ChE 344
Winter 2011
Mid Term Exam I + Solution

Thursday, February 17, 2011

Closed Book, Web, and Notes

Name________________________________

Honor Code____

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(sign at the end of exam)

1) ____/ 5 pts
2) ____/ 5 pts
3) ____/ 5 pts
4)____/ 15 pts
5) ____/ 5 pts
6) ____/ 5 pts
7)____/ 20 pts
8)____/ 20 pts
9)____/ 20 pts
Total ____/100 pts

_____ I have a Laptop with Polymath on it that I can bring to the 2nd Midterm Exam.

_____ I will need to use the computer lab for the 2nd Midterm Exam.

ChE 344
Exam I

1. Simpson's Three-eighths rule (4 points)

$$\int_{X_0}^{X^3} f(X)dX = \frac{3}{8}h\left[f(X_0) + 3f(X_1) + 3f(X_2) + f(X_3)\right]$$

2. $y = (1-\alpha w)^{1/2}$

$$\frac{dy}{dW} = -\frac{\alpha(1+\varepsilon X)}{2y}\left(\frac{T}{T_0}\right) \quad \text{where } \alpha = \frac{2\beta_0}{A_C\,\rho_C(1-\phi)P_0}, \text{ and } \beta_0 = \frac{G(1-\phi)}{g_C\rho_0 D_p\,\phi^3}\left[\frac{150(1-\phi)\mu}{D_p} + 1.75G\right]$$

$$\frac{dy}{dW} = -\frac{\alpha}{2y}\left(\frac{F_T}{F_{T0}}\right)\left(\frac{T}{T_0}\right)$$

3. Integrals

$$\int_0^X \frac{dX}{1-X} = \ln\frac{1}{1-X} \qquad \int_0^X \frac{1+\varepsilon X}{(1-X)^2}dX = \frac{(1+\varepsilon)x}{1-X} - \varepsilon\ln\frac{1}{1-X}$$

$$\int_0^X \frac{dX}{(1-X)^2} = \frac{X}{1-X} \qquad \int_0^X \frac{(1+\varepsilon X)^2}{(1-X)^2}dX = 2\varepsilon(1+\varepsilon)\ln(1-X) + \varepsilon^2 X + \frac{(1+\varepsilon)^2 X}{1-X}$$

$$\int_0^X \frac{dX}{1+\varepsilon X} = \frac{1}{\varepsilon}\ln(1+\varepsilon X) \qquad \int_0^W (1-\alpha W)^{1/2}dW = \frac{2}{3\alpha}\left[1-(1-\alpha W)^{3/2}\right]$$

$$\int_0^X \frac{1+\varepsilon X}{1-X}\,dX = (1+\varepsilon)\ln\frac{1}{1-X} - \varepsilon X \qquad \int_0^X \frac{dx}{(1-X)(\theta_B - X)} = \frac{1}{\theta_B - 1}\ln\frac{\theta_B - X}{\theta_B(1-X)} \quad \theta_B \neq 1$$

$$\int_0^X \frac{dX}{aX^2+bX+c} = \frac{-2}{2aX+b} + \frac{2}{b} \quad \text{for } b^2 = 4ac$$

where p and q are the roots of the equation.

$$aX^2 + bX + c = 0 \quad \text{i.e., } p,q = \frac{-b \mp \sqrt{b^2-4ac}}{2a}$$

$$\int_0^X \frac{dX}{aX^2+bX+c} = \frac{1}{a(p-q)}\ln\left(\frac{q}{p}\,\frac{X-p}{X-q}\right) \quad \text{for } b^2 > 4ac \qquad \int_0^X \frac{a+bX}{c+gX}\,dX = \frac{bX}{g} + \frac{ag-bc}{g^2}\ln\left[\frac{(c+gX)}{c}\right]$$

4. Finite Difference

First Point:
$$-\left.\frac{dC_A}{dt}\right)_{t0} = -\left[\frac{-3C_{A0} + 4C_{A1} - C_{A2}}{2\Delta t}\right]$$

Middle Points:
$$-\left.\frac{dC_A}{dt}\right)_{ti} = -\left[\frac{C_{A(i+1)} - C_{A(i-1)}}{2\Delta t}\right]$$

e.g.,
$$-\left.\frac{dC_A}{dt}\right)_{t3} = -\left[\frac{C_{A4} - C_{A2}}{2\Delta t}\right] = \frac{C_{A2} - C_{A4}}{2\Delta t}$$

Last Point:
$$-\left.\frac{dC_A}{dt}\right)_{t5} = -\left[\frac{C_{A3} - 4C_{A4} + 3C_{A5}}{2\Delta t}\right]$$

5. Ideal Gas Constant

$$R = \frac{8.309\ \text{kPa}\bullet\text{dm}^3}{\text{mol}\bullet\text{K}} \qquad R = \frac{1.987\ \text{BTU}}{\text{lb mol}\bullet\ °\text{R}}$$

$$R = \frac{0.73\ \text{ft}^3\bullet\text{atm}}{\text{lb mol}\bullet\ °\text{R}} \qquad R = \frac{8.3144\,\text{J}}{\text{mol}\bullet\text{K}}$$

$$R = 0.082\frac{\text{liter}\bullet\text{atm}}{\text{mol}\bullet\text{K}} = \frac{0.082\,\text{m}^3\bullet\text{atm}}{\text{kmol}\bullet\text{K}} \qquad R = \frac{1.987\ \text{cal}}{\text{mol}\bullet\text{K}}$$

Volume of Ideal Gas

1 lb mol of an ideal gas at 32°F and 1 atm occupies 359 ft^3.

(5 pts) 1) **Mole Balances, Chapter 1**

The reaction

$$A + B \rightarrow 2C$$

takes place in an unsteady PFR. The feed is only A and B in equimolar proportions. Which of the following set of equations gives the correct mole balances on A, B and C. Species A and B are disappearing and Species C is being formed.

Circle the correct answer where all the mole balances are correct

(a)

$$F_{A0} - F_A - \int^V r_A dV = \frac{dN_A}{dt}$$

$$F_{B0} - F_B - \int^V r_A dV = \frac{dN_C}{dt}$$

Wrong sign for r_A, should be $+\int^V r_A dV$

$$-F_C + 2\int^V r_A dV = \frac{dN_C}{dt}$$

(b)

$$F_{A0} - F_A + \int_0^V r_A dV = \frac{dN_A}{dt}$$

$$F_{B0} - F_B + \int^V r_A dV = \frac{dN_B}{dt}$$

Wrong sign for F_C, should be $-F_C$

$$F_C + \int^V r_C dV = \frac{dN_C}{dt}$$

(c)

$$F_{A0} - F_A + \int^V r_A dV = \frac{dN_A}{dt}$$

$$F_{B0} - F_B + \int^V r_A dV = \frac{dN_B}{dt}$$

All are correct.

$$-F_C - 2\int^V r_A dV = \frac{dN_C}{dt}$$

(d)

$$F_{A0} - F_A - \int^V r_A dV = \frac{dN_A}{dt}$$

$$F_{B0} - F_B - \int^V r_A dV = \frac{dN_B}{dt}$$

Wrong sign for $-r_A$, should be $+\int^V r_A dV$

$$-F_C + \int^V r_C dV = \frac{dN_C}{dt}$$

Solution

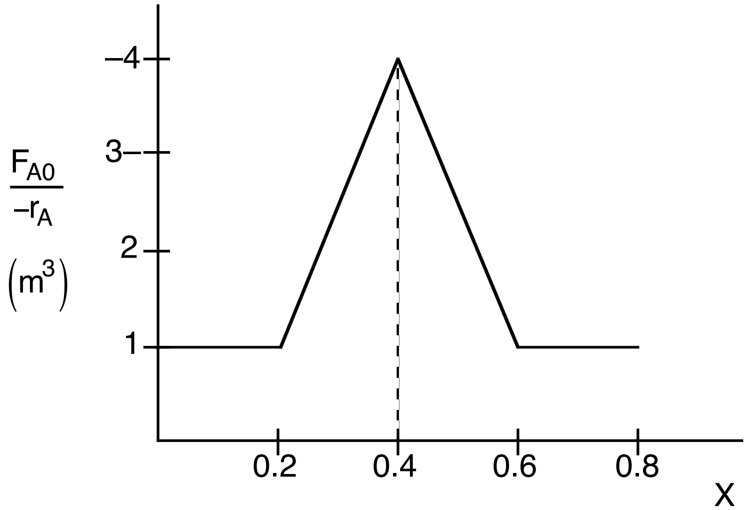
Answer is (c).

(5 pts) 2) <u>**Sizing, Chapter 2**</u>

For the gas phase reaction

$$A + B \rightarrow C$$

equimolar amounts of A and B are to be fed, i.e., $y_{A0} = 0.5$ and $\delta \neq 0$. The following the Levenspiel plot was constructed for a temperature of T = 318K and entering pressure of $P_0 = 10$ atm.



Note: $\delta \neq 0$

(a) What reactor type and size would you use to achieve 40% conversion?

Reactor Type __________ Volume __________

(b) What reactor type and size would you use to achieve 60% conversion?

Reactor Type ___________ Volume __________

(c) What reactor type and size would you use to achieve 20% conversion?

Reactor Type ___________ Volume __________

(d) What reactor type and size would you use to increase the conversion from 60% to 80%?

Reactor Type ___________ Volume __________

Note: If more than one reactor type would work for any part **(a – d)**, explain.

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(5 pts) 3) **Rates, Chapter 3**

Determine the rate law for the reaction described in each of the cases below. The rate laws should be elementary as written for reactions that are of the form either A → B or A + B → C

(a) The units of the specific reaction rate are

$$k = \left[\frac{dm^3}{mol \cdot h}\right]$$

Law __________

(b) The units of the specific reaction rate are

$$k = \left[\frac{mol}{dm^3 \cdot h}\right]$$

Law __________

(c) The units of the specific reaction rate are

$$k = \left[\frac{mol}{kg\ \ cat \cdot h(atm)^2}\right]$$

Law __________

(d) The units of the specific reaction rate are

$$k = \left[\frac{1}{h}\right]$$

Law __________

(15 pts) 4) **i>Clickers Chapters 4 and 5**

(2 pts) 4**a)** Consider the gas-phase elementary reaction

$$R \rightarrow 2S$$

which takes place in a PFR in which R and inert I are fed. If the entering concentration of R is cut by a factor of 5 while maintaining a constant entering volumetric flow rate, υ_0, how will the conversion change?

Circle the correct answer.

A) X won't change
B) X will increase
C) X will decrease

Explain____

Solution

B) X will increase

$$\frac{dX}{dV} = \frac{-r_R}{F_{R0}} = \frac{kC_{R0}(1-X)/(1+\varepsilon X)}{F_{R0}}$$

$$\varepsilon = y_{R0}\delta = y_{R0}(2-1) = y_{R0}$$

$$\frac{dX}{dV} = \frac{kC_{R0}}{\upsilon_0 C_{R0}}\frac{(1-X)}{(1+y_{A0}X)} = \frac{k(1-X)}{\upsilon_0(1+y_{R0})}$$

$$y_{R0}\downarrow \text{ then} \downarrow \left(\frac{1}{1+y_{R0}X}\right)\uparrow$$

$$\frac{dX}{dV}\uparrow \quad X\uparrow$$

\- -

$$\upsilon_0 = F_{T0}\frac{RT_0}{P_0} = \frac{F_{R0}+F_{I0}}{P_0}RT_0$$

$F_{I0}\uparrow$ as $F_{A0}\downarrow$ to keep υ_0 constant.

(3 pts) 4**b)** The liquid phase reaction

$$A + B \rightarrow 3C$$

follows an elementary rate law and is carried out in a constant volume batch reactor with stoichiometric feed. For a batch reaction time of one hour the conversion is 50%. If the same reaction is carried out in a PFR at the same temperature in which there is no pressure drop, for the same space time of one hour would the conversion be

Circle the correct answer.

A) $X > 50\%$
B) $X < 50\%$
C) $X = 50\%$
D) Insufficient information to answer definitively

Explain____

Solution
C) $X = 50\%$
$-r_A \neq f(P)$ for liquid

(2 pts) 4**c)** For the isothermal, elementary gas-phase reaction

$$2X \rightarrow Z$$

how does the PFR volume required for a given conversion change with increasing mole fraction, y_{X0}, of X when the inlet concentration of X and inlet total volumetric flow rate remain constant? There is no pressure drop and only X and Inert I enter the reactor.

Circle the correct answer.

A) V increases
B) V decreases
C) No change in V
D) Insufficient information to answer definitively

Explain____

Solution

B) V decreases

$$\upsilon = \upsilon_0(1+\varepsilon X)\ ,\ \delta = \frac{1}{2} - 1 = -\frac{1}{2}\quad \varepsilon = y_{X0}\delta = -y_{X0}/2$$

$$-r_A = kC_X^2\ ,\ C_X = C_{X0}\frac{(1-X)}{(1+\varepsilon X)}$$

$$V = \frac{F_{X0}}{k}\int\frac{(1+\varepsilon X)^2}{C_{X0}^2(1-X)^2}dX\ ,\ V = \frac{\upsilon_0}{kC_{X0}}\int\frac{\left(1-\frac{y_{X0}}{2}X\right)^2}{(1-X)^2}dX$$

$$y_{X0}\uparrow\quad (1-y_{X0}X)\downarrow\quad V\downarrow\ \text{also}\ \frac{1}{C_{X0}}\downarrow\quad V\downarrow$$

(2 pts) 4**d)** If the following liquid-phase reaction is elementary and reversible, what is the rate expression in terms of conversion when equimolar amounts of A and B are fed to the reaction?

$$A \Leftrightarrow B$$

Circle the correct answer.

A) $-r_A = kC_{A0}\dfrac{[1-X]}{K_C X}$ C) $-r_A = kC_{A0}\left([1-X]-\dfrac{1+X}{K_C}\right)$

B) $-r_A = kC_{A0}[1-X]^2$ D) $-r_A = kC_{A0}\left(1-X\left[1+\dfrac{1}{K_C}\right]\right)$

Explain____

Solution

C) $-r_A = kC_{A0}\left([1-X]-\dfrac{1+X}{K_C}\right)$

$$-r_A = k\left[C_A - \frac{C_B}{K_C}\right]$$

$$C_A = C_{A0}(1-X)$$

$$C_B = (\Theta_B + X)$$

$$C_B = (1+X)$$

$$-r_A = kC_{A0}\left[(1-X)-\frac{(1+X)}{K_C}\right]$$

(3 pts) 4**e)** Consider the reaction

$$A \rightarrow B$$

If the diameter of a PBR is doubled while keeping the turbulent flow mass flow rate, $\dot{m}$, constant, what can be said about that factor by which the rate of pressure drop (dy/dW) will be lowered?

Circle the correct answer.

A) It will be lowered by a factor of 4
B) It will be lowered by a factor of 16
C) It will be lowered by a factor of 32
D) It will be lowered by a factor of 48 or more

Explain____

Solution

D) It will be lowered by more than a factor of 48.

$$G \sim \frac{\dot{m}}{D_2^2} \ , \quad A_C \sim \pi D^2$$

$$\alpha \sim \frac{G^2}{A_C} \sim \left(\frac{1}{D^4}\right)\left(\frac{1}{D^2}\right) = \frac{1}{D^6}$$

$$\alpha_2 = \alpha\left(\frac{D_1}{D_2}\right)^6 = \alpha_1\left(\frac{1}{2}\right)^6 = \frac{\alpha_1}{64}$$

(3 pts) 4**f)** In a particular differential reactor experiment for the reaction

$$A \rightarrow B$$

the entering volumetric flow rate is doubled, leaving all other variables the same. How would you expect the measured outlet flow rate of B, to change under conditions of differential reactor conversion?

Circle the correct answer.

A) Molar flow rate of product will go up
B) Molar flow rate of product will go down
C) No Change

Explain____

Solution

C) No Change

$$F_B = \Delta W \cdot r_B'$$

$$r_B' = -r_A'$$

$$-r_A' \approx -r_{A0}$$

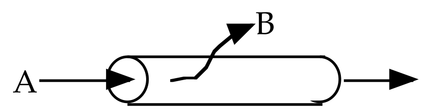
$F_B = W\left(-r_{A0}'\right)$ Not a function of υ_0.

(5 pts) 5) **<u>Membrane Reactors, Chapter 6</u>**

(2 pts) 5**a)** Consider the gas phase reaction

$$2A \rightleftarrows B + C$$

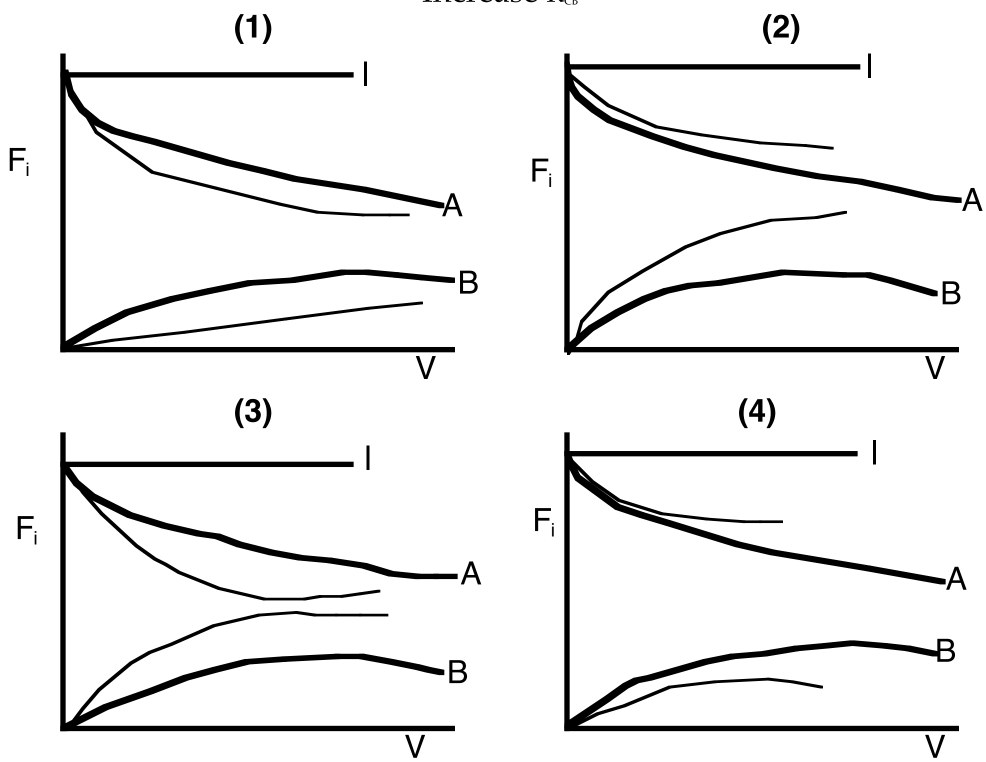
On the figure below is a sketch the molar flow rates F_A, F_B, and F_I for species A and B as a function of membrane volume. The dark lines, A and B, represent the base case while the lighter lines represents possible profiles when the mass transfer coefficient for B, k_{CB}, is increased. Which figure correctly corresponds to an increase in the mass transfer coefficient k_{CB}?



Circle the correct answer.

A) 1
B) 2
C) 3
D) 4

Increase k_{CB}



Explain____

<u>Solution</u>

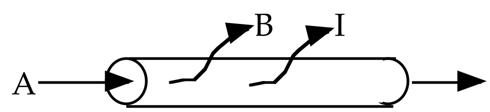
Ans. A) 1: B diffuses out faster moving the reaction faster to the right so both the concentrations of A and B are smaller.

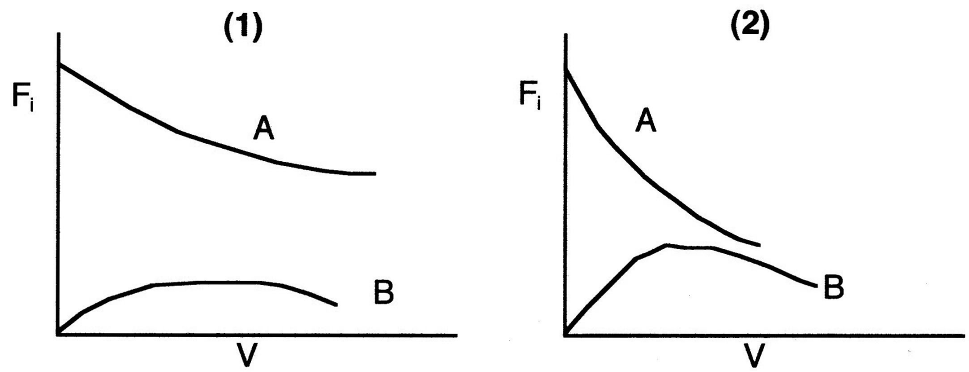
As B is removed, the reaction will continue to proceed to the right. The rate at which it proceeds to the right depends upon the rate of removal of B. If k_{CB} is small in the conversion will always increase but at a very slow rate. If B is removed very very rapidly, the reaction will behave as a irreversible reaction.
On the figure below sketch the molar flow rates F_A, F_B, and F_I as a function of IMRCF volume.

(3 pts) 5**b)** Membrane Reactor 50% A and 50% I inerts

$$2A \rightleftarrows B + C$$

Both B and inerts I diffuse out. Which of the following figures has the greatest mass transfer coefficient for the inerts, k_{CI} for the rate of removal of inerts? All other constants remain the same.





Circle the correct answer.

A) 1
B) 2

Explain____

____

Solution

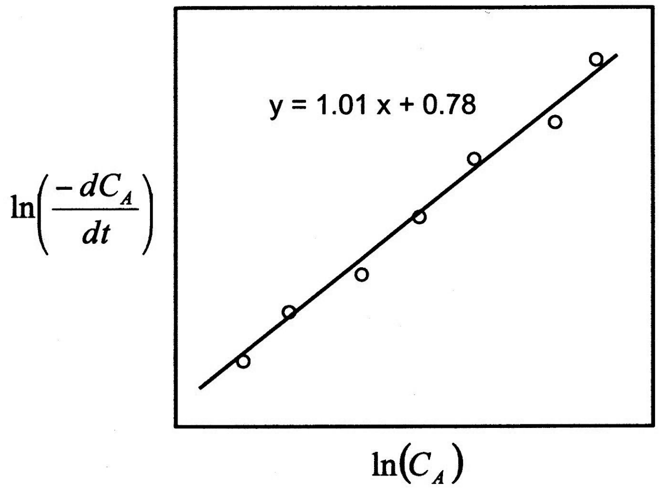
B) 2
For large k_{CI}, I diffuses out of the membrane and as a result that the concentration of C_A is increased for constant T and P.

$$C_A = y_A \frac{P_0}{RT_0} \quad , \quad y_I \downarrow \quad y_A \uparrow \quad C_A \uparrow \quad -r_A \uparrow$$

Consequently the reaction rate will proceed more rapidly at the entrance to the reactor before approaching equilibrium at some point down the reactor.

(5 pts) 6) **Analysis of Data, Chapter 7**

(2 pts) 6**a)** From the following plot, what is the reaction order with respect to A?



Circle the correct answer.

A) 0
B) 0.5
C) 0.78
D) 1
E) 2

Explain____

____

Solution

D) 1
$\text{Slope} = 1.01 \approx 1$

(3 pts) 6**b)** The following reaction, batch experiments are conducted to evaluate the reaction kinetics. The slope of a ln (r_B) versus ln (C_B) plot is measured to be 1.02 and the intercept is 0.42 when A is in great excess. What is the *overall* reaction order?

$$A + 2B \rightarrow \text{Products}$$

Circle the correct answer.

A) 0.42
B) 1.02
C) 1.44
D) Can't tell on the basis of this experiment

Explain____

Solution

D) Can't tell on the basis of this experiment

$$-r_A = \frac{-r_B}{2} = kC_A^{\alpha}C_B^{\beta} = \ln\left(\frac{-r_B}{2}\right) = \ln\ k + \alpha\ \ \ln\ C_A + \beta\ \ \ln\ C_B$$

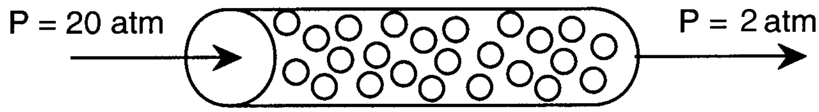
Both C_A and C_B vary, need to find α by varying C_A

(20 pts) 7) **<u>Pressure Drop, Chapter 5</u>**

The gas phase reaction

$$A + B \longrightarrow C + D$$

is carried out isothermally at 227°C in a packed bed reactor with 100 kg of catalyst. The reaction is first order in A and first order in B.



The entering pressure was 20 atm and the exit pressure is 2 atm. The feed is equal molar in A and B and is in the flow in the turbulent regime with F_{A0} = 10 mol/min and $C_{A0} = 0.244$ mol/dm^3. Currently 80% conversion is achieved. Intra particle diffusion effects in the catalyst particles can be neglected.

(a) What is the specific reaction rate?

k = ________________

(b) What would be the conversion if the particle size were doubled and there are no internal mass transfer limitations?

X = ________________

<u>Solution</u>

(a)

$$\frac{dX}{dW} = \frac{-r_A'}{F_{A0}} = \frac{kC_{A0}^2(1-X)^2 y^2}{F_{A0}} = \frac{kC_{A0}^2(1-X)^2(1-\alpha W)}{F_{A0}}$$

$$\frac{X}{1-X} = \frac{kC_{A0}^2}{F_{A0}}\left[W - \frac{\alpha W^2}{2}\right]$$

$$y = \frac{2}{20} = (1-\alpha W)^{1/2}$$

$$y^2 = (1-\alpha W)$$

$$\alpha = \frac{1-y^2}{W} = \frac{1-0.01}{100} = \frac{0.99}{100}$$

$$\boxed{\alpha = 9.9\times 10^{-3}}$$

$$\frac{0.9}{1-0.9} = \frac{k[0.244]^2}{10}\left[\frac{100-\left(9.9\times 10^{-3}\times 10^4\right)}{2}\right]$$

$$9 = k[0.059][100-49.5]/10$$

$$\boxed{k = \frac{(9\cdot 10)}{(50.5)(0.059)} = 30.2\,\frac{\text{dm}^3}{\text{mol min}}}$$

(b) For the turbulent flow

$$\alpha \sim \frac{1}{D_P}$$

$$\alpha_2 = \alpha_1\frac{D_{P1}}{D_{P2}} = \frac{\alpha_1}{2} = \frac{9.9\times 10^{-3}\,\text{kg}^{-1}}{2} = 4.95\times 10^{-3}\,\text{kg}^{-1}$$

$$\frac{X}{1-X} = \frac{(30.2)(0.244)^2}{10}\left[100 - \frac{4.95\times 10^{-3}(100)^2}{2}\right]$$

$$= 0.18\left[100 - 24.7\right] = 13.5$$

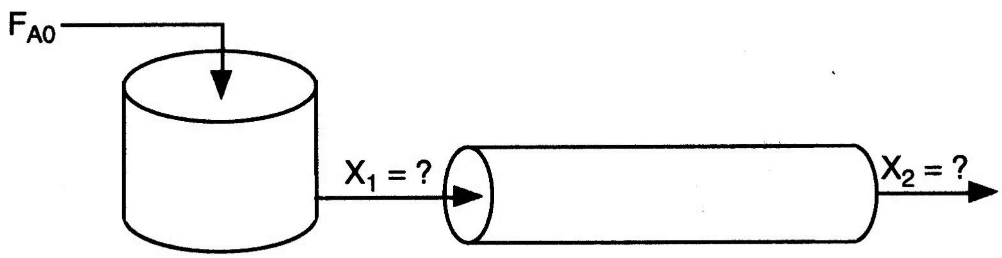
$$\boxed{X = 0.93}$$

(20 pts) 8) ***Modified California Problem P5-20$_B$***

The elementary gas phase reaction

$$A + B \rightarrow C + D$$

takes place isobarically and isothermally in a PFR where 50% conversion is achieved. The feed is equimolar in A and B. It is proposed to put a CSTR of equal volume upstream, i.e.,



of the PFR. What will be the intermediate and exit conversions X_1 and X_2 respectively? The entering flow rates and all other variables remain the same as that for the single PFR.

$X_1 =$ ________

$X_2 =$ ________

<u>*Solution*</u>

Case 1

Mole Balance $\frac{dX}{dV} = -r_A$

Rate Law $-r_A = kC_AC_B$

Stoichiometry

Gas $\delta = 0,\ \Theta_B = 1$

$$C_A = C_{A0}(1-X)$$

$$C_B = C_{A0}(1-X)$$

Combine $-r_A = kC_{A0}^2(1-X)^2$

$$\frac{dX}{dV} = \frac{kC_{A0}^2}{F_{A0}}\frac{(1-X)^2}{}$$

$$\frac{dX}{(1-X)^2} = \frac{kC_{A0}^2}{F_{A0}}dV$$

$V = 0\ ,\quad X = 0$

$V = V,\quad X = 0.5$

$$\int_0^X \frac{dX}{(1-X)^2} = \frac{X}{1-X} = \frac{kC_{A0}^2}{F_{A0}} V$$

$$\frac{kC_{A0}^2}{F_{A0}} V = \frac{0.5}{1-0.5} = 1$$

Case 2

(1) $V_{CSTR} = \frac{F_{A0}X}{-r_A}$

(2) & (3) Rate Law, Stoichiometry same as Case 1

$$V_{CSTR} = \frac{F_{A0}X_1}{kC_{A0}^2(1-X_1)^2}$$

$$\frac{VkC_{A0}^2}{F_{A0}} = 1 = \frac{X_1}{1-2X_1+X_1^2}$$

$$1-2X_1+X_1^2 = X_1$$

$$X_1^2 - 3X_1 + 1 = 0$$

$$X_1 = \frac{3 \pm \sqrt{9-4}}{2} = \frac{3-\sqrt{5}}{2} = \frac{3-2.24}{2} = 0.38$$

PFR $X_1 = 0.38$

$$\frac{dX}{dV} = \frac{kC_{A0}^2(1-X)^2}{F_{A0}}, \quad \int_{X_1}^{X_2} \frac{dX}{(1-X)^2} = \frac{kC_{A0}^2 V}{F_{A0}}$$

$V = 0 \quad X = X_1 = 0.38$

$V = V \quad X = X_2$

$$\frac{kC_{A0}^2 V}{F_{A0}} = 1 = \frac{1}{1-X_2} - \frac{1}{1-X_1}$$

$$\frac{1}{1-X_2} = 1 + \frac{1}{1-X_1} = 1 + \frac{1}{0.62} = 2.62$$

$$1 - X_2 = 0.38$$

$$X_2 = 0.62$$

(20 pts) 9) **P5-9$_B$ Study Problem on Syllabus.**

The gas phase reaction

$$A \rightarrow B + C$$

follows an elementary rate law and is to be carried out first in a PFR and then in a separate experiment in a CSTR. When Pure A is fed to a 10 dm^3 PFR at 300K and a volumetric flow rate of 5 dm^3/s, the conversion is 80%. When a mixture of 50% A and 50% inert (I) is fed to a 10 dm^3 CSTR at 320K and a volumetric flow rate of 5 dm^3/s the conversion is also 80%. What is the activation energy in cal/mol?

E = ________________cal/mol

Solution

P5-9

PFR

$$\frac{dX}{dV} = \frac{-r_A}{F_{A0}} = \frac{kC_{A0}(1-X)}{C_A\upsilon_0(1+\varepsilon X)} = \frac{k(1-X)}{\upsilon_0(1+\varepsilon X)}$$

$$\int_0^X \frac{(1+\varepsilon X)}{(1-X)}dX = \int k\frac{dV}{\upsilon_0} = k\tau$$

$$k = \frac{1}{\tau}\left[\left[(1+\varepsilon)\ln\frac{1}{1-X}\right] - \varepsilon X\right]$$

$$\tau = \frac{10\text{dm}^3}{5\,\text{dm}^3/\text{s}} = 2\text{s}$$

$$\varepsilon = y_{A0}\delta = 1(1+1-1) = 1$$

$$k = \frac{1}{2}\left[(1+1)\ln\left(\frac{1}{1-0.8}\right) - 0.8\right]$$

$$k = \frac{1}{2}[2\ \ 1.61 - 0.8] = 1.209 \ \text{ at } \ 300\text{K}$$

CSTR

$$V = \frac{F_{A0}X}{-r_A} = \frac{\upsilon_0 C_{A0}X}{kC_{A0}\frac{(1-X)}{(1+\varepsilon X)}} = \frac{\upsilon_0 X(1+\varepsilon X)}{k(1-X)}$$

$$\varepsilon = \frac{1}{2}(1+1-1)$$

$$\varepsilon = 0.5$$

$$k = \frac{1}{\tau}\frac{X(1+\varepsilon X)}{(1-X)} = \frac{1}{2}\left[\frac{0.8(1+0.5(0.8))}{0.2}\right]$$

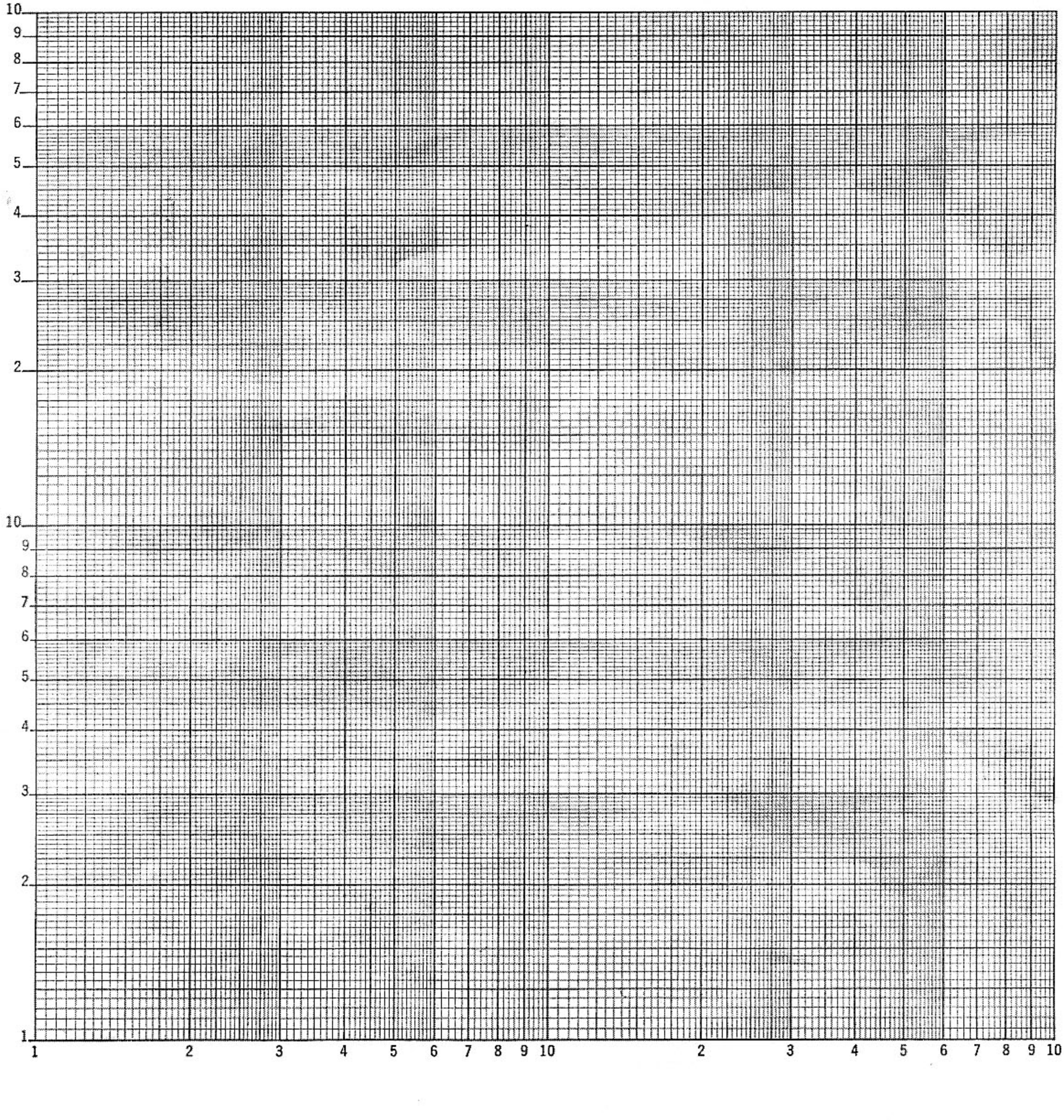
$$= 2.8$$

$$\ln\frac{k_2}{k_1} = \frac{E}{R}\left[\frac{1}{T_1} - \frac{1}{T_2}\right]$$

$$\ln\frac{2.8}{1.21} = \frac{E}{R}\left[\frac{1}{300} - \frac{1}{320}\right] = \frac{E}{R}\frac{20}{(320)(300)}$$

$$E = R\frac{(300)(320)}{20}\ln\frac{2.8}{1.21} \quad , \quad R = 1.987\frac{cal}{mol°K}$$

$$E = 8010\frac{cal}{mol}$$



Logarithmic, 2 x 2 Cycles