Name: Soln

Exam #1

ChBE 2100A
Chemical Process Principles

Friday, June 5, 2015

The exam consists of 4 problems worth the points indicated (42 points total). Please write your final answers in the space provided in the specified units, or box them if no space provided. If you need additional space, use blank sheets and staple them to the end of the exam with your work clearly labeled with the question number and letter and your name. Use the accompanying packets for equations/notes and unit conversions/data from tables (includes entire Felder & Rousseau appendix except B.6 Steam Tables listed by pressure). Please don't write on the packets and return them with your exam. Good luck!

Honor Code:
I commit to uphold the ideals of honor and integrity by refusing to betray the trust bestowed upon me as a member of the Georgia Tech community.

Signature

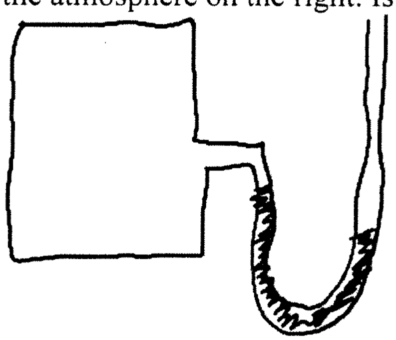
#1 (4 points)

(a)

Based on the following process with gas A, which of the following could **NOT** explain the difference in mass flow rates.

i. accumulation of A within the process
ii. faulty measurements for flow rates
iii. leak in the process
iv. temperature in process is lower than temperature of inlet stream so density of A increases
v. none of the above

(b) The (poorly drawn) manometer below is connect to a sealed tank of air on the left and open to the atmosphere on the right. Is the tank pressurized (P>1 atm) or under vacuum (P<1 atm)?



vacuum
$P < 1$ atm

(c) Consider the following expression where k is in mol/s, E is in J/mol, and T is in K.
$k = 5.4\text{x}10^{-3}e^{(-E/(8.314*T))}$
What are the units of $5.4 \text{ X } 10^{-3}$ and 8.314?

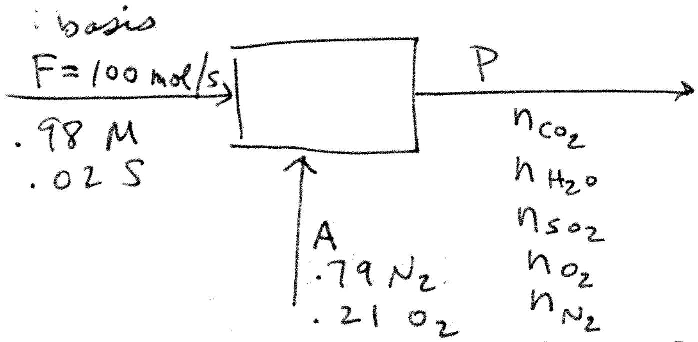
5.4×10^{-3} mol/s

$8.314 \ \frac{J}{mol \cdot K}$

$$\frac{\left(\frac{J}{mol}\right)}{8.314 \quad (K)}$$

#2 (12 points)
Methane is combusted completely in a furnace with 60% excess air (excess relative to methane). However, the methane is contaminated with sulfur such that the overall fuel contains 98mol% CH_4 and 2mol% S. The sulfur also combusts, to form the undesired product SO_2. Determine the composition (mole fractions) of the furnace exit stream on a dry basis.

$$\boxed{\begin{aligned} X_{CO_2} &= \frac{98}{1395} = 0.07 \\ X_{SO_2} &= \frac{2}{1395} = 0.001 \\ X_{O_2} &= \frac{115.5}{1395} = 0.08 \\ X_{N_2} &= \frac{1179.5}{1395} = 0.85 \end{aligned}}$$



$n_m = 0$, $n_s = 0$ } assume all combusted since excess O_2, + otherwise couldn't solve (DOF)

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

$$S + O_2 \longrightarrow SO_2$$

XS air

$$60\% = 100\% \times \left(\frac{.21A - .98(100\,\text{mol/s})\left(\frac{2O_2}{1M}\right)}{.98(100\,\text{mol/s})\left(\frac{2O_2}{1M}\right)} \right)$$

$A = 1493$ mol/s

$n_i = n_{i_0} + \sum \nu_i \xi_j$

$n_m = 0 = 98\text{ mol/s} + \xi_1$ $\qquad \xi_1 = 98\text{ mol/s}$

$n_s = 0 = 2\text{ mol/s} + \xi_2$ $\qquad \xi_2 = 2\text{ mol/s}$

$n_{CO_2} = 0 + \xi_1 = 98\text{ mol/s}$

$n_{H_2O} = 0 + 2\xi_1 = 196\text{ mol/s}$

$n_{SO_2} = \xi_2 = 2\text{ mol/s}$

$n_{O_2} = .21(\underset{3136}{\overset{1493}{\cancel{\ }}}) - 2(98\text{ mol/s}) - 2\text{ mol/s} = 115.5\text{ mol/s}$

$n_{N_2} = .79(1493) = 1179.5\text{ mol/s}$

$P = 98 + 196 + 2 + 115.5 + 1179.5 = 1591\ \frac{\text{mol}}{\text{s}} - 196 = 1395\text{ mol/s}$ dry P

~~P = 98 + 196 + ...~~

#3 (18 points)
A safety overflow tank receives flow from a reactor bypass stream when the reactor temperature and pressure are too high. For a period of 6 hours the reactor conditions dictate bypass into the safety tank at a constant flow rate of 5 kmol/min. The stream is gaseous and contains the reactants acetylene and hydrogen (30mol% C_2H_2 and 70mol% H_2), both combustible materials. In the reactor these combine to form (C_2H_6) but in the safety tank the temperature and pressure are too low for any reaction to occur.

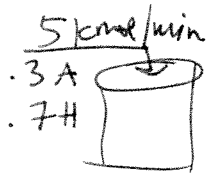
(a) If the safety tank contains 150 kmol of air initially, how many kmol are in the tank after the 6 hour bypass is over?

(b) After the bypass period is over, a vent opens in the tank which vents the contents of the tank into the atmosphere at a flow rate of 3 kmol/min. This continues until there is only 150 kmol total in the tank, space is available if the bypass system needs to be used later. At the end of this venting period, what is the mole fraction of acetylene in the tank? If you could not solve part a, assume values for the numbers you need and move on to solve part b.

(c) Why is venting the contents of the safety tank a bad idea? What would you do instead? There is more space on the next page.

venting combustible could cause explosion if spark, bad for environment ...
instead - burn it or recycle it

a)



t=0 150 kmol air
t→6 hrs

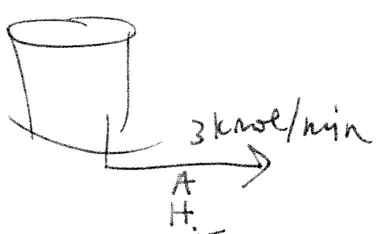
total mass bal
acc = in − ~~out~~ + ~~gen~~ − ~~cons~~

$$\frac{1}{N}\frac{dN}{dt} = 5 \text{ kmol/min}$$

$$\int_{150\text{ kmol}} dN = 5 \text{ kmol/min} \int_0^{6\times 60\text{ min}} dt$$

$$N = 1950 \text{ kmol}$$

b)



total mass bal
acc = − out

$$\frac{dN}{dt} = -3 \text{ kmol/min}$$

$$\int_{1950\text{ kmol}}^{150\text{ kmol}} dN = -3 \frac{\text{kmol}}{\text{min}} \int_0^t dt$$

$$N - 1950 \text{ kmol} = -3 \frac{\text{kmol}}{\text{min}} t$$

$$150 - 1950 = -3t$$

$t = 600$ min $= 10$ h

Extra space #3

A. acc = -out

$$\frac{dN_A}{dt} = -\dot{n}_A$$

$$\frac{dN_A}{dt} = -x_A \dot{n} = -\frac{N_A}{N}\dot{n}$$

$$\frac{dN_A}{dt} = \frac{-N_A}{(-3t+1950)\text{ kmol}}\left(3\,\frac{\text{kmol}}{\text{min}}\right)$$

$$\int_{N_{A0}}^{N_A} \frac{dN_A}{N_A} = \int_0^{600} \frac{\cancel{6}\,-\cancel{3}}{-\cancel{6}\cancel{3}\,t \pm \frac{1950}{3}}\,dt$$

N_a at $t = 0$ for draining?

1950 kmol total

- 150 kmol air

- 1800 kmol (30% A, 70% H)

.3(1800) = 540 kmol

$$\ln N_A - \ln(540\text{ kmol}) = -\left[\ln\left(-600 + \frac{1950}{3}\right) - \ln\left(-0 + \frac{1950}{3}\right)\right.$$

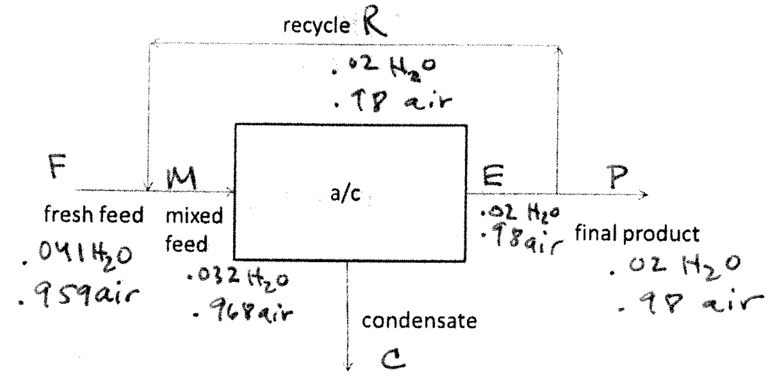
N_A = 41.5 kmol

$$x_A = \frac{N_A}{N} = \frac{41.5}{150} = 27.7\%$$

or realize fractions won't change while venting

so $\frac{540}{1950} = 27.7\%$

#4 (8 points)
When you turn the air conditioning in your car to "max" (or push the button with the curving arrow on it), it recycles already cooled air from the cabin instead of getting all of the air feed from the outside. If the outside air (fresh feed) contains 4.1wt% water and 95.9wt% air, and the desired cabin air should contain 2wt% water and 98wt% air, what is the ratio recycled air to fresh air entering the air conditioner? How much liquid water is condensed per kg of cooled "final product" air? The mixed fresh-recycle feed to the a/c unit has 3.2wt% water and 96.8wt% air.



Basis $F = 100$ kg/min

Mixer: $\overset{100}{F} + R = M$

$.959(100) + .98R = .968M$

$95.9 + .98(M-100) = .968M$

$-2.1 + .98M = .968M$

$-2.1 = -0.012M$

$M = 175$ kg/min $\qquad R = 175 - 100 = 75$ kg/min

$$\boxed{\frac{R}{F} = \frac{75}{100} = .75}$$

a/c: $\underset{175}{M} = E + C$

$.968(175) = .98E$

$E = 172.9$ kg/min

$C = 175 - 172.9 = 2.1$ kg/min

split:

$E = P + R$

$P = E - R = 172.9 - 75$

$P = 97.9$ kg/min

$$\frac{C}{P} = \frac{2.1 \text{ kg}_{H_2O}/\text{min}}{97.9 \text{ kg}_{air}/\text{min}} = \boxed{0.02 \text{ kg } H_2O/\text{kg product air}}$$