1 It all adds up (25 pts)

Two liquids are said to form an *ideal mixture* if the volume of a mixture of the two is equal to the sum of the volumes of the individual components. An ideal mixture has the property that:

$$\frac{1}{\rho} = \sum_i \frac{x_i}{\rho_i}$$

where ρ is the density of the mixture, ρ_i is the density of component i, and x_i is the *mass fraction* of component i. Following is some data for mixtures of ethanol and hexane:

	ethanol wt %	density (g/cm^3)
Mixture 1	10.0	0.68
Mixture 2	90.0	0.78

1.1 (10 pts) The gauge pressure at the bottom of a 1.00 m tall drum of some ethanol/hexane mixture is 7120 Pa. What is the density of the mixture?

$$P = \rho g h$$

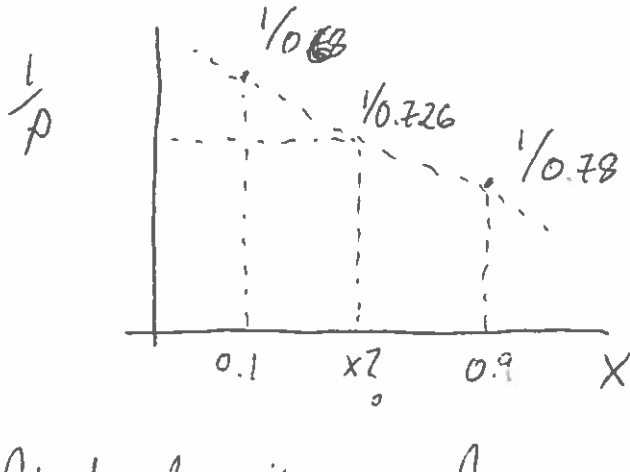
$$\rho = \frac{P}{gh} = \frac{7120\ Pa}{\text{[illegible]}\ kg/m^3 \cdot 9.8\ m/s^2 \cdot 1\ m}$$

$$= 726\ kg/m^3$$

$$= 0.726\ g/cm^3$$

Problem 1 continued

1.2 (15 pts) Estimate the composition (wt %) of the mixture in the drum, assuming ethanol and hexane form an ideal mixture.



Could find densities of pure hexane and ethanol from line

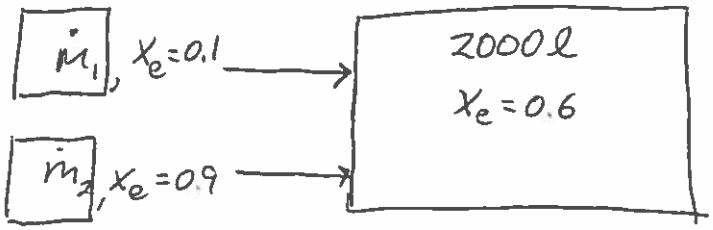
↳ $\rho_{hexane} = 0.669$ $\rho_{ethanol} = 0.794$

$$\frac{1}{0.726} = x \cdot \frac{1}{0.794} + (1-x) \cdot \frac{1}{0.669}$$

2 All mixed up (45 pts)

Two liquid streams flow into a 2000.0 L tank. One stream is 10.0%(w/w) ethanol and balance hexane, while the other is just the opposite, 10.0%(w/w) hexane in ethanol. The densities of these two streams is given in Problem 1. It takes 22 minutes for the two streams combined to fill the tank. When it is full, the tank is found to contain a 60.0%(w/w) ethanol mixture with a density of 0.74.

2.1 (10 pts) Make a sketch of this process, labeling all flows and compositions and identifying any unknowns by placing a box around them.



2.2 (5 pts) Is this process steady-state or transient?

transient

2.3 (5 pts) What is the name of this type of process?

semi-batch

2.4 (5 pts) Below is the general material balance expression. Identify which terms are zero, which are non-zero, and the signs of the non-zero terms for the species in this process.

output = input + generation - consumption - accumulation

(output: >0; generation: 0; consumption: 0; accumulation: >0)

Problem 2 continued

2.5 (10 pts) Write down integral mass balance expressions for ethanol and for hexane. Your mass balance expressions should have the same two unknowns as in your diagram above.

input = accumulation

ethanol: $\dot{m}_1 \cdot (0.1) \cdot t + \dot{m}_2 \cdot (0.9) \cdot t = 2000\,l \cdot \rho \cdot 0.60$

$t = 22\,min \quad \rho = 0.74\,g/cm^3$

hexane: $\dot{m}_1 (0.9) \cdot t + \dot{m}_2 (0.1)\, t = 2000 \cdot \rho \cdot 0.40$

2.6 (10 pts) Solve your mass balances for the two unknowns.

$\dot{m}_1 \cdot 2.2\,min + \dot{m}_2 \cdot 19.8\,min = 888\,kg$

$\dot{m}_1 \cdot 19.8\,min + \dot{m}_2 \cdot 2.2\,min = 592\,kg$

$$\begin{pmatrix} 2.2 & 19.8 \\ 19.8 & 2.2 \end{pmatrix} \begin{pmatrix} \dot{m}_1 \\ \dot{m}_2 \end{pmatrix} = \begin{pmatrix} 888 \\ 592 \end{pmatrix}$$

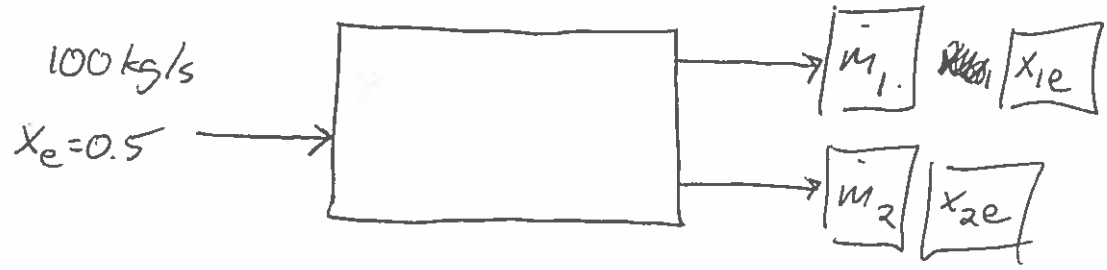
$\dot{m}_1 = 25.2\,kg/min$

$\dot{m}_2 = 42.0\,kg/min$

3 You gotta keep them separated (30 pts)

A 50% mixture by weight of ethanol and hexane is introduced continuously into a steady-state separator. One outlet stream gets 60% (by weight) of the inlet ethanol and 50% of the inlet hexane while a second outlet contains the remainder of each.

3.1 (10 pts) Make a sketch of this process, labeling all flows and compositions and identifying unknowns by drawing boxes around them. Assume an inlet basis of 100 kg/s.



ethanol split: $x_{1e} \cdot \dot{m}_1 = 100\ kg/s \cdot (0.5)(0.6)$

hexane split: $(1 - x_{1e}) \cdot \dot{m}_1 = 100\ kg/s \cdot (0.5)(0.5)$

3.2 (5 pts) Count the number of unknowns and identify the equations and other pieces of information that relate them. How many degrees of freedom does the system have?

4 unknowns
- 2 mass balances
- 1 relation on ethanol split
- 1 relation on hexane split

0 DOF

3.3 (15 pts) Based on your degree of freedom analysis, determine all the flow rates and compositions that can be determined.

ethanol + hexane splits give us 2 eqs, 2 unknowns

ethanol: $x_{1e} \cdot \dot{m}_1 = 30\ kg/s$

hexane: $\dot{m}_1 - 30\ kg/s = 25\ kg/s$

$\dot{m}_1 = 55\ kg/s$ $\quad x_{1e} = \frac{30}{55} = 0.54$

total mass balance:

$100\ kg/s = \dot{m}_1 + \dot{m}_2 \rightarrow \dot{m}_2 = 45\ kg/s$

ethanol mass balance

$100\ kg/s \cdot 0.5 = \left(55\ \frac{kg}{s}\right)(0.54) + \left(45\ \frac{kg}{s}\right) \cdot x_{2e}$

$x_{2e} = 0.44$