Problem 1) (40 points)

A system for processing two feed streams of binary ethanol-water has been designed. The first feed, a saturated vapor containing 62% ethanol is introduced into a partial condenser (unit op 1) at a flow rate of 150 kg mole/hr. The second feed, a saturated liquid containing 20% ethanol, is introduced into a flash chamber (unit op 2) at a flow rate of 130 kg mole/hr. 29.6% of the feed to unit op 2 is vaporized in the flash chamber. The liquid exiting the partial condenser and the vapor exiting the flash chamber have the same mole fraction of ethanol and are both sent to a third unit op which mixes these streams and adds additional heat such that the exiting vapor stream from unit op 3 has a mole fraction of 0.68 ethanol. Calculate the following after constructing a flow chart of this process (not necessarily in this order).

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

2) All of the liquid and vapor flow rates leaving the first unit op.

3) The percent condensed in unit op 1.

4) The ratio of the exiting vapor flow rate to the total feed flow rate in unit op 3.

5) If the objective was to produce a vapor at the composition of the vapor exiting unit op 3 from these two initial feed streams to the overall process, what would have been a much simpler and more energy efficient way of producing this stream? (extra credit: show this approach also on the figure with some representative numbers).

Note: The equilibrium curve for the Ethanol/Water system is given in accompanying figure.
4) \[
\frac{V_5}{L_1 + V_2} = \frac{67.05}{78.95 + 38.48} = \frac{67.05}{117.43} = 0.576
\]

\[\text{\textcolor{red}{\sqrt{18}}}\]

\[L = V + L\]
\[117.43 = V + L\]

\[117.93 (0.48) = 0.68V + 0.22L\]
\[56.95 = 0.68V + 0.22L\]
\[56.95 = 0.68(117.43 - L), 0.22L\]
\[56.95 = 79.85 - 0.68L + 0.22L\]
\[56.95 = 79.85 - 0.46L\]
\[L = 22.9\]

\[L_3 = 49.78 \text{ kg mol}^{-1} \text{ L}^{-1}\]

\[V_3 = 67.65 \text{ kg mol}^{-1} \text{ L}^{-1}\]
Equilibrium Data for Ethanol-Water at 101.43 kPa

Graph showing the relationship between mole fraction in the liquid and mole fraction in the vapor. Points marked include (0.09, 0.485) and (0.485, 0.77).
Problem 2) (20 points)

A one stage extraction system is designed to recover ethylene glycol from water using furfural as the solvent. 200 kgmoles/hr of a feed containing 35% ethylene glycol in water is contacted with a stream of pure furfural solvent in the first extraction stage. Using the accompanying figure, calculate the following (note: you can use approximate tie lines using your eye).

1) Find the minimum and maximum amounts of solvent that could be employed to effect some separation in this system.

2) Using a solvent flow rate that is 12 times the minimum solvent value, determine the mixing point, extract and raffinate compositions and the flow rates leaving the first stage.

\[ S + F = M = E + R \]

\[ 200 + 700 = M = 4(200) \]

\[ 70 = 4(200) \times y_e \]

\[ y_e = 0.15 \]

\[ \frac{y_c}{1-y_c} = \frac{M}{F} \]

\[ \frac{S_{min}}{200} = \frac{0.92}{1-0.92} \]

\[ S = 2.800 \text{ kgmin}\text{l}_{hv} \]

\[ \frac{5_{min}}{700} = \frac{0.1}{1-0.1} \]

\[ S = 37.2 \text{ kgmin}\text{l}_{hv} \]

\[ \frac{2.2}{12} = 2.6(0.4) \text{ kgmol}\text{l}_{hv} = S \]

\[ M(0.28 y_0, 0.15 y_e, 0.57 y_c) \]
\[ M = E + R \]

\[ \text{HgO} \cdot 0.4 = E + R \]

\[ E = \text{HgO} \cdot 0.4 - R \]

\[ M \nu_k^m = E \nu_b^c + R \nu_b^d \]

\[ \text{HgO} \cdot 0.4 = E(0.071 + R(0.28)) \]

\[ 69.94 = 0.07E + 17.8R \]

\[ 69.94 = 0.07(\text{HgO} \cdot 0.4 - R) + 17.8R \]

\[ 69.94 + 17.8R = 0.07R + 17.8R \]

\[ 87.81 = 0.71R \]

\[ R = 177.7 \text{ kJ mol}^{-1} \text{hr}^{-1} \]
Problem 3) 24 points

A hydrocarbon gas enters an absorption system at the following molar flow rates in lb mol/hr: 160 ethene, 120 ethane, 240 propene, 25 isobutane, 6 n-pentane and 1 n- hexane. Absorption is carried out at 150 psia and an average temperature of 100 °F using a high molecular weight oil at a molar flow rate of 200 lb mol/hr, in a column with 8 trays that you can consider full equilibrium stages. Use this information along with the data obtained from the accompanying figure to determine the solute molar flow rates in the vapor and liquid streams leaving the absorption column.

\[
V = \begin{cases} 
160 \text{ ethene} & = 0.94 \\
120 \text{ ethane} & = 0.72 \\
240 \text{ propene} & = 1.44 \\
25 \text{ isobutane} & = 0.13 \\
6 \text{ n-pentane} & = 0.03 \\
1 \text{ n- hexane} & = 0.001 \\
\end{cases}
\]

\[
P = 150 \text{ psia,} \\
T = 100 \text{ °F}
\]

\[
N = 8, \\
V = 200 \text{ lb mol/hr}
\]

Solute mass balance:

\[
L = 200 \text{ lb mol/hr} \\
\text{k values from chart}
\]

\[
A = \frac{L}{K} \\
S = \frac{1}{A}
\]

\[
\text{ethene} \\
k = 5.8 \\
L = 200 \\
V = 160
\]

\[
A = \frac{200}{5.8(150)} = 0.277 \\
S = \frac{1}{A} = \frac{1}{0.277} = 3.64 \text{ lb mol/hr}
\]

\[
ek = 3.8 \\
L = 200 \\
V = 120
\]

\[
A = \frac{200}{3.8(150)} = 0.49 \\
S = \frac{1}{A} = \frac{1}{0.49} = 2.04 \text{ lb mol/hr}
\]

\[
k = 1.4 \\
L = 200 \\
V = 240
\]

\[
A = \frac{200}{1.4(150)} = 0.59 \\
S = \frac{1}{A} = \frac{1}{0.59} = 1.69 \text{ lb mol/hr}
\]

\[
k = 0.8 \\
L = 200 \\
V = 25
\]

\[
A = \frac{200}{0.8(150)} = 14.54 \\
S = \frac{1}{A} = \frac{1}{14.54} = 0.069 \text{ lb mol/hr}
\]
Problem 4) 16 points

a) For a non-ideal binary equilibrium system with attractive interactions between the two species in a binary mixture, construct a representative y-x equilibrium curve for this system.

\[ y \]
\[ x \]

b) 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?

\[ 2; K_i > 1 \text{, want } K_i < 1 \]

\[ \text{increase pressure, because } K_i \text{ decreases with increasing pressure} \]

\[ \checkmark \]
c) Explain briefly in words why countercurrent operation is more efficient than concurrent and crosscurrent systems.

Counter current operation is more efficient because there is already a high concentration of A in the stream going in the reverse direction, increasing the efficiency. (In the photo given, the larger surface area for A)

In concurrent or cross stages, what goes in is what comes out same % extraction

d) 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 when the vapor and liquid are beginning to mix and reach the equilibrium point.