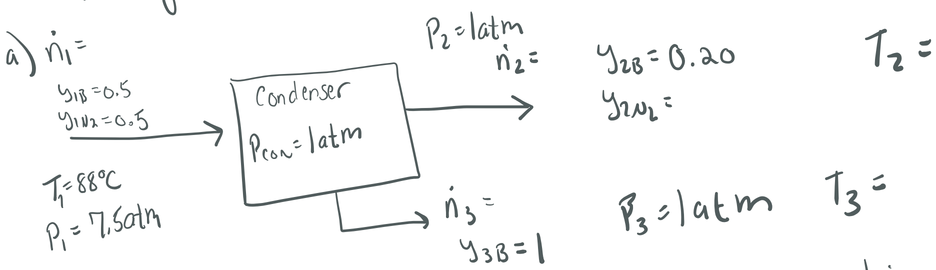
Zippo Lighters

a)



b) additional info: $\dot{V}_1 = 1000\ L/min$, the 1:1 ratio is incorporated in the PFD

Want to know: $\dot{V}_2$, $T_{condenser}$, $\dot{V}_3$

c)

+3 unknowns ($\dot{n}_1$ $\dot{n}_2$ $\dot{n}_3$)
+0 chemical rxns
− 2 independent material balances (B, N_2)
− 1 additional eq. ($P_1 V_1 = n_1 R T_1 z$)

0 DOF hooray! Can solve for all identified unknowns $\dot{n}_1$, $\dot{n}_2$ $\dot{n}_3$

d) How to solve

1. Check if the inlet stream behaves ideally

$$\hat{V} = \frac{RT_1}{P} \qquad \hat{V} = \frac{\left(0.0821\ \frac{L\cdot atm}{mol\cdot K}\right)(361\,K)}{7.5\ atm} = 3.95 \ , \qquad \hat{V} < 5\ \frac{L}{mol}$$

Cannot use ideal gas— must use the compressibility factor equation of state!

2. Need to read z from charts using T_r, P_r

This is a mixture so we need to calculate T_c' and P_c'

$$T_r = \frac{T}{T_c'} \qquad T_c' = y_{1B} T_{cB} + y_{1N_2} T_{cN_2} = 275.5K$$

$$P_r = \frac{P}{P_c'} \qquad P_c' = y_{1B} P_{cB} + y_{1N_2} P_{cN_2} = 35.5\ atm$$

From table B.1
$T_{c,B} = 425.17\ K$
$T_{c,N_2} = 126\ K$
$P_{c,B} = 37.47\ atm$
$P_{c,N_2} = 33.5\ atm$

Plugging it in ... $T_r = \frac{361\,K}{275.5K}$ $P_r = \frac{7.5 atm}{35.5 atm}$ $\boxed{z = 0.98}$

$T_r = 1.31$ $P_r = 0.21$

3. After find 2, I would use $P_1\dot{V}_1 = z\dot{n}_1RT_1$ to calculate $\dot{n}_1$

Then, I would write the material balances:

N_2: $y_{1N_2}\dot{n}_1 = \dot{n}_2 y_{2N_2} + 0$

given

calculated

B: $y_{1B}\dot{n}_1 = \dot{n}_2 y_{2B} + \dot{n}_3 \cancel{y_{3B}}^{1}$

total: $\dot{n}_1 = \dot{n}_2 + \dot{n}_3$

4. solve N_2 balance for $\dot{n}_2$.

5. Solve total for $\dot{n}_3$

6. Use $\dot{n}_3$ to calculate $\dot{V}_3$. Stream 3 is a liquid, so I will use the ρ and MW.

$$\dot{V}_3\left(\frac{L}{min}\right) = \frac{\dot{n}_3\left(\frac{mol}{min}\right)\cdot MW_B\left(\frac{g}{mol}\right)}{\rho_{B,liq}\,(g/L)}$$

not in Table B.1, found it online from NIST chemical webbook

From Table B.1

$MW_B = 58.12$

$\rho_{B,liq} = SG\cdot\rho_{H_2O}$

$SG = 0.60$ g/mL

Last - calculate $T_{condenser}$.

VLE and an ideal vapor in stream 2 (low pressure) → Raoult's Law

$y_{2B}P = x_{2B}P_B^{sat}$ and $P_B^{sat} = 10\text{\^{}}\left[A - \frac{B}{T+C}\right]$

where $A = 6.82485$
$B = 943.453$
$C = 239.711$

Table B.4

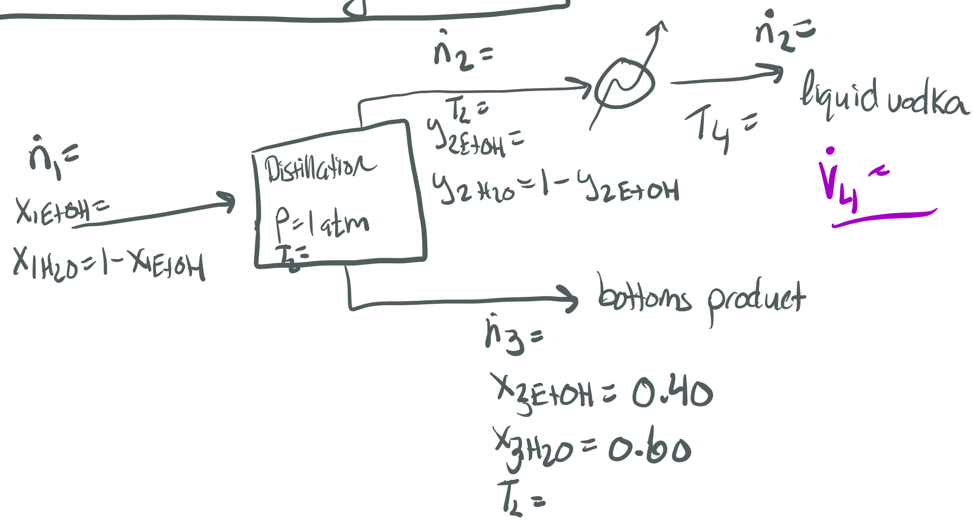
7. Convert $P_B^{sat} = 1atm \left| \frac{760mmHg}{1atm} \right.$

8. Plug P_B^{sat} into Antoinne — Solve for $T_{condenser}$. (°C).

Done!

Quantitative: Distilling Vodka

a)



b) T_{bub} can be read directly from the Txy diagram.

x-axis is x_{H_2O}, y_{H_2O}

at $x_{2H_2O} = 0.60$, $\boxed{T_{bub} = 81°C}$

see Txy diagram below

at $T = 81°C$, $\boxed{\begin{array}{l} y_{2H_2O} = 0.4 \\ y_{2EtOH} = 0.6 \end{array}}$

c) at 90°C, what is the ABV?

$$ABV = \frac{V_{ethanol}}{V_{vodka}} = \frac{V_{ethanol}}{V_{ethanol} + V_{H_2O}} =$$

In order to calculate the $\dot{V}_{ethanol}$ and $\dot{V}_{H_2O}$ in the liquid condensate, we need to first know $\dot{n}_{ethanol}$ and $\dot{n}_{H_2O}$ for Stream 2. Just like we do for converting between mass and mole fractions, we can assume a basis:

calc mol EtOH → g EtOH → V EtOH
calc mol H2O → g H2O → V H2O

then $\frac{V_{EtOH}}{V_{H_2O} + V_{EtOH}}$

$$\frac{100\ \text{mol}}{} \left|\ \frac{0.35\ \text{mol EtOH}}{\text{mol}}\ \right|\ \frac{46.07\ \text{g}}{1\ \text{mol EtOH}}\ \left|\ \frac{\text{L EtOH}}{789\ \text{g EtOH}}\right. = 2.3\ \text{L EtOH}$$

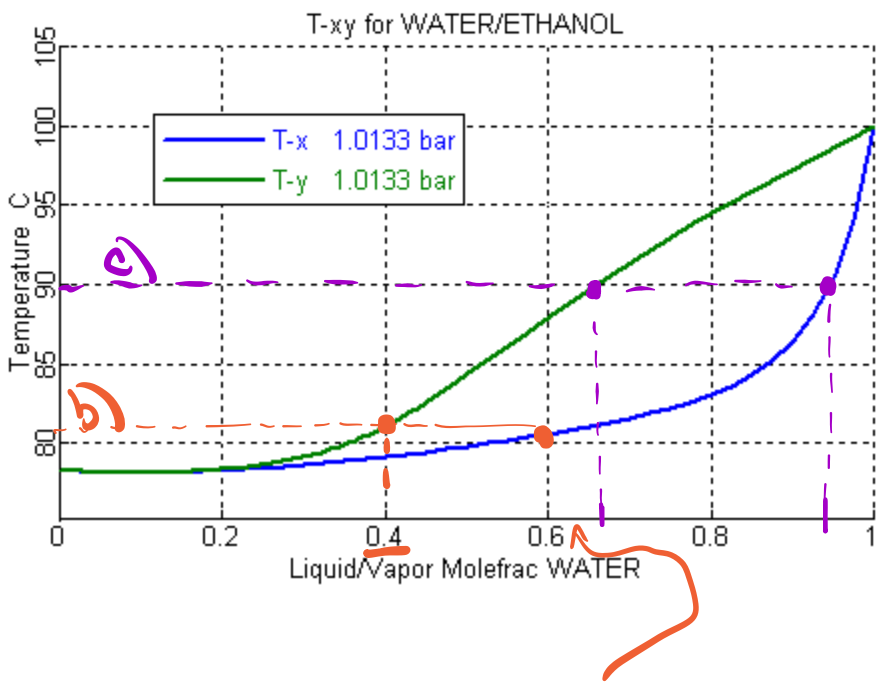
$$\frac{100\ \text{mol}}{} \left|\ \frac{0.65\ \text{mol } H_2O}{\text{mol}}\ \right|\ \frac{18.02\ \text{g}}{1\ \text{mol } H_2O}\ \left|\ \frac{1\ \text{L } H_2O}{1000\ \text{g } H_2O}\right. = 1.08\ \text{L } H_2O$$

$$ABV = \frac{2.3\text{L}}{2.3\text{L} + 1.8\text{L}}$$

$$\boxed{ABV = 0.54}$$

For context - this is 54% alcohol, so 100 proof vodka.

ChemE in action!



$x_{2H_2O} = 1 - x_{2EtOH} = 1 - 0.4 = 0.60$

and $y_{2H_2O} = 0.4$

d) If $T = 90°C$ and $\dot{V}_4 = 1$ L/hour. How much feed solution do you need? $P_2 = 1$ atm

According to Txy... $y_{2H_2O} = 0.65$ $x_{3H_2O} = 0.95$

* can use $\dot{n}_2$ to calculate $\dot{V}_4$ (moles of liq → volume), $\rho_{EtOH} =$

$MW_{EtOH} =$

3 unknowns ($\dot{n}_1$, x_{1EtOH}, $\dot{n}_3$)

−2 independent material balances (EtOH, H_2O)

0 additional equations

1 DOF * Not enough info to solve! We already used Raoult's Law (via Txy diagram). Need $\dot{n}_1$, $\dot{n}_2$