32430: Separations Processes:

EXAM 2, Fall 2008

Closed Book/Notes

Please put all answers in boxes and write as clearly as possible.
(Thanks)

1) 42
2) 25
3) 20

\[87\]
Problem 1) (45 points)

1) A distillation column is to be employed for the separation of propane from butane. The column operates at 1 atm pressure and the equilibrium data is plotted in the attached figure. A saturated liquid sidestream is removed with a propane composition of 0.35. A partial reboiler and a partial condenser are employed in this system. The resulting vapor distillate product, has a composition of 0.94. In addition, not all of the liquid from the partial condenser is returned to the top of the column. Some of this saturated liquid is removed from the system as a liquid distillate product stream (i.e. there are two distillate product streams). The feed to this column consists of 100 lb/moles/hr of 35% butane feed stream which is 40% saturated vapor. The reflux ratio for this system is defined as \( L_r/(D_{total}) \) and is equal to 1.36. The flow rates of the vapor distillate, the liquid distillate and the sidestream are set equal. Furthermore, 2% of the propane entering in the feed leaves the system in the bottoms product. Assuming constant molal overflow, construct a schematic of this column and determine the following:

1) All external flow rates and compositions. ✓
2) All internal flow rates. ✓
3) The equation for the top operating line and the intersection of this line with the \( x=y \) line. (What is the significance of the composition?) ✓
5) On accompanying figure construct all appropriate operating lines and \( Q \) lines. ✓
6) The number of stages and optimum location of the feed and the side stream. (counting from the bottom up).

\[ \frac{6.5 \text{ stages}}{\text{ PR}} = \frac{5.5 \text{ stages}}{\text{ PR+PC}} \]

Sidestream should be between \( \text{ PR } \) and \( \text{ Tray 1} \)
Feed should be on top of Tray 3

Intersection is at \( (0.94, 0.94) \) This is because the PC acts as a stage
\[ V_B = \frac{V}{B} = 2.704 \]

\[ F = 100 \text{ lbmol/hr} \]
\[ Z_F = 0.65 \]
\[ b = 0.6 \]

\[ X_B = 0.121 \]

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\[ F = D_1 + D_2 + S + B = 100 = 3S + B \]

\[ 100(0.65) = D_1(0.94) + D_2(0.85) + S(0.35) + 1.3 \]

\[ S = 29.766 \text{ lbmol/hr} \]

\[ D_1 = 29.766 \text{ lbmol/hr} \]

\[ D_2 = 29.766 \text{ lbmol/hr} \]

\[ B = 29.766 \]

\[ X_S = 0.35 \]

\[ X_B = 0.121 \]

\[ X_B = 0.121 \]

\[ L_R = \frac{1.34}{D_1 + D_2} \]

\[ \frac{L_R}{59.532} = 1.34 \]

\[ L_R = 80.944 \text{ lbmol/hr} \]

\[ V = D_1 + D_2 + L_R \]

\[ V = 140.496 \text{ lbmol/hr} \]

\[ V' = V - 40 \]

\[ V' = 100.496 \text{ lbmol/hr} \]

\[ L' = LR + 60 \]

\[ L' = 140.964 \text{ lbmol/hr} \]

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\[ \left( \frac{q_{LINE}}{q_{RECTIFYING}} \right) = -1.5x + 1.083 \]

\[ \left( \frac{q_{RECTIFYING}}{q_{STRIPP}} \right) = \frac{5.763x + 0.3983}{1} \]

\[ \frac{L'}{V'} = 1.403 \]

\[ 0.5763 = \frac{4U}{0.1} \]

\[ 0.5763 = 1 \]

\[ y = x + 0.1 \]

\[ y = 1.3698x - 0.0447 \]

\[ L = 191.198 \text{ lbmol/hr} \]

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Equilibrium Data for Propane-Butane at 101.43 kPa
Problem 2) (35 points)

We are using a distillation column with a total condenser and a partial reboiler to separate a binary ethanol-water feed whose equilibrium data is given in the attached figure. The distillation column is used to process the following feed stream at 1 atm: 210 kg mole/hr of 48 mole % ethanol with 66.7% saturated vapor. The reflux (R) at the top of the column is set at 1.82 times the minimum reflux. The distillate composition is \( x_D = 0.82 \). Constant molal overflow can be assumed. The heat of vaporization is 1030 kJ/kg mole for the composition in the reboiler. The flow rate of vapor into the condenser from the top of the column is 196 kg mole/hr. Construct a flow chart for this distillation column and determine the following (assuming constant molal overflow):

1) All external flow rates and compositions. ✓

2) Minimum and actual reflux in the condenser. ✓

3) The heat duty in the reboiler. ✓

4) On Figure 1 construct all appropriate operating lines and Q lines.

5) The number of stages and optimum location of the feed. \( \text{Feed between PR & Tray 1} \)

6) The number of stages if the Murphree efficiency based on the vapor phase is 75%. \( \text{16 stages + PR} \)
\[ F = 210 \text{ Kmol/hr} \]
\[ Z_f = 0.48 \]
\[ \frac{Z_f}{9} = \frac{1}{3} \]

\[ 270 = D + B \]
\[ 18 = 110.148 \text{ Kmol/hr} \]
\[ 210(0.48) = 99.852(x_B) + 110.148(x_B) \]
\[ x_B = 0.172 \]

\[ H_v = 1030 \text{ KJ/Kmol} \]
\[ D = 99.852 \text{ Kmol/hr} \]
\[ L = 96.148 \text{ Kmol/hr} \]

\[ L = L + 70 \]
\[ L = 166.148 \text{ Kmol/hr} \]

\[ Q_R = \bar{V} H_v = 1030 \times 56 = 57680 \text{ KJ/hr} = 16.02 \text{ KW} \]

\[ \frac{L}{V} = 0.4906 \]

\[ \frac{L}{V} = 2.9669 \]
Figure 2: Equilibrium Data for Ethanol-Water at 101.43 kPa

\[ \Delta y = \frac{.175}{.555} = .315 \]

\[ R_{\text{min}} = .2907 \]
Problem 3) (20 points)

A flash chamber is operating at 50 °C and 200kPa is separating 1,000 kg moles/hr of a feed that is 30 mole % propane, 10 mole % n-butane, 15 mole % n-pentane and 45 mole % n-hexane. Find the mole fraction of n-butane in the liquid leaving the flash chamber. (note: the K values for propane, n-butane, n-pentane and n-hexane at these conditions are 7, 2.4, 0.8, and 0.3, respectively).

\[
\begin{align*}
Z_i & = K_i \\
C_3 & = 3.7 \\
C_4 & = 1.24 \\
nC_5 & = 1.15 \\
nC_6 & = 0.45
\end{align*}
\]

\[\psi = 0.5 \]

\[
f(5) = -0.45 - 0.0824 + 0.0846 = -0.6745
\]

\[
f'(5) = 0.675 + 0.0678 + 0.0674 + 0.5279 = 1.2721
\]

\[
\psi = 0.5 + \frac{0.6745}{1.2721} = 0.5774
\]

\[
f(0.5774) = -0.4424 - 0.0816 + 0.0334 + 0.4904 = 0
\]

\[
f'(0.5774) =
\]

\[
\psi = \frac{V}{F}
\]

\[
X_i = \frac{Z_i}{1 + \psi(K_i - 1)} = \frac{0.1}{1 + 0.5774(2.4 - 1)}
\]

\[
X_{nC_4} = 0.058
\]