Vapor Maldistribution Studies on Structured and Random Packings

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ABSTRACT

Results of vapor maldistribution studies using one structured packing and two random packings in a 1.22 m (4 foot) diameter distillation column are presented. For the structured packing, Mellapak 250.Y®, the studies were made at total reflux with ortho/para xylene at 100 mm Hg absolute pressure using a 1.69 m (5.53 foot) bed depth. The test was divided into three parts, a baseline test and two vapor maldistribution tests. The maldistribution tests included a 50 per cent center blockage and a 30 per cent chordal blockage. For the center blockage test, 50 per cent of column cross section area was blocked at the bottom of the bed. For the chordal blockage test, 30 per cent of the column cross section was blocked at the bottom. Using 25 mm (1 inch) stainless steel Pall rings, a test was conducted with cyclohexane/n-heptane at 1.0 bar (14.7 psia) with a bed depth of 3.66 m (12 foot). In addition to a baseline test, two vapor maldistribution tests were run. A vapor deflection baffle and a 50 per cent chordal blockage were utilized. Using No. 2 Nutter Rings, a test was performed with cyclohexane/n-heptane at 0.34 and 1.65 bar (5 and 24 psia) in a 4.27 m (14 foot) bed. Only one vapor maldistribution test, a 30 per cent chordal blockage, was done for this packing. For all the tests, a high quality liquid distributor was used. The study shows no significant effects of vapor maldistribution on packing efficiency and maximum useful capacity.

INTRODUCTION

Packed towers are extensively used for distillation and absorption as they provide good gas-liquid contacting with a low bed pressure drop. Good performance of a packed bed depends critically on vapor and liquid distribution. Controlled liquid maldistribution studies on random packing and structured packing were conducted in a commercial scale experiment at Fractionation Research Inc. (Kunesh, Lahm and Yanagi, 1987; Fitz, King and Kunesh, 1999). Previous vapor maldistribution studies (Porter, Ali, Hassan and Aryan, 1993, Muir and Briens, 1986) have primarily emphasized the hydraulic performance of vapor distributors. However, few studies have been done on their mass transfer performance, particularly in the way of commercial-scale experimental studies. This paper presents experimental studies of vapor maldistribution by Fractionation Research, Inc. (F.R.I.). The studies were conducted using one structured packing and two random packings. For the structured packing test, Sulzer Chemtech Mellapak 250.Y was used. The studies were conducted at total reflux with ortho/para xylene at 100 mm Hg absolute pressure with a bed depth of 1.69 m (5.53 foot). In addition to a baseline test, two different vapor maldistribution tests were performed, a 50 per cent center blockage and a 30 per cent chordal blockage. Using 25 mm (1 inch) stainless steel Pall rings, a test was conducted with cyclohexane/n-heptane at 1.0 bar (14.7 psia) with a bed depth of 3.66 m (12 foot). In addition to a baseline test, two vapor maldistribution tests were run for this packing, a vapor deflection baffle and a 50 per cent chordal blockage. Using No. 2 Nutter Rings, a test was performed with cyclohexane/n-heptane at 0.34 and 1.65 bar (5 and 24 psia) in a 4.27 m (14 foot) bed depth. Only one vapor maldistribution test, a 30 per cent chordal blockage, was done for this packing. For all the tests conducted, a high quality liquid distributor was used.

EXPERIMENTAL EQUIPMENT

Packings

The 25 mm (1 inch) Pall rings tested in this study have a specific area of 207 m^2/m^3 (57 ft^2/ft^3). The Mellapak 250Y used in this test was a new batch of packing. The packing has a specific area of 250 m^2/m^3 (76.2 ft^2/ft^3). This packing is essentially the same as that used in earlier test (Fitz, Kunesh and Shariat, 1998) but with different surface treatment and thinner. The current packing is 0.15 mm thick whereas the packing used earlier had sheets 0.2 mm thick. The No. 2 Nutter Rings are random packing with a specific area of 95 m^2/m^3 (29 ft^2/ft^3).

Liquid Distributors

For all the tests, a high quality liquid distributor was used. The F.R.I. tubed drip pan (TDP) distributor was used for the No. 2 Nutter Rings test. **Figure 1** shows the TDP liquid distributor. This is a short tube distributor with 121 drip tubes that project below and above the pan floor to reduce obstruction by dirt and scale. The inside diameter of the tube for this test was 5 mm. For the 25 mm (1 inch) Pall Ring test, a similar liquid distributor was used. This distributor has 121 individually adjustable liquid pour points with slotted tubes. More information about this distributor and the auxiliary devices can be found in the paper published in 1987 (Kunesh, Lahm and Yanagi). In the structured packing Mellapak 250Y test, the VKG liquid distributor, fabricated by Sulzer Chemtech, shown in **Figure 2**, was used for the test. This is a trough-orifice type liquid distributor with high open area (45 per cent of column cross sectional area) for the vapor flow. It is specifically designed for the low pressure high vapor rate systems. It has 128 orifices with a 4.3 mm diameter, which gives the pour point density 108/m^2 for a 1.22 m (4 foot) diameter column.

Column Configurations and Maldistribution Devices

Figures 3-5 show the column configuration of the 25 mm (1 inch) Pall Ring tests and vapor maldistribution devices in the F.R.I. high pressure column, locating the vapor straightening section, packing support grid, samplers, packed bed, thermowells, pressure taps, liquid distributor, and other equipment. The support plate was installed 2.0 m (79 inch) above the center of the vapor inlet. 3.66 m (12 foot) of 25 mm (1 inch) stainless steel Pall rings were dry-packed. The liquid distributor was suspended 0.46 m (18 inch) above the bed. As shown in **Figure 4**, a movable oval shaped baffle was installed below the packing support plate to study the effects of vapor maldistribution on packing efficiency. By rotating the baffle, the vapor flow could be changed from an even distribution to various degrees of maldistribution. The baffle cross-section area was 54 per cent of the column cross-section, with axes of 1.12 m (44 inch) and 0.84 m (33 inch). The effects of the baffle on the vapor distribution were tested before and after installation. Using a blower, air was introduced to the vapor inlet, and the vapor profile was sampled with an anemometer at the level where the packing support plate was to be installed. When the baffle was aligned with the air flow, the velocity profile was the same as for the condition without the baffle. The baffle position causing the most uneven velocity profile was at 75 degree to the vapor flow. After the test with deflecting baffle, the bottom of the column was rearranged to the configuration shown in **Figure 5**, simulating vapor entering the bottom of the column close to the support plate. The vapor straightening trays and the vapor baffle were removed, and a solid tray was installed 0.50 m (20 inch) below the packing support plate, blanking off 50 per cent of the vapor space below the packing support plate. A 51 mm (2 inch) weir prevented any liquid falling on the tray from entering the vapor stream, making the effective clearance between the tray and the packing support plate 457 mm (18 inch). A downcomer carried the liquid from the tray to the bottom of the column.

Figure 6 shows the column configuration for the No. 2 Nutter Rings test, locating vapor maldistribution device, the segmental pan, packing support grid, samplers, packed bed, thermowells, pressure taps, liquid distributor, and other equipment. The segmental pan, which blocked 30 per cent of the vapor space up to the support plate, was installed as shown in **Figure 6.** The packing was dry packed directly from shipping cartons. The depth of the bed was 4.27 m (14 foot). The F.R.I. tubed drip pan distributor was installed 0.46 m (18 inch) above the packed bed. A baseline test was conducted before the vapor maldistribution test. After the baseline test, the vapor distributor (a bubble cap tray) and vapor straightening device (three sieve trays) were removed.

Figures 7-9 show the column configurations of structured packing Mellapak 250Y tests. **Figure 7** shows the column configuration for the baseline test of Mellapak 250Y structured packing, locating packing support grid, samplers, packed bed, thermowells, pressure taps, liquid distributor, and other equipment. There was no vapor distributor/liquid collector installed below the packed bed. Eight layers of Mellapak 250Y structured packing was installed to a bed depth of 1.69 m (5.53 foot). The VKG liquid distributor was installed 152 mm (6 inch) above the top of the packed bed.

Figure 8 shows the column configuration for the center block test of Mellapak 250Y structured packing. After finishing the baseline test, the manway below the packing support grid was opened. Leaving everything from the baseline test unchanged, a circular pan was installed and two additional below bed samplers were added. The circular pan, **Figure 10,** was centrally placed below the bed against the packing support grid. The pan blocked 50 per cent column cross section area for vapor flow and collected the liquid descending from the support grid. The collected liquid flowed to the bottom of the column by means of a 102 mm (4 inch) diameter pipe downcomer to a 203 mm (8 inch) diameter 152 mm (6 inch) deep seal pan. The slotted (notched) sleeves were inserted between the bottom of the packing and the circular pan to minimize vapor entering (leaking) into the space above the pan. Since the arms of the cross sampler extended all the way to the column wall, notches were cut in the side walls of the circular pan.

Figure 9 shows the column configuration for the chordal block test of Mellapak 250Y structured packing. After finishing the center block test, the manway below the packing support grid was opened. The circular pan was disassembled and taken out through the manway. Leaving everything unchanged, a segmental pan, shown in **Figure 11,** was installed. The segmental pan was placed below the bed against the packing support grid on the south side of the column. The pan blocked 30 per cent of the column cross section area for vapor flow and collected the liquid descending from the support grid. The collected liquid flowed to the bottom of the column by means of a 102 mm (4 inch) diameter pipe downcomer to a 203 mm (8 inch) diameter 152 mm (6 inch) deep seal pan. Two sheet metal plates were inserted between the bottom of the packing and the segmental pan to minimize vapor entering (leaking) into the space above the pan.

RESULTS AND DISCUSSIONS

The results of the test with the 25 mm (1 inch) Pall rings are shown in **Figure 12** . The test was conducted with cyclohexane/n-heptane at 1.0 bar (14.7 psia). The figure includes both the baseline test and two vapor maldistribution tests. It can be seen from this figure that the amount of vapor maldistribution did not affect the separation efficiency of the bed.

Figure 13 shows the test results for the No. 2 Nutter Rings with cyclohexane/n-heptane at 0.34 and 1.65 bar (5 and 24 psia). The figure shows both the baseline test results and those of vapor maldistribution results. As may be seen in this figure, the imposed vapor maldistribution had little, if any, effect on the mass transfer efficiency of the packing for both pressures.

Figure 14 shows the efficiencies of vapor maldistribution tests of Mellapak 250Y structured packing with o/p xylene at 100 mm Hg absolute pressure. The HETP's for the baseline test are very close to those for both center block and chordal block tests as shown in this figure. As indicated in this figure, the maximum useful capacity of the baseline test is essentially same as those of center block and chordal block tests. Therefore, for the system tested, vapor maldistributions (both center block and chordal block) do not have any significant effect on packing efficiency and maximum useful capacity. **Figure 15** presents the typical composition profiles of baseline, center block and chordal block tests at different vapor rates. As shown in this figure, composition profiles for all three tests are very similar, which confirms the efficiency results.

CONCLUSIONS

For the random packings and structured packing tested, vapor maldistributions do not have any significant effect on packing efficiency and maximum useful capacity. A very short bed depth is sufficient to suppress initial vapor maldistribution.

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Muir L. A.; Briens C. L. Low Pressure Drop Gas Distributors for Packed Distillation Columns, The Canadian Journal of Chemical Engineering, Vol. 64 December 1986

Porter K. E.; Ali Q. H.; Hassan A. O.; Aryan A. F. Gas Distribution in Shallow Packed Bed, Ind. Eng. Chem. Res. 1993, 32, 2408-2417.

Figure 1. F.R.I. TDP distributor

Figure 2. VKG distributor

Figure 3. Configuration of 25 mm Pall rings Test

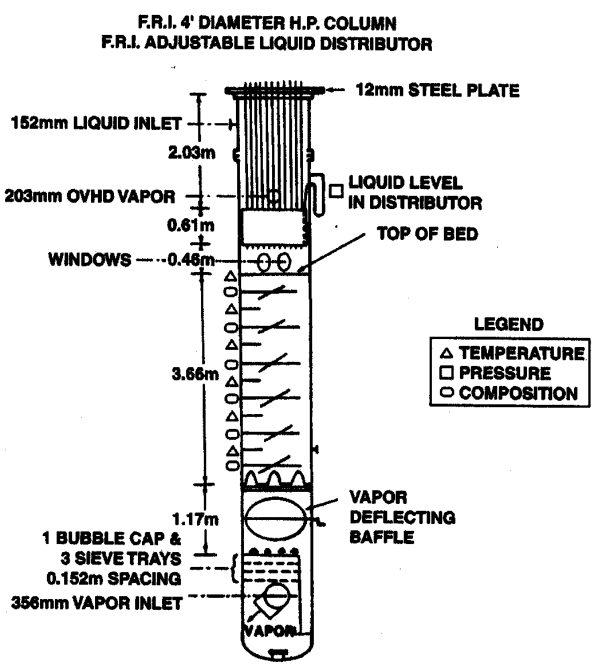

Figure 4. Vapor Deflecting Baffle

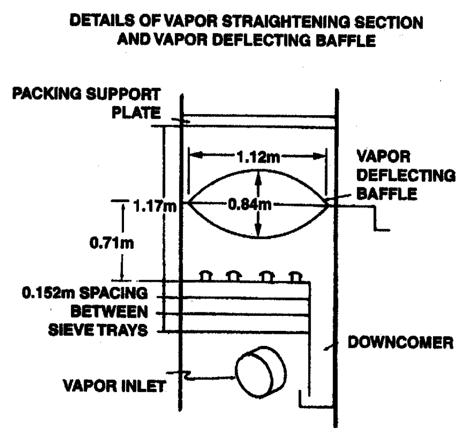

Figure 5. 50 % Segmental Blockage

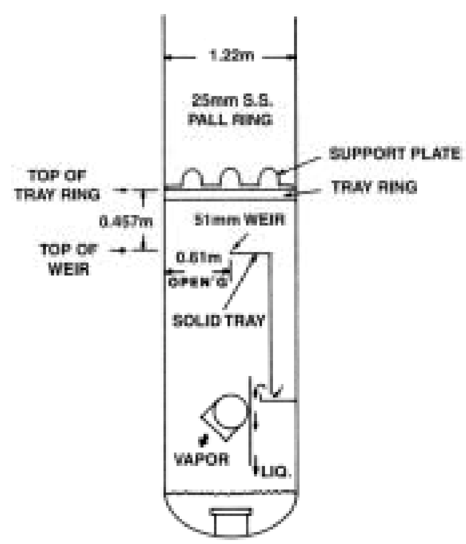

Figure 6. Configuration of Nutter Rings No. 2 Test

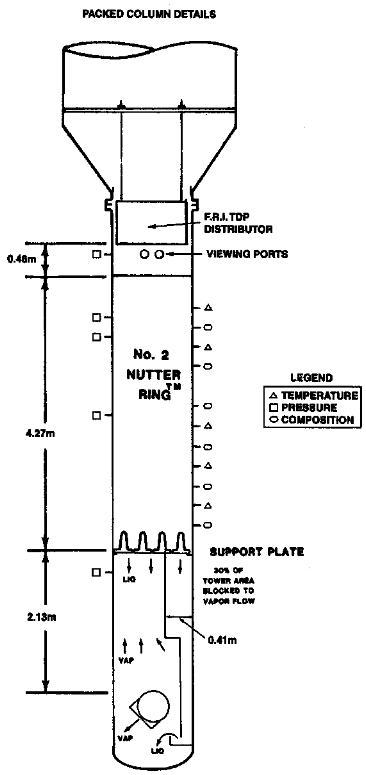

Figure 7. Mellapak 250Y Test (baseline)

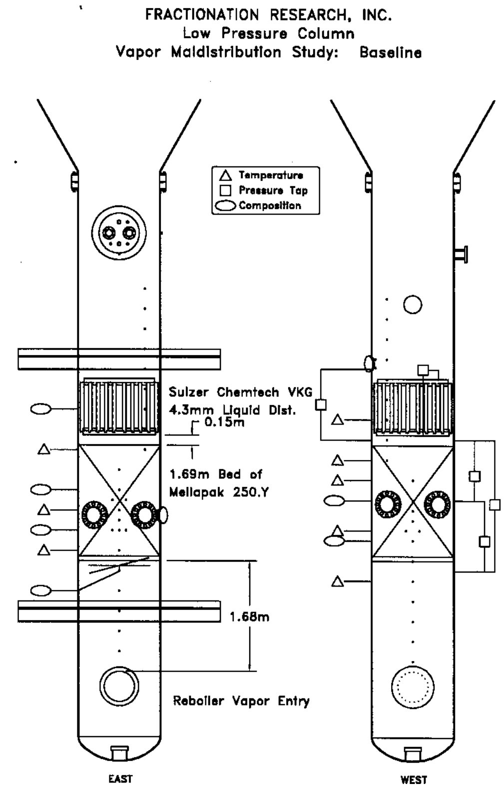

Figure 8. Mellapak 250Y Test (Center Block)

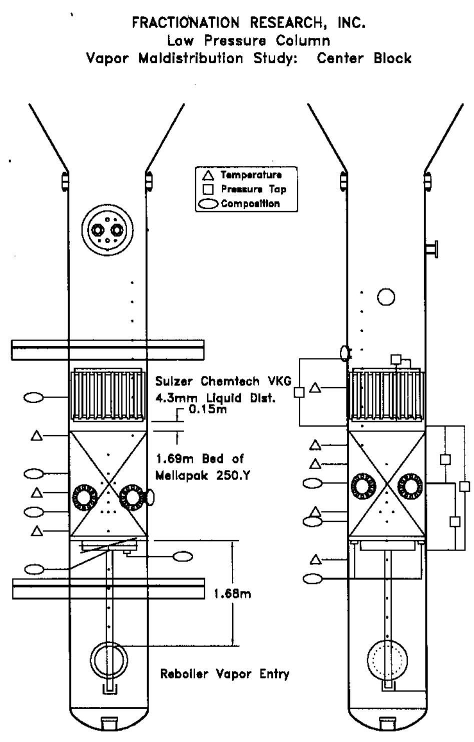

Figure 9. Mellapak 250Y Test (Chordal Block)

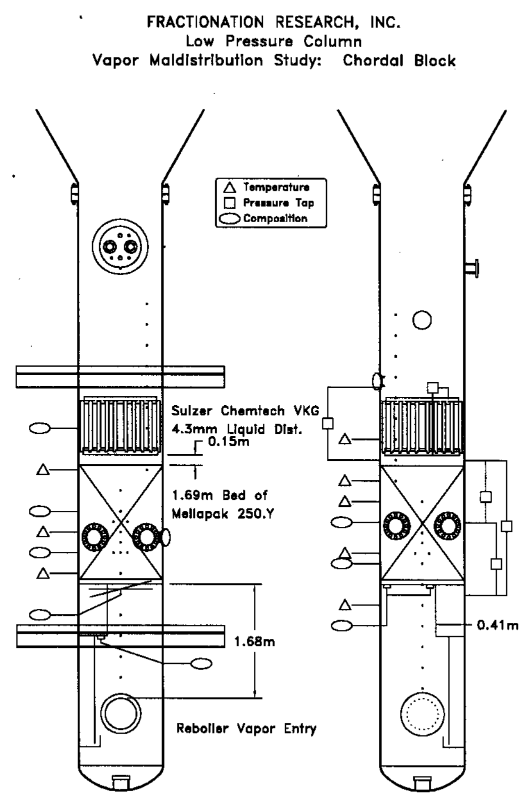

Figure 10. Circular Pan

Figure 11. Segmental Pan

Figure 12. Vapor Maldistribution
Test Efficiency of 25 mm Pall rings
cyclohexane/n-heptane 1.0 bar, 3.66 m Bed Depth

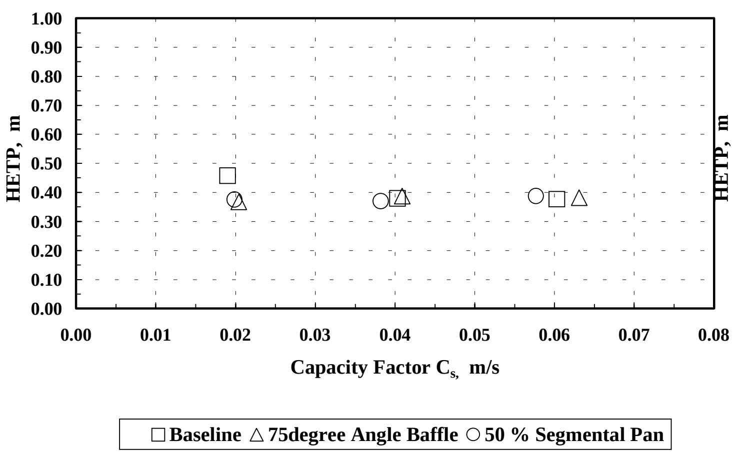

Figure 13. Vapor Maldistribution
Test Efficiency of Nutter ring No. 2
cyclohexane/n-heptane, 4.27 m Bed Depth

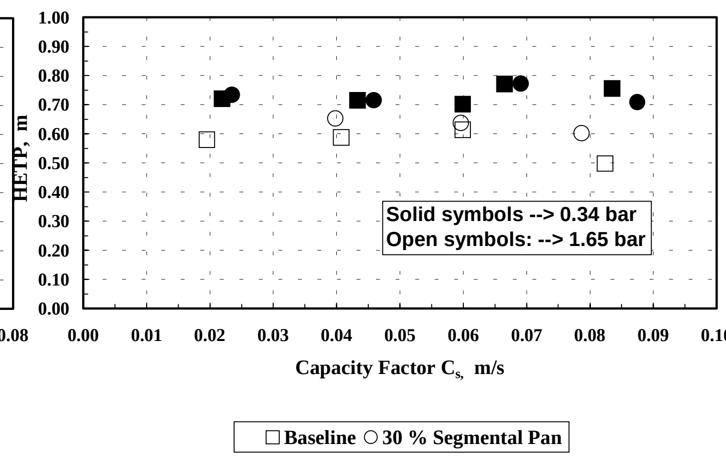

Figure 14. Vapor Maldistribution
Test Efficiency of Mellapak 250Y
o/p xylene 100 mm Hg, 1.69m Bed Depth

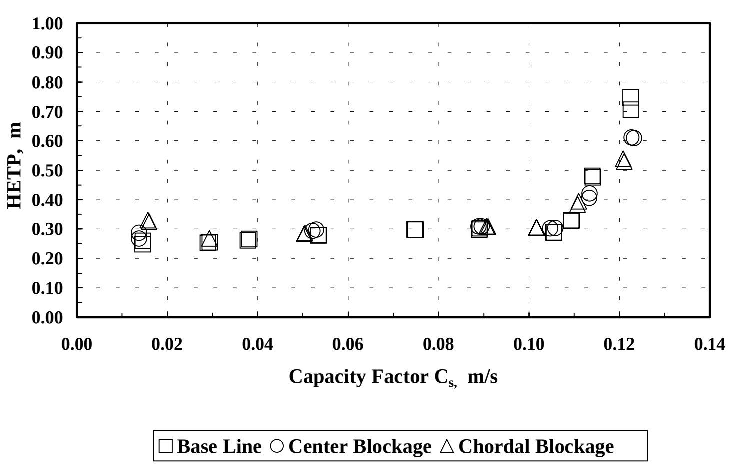

Figure 15. Vapor Maldistribution
Test Composition Profiles
o/p xylene 100 mm Hg, 1.69 m Bed Depth