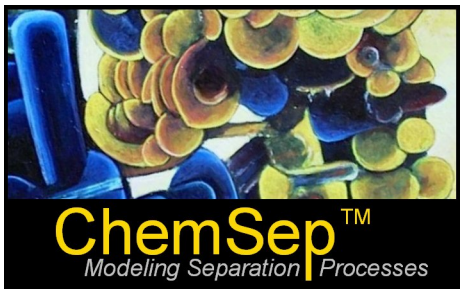


Depropanizer

In his book *Random Packings and Packed Towers, Design and Applications* R. Strigle (Gulf, 1987) describes a column for the recovery of propylene and propane from the C4 and heavier hydrocarbons. The top product is to contain no more than 1 mole% C4 hydrocarbons while the bottom product should have no more than 2 mole% C3 hydrocarbons. An existing column that is 5 ft in diameter with 22 trays (of a type unspecified) that are 24 inches apart is being considered for refitting with packing. The column is operated with a top pressure of 220 psia. The feed is liquid at 115 F and undergoes a 2.4 mol % flash on entry to the column. Strigle states that the feed flow to the column is 47,620 lb/hr, the bottoms product flow rate is 8,440 lb/hr, and the reflux flow rate is 66,600 lb/hr. Strigle reports that the column is equivalent to 14 theoretical stages (plus condenser and reboiler), with the feed in the middle.

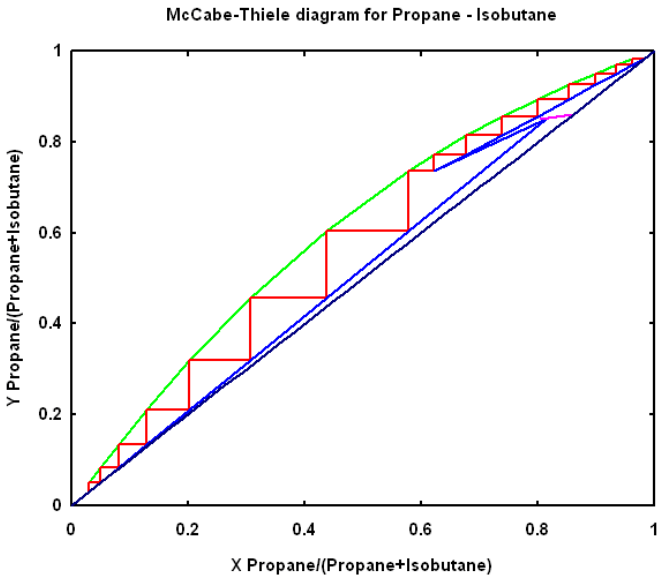
Feed specifications and product compositions

Component mole%	Feed	Distillate	Bottoms
Propylene	62.4	71.3	1.06
Propane	24.6	28.0	0.90
Isobutane	4.0	0.50	28.1
1-butene	6.0	0.17	46.2
Isopentane	0.5	0	3.95
n-Hexane	2.0	0	15.8
n-Heptane	0.5	0	3.95
Total mass flow (lb/h)	47619.9	39179.9	8440.0

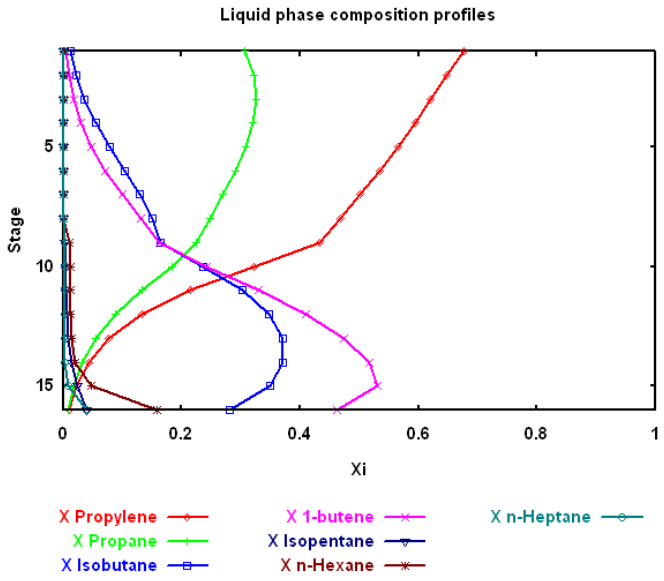
With this information we are able to conduct a preliminary simulation based on the equilibrium stage model in *ChemSep*^{TM}. We assumed constant pressure operation. Thermodynamic properties were calculated from the Chao-Seader model (Strigle does not tell us which model he used). The feed pressure was assumed to be the same as the column pressure. Specifying the bottoms flow rate in lb/hr and the reflux ratio (calculated from the reflux and distillate flows given by Strigle as 1.7) resulted in the product flows as shown in the table above, where trace compositions are shown as zero mole%. As can be seen from the table the combined C3 mole fractions in the bottom is 1.96 mole% which just meets the specification. The combined C4 concentration in the distillation is only 0.7 mole%, indicating that the feed position isn't optimal. This is easily checked by a means of a pseudo-binary McCabe-Thiele diagram for the key components propane and isobutane (drawn automatically by *ChemSep*^{TM}).

Moving the feed up three stages lowers the bottoms C3 concentration to just 1.0 mol%! This suggests that we should be able to lower the reflux flow. In fact, the reflux ratio can be reduced to just 1.22 and still meet the 2 mole% specification for the C4's in the bottoms resulting in a reduction of 28% for the condenser duty and 20% for the reboiler! The lower reflux also implies a significant reduction in internal traffic.

We now model the column with a nonequilibrium model of a column with 22 trays (plus condenser and reboiler). Strigle does not state what kind of tray was used in the existing column; we have assumed sieve trays, 11 trays above the feed and 11 below. For this first simulation we did not specify any column design details except for the tray spacing as 2 feet (as done also by Strigle) and the fraction of flood (80%). *ChemSep*^{TM} estimated the tray layout and key design parameters. We forced all trays to have the same design to obtain a column that had the same diameter over its height. In



(a) The McCabe-Thiele diagram for the equilibrium column



(b) Liquid mole fractions profiles

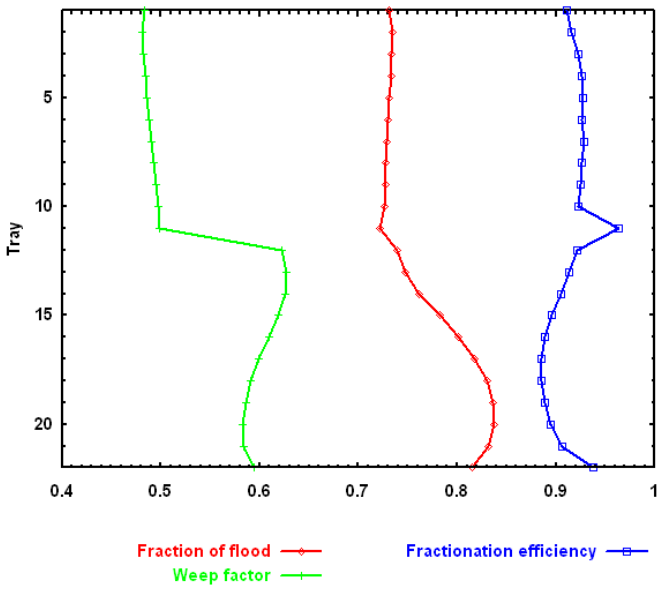
the table below we summarize the tray layout obtained using a reflux ratio of 1.7.

Sieve tray models and computed layout

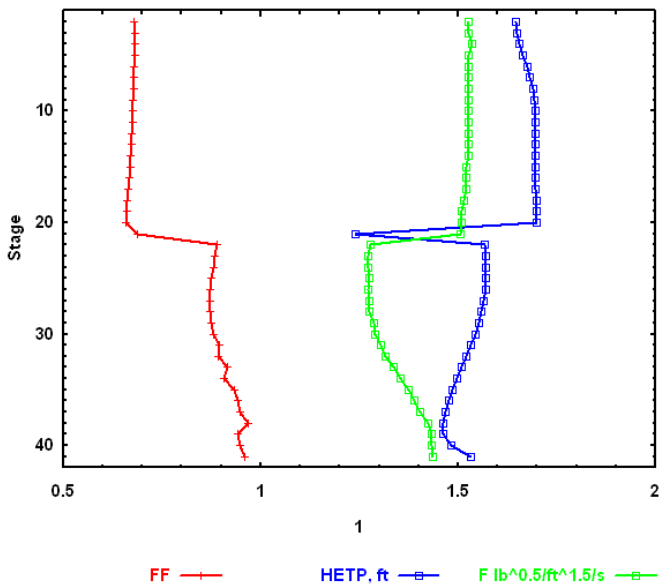
Mass transfer coefficient	Chan-Fair	Column diameter (ft)	5.37
Liquid phase resistance	Included	Number of flow passes	2
Vapour flow model	Plug	Liquid flow path length (ft)	1.75
Liquid flow model	Plug	Active area (%total)	75
Pressure drop	Estimated	Total hole area (%active)	10
Entrainment	None	Downcomer area (%total)	12.4
Design method	%flood	Hole diameter (”)	0.0156
Fraction of flooding	0.80	Hole pitch (”)	0.049
Tray spacing (ft)	2.00	Weir type	Segmental
		Weir length (ft)	6.32
		Weir height (”)	2
		Downcomer clearance (”)	1.5
		Deck thickness (”)	0.1

The trayed column easily meets both product specifications and is also well balanced: the top product contained 0.51 mole% C4’s and the bottoms 0.48 mole% C3’s. From the tray efficiency plot we see that the tray efficiencies are around 90 %, which is normal for this kind of operation. Inspecting the fraction of flooding profile we observe that the bottom section is limiting the capacity of the column as it peaks at tray 20 (from the top). Turndown is a factor 2.7 for the trays in the rectifying section versus about 1.9 for the trays in the stripping section. This can be improved by using different tray layouts in the rectifying and stripping section. Observe that combining the two sections caused the design method to come with a tray layout with a maximum of 83% of flood. But the actual column is only 5 ft in diameter, not 5.37 ft! This implies that at this reflux ratio the stripping section would be flooding ($83\% * 5.37^2/5^2 = 96\%$) and can explain why Strigle used a low tray efficiency of just $14/22 = 64\%$. When the reflux ratio is lowered down to 0.92 the 5ft double pass sieve tray *can* operate at around 90% of flood (stripping section) and tray efficiencies remain high at 90+% resulting

in 1.94 mole% C3 in the bottoms and 0.67 mole% C4 in the distillate.



(a) Sieve tray efficiency and operation



(b) Packed column HETP and operation

Strigle refits his column with #50 IMTP packing with 19.5 ft of packing above the feed and 18.5 feet below the feed. Here we simulated the packed column with two beds each 19.7 ft high in plug flow. The C3 bottom specification of 2 mole% still can be met when we lower the reflux ratio to 1.25. *ChemSep*^{TM} reports that at this reflux ratio the stripping section operates at 87–97% of flooding with the highest values in the bottoms of the stripping section. This contrasts with Strigle who states that the highest loading occurs at the top of the stripping section. The difference appears to be due to our accounting for the changing vapor density (due to the concentration changes). This causes the F factor to peak at the bottom of the stripping section. Thus, our packed column does not have a higher throughput whereas Strigles mentions a 7 % improvement in throughput. The HETP observed is 1.7 ft (about 20 inch) in the rectification section and 1.5-1.6 ft (about 18-19 inch) in the stripping section. However, at high pressures backmixing (of both liquid and vapor) can occur. When we simulate the packing in mixed flow the HETP's increase: 20 to 22 inch. The values compare very well to those Strigle reports for C3/C4 fractionation in his Table 9-4 (19-22 inch). Unfortunately, the higher HETP's cause the product specifications not to be met unless the reflux ratio is increased, which is not possible because the packed column was already flooding at RR=1.25!

Conclusion

We have used *ChemSep*^{TM} to determine if an existing tray column can be refitted with #50 IMTP packing. This design exercise was posed in *Random Packings and Packed Towers, Design and Applications* by R. Strigle. Although not all details of the exercise are in agreement with Strigle we find that a packed column can meet the purity specifications but that it provides no capacity advantage over a convential double pass sieve tray.