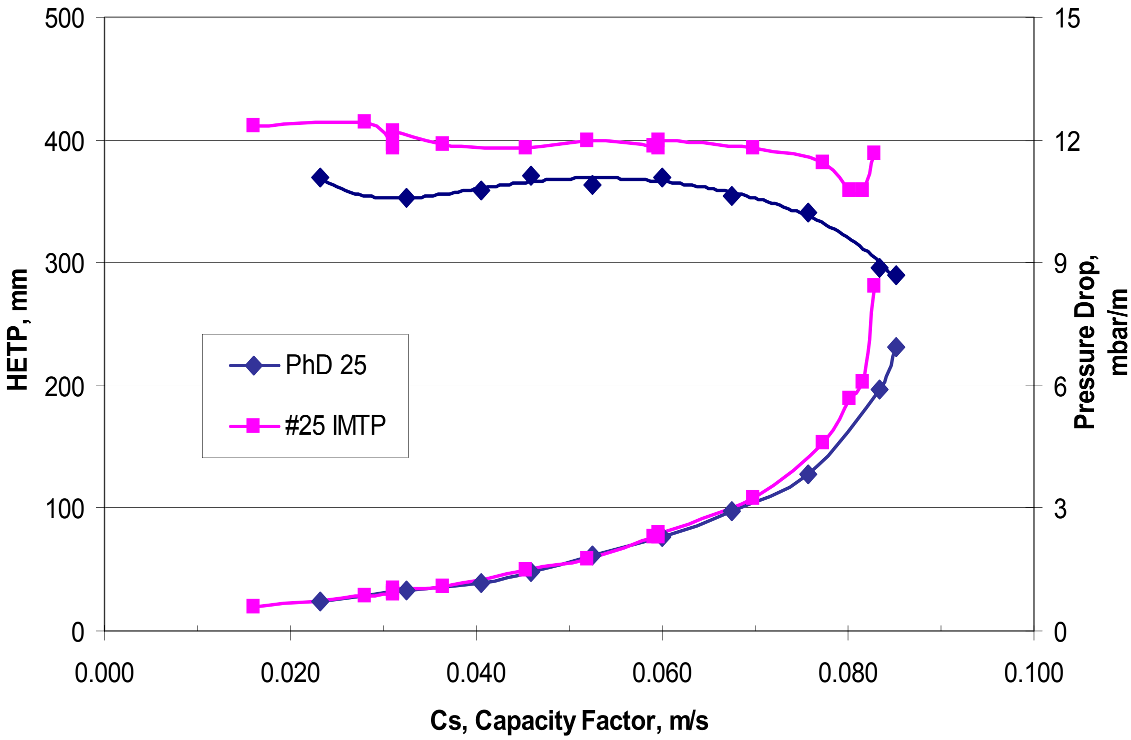

Figure 10
Intalox® PhD25 Packing vs. #25 IMTP® Packing
Iso-Octane/Toluene, 0.987 bar

Figure 11, “Intalox PhD 60 Packing - Iso-Octane/Toluene, 0.987 bar and 0.133 bar”, gives HETP VS Capacity curves for Intalox PhD 60 packing at 0.987 bar and 0.133 bar.

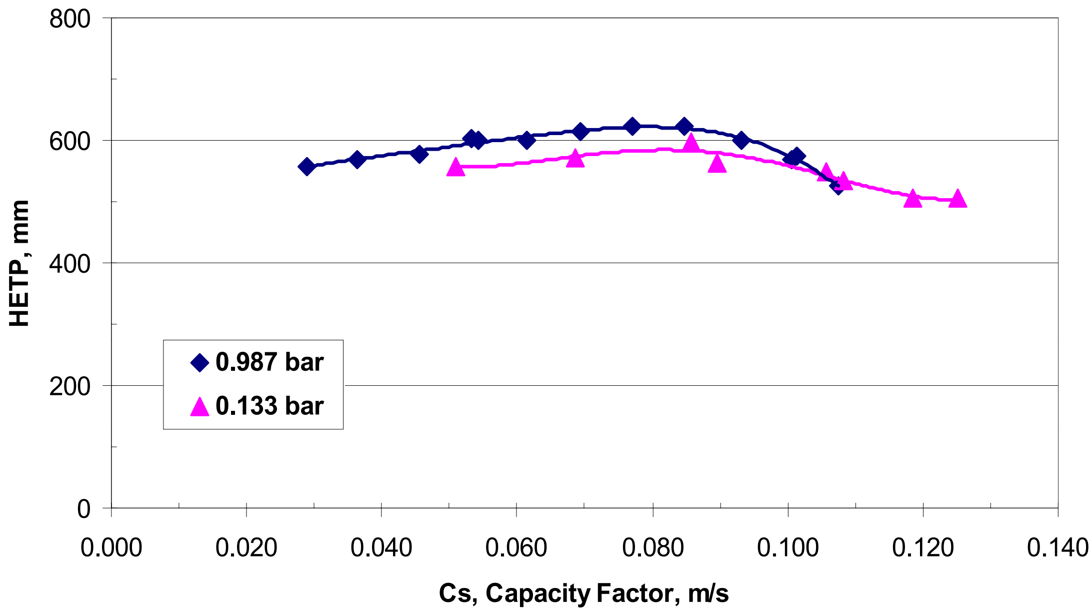

Figure 11
Intalox® PhD 60 Packing
iso-Octane / Toluene Distillation

Figure 12, "Intalox PhD 60 Packing vs. #60 IMTP Packing - Iso-Octane/Toluene, 0.987 bar", gives the comparison of Intalox PhD 60 packing to # 60 IMTP packing. The figure shows that the HETP of Intalox PhD 60 is 15.24% more efficient than # 60 IMTP packing and has 0.65% less capacity, see Table 3. The Intalox PhD is an ideal choice for improving the performance of a tower packed with #60 IMTP packing. Intalox PhD 60 packing is also an ideal choice to improve the performance of towers packed with other large random packings that have lower efficiencies than IMTP Packing.

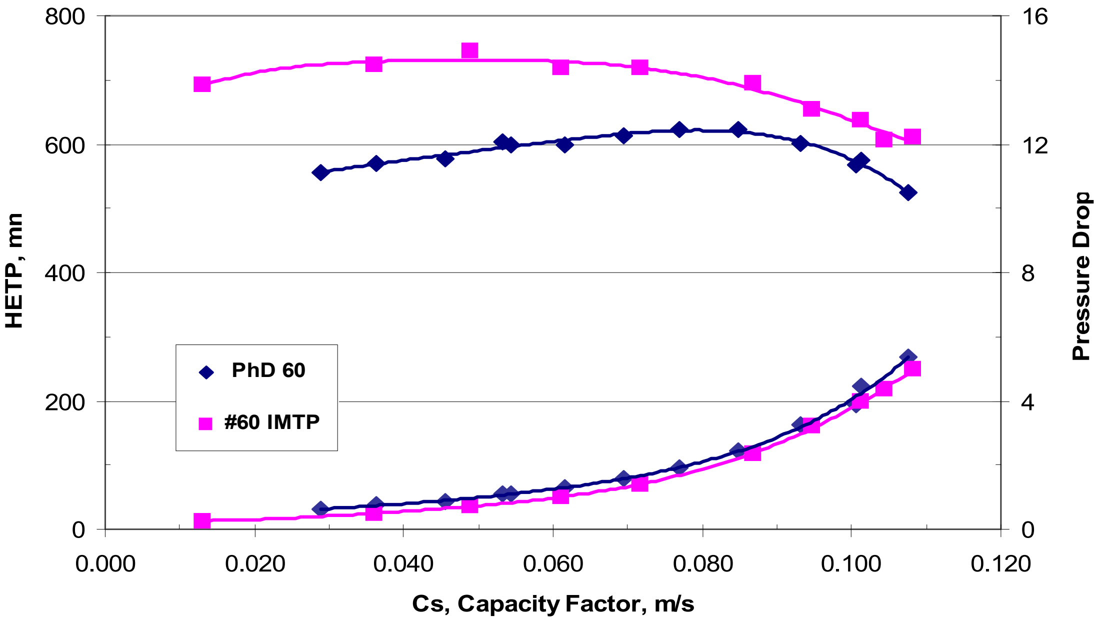

Figure 12
Intalox® PhD60 Packing vs. #60 IMTP®
Iso-Octane/Toluene, 0.987 bar

Figure 13, "Intalox PhD 60 Packing vs. #50 & #60 IMTP Packing - Iso-Octane/Toluene, 0.987 bar", gives the comparison of Intalox PhD 60 packing to No 50 IMTP packing and No. 60 IMTP packing. The figure shows that the HETP of Intalox PhD 60 is 0.48% greater (less efficient) than No. 50 IMTP packing and has 6.86% greater capacity. Since the efficiency of Intalox PhD 60 is essentially the same as #50 IMTP packing, the capacity of a tower packed with # 50 IMTP packing or a less efficient 50 mm random packing can be increased by replacing the packing with Intalox PhD 60 packing. In the case where a less efficient packing than #50 IMTP packing is being replaced, the separation efficiency will also be improved.

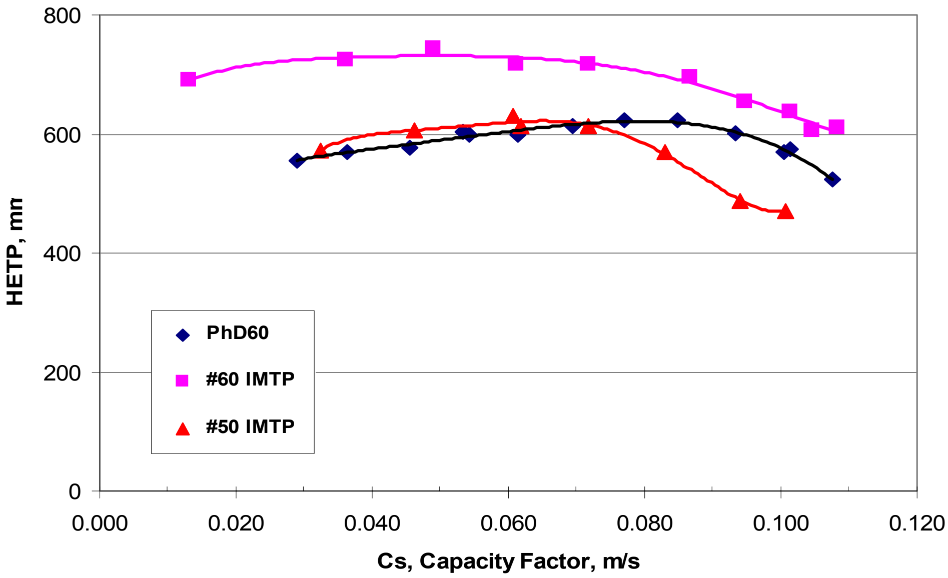

Figure 13
Intalox® PhD60 Packing vs. IMTP® Packing
Iso-Octane/Toluene, 0.987 bar

Figure 14, "Intalox PhD 60 Packing - Cyclohexane/n-Heptane, 1.655 bar and 4.137 bar", gives HETP VS Capacity curves for Intalox PhD 60 packing at 1.655 bar and 4.137 bar.

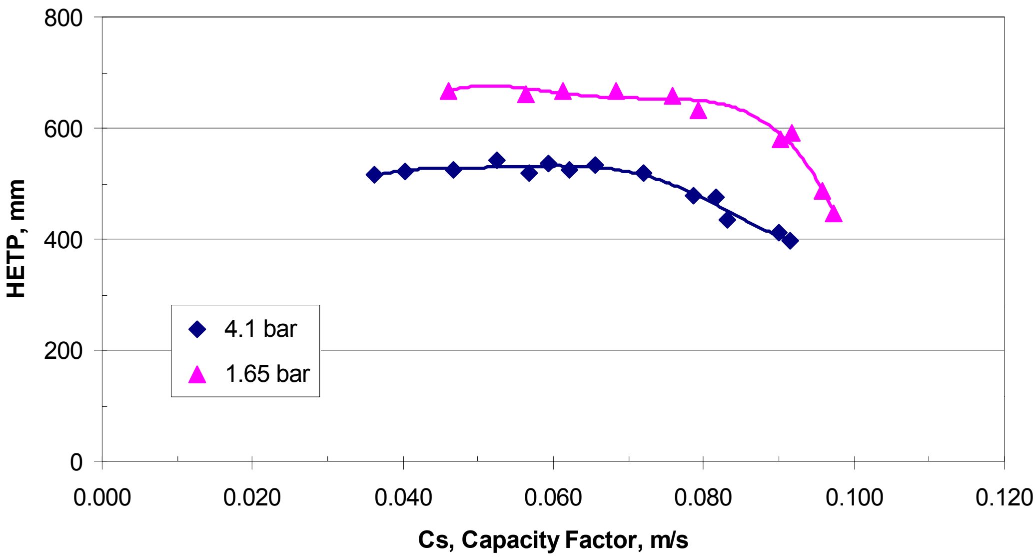

Figure 14
Intalox® PhD 60 Packing
Cyclohexane / n-Heptane Distillation

CONCLUSION

The Intalox PhD packing is more efficient than IMTP packing with the same or greater capacity depending the sizes being compared. Because of Intalox PhD packing combination of efficiency and capacity characteristics, it is possible to replace the packing in existing distillation towers and improve the separation and or the capacity. The improved efficiency could also be used to lower the reflux ratio and there by reduce the energy consumption.

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