PROBLEMS

5.1. Consider a gas-phase reaction 2A→R + 2S with unknown kinetics. If a space velocity of 1/min is needed for 90% conversion of A in a plug flow reactor, find the corresponding space-time and mean residence time or holding time of fluid in the plug flow reactor.

5.2. In an isothermal batch reactor 70% of a liquid reactant is converted in 13 min. What space-time and space-velocity are needed to effect this conversion in a plug flow reactor and in a mixed flow reactor?

5.3. A stream of aqueous monomer A (1 mol/liter, 4 liter/min) enters a 2-liter mixed flow reactor, is radiated therein, and polymerizes as follows:

$$A \overset{+A}{\rightarrow} R \overset{+A}{\rightarrow} S \overset{+A}{\rightarrow} T \ldots$$

In the exit stream C_A = 0.01 mol/liter, and for a particular reaction product W, C_W = 0.0002 mol/liter. Find the rate of reaction of A and the rate of formation of W.

5.4. We plan to replace our present mixed flow reactor with one having double the volume. For the same aqueous feed (10 mol A/liter) and the same feed rate find the new conversion. The reaction kinetics are represented by

$$A \rightarrow R, \qquad -r_A = kC_A^{1.5}$$

and present conversion is 70%.

5.5. An aqueous feed of A and B (400 liter/min, 100 mmol A/liter, 200 mmol B/liter) is to be converted to product in a plug flow reactor. The kinetics of the reaction is represented by

$$A + B \rightarrow R, \qquad -r_A = 200C_AC_B\,\frac{mol}{liter{\cdot}min}$$

Find the volume of reactor needed for 99.9% conversion of A to product.

5.6. A plug flow reactor (2 m^3) processes an aqueous feed (100 liter/min) containing reactant A (C_{Ao} = 100 mmol/liter). This reaction is reversible and represented by

$$A \rightleftharpoons R, \qquad -r_A = (0.04\,min^{-1})C_A - (0.01\,min^{-1})C_R$$

First find the equilibrium conversion and then find the actual conversion of A in the reactor.

5.7. The off gas from a boiling water nuclear power reactor contains a whole variety of radioactive trash, one of the most troublesome being Xe-133 (half life = 5.2 days). This off gas flows continuously through a large holdup tank in which its mean residence time is 30 days, and where we can assume that the contents are well mixed. Find the fraction of activity removed in the tank.

5.8. A mixed flow reactor (2 m^3) processes an aqueous feed (100 liter/min) containing reactant A (C_{Ao} = 100 mmol/liter). The reaction is reversible and represented by

$$A \rightleftharpoons R, \qquad -r_A = 0.04C_A - 0.01C_R\,\frac{mol}{liter{\cdot}min}$$

What is the equilibrium conversion and the actual conversion in the reactor?

5.9. A specific enzyme acts as catalyst in the fermentation of reactant A. At a given enzyme concentration in the aqueous feed stream (25 liter/min) find the volume of plug flow reactor needed for 95% conversion of reactant A (C_{Ao} = 2 mol/liter). The kinetics of the fermentation at this enzyme concentration is given by

$$A \xrightarrow{enzyme} R, \qquad -r_A = \frac{0.1C_A}{1+0.5C_A} \frac{mol}{liter \cdot min}$$

5.10. A gaseous feed of pure A (2 mol/liter, 100 mol/min) decomposes to give a variety of products in a plug flow reactor. The kinetics of the conversion is represented by

$$A \rightarrow 2.5\ (products), \quad -r_A = (10\ min^{-1})C_A$$

Find the expected conversion in a 22-liter reactor.

5.11. Enzyme E catalyses the fermentation of substrate A (the reactant) to product R. Find the size of mixed flow reactor needed for 95% conversion of reactant in a feed stream (25 liter/min) of reactant (2 mol/liter) and enzyme. The kinetics of the fermentation at this enzyme concentration are given by

$$A \xrightarrow{enzyme} R, \qquad -r_A = \frac{0.1C_A}{1+0.5C_A} \frac{mol}{liter \cdot min}$$

5.12. An aqueous feed of A and B (400 liter/min, 100 mmol A/liter, 200 mmol B/liter) is to be converted to product in a mixed flow reactor. The kinetics

$$A + B \rightarrow R, \qquad -r_A = 200C_AC_B \frac{mol}{liter \cdot min}$$

Find the volume of reactor needed for 99.9% conversion of A to product.

5.13. At 650°0 phosphine vapor decomposes as follows:

$$4PH_3 \rightarrow P_4(g) + 6H_2, \qquad -r_{phos} = (10hr^{-1})C_{phos}$$

What size of plug flow reactor operating at 649°C and 11.4 atm is needed for 75% conversion of 10 mol/hr of phosphine in a 2/3 phosphine- 1/3 inert feed?

5.14. A stream of pure gaseous reactant A (C_{AO} = 660 mmol/liter) enters a plug flow reactor at a flow rate of F_{Ao} = 540 mmol/min and polymerizes there as follows

$$3A \rightarrow R, \qquad -r_A = 54 \frac{mmol}{liter \cdot min}$$

How large a reactor is needed to lower the concentration of A in the exit stream to C_{Af} = 330 mmol/liter?

5.15. A gaseous feed of pure A (1 mol/liter) enters a mixed flow reactor (2 liters) and reacts as follows:

$$2A \rightarrow R, \qquad -r_A = 0.05C_A^2 \frac{mol}{liter \cdot min}$$

Find what feed rate (liter/min) will give an outlet concentration C_A = 0.5 mol/liter.

5.16. Gaseous reactant A decomposes as follows:

$$A \rightarrow 3R, \qquad -r_A = (0.6\, min^{-1})C_A$$

Find the conversion of A in a 50% A-50% inert feed (v_0 = 180 liter/min, C_{Ao} = 300 mmol/liter) to a 1 m^3 mixed flow reactor.

5.17. 1 liter/s of a 20% ozone-80% air mixture at 1.5 atm and 93°C passes through a plug flow reactor. Under these conditions ozone decomposes by homogeneous reaction

$$2O_2 \rightarrow 3O_2, \qquad -r_{ozone} = kC_{ozone}^2, \qquad k = 0.05\frac{liter}{mol{\cdot}s}$$

What size reactor is needed for 50% decomposition of ozone? This problem is a modification of a problem given by Corcoran and Lacey (1970).

5.18. An aqueous feed containing A (1 mol/liter) enters a 2-liter plug flow reactor and reacts away ($2A \rightarrow R$, $-r_A = 0.05\, C_A^2$ mol/liter ·s). Find the outlet concentration of A for a feed rate of 0.5 liter/min.

5.19. Pure gaseous A at about 3 atm and 30°C (120 mmol/liter) is fed into a 1 liter mixed flow reactor at various flow rates. There it decomposes, and the exit concentration of A is measured for each flow rate. From the following data find a rate equation to represent the kinetics of the decomposition of A. Assume that reactant A alone affects the rate.

v_0, liter/min	0.06	0.48	1.5	8.1	$A \rightarrow 3R$
C_A, mmol/liter	30	60	80	105	

5.20. A mixed flow reactor is being used to determine the kinetics of a reaction whose stoichiometry is $A \rightarrow R$. For this purpose various flow rates of an aqueous solution of 100 mmol A/liter are fed to a 1-liter reactor, and for each run the outlet concentration of A is measured. Find a rate equation to represent the following data. Also assume that reactant alone affects the rate.

v, liter/min	1	6	24
C_A, mmol/liter	4	20	50

5.21. We are planning to operate a batch reactor to convert A into R. This is a liquid reaction, the stoichiometry is $A \rightarrow R$, and the rate of reaction is given in Table P5.21. How long must we react each batch for the concentration to drop from C_{Ao} = 1.3 mol/liter to C_{Af} = 0.3 mol/liter?

Table P5.21

C_A, mol/liter	$-r_A$, mol/liter ·min
0.1	0.1
0.2	0.3
0.3	0.5
0.4	0.6
0.5	0.5
0.6	0.25
0.7	0.10
0.8	0.06
1.0	0.05
1.3	0.045
2.0	0.042

5.22. For the reaction of Problem 5.21, what size of plug flow reactor would be needed for 80% conversion of a feed stream of 1000 mol A/hr at C_{AO} =1.5 mol/liter?

5.23. (a) For the reaction of Problem 5.21, what size of mixed flow reactor is needed for 75% conversion of a feed stream of 1000 mol A/hr at C_{Ao}= 1.2 mol/liter?

(b) Repeat part (a) with the modification that the feed rate is doubled, thus 2000 mol A/hr at C_{Ao} = 1.2 mol/liter are to be treated.

(c) Repeat part (a) with the modification that C_{Ao} = 2.4 mol/liter; however, 1000 mol A/hr are still to be treated down to C_{Af} = 0.3 mol/liter.

5.24. A high molecular weight hydrocarbon gas A is fed continuously to a heated high temperature mixed flow reactor where it thermally cracks (homogeneous gas reaction) into lower molecular weight materials, collectively called R, by a stoichiometry approximated by A→5R. By changing the feed rate different extents of cracking are obtained as follows:

F_{Ao}, mmillimol/hr	300	1000	3000	
$C_{A.out}$, millimol/liter	16	30	50	60

The internal void volume of the reactor is V = 0.1 liter, and at the temperature of the reactor the feed concentration is C_{Ao} = 100 millimol/liter. Find a rate equation to represent the cracking reaction.

5.25. The aqueous decomposition of A is studied in an experimental mixed flow reactor. The results in Table PS.25 are obtained in steady-state runs. To obtain 75% conversion of reactant in a feed, C_{Ao} = 0.8 mol/liter, what holding time is needed in a plug flow reactor?

Table P5.25

Concentration of A, mol/liter		Holding Time,
In Feed	In Exit Stream	sec
2.00	0.65	300
2.00	0.92	240
2.00	1.00	250
1.00	0.56	110
1.00	0.37	360
0.48	0.42	24
0.48	0.28	200
0.48	0.20	560

5.26. Repeat the previous problem but for a mixed flow reactor.

5.27. HOLMES: You say he was last seen tending this vat . . . .

SIR BOSS: You mean "overflow stirred tank reactor," Mr. Holmes.

HOLMES: You must excuse my ignorance of your particular technical jargon, Sir Boss.

SIR BOSS: That's all right; however, you must find him, Mr. Holmes.

Imbibit was a queer chap; always staring into the reactor, taking deep breaths, and licking his lips, but he was our very best operator. Why since he left, our conversion of googliox has dropped from 80% to 75%

HOLMES (tapping the side of the vat idly): By the way, what goes on in the vat?

SIR BOSS: Just an elementary second-order reaction, between ethanol and googliox, if you know what I mean. Of course, we maintain a large excess of alcohol, about 100 to 1 and . . . .

HOLMES (interrupting): Intriguing, we checked every possible lead in town and found not a single clue.

SIR BOSS (wiping away the tears): We'll give the old chap a raise-about twopence per week-if only he'll come back.

DR. WATSON: Pardon me, but may I ask a question? HOLMES: Why certainly, Watson.

WATSON: What is the capacity of this vat, Sir Boss?

SIR BOSS: A hundred Imperial gallons, and we always keep it filled to the brim. That is why we call it an overflow reactor. You see we are running at full capacity-profitable operation you know.

HOLMES: Well, my dear Watson, we must admit that we're stumped, for without clues deductive powers are of no avail.

WATSON: Ahh, but there is where you are wrong, Holmes. (Then, turning to the manager): Imbibit was a largish fellow-say about 18 stone-was he not?

SIR BOSS: Why yes, how did you know? HOLMES (with awe): Amazing, my dear Watson!

WATSON (modestly): Why it's quite elementary, Holmes. We have all the clues necessary to deduce what happened to the happy fellow. But first of all, would someone fetch me some dill?

With Sherlock Holmes and Sir Boss impatiently waiting, Dr. Watson casually leaned against the vat, slowly and carefully filled his pipe, and- with the keen sense of the dramatic-lit it. There our story ends.

(a) What momentous revelation was Dr. Watson planning to make, and how did he arrive at this conclusion?

(b) Why did he never make it?

5.28. The data in Table PS.28 have been obtained on the decomposition of gaseous reactant A in a constant volume batch reactor at 100°C. The

Table P5.28

t, sec	PA , atm	t, sec	,PA , atm
0	1.00	140	0.25
20	0.80	200	0.14
40	0.68	260	0.08
60	0.56	330	0.04
80	0.45	420	0.02
100	0.37		

stoichiometry of the reaction is $2A \rightarrow R + S$. What size plug flow reactor (in liters) operating at 100°C and 1 atm can treat 100 mol A/hr in a feed consisting of 20% inerts to obtain 95% converson of A?

5.29. Repeat the previous problem for a mixed flow reactor.

5.30. The aqueous decomposition of A produces R as follows:

$$A \rightleftharpoons R$$

The following results are obtained in a series of steady state runs, all having no R in the feed stream.

Space Time, τ, sec	C_{Ao}, In Feed, mol/liter	C_{Af}, In Exit Stream, mol/liter
50	2.0	1.00
16	1.2	0.80
60	2.0	0.65
22	1.0	0.56
4.8	0.48	0.42
72	1.00	0.37
40	0.48	0.28
112	0.48	0.20

From this kinetic information, find the size of reactor needed to achieve 75% conversion of a feed stream of v = 1liter/sec and C_{Ao} = 0.8 mol/liter.

In the reactor the fluid follows

(a) plug flow

(b) mixed flow