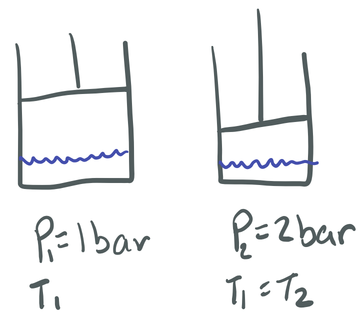
1.

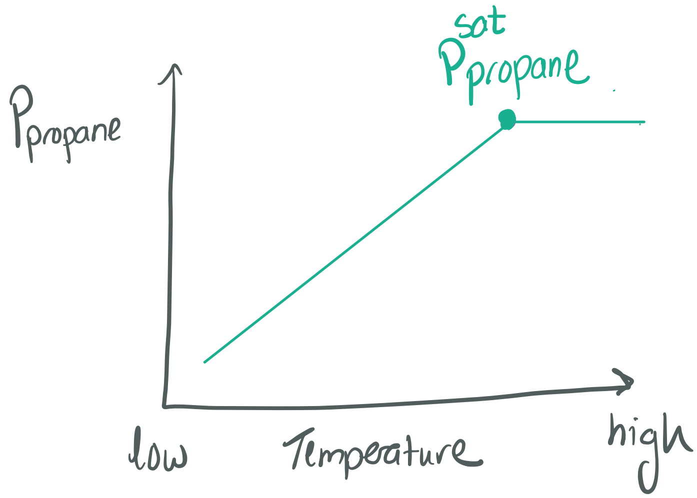



at the new equilibrium, the partial pressure of the water

$\boxed{\text{b. Remains the same}}$

The partial pressure of a saturated vapor is the psat. psat only depends on temperature (look at the Antoinne Equation)

2.




The partial pressure describes how much of the total pressure comes from the propane.

$y_i P = P_i^{\circ}$

The partial pressure of the propane describes how much of the total pressure comes from the propane $y_i P = P_i$. for an ideal gas. When it is super-heated, the propane stays in the gas phase (constant $P_{propane}$) until it hits the $P^{sat}_{propane}$, After this, the $P^{sat}_{propane} = P_{propane}$. We know that the $P^{sat}_{propane}$ decreases with temperature (Antoinne Equation). This will continue until the psat is $\approx 0$.

3. If $T = 80°C$, use Antoine Equation to calculate $P^{sat}$.

$$P_A^{sat} = 10^\wedge\left[A - \frac{B}{T+C}\right]$$

where $A = 4.42448$, $B = 1312.253$, $C = -32.445$, $T = 353K$

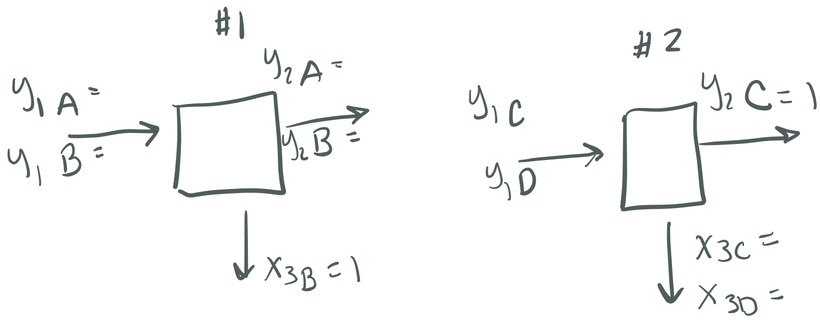
Taken from NIST chemical webbook. $T \equiv K$, $P \equiv bar$

$P_A^{sat} = 2.1$ bar

OR

$P_A^{sat} = 1600$ mmHg

4.




Write Raoult's law for both systems.

$y_{2B}P = \cancel{x_{3B}}^{\,1} P_B^{sat}$

$y_{2B}P = P_B^{sat}$

$P_B = P_B^{sat}$

$\cancel{y_{1C}}^{\,1} P = x_{3C} P_C^{sat}$

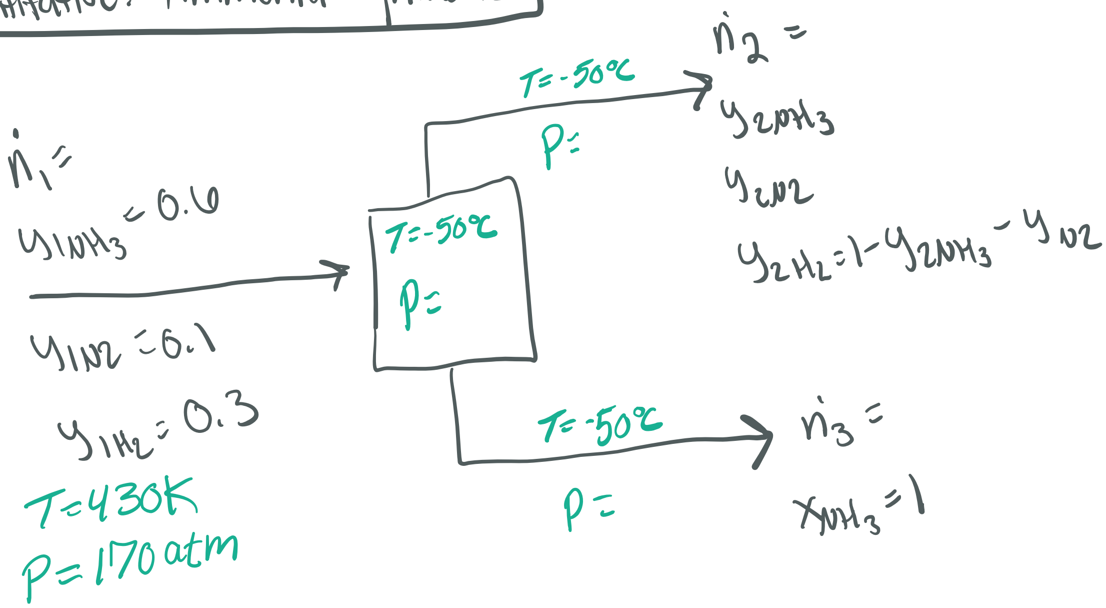
$P_C = x_{3C} P_C^{sat}$

$P_C = x_{3C} P_C^{sat}$

So only $\boxed{a)\ P_B = P_B^{sat}}$

# $\boxed{\text{Quantitative: Ammonia Synthesis}}$

a)




Extra Info

20% $NH_3$ fed is condensed $\rightarrow$ $\dfrac{\dot{n}_3}{\dot{n}_1 y_{1NH_3}} = 0.20$

$\dot{V}_1 = 1.4\ L/s$

want to know

$P_{condenser}$ $\quad y_{2NH_3} \quad y_{2N_2} \quad y_{2H_2} \quad \dot{V}_3$

b)

I won't consider $\dot{n}_1$ an unknown because we can calculate it from an EOS

DOF

5 unknowns $(\dot{n}_2 \quad \dot{n}_3 \quad P \quad y_{2N_2} \quad y_{2NH_3})$

$-$ 3 mat. balances ($NH_3$ $N_2$ $H_2$)

$-$ 2 Add. eq's (2 Raoult/Antoine + 20% condensed)

0 DOF! we can get to work :)

First, I will use an EOS to solve for $\dot{n}_1$
Then I'll have enough info to work through Raoult's + the material balances.

c) <u>EOS to solve for $\dot{n}_1$</u>. We have high Pressure (147 atm) so I will use the compressibility factor EOS.

$$P\dot{V}_1 = \dot{n}_1 R T_1 z$$

To solve for $\dot{n}_1$ we need to calculate z.
Since stream 1 is a mixture, we know to calculate the $P'_c$ and $T'_c$ using Kay's Rule.

$$T'_c = \sum y_i T_{c_i} = y_{1NH_3} T_{c,NH_3} + y_{1N_2} T_{cN_2} + y_{1H_2} T_{cH_2}$$

$$P'_c = \sum y_i P_{c_i} = y_{1NH_3} P_{cNH_3} + y_{1N_2} P_{cN_2} + y_{1H_2} P_{cH_2}$$

* all $T_c$ and $P_c$ are found in Table B.1
Calc, $T_r$ and $P_r$
Then, use the compressibility charts to find z.
Then calculate $\dot{n}_1$

## Use material balances + Raoult's to calculate vapor phase composition.

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

$H_2$: $\dot{n}_1 y_{1H_2} = \dot{n}_2 y_{2H_2}$

$NH_3$: $\dot{n}_1 y_{1NH_3} = \dot{n}_2 y_{2NH_3} + \dot{n}_3$

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

and $0.20 = \dfrac{\dot{n}_3}{\dot{n}_1 y_{1NH_3}}$

$y_{2NH_3} P = P_{NH_3}^{sat}$ where $P_{NH_3}^{sat} = f(T)$

We want to know P which comes from Raoult's so we need to find a way to solve for $y_{2NH_3}$ first!

1. calculate $\dot{n}_3$ using % condensed ratio
2. total balance to get $\dot{n}_1 = \dot{n}_2 + \dot{n}_3 \Rightarrow \dot{n}_2$
3. Solve $NH_3$ balance for $y_{2NH_3}$
4. Use Antoine to calc. $P_{NH_3}^{sat}$
5. Use $P_{NH_3}^{sat}$ and $y_{2NH_3}$ in Raoult's to calc P!
6. use $H_2$ balance to calc $y_{2H_2}$
7. $1 - y_{2NH_3} - y_{2H_2} = y_{2N_2}$

## Calculate $\dot{V}_3$ from $\dot{n}_3$

$$\dot{V}_3 = \dot{n}_3\left(\frac{mol}{s}\right) M_w\left(\frac{g}{mol}\right) \cdot \frac{1}{\rho}\left(\frac{L}{g}\right)$$

$\boxed{\text{** Up until this point is what I would expect on a quiz or a midterm **}}$

d) Now that we've laid out the process— let's crunch some numbers! I did mine in excel

## EOS to solve for $\dot{n}_1$

$$T'_c = \sum y_i T_{c_i} = y_{1NH_3} T_{c,NH_3} + y_{1N_2} T_{cN_2} + y_{1H_2} T_{cH_2}$$

$$= 0.6(405.5\,K) + 0.1(121\,K) + 0.3(154.9\,K)$$

$$T'c = 301.9K$$

$$P'_c = \sum y_i P_{c_i} = y_{1NH_3} P_{cNH_3} + y_{1N_2} P_{cN_2} + y_{1H_2} P_{cH_2}$$

$$= 0.6(111.5) + 0.1(33.5) + 0.3(50.2)\,atm$$

$$P'c = 111.5\text{ atm}$$

$$\left.\begin{aligned} T_r &= \frac{450K}{301.9K} = 1.5 \\ P_r &= \frac{170atm}{85.4atm} = 2 \end{aligned}\right\}$$

using the compressibility charts

$$Z = 0.84$$

$$P_1 \dot{V}_1 = \dot{n}_1 R T_1 Z$$

$$\dot{n}_1 = \frac{P_1 \dot{V}_1}{R T_1 Z} = \frac{(170atm)(1.4\frac{L}{s})}{0.0821\frac{L\,atm}{mol \cdot s}(450K)(0.84)} = 7.7\frac{mol}{s}$$

## Material balances + Raoult's to calc $y_i$'s

1. calc $\dot{n}_3$ → $\frac{\dot{n}_3}{\dot{n}_1 y_{1NH_3}} = 0.20$ , $\dot{n}_3 = 0.2\left(7.7\frac{mol}{s}\right)(0.6)$

$\dot{n}_3 = 0.92\ mol/s$

2. use $\dot{n}_3$ to calc $\dot{n}_2$

$\dot{n}_1 = \dot{n}_2 + \dot{n}_3$ → $\dot{n}_2 = 7.7\ mol/s - 0.92\ mol/s$

$\dot{n}_2 = 6.7\ mol/s$

3. solve $NH_3$ balance for $y_{2NH_3}$

$\dot{n}_1 y_{1NH_3} = \dot{n}_2 y_{2NH_3} + \dot{n}_3$

$$y_{2NH_3} = \frac{\dot{n}_1 y_{1NH_3} - \dot{n}_3}{\dot{n}_2}$$

$$y_{2NH_3} = \frac{7.7\frac{mol}{s}(0.6) - 0.92\frac{mol}{s}}{6.7\ mol/s}$$

$y_{2NH_3} = 0.54$

## 4+5. Antoine Equation + Raoults

$$\log_{10} P_{NH_3}^{sat} = A - \frac{B}{T+C}$$

$A = 7.55466$
$B = 1002.711$
$C = 247.885$

$P_{NH_3}^{sat} = 307\ mmHg$

$y_{2NH_3} P = P_{NH_3}^{sat}$

$$P = \frac{P_{NH_3}^{sat}}{y_{2NH_3}} = \frac{307\ mmHg}{0.54} = P = 563\ mmHg$$

$P = 0.74\ atm$

6. $H_2$ balance to calc $y_{2H_2}$

$\dot{n}_1 y_{1H_2} = \dot{n}_2 y_{2H_2}$    $y_{2H_2} = \dfrac{\dot{n}_1 y_{1H_2}}{\dot{n}_2} = y_{2H_2} = 0.34$

7. $1 - y_{2H_2} - y_{2NH_3} = y_{2N_2}$    $y_{2N_2} = 1 - 0.34 - 0.54$

$y_{2N_2} = 0.11$

8. Finally! We can calculate $\dot{V}_3$ ... last one!

$$\dot{V}_3 = \dot{n}_3\left(\frac{mol}{s}\right) M_w\left(\frac{g}{mol}\right) \cdot \frac{1}{\rho}\left(\frac{L}{g}\right)$$

$$\dot{V}_3 = 0.92\,\frac{mol}{s}\left(17.03\,\frac{g}{mol}\right)\left(\frac{1\ m^3}{0.73\ kg}\right)\left(\frac{1000\ L}{1\ m^3}\right)\left(\frac{1\ kg}{1000\ g}\right)$$

$$\dot{V}_3 = 21\ L/s$$

Remember how long this took when you ask for numerical answers in class — my hand is cramping up! We would spend a full 50 minutes doing algebra :)