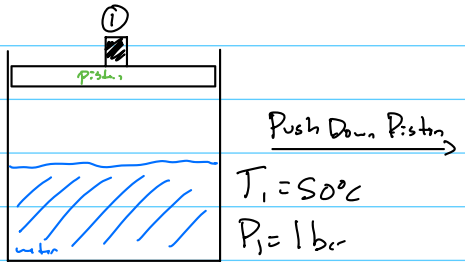
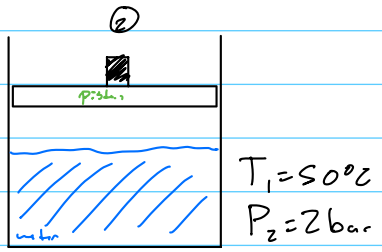
Conceptual Questions

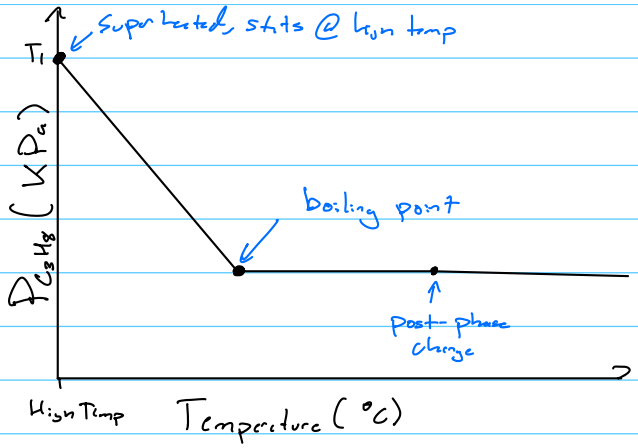
1. (3 points) Water is in equilibrium at 50°C with air in a piston-cylinder system. The total pressure is 1 bar. The pressure is raised to 2 bar by pushing down on the piston at constant temperature. At the new equilibrium, the partial pressure of the water _____.
   a. Increases
   b. Remains the same
   c. Decreases





$T_1 = T_2$ and vapor pressure determines partial pressure. vapor pressure is dependent on the system temperature.

2. (3 points) A piston-cylinder (variable volume container) contains superheated propane. Construct a plot (you can draw it by hand) with the partial pressure of propane on the y-axis and temperature on the x-axis. Then, draw a line that describes the how the partial pressure of propane changes during cooling. *Justify you answer, it may be useful to label key temperatures on the plot.*



The propane gas is superheated so we will treat it as an ideal gas starting at a high temperature T_1. The temperature drops gradually and thus the partial pressure drops (linearly as ideal behavior is assumed). The temp eventually reaches the boiling point (saturation point), where the propane will begin to change phases which is isobaric. Now most of the propane is liquid and any further temperature changes will result in minimal pressure changes.

Conceptual Questions (Continued)

3. (3 points) A pure stream of saturated acetone vapor is fed to a furnace. The acetone vapor has a temperature of 80°C. What is the vapor pressure of the stream?

Acetone Vapor at 80°C (pure & saturated)

(i) Convert $80°C + 273.15 = 353.15\ K$

(ii) Determine A, B, C from *NIST chemical webbook

$259.16K < 353.15K < 507.60K$ { $A = 4.42448$, $B = 1312.253$, $C = -32.445$

(iii) Calculate Vapor pressure $P^{sat}_{Acetone}$ from Antoine EQ

$$\log_{10} P^{sat}_{Ac} = 4.42448 - \frac{1312.253}{353.15 + -32.445}$$

$$P^{sat}_{Ac} = 10^{(0.3327)} = 2.15\ bar$$

2.15 bar

4. (3 points) Consider two different continuous, steady state partial condensers operating at equilibrium conditions. The feed to condenser #1 is a mixture of two gases (A and B) and the condensate is pure B. The feed to condenser #2 is a mixture of two gases (C and D) and the condensate contains a mixture of C and D. The vapor phase contains pure C. Which of the following statements is true? Circle all that apply.

a. $P_B = P_B^{sat}$
b. $P_A = P_A^{sat}$
c. $P_C = P_C^{sat}$
d. $P_D = P_D^{sat}$

Condenser #1

Feed: Mix of A & B

Condensate: Pure B B is in VLE

Vapor: Mix of A & B

a) $P_B = P_B^{sat}$
True as B is the condensing component

b) $P_A = P_A^{sat}$
Not true, A still remains entirely in vapor

Condenser #2

Feed: Mix of C & D

Condensate: Mix of C & D C in VLE

Vapor: Pure C

*VLE is Gas Saturated with volatile component of the liquid

c) $P_C = P_C^{sat}$
Not true, $P_2 < P_C^{sat}$ as C is somewhat a vapor

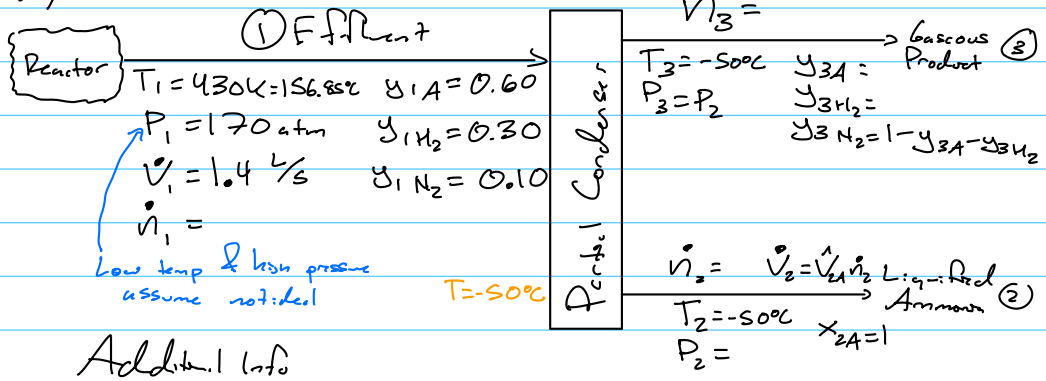
d) $P_D = P_D^{sat}$
True, D is completely volatilized

Ammonia Production

$N_2 + 3H_2 \rightarrow 2NH_3$ Stream 1: $\dot{V} = \frac{0.0821(430)}{170} = 0.20 \frac{L}{s} < 20$

Normalized: $N_2 + 3H_2 \rightarrow 2A$

a)



Want to Know
- P_2
- y_{3i}
- $\dot{V}_2$

Partial Condenser
- Ammonia V2E
- No rxn, one condensible species

Additional Info

⭐ $\dot{n}_2 x_{2A} = 0.20 \dot{n}_1 y_{1A}$ Given

⭐ $y_{3A} P_3 = x_{2A} P_A^{sat}$ Raoults

🍃 $\log P_A^{sat} = A - \frac{B}{T_3 + C}$ Antoines

🔵 $P_1 \dot{V}_1 = z \dot{n}_1 R T_1$ Compressibility

b) DoF Analysis

7 Unknowns ($\dot{n}_1, \dot{n}_2, P_2, \dot{n}_3, y_{3A}, y_{3H_2}, P_A^{sat}$)

+0 Chemical Reactions (Reactor is prior process)

-3 Indep Material Balances (3 species: A, N_2, H_2)

-4 Additional EQs (⭐, 🔵, 🍃, and ⭐)

0 DoF !!

One subsystem but there are many steps!

Plan of Action

(i) Solve for $\dot{n}_1$ by finding T_r and P_r and using Table B.1 for compressibility factor z 🔵

(ii) Solve for P_A^{sat} using A, B, C from table B.4 with 🍃

(iii) Determine compositions of stream 3 using material balances

(iv) Solve for P_2 using ⭐ ($P_2 = P_3$)

(v) Solve for $\dot{V}_2$ by getting $\dot{n}_2$ from ⭐ and $\hat{V}_{2A}$ from wolfram (w/ P_2 & T_2)

Ammonia Production (Continued)

c) (i) Solve for $\dot{n}_1$ by finding T_r' and P_r' and using Table B.1 for compressibility factor z ★

$T_r' = \frac{T}{T_c'}$, $P_r' = \frac{P}{P_c'}$ T_{cA} {Ch3} = 405.5, P_{cA} {Ch3} = 111.3 ★ Used Table B.1 for T_c/P_c values

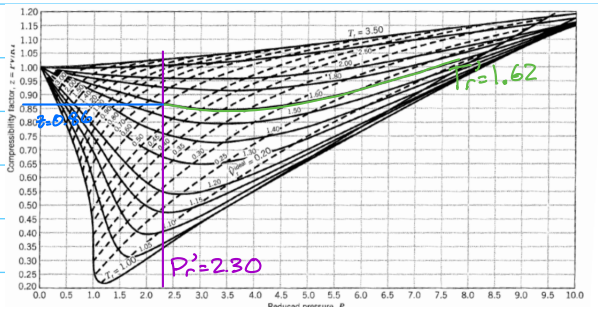
$T_c' = \sum y_i T_{ci}$, $P_c' = \sum y_i P_{ci}$ $T_{cH_2} = 33.3$, $P_{cH_2} = 12.8$

$T_{cN_2} = 126.20$, $P_{cN_2} = 33.5$

$\Rightarrow T_c' = 0.60^{NH_3}(405.5) + 0.30^{H_2}(33.3) + 0.10^{N_2}(126.20) = 265.9\,K$

$P_c' = 0.60^{NH_3}(111.3) + 0.30^{H_2}(12.8) + 0.10^{N_2}(33.5) = 73.97\,atm$

$\Rightarrow T_r' = \frac{430\,K}{265.9\,K} = 1.62$, $P_r' = \frac{170\,atm}{73.97} = 2.30$



$z = 0.86$, so now we can find $\dot{n}_1$ from ⊛

$P_1\dot{V}_1 = \dot{n}_1 z RT$

$\dot{n}_1 = \frac{(170\,atm)\cdot(1.4\,L/s)}{0.86\left(0.0821\frac{L\cdot atm}{mol\cdot K}\right)(430K)} = 7.84\,mol/s$

(ii) Determine A, B, C for ammonia to determine P_A^{sat} from ⊛

★ Table B.4: (ammonia @ -50°C) ↑ In range [-83, 60]

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

$\log_{10} P_A^{sat} = 7.55466 - \frac{1002.711}{-50°C + 247.885}$

$\Rightarrow P_A^{sat} = 10^{(2.48752)}$

$P_A^{sat} = 307.3\,mm\,Hg$

(iii) Material Balances

A: $\dot{n}_1 y_{1A} = \dot{n}_2 x_{2A} + \dot{n}_3 y_{3A}$

H_2: $\dot{n}_1 y_{1H_2} = \dot{n}_3 y_{3H_2}$

N_2: $\dot{n}_1 y_{1N_2} = \dot{n}_3 y_{3N_2}$

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

Relevant EQ: ⊛ ★ $\dot{n}_2 x_{2A} = 0.20\,\dot{n}_1 y_{1A}$

How to solve

(i) Solve for $\dot{n}_2$ using ⊛

(ii) Solve for $\dot{n}_3$ using Total balance

(iii) Solve for y_{3A} using A balance

(iv) Solve for y_{3H_2} using H_2 balance

> Can get y_{3N_2} from PFD

(iv) and (v) require numerical results and are hence done in part (d)

(d) From some numerical solving in (c), we have $\dot{n}_1 = 7.84\ mol/s$, $P_A^{sat} = 307.3\ mm\ Hg$

(i) Follow (c.iii) to get compositions of each stream

(i) Solve for $\dot{n}_2$ using ⊛: $\dot{n}_2 x_{2A} = 0.20\,\dot{n}_1 y_{1A}$

$$\dot{n}_2 = \frac{0.20\,\dot{n}_1 y_{1A}}{x_{2A}} = \frac{0.20(7.84\ mol/s)(0.60)}{1} = 0.94\ mol/s$$

(ii) Solve for $\dot{n}_3$ using Total balance: $\dot{n}_1 = \dot{n}_2 + \dot{n}_3$

$$\dot{n}_3 = \dot{n}_1 - \dot{n}_2 = 7.84 - 0.94\ mol/s = 6.90\ mol/s$$

(iii) Solve for compositions with remaining balances & PFD

$\dot{n}_1 y_{1A} = \dot{n}_2 x_{2A} + \dot{n}_3 y_{3A}$

$$y_{3A} = \frac{\dot{n}_1 y_{1A} - \dot{n}_2 x_{2A}}{\dot{n}_3} = \frac{7.84(0.60) - 0.94}{6.90} = 0.55$$

$\dot{n}_1 y_{1H_2} = \dot{n}_3 y_{3H_2}$

$$y_{3H_2} = \frac{\dot{n}_1 y_{1H_2}}{\dot{n}_3} = \frac{7.84(0.30)}{6.90} = 0.34$$

$y_{3N_2} = 1 - y_{3A} - y_{3H_2}$

$y_{3H_2} = 1 - 0.55 - 0.34 = 0.11$

(ii) Solve for P_3 using Raoults Law ⊛: $y_{3A} P_3 = x_{2A} P_A^{sat}$

$$P_A^{sat} = 307.3\ mm\ Hg \cdot \frac{1\ atm}{760\ mm\ Hg} = 0.40\ atm$$

$$P_3 = \frac{x_{2A} P_A^{sat}}{y_{3A}} = \frac{1(0.40\ atm)}{0.55} = 0.73\ atm = P_3 = P_2 = P_{condensor}$$

(iii) Determine $\hat{V}_2$ using Ammonia at system P and T and ✱ wolfram alpha

Ammonia @ $P_2 = 0.73\ atm$, $T_2 = -50°C$ $\xrightarrow[\text{alpha}]{\text{wolfram}}$ $\hat{V}_{2A} = 24.26\ \frac{cm^3}{mol} \times \frac{1L}{1000\ cm^3} = 0.02426\ L/mol$

(iv) Calculate $\dot{V}_2$ from PFD

$$\dot{V}_2 = \hat{V}_{2A}\dot{n}_2 = 0.02426\ L/mol\,(0.94\ mol/s) = 0.023\ L/s$$

(v) Solution in Summary

$y_{3A} = 0.55$	$P_2 = 0.73\ atm$
$y_{3H_2} = 0.34$	$\dot{V}_2 = 0.023\ L/s$
$y_{3N_2} = 0.11$	

e) (5 points) How could you adjust the operating conditions of the condenser to increase the percent of ammonia liquefied in the process?

✱ Wolfram
Ammonia Boiling Point: -33°C

To have a higher percentage of ammonia be liquified you could either decrease the operating temperature or increase the operating pressure. Ammonia has a relatively low boiling point of -33.33C, so operating a even lower temperatures will enhance the condensation process. Increasing the pressure will allow the ammonia to condense more at a given temperature, resulting in higher percentages of ammonia being liquified.

Reflection Question

1. **(3 points)** We have now finished material balances on non-reactive processes, single phase systems/equations of state and multiphase systems/vapor-liquid equilibrium.
    a. Is there anything you still find confusing about the course content (units 1-5)?
    b. How did you prepare for quiz 1?
    c. How do you plan to prepare for quiz 2?

I don't find much confusing about the current content. Having ECHE225 under my belt allows me to digest the course content on VLE and phase change fluids well as there is a large amount of overlap. For quiz 1, I studied the Test Yourself sections in the textbook, redid example problems from class, and also redid difficult homework problems. Doing these problems cold turkey was beneficial to my success on the first quiz and gave me a good idea of what I needed to do to succeed. As for the second quiz, I plan on doing the same study method, though I will be adding in a lot of graph reading as well. This would be following along with the class examples and homework to see if I can calculate the same reduced values to yield compressibility factors. Also, I'll be using the Antoine equation chart to solve for the saturated pressure based on some given quantities. Finally, I'll be looking more into Raoult's Law and will be doing some model calculations and setup. This would come from lecture notes, handouts, and homework assignments. If by that point I am not feeling confident with the material, I will attend office hours, reach out to TAs, and watch YouTube videos.