Chemical Engineering Separations

EXAM 2, Fall 2007

Closed Book/Notes

Please put all answers in boxes and write as clearly as possible.
Problem 1) (25 points)

We are using a distillation column with a partial condenser and direct steam injection into the reboiler to separate ethanol from water. The distillation column is used to process two feed streams at 1 atm. Feed 1: 85 kgmole/hr of 21.5 mole % ethanol, 40 % saturated vapor; Feed 2: 100 kgmole/hr of 62 mole % ethanol, saturated liquid. (note: Operating pressure is 101.3 kPa and a binary equilibrium diagram is given in Figure 1). The bottoms product is a saturated liquid and has a mole fraction of \( x_B = 0.04 \), and the distillate \( y_D = 0.84 \) (both mole fractions ethanol, with ethanol being the more volatile component). The direct steam is a saturated vapor with a flow rate of 34 kgmole/hr. Constant molal overflow can be assumed. The reflux \( (R) \) at the top of the column is set at 0.563. The heat of vaporization is 1080 kJ/kgmole for the composition in the condenser. 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) All internal flow rates.

4) The heat duty in the condenser.

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

6) The number of stages and optimum location of the two feed streams.

7) The number of stages if the Murphree efficiency based on the vapor phase is 75%.
1) \[100 + 85 + 34 = D + B\]
   \[(0.62 \times 100) + (0.28 \times 85) = 0.84D + 0.04B\]

\[D = 89.34 \text{ kg/hL}, \quad B = 129.61 \text{ kg/hL}\]

2) \[N = \frac{L}{D} = 0.563 \quad \Rightarrow \quad L = 56.33\]
   \[V = L + D = 139.71\]

3) \[R = \frac{L}{D} = 0.563 \quad \Rightarrow \quad L = 56.33\]
   \[V = V = 139.71\]

4) \[Q_c = L(\Delta H_v) = (56.33)(1080) = 54,345 \text{ J/kg hL}\]
   \[\Delta H_v = Q_c / Q_{w} = 54,345 / 5000 = 10.87\]
1) \( y = \frac{5.52}{5} = 1.104 \)
2) \( F_1 = 0.25, q = 0.6, \frac{b}{q} = -1.5 \)
\( X_b = 0.09 \)
\( L = \frac{52.52}{139.72} = 0.36 \)
\( \frac{L}{V} = 0.36 \)
\( \frac{L}{V} = \frac{150.32}{139.72} = 1.076 \)
\( \frac{L}{V} = \frac{261.32}{105.72} = 1.964 \)

See graph

6) PC + 3 STAGE + PR = 5 TOTAL STAGES
  \( F_1 \) into PR
  \( F_2 \) into STAGE 2

7) PC + 5 STAGE + PR = 7 STAGE
  \( F_1 \) into PR
  2 PH off if with N.F.
  Fix PA to or PC
Figure 1: Equilibrium Data for Ethanol-Water at 101.43 kPa
Problem 2) (45 points)

A distillation column is used to process a feed stream at 1 atm. (250 kg mole/hr of 40 mole % propane, 33 % saturated liquid). (note: a binary equilibrium diagram is given in Figure 1). A total condenser and a partial reboiler are employed in this system. The distillation tower has two exiting streams, a distillate product (xD=0.96) and a bottoms product. The reflux ratio in the condenser is set at 1.484 times the minimum reflux. The vapor flow rate entering the total condenser at the top of the column is 440.2 kg mole/hr. A cooling coil is placed in the column in such a way that 47% of the vapor leaving the first actual tray from the bottom (not including the partial reboiler) is condensed. Construct a flow chart for this distillation column and determine the following (assuming constant molar overflow):

1) All external flow rates and compositions.

2) The minimum and actual reflux ratios.

3) The minimum number of stages.

4) On Figure 1 construct all appropriate operating lines and Q lines for the actual reflux condition.

5) The number of stages and optimum location of the feed stream.
1) \( \nu = L + 0.648 \times 1.53 = 273.6 \)  
\( 250 = A \times 0.4 \)  
\( \phi = 0.33 \)  
\( \frac{\phi}{\phi - 1} = -0.493 \)  
\( \frac{L}{\nu} = 0.761 \)  
\( R_{\text{MIN}} = \frac{\frac{L}{\nu}}{1 - \frac{\phi}{\phi - 1}} = 2.35 \)  
\( A_{\text{DET}} = 3.5 \)  

2) \( \frac{L}{\nu} = 0.96 \)  
\( Z_F = 0.4 \)  
\( \nu = 0.33 \)  
\( \frac{L}{\nu} = 0.493 \)

From Dumas, \( \frac{L}{\nu} \) in \( \text{MIN} \) = 0.761  
\( R_{\text{MIN}} = \frac{\frac{L}{\nu}}{1 - \frac{\phi}{\phi - 1}} = 2.35 \)  
\( A_{\text{DET}} = 3.5 \)  

\( V = L + 0.6 \)  
\( \phi = \frac{L}{\nu} = 3.5 \)  
\( D = 98 \)  
\( L = 842.2 \)  
\( \phi = 152 \)  
\( F = D + B \)  
\( B = 153 \)  
\( z_p F = x_k B + x_p D \)  
\( x_k = 0.04 \)
3) \( N_{\text{min}} = 7 \) total stages \( A \& N \)

4) see graph

5) \( N_{\text{act}} = 11 \) total stages

Feed, 5th stage from bottom

Full if all other \( n \)'s not met

-3 "After"
3) (10 points)
The following stream is at 200 psia and 200°F. Determine whether it is a subcooled liquid, a superheated vapor or whether it is partially vaporized.

<table>
<thead>
<tr>
<th>Component</th>
<th>lbmol/h</th>
<th>z_i</th>
<th>K value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_2</td>
<td>60</td>
<td>0.14</td>
<td>2.056</td>
</tr>
<tr>
<td>nC_4</td>
<td>200</td>
<td>0.46</td>
<td>0.925</td>
</tr>
<tr>
<td>nC_5</td>
<td>175</td>
<td>0.4</td>
<td>0.52</td>
</tr>
</tbody>
</table>

If \( f(0) > 0 \) then subcooled liquid

\[
\begin{align*}
  f(0) &= 3 z_i (1 - z_i) = 0.14(1 - 2.056) + 0.46(1 - 0.925) + 0.4(1 - 0.52) \\
  &= 0.67866 > 0 \quad \therefore \text{subcooled liquid}
\end{align*}
\]

Future work is finite but must state subcooled liquid.

If \( \sum z_i x_i > 1 \) then have subcooled liquid

\[
\sum z_i x_i = (0.14 \times 2.056) + (0.46 \times 0.925) + (0.4 \times 0.52) = 0.92
\]

\( \therefore \text{subcooled liquid} \)