32430: Chemical Engineering Separations
EXAM 1, Fall 2012

Closed Book/Notes

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

1) 35
2) 19
3) 4
4) 8

66
Problem 1) (35 points)

170 kg mole/hr of a binary ethanol-water saturated liquid is processed in a system consisting of two unit operations. The feed is first fed into a flash chamber. The vapor stream exiting from the flash chamber is then sent to a partial condenser where the liquid stream exiting from the partial condenser is recycled back into the initial flash chamber at a rate of 115.57 kg mole/hr. (note: The compositions of the two liquid feeds to the initial flash chamber are not equal). 62% of the total vapor fed into the partial condenser is condensed. The vapor exiting from the partial condenser contains 78 mole % ethanol. Calculate the following after constructing a flow chart of this process.

1) The vapor and liquid compositions leaving the two unit operations.

2) All of the liquid and vapor flow rates in this process.

3) The percent vaporized in the flash chamber.

4) The effective composition of the total feed to the flash chamber

5) The composition of the feed to the overall process.

6) The yield of the overall process for ethanol recovery in the exiting vapor stream.

Note: The equilibrium curve for the Ethanol/Water system is given in accompanying figure.

\[ 170 = V_L + L_1 \]

\[ \frac{V_1}{L} = \psi_1 \]

\[ 0.62 \times 115.57 \text{ kg mole/hr} = V_L + L_1 \]

\[ x_2 = 0.54 \text{ (from the graph)} \]

\[ \frac{\psi_1 - 1}{\psi_1} x_2 + \frac{Y_1}{\psi_2} \]

\[ 0.78 = \frac{0.38 - 1}{0.38} (0.54) + \frac{Y_1}{0.58} \]

\[ Y_1 = 0.63 \Rightarrow x_1 = 0.18 \text{ (from the graph)} \]
\[ F = V_L + L_1 \]
\[ F = L_2 = V_1 + L_1 \]
\[ V_1 = V_L - L_2 \]
\[ V_0 = V_L + L_1 \]
\[ 285.5 = V_1 + L_1 \]
\[ V_1 = V_L + 115.57 \]
\[ V_1 - V_L = 115.57 \]

\[ 0.63 V_1 = 0.54 L_2 + 0.78 V_2 \]
\[ 0.63 V_L = 62.4 + 0.78 V_2 \]

\[ \frac{V_1}{0.63} = V_L + 115.57 \]
\[ V_L = 69.33 \text{ km/hr} \]

\[ V_1 = 184.90 \text{ km/hr} \]
\[ L_1 = 100.67 \text{ km} \]
1) Work on previous page and graph.

\[ X_1 = 0.18 \quad Y_1 = 0.63 \]
\[ X_L = 0.54 \]

2)

\[ F = 170 \text{ kmol/hr} \]
\[ L_2 = 115.97 \text{ kmol/hr} \]
\[ V_1 = 184.90 \text{ kmol/hr} \]
\[ V_2 = 69.88 \text{ kmol/hr} \]
\[ L_1 = 100.33 \text{ kmol/hr} \]

Work on bond of last page.

3)

\[ \frac{V_1}{L_1F} + F = \frac{184.90}{170 + 115.97} = 0.647 \text{ or } 64.7\% \text{ vaporized in the flush} \]

4)

\[ F_2 + L_2x_2 = (F + L) z_{\text{net}} \]
\[ 170 z = 100.33(0.18) + 69.33(0.98) \]
\[ z = 0.42 \]
\[ z_{\text{net}} = 0.42 \]

5)

\[ +4 \]

6)

\[ \frac{V_2}{F_2} = \frac{69.33(0.98)}{170(0.18)} = 0.757 \text{ or } 75.7\% \text{ yield} \]
Equilibrium Data for Ethanol-Water at 101.43 kPa
Problem 2) (25 points)

The following process is designed to recover ethylene glycol from water using furfural as the solvent. Two feed streams, F1 (total flow rate of 140 kg/hr containing 35% ethylene glycol) and F2 (total flow rate of 120 kg/hr containing 46% ethylene glycol) are contacted with 516.1 kg/hr of furfural in an extraction stage. The exiting raffinate from this first stage is then contacted with an additional stream of pure furfural in a second extraction stage. The raffinate exiting the second stage contains 15% ethylene glycol and the total extract exiting the second stage has a mass flow rate of 1003 kg/hr. Using the equilibrium diagram in the attached figure (ignore the M, R, and E points indicated on the graph, determine your locations for this problem) and appropriate mass balances and/or level rule calculations, determine the following after constructing a flow chart of the process (note: use your eye to construct needed tie lines between given tie lines, your solution path may not be in this exact order):

1) The composition of the mixing point for the first stage.
2) The compositions and mass flow rates of the extract and raffinate streams from the first stage.
3) The amount of pure furfural entering the second stage.
4) The compositions and mass flow rates of the extract and raffinate streams from the second stage.

\[ F = F_1 + F_2 = 140 + 120 = 260 \text{ kg/hr} \]

\[ F_{x_{E}} = F_1 x_{E1} + F_2 x_{E2} = 140 \times 0.35 + 120 \times 0.46 = 119.2 \text{ kg/hr} \]

\[ 240 x_{E} = 119.2 \times 0.35 + 120 \times 0.46 \]

\[ x_{E} = 0.40 \]

\[ F + S_1 = E_1 + R_1 \]

\[ F + S_1 + S_2 = E_2 + R_2 + E_1 \]

\[ S_2 + R_1 = E_2 + R_2 \]

\[ F_{x_{E}} = E_1 x_{E1} + E_2 x_{E2} + R_1 x_{E1} \]

\[ 240(0.40) = 516.1(0.15) + 1003 x_{E2} + E_2(119.2) \]
1) \[ \frac{F_{x_{m_1}}}{F + S_1} = x_{w_{m_1}} \]

\[ \frac{260}{260 + 516.1} = x_{w_{m_1}} = 0.20 \quad \text{(from the figure)} \]

\[ x_{e_1 m_1} = 0.14 \]

\[ x_{w_1 m_1} = 0.66 \]

2) \[ x_{e_1 E_1} = 0.32 \]

\[ x_{w_1 E_1} = 0.58 \]

\[ x_{e_1 E_1} = 0.1 \]

\[ E_1 = 2.54 \times R_1 \]

\[ \frac{R_1}{E_1} = \frac{0.88 - 66}{66 - 1} \]

\[ F + S = E_1 + R_1 \]

\[ 260 + 516.1 = 2.54 \times R_1 + R_1 \]

\[ R_1 = 219.2 \text{ kg/hr} \]

\[ E_1 = 556.1 \text{ kg/hr} \]

3) \[ x_{e_1 m_1} = 0.06 \]

\[ x_{w_1 m_1} = 0.09 \]

\[ x_{e_1 m_1} = 0.85 \]

\[ \frac{219.2}{219.2 + S_2} = 0.09 \]

\[ S_2 = 193.4 \text{ kg/hr} \]

\[ 390.8 \text{ kg/hr} \]

4) \[ x_{e_1 E_2} = 0.15 \]

\[ x_{w_1 E_2} = 0.76 \]

\[ x_{e_1 E_2} = 0.09 \]

\[ x_{e_1 E_2} = 0.91 \]

\[ S_2 + R_1 = E_2 + R_2 \]

\[ 1193.4 + 219.2 = 1003 + R_2 \]

\[ R_2 = 409.6 \text{ kg/hr} \]
Problem 3) 25 points

A still is charged with 40 mol of a mixture of benzene and toluene containing 0.35 mole fraction benzene. Feed of the same composition is supplied at a rate of 10 mol/h and the heat rate is adjusted so that the liquid level in the still remains constant. No liquid leaves the still pot and $K_{eq} = 2.1$. (note: assume that you can use a constant $K$ approximation for this problem). How long will it be before the instantaneous distillate composition (the one in equilibrium with the liquid) falls to 0.42 mole fraction benzene.

\[ w_0 = 40 \text{ mol} \]
\[ x_e = 0.35 \quad x_0 = 0.65 \]
\[ K_{eq} = 2.1 \quad y_e = 0.42 \]
\[ F = 10 \text{ mol/h} \]

\[
\ln \frac{w}{w_0} = \frac{1}{K-1} \ln \frac{x}{x_0}
\]

\[
y = Kx
\]

\[
y_e = 2.1(0.35)
\]
\[
y_0 = 0.755
\]

\[
0.42 = 2.1x \\
x = 0.2
\]

\[
\ln \frac{w}{w_0} = \frac{1}{K-1} \ln \frac{x}{x_0}
\]

\[
\ln \frac{w}{40} = \frac{1}{2.1-1} \ln \frac{0.2}{0.755}
\]

\[
w = 22.86 \text{ mol}
\]

\[
40 - 22.86 = 17.14 \text{ mol}
\]

\[
17.14 \text{ mol} = 10 \text{ mol/h} \times t
\]

\[
t = 1.71 \text{ hr} \\
or 10.28 \text{ min}
\]
Problem 3) Correct Answer

\[ \frac{dx}{dt} = \frac{F_x - \frac{\omega}{\nu}}{m} \]

\[ t = 3.297 \text{ hr} \]

\[ \ln \left( \frac{35 - 21}{21} \right) + \frac{35}{35} - \frac{35}{21} = 2.5t \]
Problem 4) 15 points (answer each question briefly)

a) When carrying out a multicomponent bubble point calculation, if a selected temperature and pressure results in the bubble point criteria being greater than 1, how should you modify your pressure estimate for the next iteration assuming that the temperature remains constant and why?

For the next iteration, you would increase your pressure estimate, because, assuming temperature remains constant, this would decrease the $K_i$ values for the individual components and thereby lower your iteration criteria closer to 1.

$$\sum x_i K_i = 1$$

If $P \uparrow$, $K \downarrow$
If $P \downarrow$, $K \uparrow$

a) For a non-ideal binary equilibrium system with repulsive interactions between the two species in a binary mixture, construct a representative y-x equilibrium curve for this system.
b) What is a quick check that you can do to determine if you will have only one phase coming out of a multicomponent flash distillation?

You can check all of your $K$ values. If they are all greater than 1, then you have a superheated vapor. If your $K$ values are all less than 1, you have a subcooled liquid. If you have $K$ values both greater than and less than 1, you can also check the Ruthford-Rice equation. If $f(\psi=0) > 0$ then you have a subcooled liquid whereas if $f(\psi=1) < 0$ you have a superheated vapor. If none of these conditions are met, it can be expected that you will have more than 1 phase coming out of a multicomponent flash distillation.

c) For an extraction system where the two phases are partially miscible, what does the mixing point for a given stage represent?

The mixing point is the azeotropic equilibrium point for the two phases for a given stage.