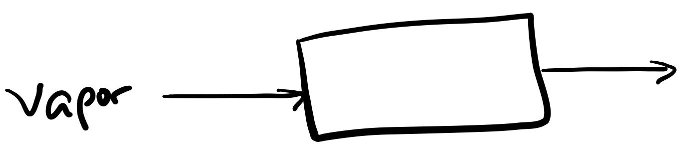
Name_______________________________ Student ID________________________

CHEE 2331 Exam 2 – March 9, 2016

State all assumptions, show all work. Credit will not be given for unsupported answers. Please note the UH Academic Honesty Policies are in effect. There are 3 problem statements/questions. You are given 60 minutes to complete the exam. When done with your exam, do not leave your seat. When time is called, turn your exam over and remain seated until the exam is collected.

Data for molecules A, B and C are located at the end of the exam as is a gas constant, conversion table and compressibility factor chart.

1. The feed to a condenser is a vapor containing 80.0 mol% A and the rest is B. The condenser temperature is 40°C.
   a. (10 points) <u>What is the minimum pressure</u> if I want the condenser to operate as a total condenser (all vapor condenses)?
   b. (10 points) <u>What is the minimum pressure</u> if I want it to operate as a partial condenser (some vapor condenses)?
   c. (5 points) Say I have a total condenser and I now have two outlet streams. One is 75 kmol/h and the other is 1.5x that rate. <u>What are the mol% compositions of each stream</u>?



total condenser → all liq
part " → liq + vap

A) total condenser, all liq
Bubble pt calculation
$P = \sum y_i P = \sum x_i p_i^*$ via Raoult's Law
need p_i^* (know x_i and don't need y_i since I am only looking for P)

p_i^* via Antoine's eqn $\log p_i^* = A - \frac{B}{T+C}$

$\log p_A^* = 6.825 - \frac{943}{240+40}$ $p_A^* = 2865.12$ mm Hg

$p_B^* = 877.5$ mm Hg

$0.8(2865) + 0.2(877.5) = P = 2467$ mm Hg

B) partial condenser

dew pt is minimum to have <u>some</u> liquid

$\sum x_i = 1 \qquad y_i P = x_i p_i^* \rightarrow \sum \frac{y_i P}{p_i^*} = 1$

$P_{min} = \frac{1}{\sum \frac{y_i}{p_i^*}}$ y_i known, need p_i^* (already calculated above)

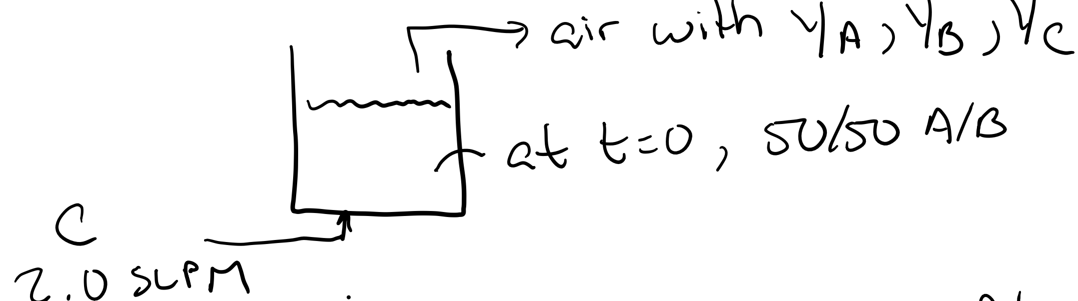
$P_{min} = \frac{1}{\frac{0.8}{2865} + \frac{0.2}{877.5}} = 1972$ mm Hg

C) composition? same as entering! All vapor went to liq + then split

80% A, 20% B

2. (30 points) I have a vessel in a pressurized system, at 3 atm and 40°C. The vessel is initially filled with an equimolar mixture of A and B. I bubble gaseous C, which can be considered an ideal gas, into the bottom of the vessel and these bubbles rise, spending a very long time going through the liquid. For a flow of C of 2.0 standard L/min, and noting C is insoluble in A and B, determine the molar flow rates at which A and B are exiting the vessel at the beginning of the bubbling process. Tell me why is "spending a very long time going through the liquid" important?

flow $= \dot{n}_v$



I know the flow of C, so can find molar flow of C out (ideal gas, insoluble in liq). Then if I can find y_A, y_B via Raoult's Law, can find y_C then total flow...

The P_i^* data are the same as from problem 1 (40°C)

$P_A^* = 2865$ mm Hg

$P_B^* = 877.5$ mm Hg

$y_i P = x_i P_i^*$ $\quad y_A = \frac{x_A P_A^*}{P} = \frac{0.5(2865)}{3(760)}$

$y_A = 0.628$

$y_B = \frac{0.5(877)}{3(760)} = 0.192$

$y_C = 1 - 0.192 - 0.628 = 0.179$

moles C in $\frac{2.0 \frac{L}{min}}{22.4\ L/mol}$ @ STP $= 0.0893 \frac{mol}{min}$

moles C in = moles C out

$$0.0893 = 0.179 \cdot \dot{n}_V$$

$$\dot{n}_V = 0.498 \text{ mol/min}$$

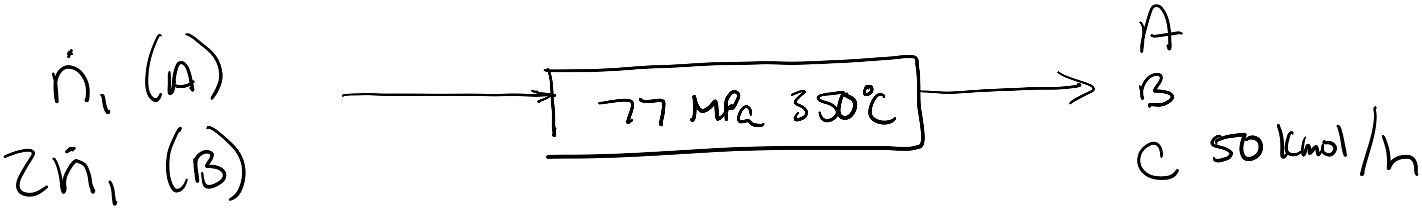
$\therefore$ $\dot{n}_A$ (molar flow of A out)

$$= (0.498)(0.628) = 0.313 \text{ mol/min}$$

$$\dot{n}_B = 0.498(0.192) = 0.0959 \text{ mol/min}$$

Using the above approach, we assumed we reached saturation of the liquid into the vapor (p_i^{sat}). Thus there needs to be long contact times.

3. (40 points) The reaction A + 2B → C (A, B and C are all gas-phase) has a 30% conversion over a catalyst bed, where the reaction takes place at 77.0 MPa absolute pressure and 350°C. The feed consists of 1:2 A:B. The target is to make 50 kmol/h of C product. What are the molar flow rates of the A and B feed components? What is the volumetric flow rate in L/h of the feed gas?



A + 2B → C   30% conversion

molar flow rates

$$\frac{50 \text{ kmol C made}}{h} \bigg| \frac{1 \text{ kmol A reacts}}{1 \text{ kmol C made}} \bigg| \frac{\dot{n}_1 \text{ kmol A}}{0.30 \text{ kmol A reacts}}$$

$\dot{n}_1 = 166.7$ kmol A/h

$2\dot{n}_1 = 333.3$ kmol B/h

vol flow rate

I have $\dot{n}$ $P\dot{V} = \dot{n}RT$ if ideal. Is it ideal?

need z → need T_r', P_r'

$T_c' = \frac{1}{3}(133) + \frac{2}{3}(41.3) = 71.6$ K

$P_c' = \frac{1}{3}(34.5) + \frac{2}{3}(20.8) = 25.3$ atm

$T_r' = \frac{350+273}{71.6} = 8.7$

$$P_r' = \frac{77 \text{ MPa}}{25.3 \text{ atm}} \bigg| \frac{1 \text{ atm}}{0.101325 \text{ MPa}} = 30$$

from chart $z = 1.35$

$$\dot{V} = \frac{Z \dot{n} R T}{P}$$

$$\frac{1.35 \mid (167 + 333)\ \text{kmol} \mid 0.08206\ \text{L}\cdot\text{atm} \mid 1000\ \text{mol} \mid 623\ \text{K}}{\mid \text{h} \mid \text{mol}\ \text{K} \mid \text{kmol} \mid}$$

$$\frac{\mid 0.10325\ \text{MPa}}{77\ \text{MPa} \mid 1\ \text{atm}}$$

$$\underline{\dot{V} = 45{,}410\ \text{L/h}}$$

FACTORS FOR UNIT CONVERSIONS

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz 1 lb_m = 16 oz = 5×10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μm) = 10^{10} angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = $1/3$ yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 L = 10^6 cm^3 = 10^6 mL = 35.3145 ft^3 = 219.97 imperial gallons = 264.17 gal = 1056.68 qt 1 ft^3 = 1728 $in.^3$ = 7.4805 gal = 0.028317 m^3 = 28.317 L = 28,317 cm^3
Force	1 N = 1 kg·m/s^2 = 10^5 dynes = 10^5 g·cm/s^2 = 0.22481 lb_f 1 lb_f = 32.174 lb_m·ft/s^2 = 4.4482 N = 4.4482×10^5 dynes
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bar = 1.01325×10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb_f/$in.^2$ (psi) = 33.9 ft H_2O at 4°C = 29.921 in. Hg at 0°C
Energy	1 J = 1 N·m = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb_f/s = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp

Example: The factor to convert grams to lb_m is $\left(\frac{2.20462\ lb_m}{1000\ g}\right)$.

	Critical Constants		Antoine's Equation Constants		
Molecule	T_c (K)	P_c (atm)	A	B	C
A	133	34.5	6.825	943	240
B	41.3	20.8	6.844	1061	232
C	513.2	78.5	7.879	1473	230

Antoine's Equation → $log_{10}p^* = A - \frac{B}{T+C}$ for pressure in mm Hg

Raoult's Law → $y_iP = x_ip_i^*$

Gas Constant → 0.08206 L·atm/(mol·K)

Clapeyron equation → $\frac{dp^*}{dT} = \frac{\Delta\bar{H}_V}{T(\bar{V}_g - \bar{V}_l)}$