BT209

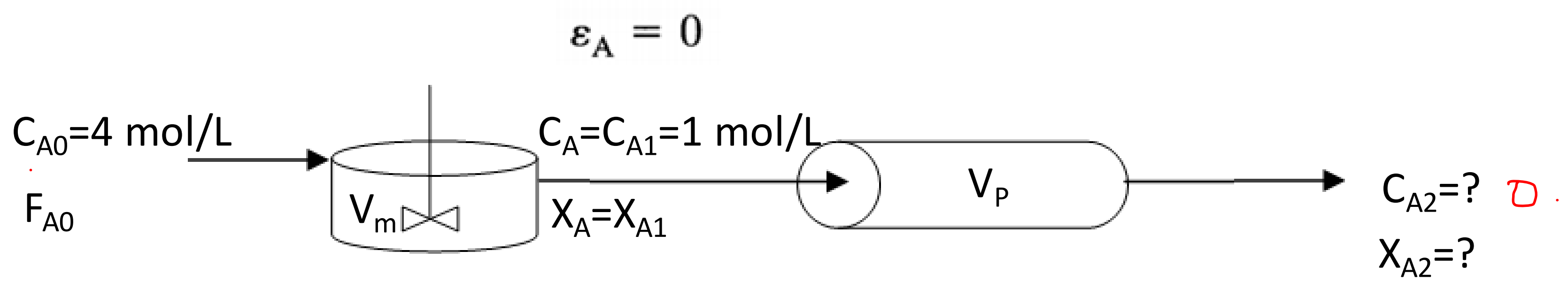
Bioreaction Engineering

16/03/2023

Problem 1

An aqueous reactant stream (4 mol A/liter) passes through a mixed flow reactor followed by a plug flow reactor. Find the concentration at the exit of the plug flow reactor if in the mixed flow reactor $C_A = 1$ mol/liter. The reaction is second-order with respect to A, and the volume of the plug flow unit is three times that of the mixed flow unit.

Solution: Problem 1



$V_P=3V_m$

For mixed flow reactor/CSTR

$$\frac{V_m}{F_{A0}} = \frac{\tau_m}{C_{A0}} = \frac{\Delta X_A}{-r_A} = \frac{X_A}{-r_A} = \frac{C_{A0} - C_A}{C_{A0}(-r_A)}$$

$-r_A = kC_A^2 = kC_{A1}^2 = k(1)^2 = k$

$$k\tau_m = \frac{C_{A0} - C_{A1}}{C_{A1}^2} = \frac{4-1}{1} = 3$$

For PFR

$$\frac{V_P}{F_{A0}} = \frac{\tau_p}{C_{A0}} = \int_{X_{A1}}^{X_{A2}} \frac{dX_A}{-r_A} = -\frac{1}{C_{A0}} \int_{C_{A1}}^{C_{A2}} \frac{dC_A}{-r_A}$$

$V_P=3V_m$ Therefore, $\tau_P=3\tau_m$

$-r_A=kC_A^2$

$$k\tau_p = 3k\tau_m = 9$$

$$\frac{C_{A2}}{C_{A1}} = \frac{1}{1+k\tau_p C_{A1}} = \frac{1}{1+9(1)} = 0.1$$

C_{A2}=0.1 mol/l

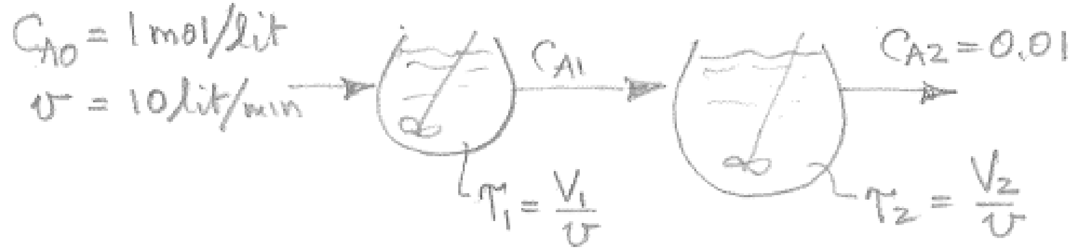
Problem 2

We wish to treat 10 liters/min of liquid feed containing 1 mol A/liter to 99% conversion. The stoichiometry and kinetics of the reaction are given by

$$A \rightarrow R, \qquad -r_A = \frac{C_A}{0.2 + C_A} \frac{\text{mol}}{\text{liter} \cdot \text{min}}$$

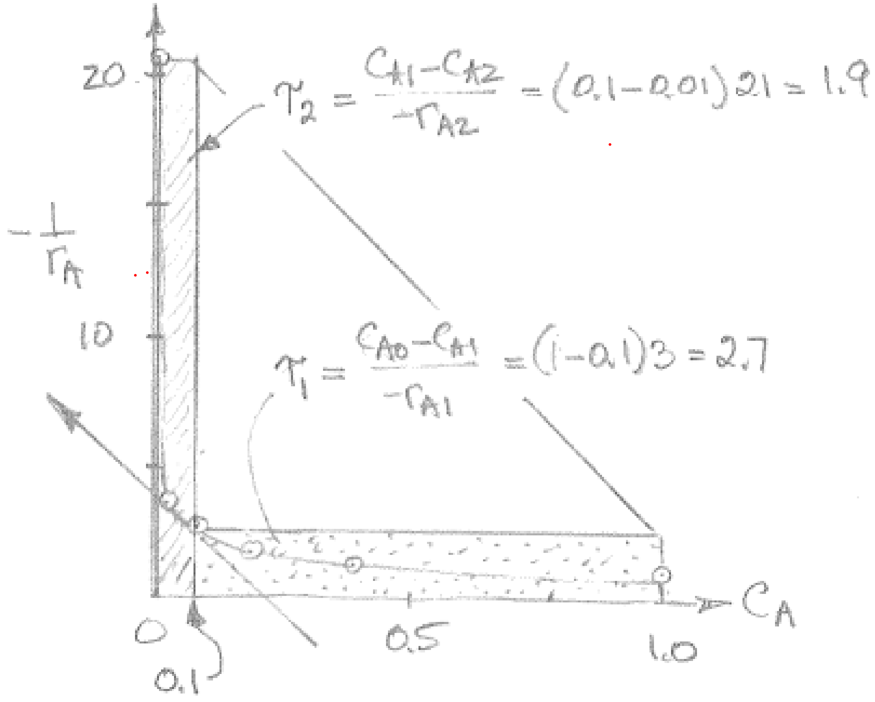
Suggest a good arrangement for doing this using two mixed flow reactors, and find the size of the two units needed. Sketch the final design chosen.

solution

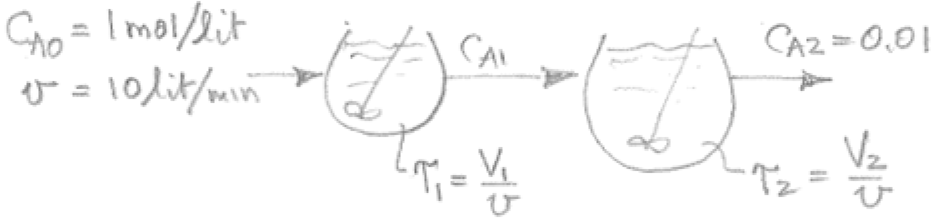


$$-r_A = \frac{C_A}{0.2+C_A}, \ \frac{\text{mol}}{\text{lit}\cdot\text{min}}$$

It is best to solve this graphically. Thus by the method of maximization of rectangles



C_A	$-\frac{1}{r_A} = \frac{0.2+C_A}{C_A}$
1	1.2
0.4	1.5
0.2	2
0.1	3
0.08	3.5
0.01	21



$y=(1/-r_A)$, $dy/dCA=-0.2/C_A^2$

Let at C* SLOPE WILL BE SAME, dy/dCA at C*= [y(at C_2)-y(at C*)]/(Co-C*)

Therefore, $-0.2/C_A^2$ = [y(at C2)-y(at C*)]/(Co-C*)=[21-(0.2/C* +1)]/(1-C*)]

By trial and error method, C*=0.106

Tou1 =(C1-Co)/(-rA)=(1-0.1)*3=2.7

Tou2 =(C2-C1)/(-rA)=(0.1-0.01)*21=1.9

V1=2.7*10=27 LIT

V2=1.9*10=19 lit

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0.1	3
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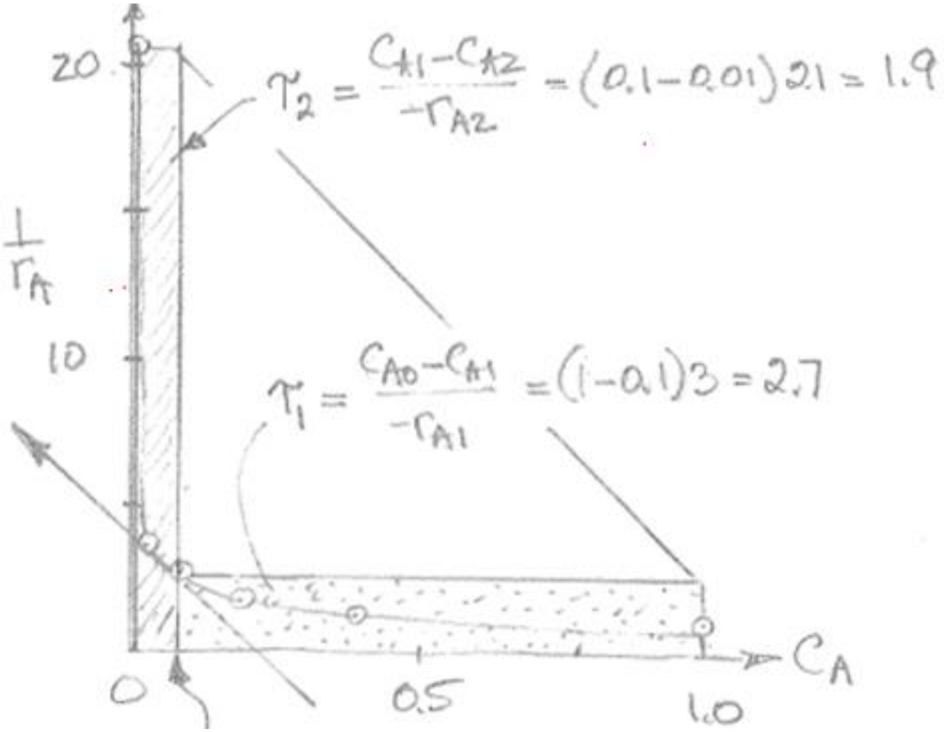

Method -2

From CSTR design equation write V_1 and V_2.

Put

$$\frac{d\ (V1 + V2)}{d_{xA1}} = 0$$

or

$$\frac{d\ (V1 + V2)}{d_{CA1}} = 0$$

Problem 3

Originally we planned to lower the activity of a gas stream containing radioactive Xe-138 (half life 14 minutes) by having it pass through two CSTR in series having the residence time/space time of 2 weeks in each tank. It has been suggested that we replace the two tanks with a PFR. What should be the mean residence time/space time in the PFR for the same extent of radioactive decay?

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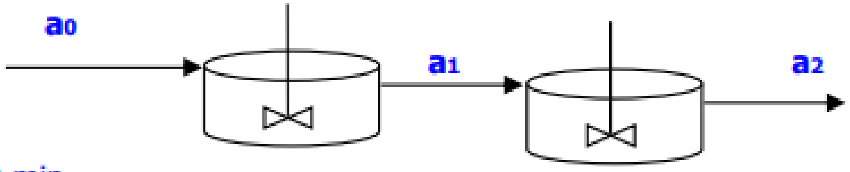
Solution:



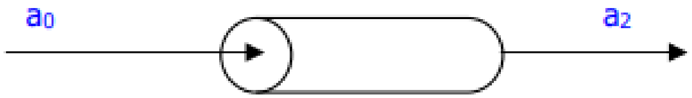
τ = 2 weeks = 20160 min

Radioactive decay follows first order kinetics, so here

$$k = \frac{\ln 2}{t_{1/2}} = \frac{0.6931}{14\,\text{min}} = 0.0495\,\text{min}^{-1}$$

$$\frac{a_2}{a_0} = \frac{a_2}{a_1}\frac{a_1}{a_0} = \frac{1}{(1+k\tau)^2} = \frac{1}{\left[1+(0.0495\times 20160)\right]^2} = 1.0017\times 10^{-6}$$

For PFR:



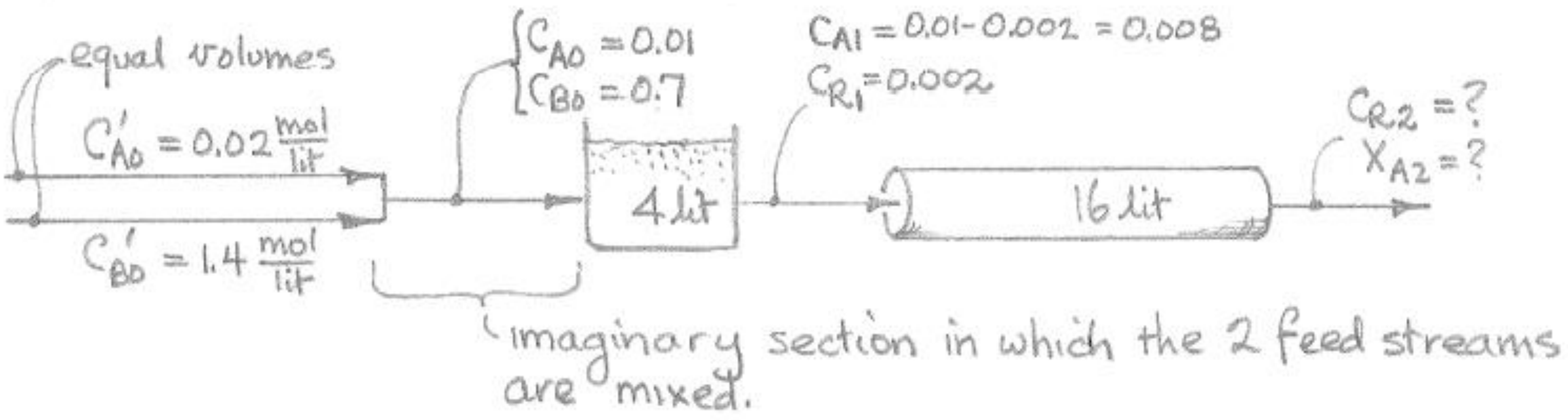
τ_p = ?

$$\frac{a_2}{a_0} = 1.0017\times 10^{-6} = e^{-k\tau_p} = e^{-0.0495\tau_p}$$

$$\tau_p = \frac{\ln\left(1.0017\times 10^{-6}\right)}{-0.0495} = 279\,\text{min} = 4.65 hr$$

Problem 4

The elementary irreversible aqueous-phase reaction $A + B \rightarrow R + S$ is carried out isothermally as follows. Equal volumetric flow rates of two liquid streams are introduced into a 4-liter mixing tank. One stream contains 0.020 mol A/liter, the other 1.400 mol B/liter. The mixed stream is then passed through a 16-liter plug flow reactor. We find that some R is formed in the mixing tank, its concentration being 0.002 mol/liter. Assuming that the mixing tank acts as a mixed flow reactor, find the concentration of R at the exit of the plug flow reactor as well as the fraction of initial A that has been converted in the system.



Simplification: Since $C_{A0} = 1/70 \cdot C_{B0}$ we may assume that $C_{B0} \cong$ constant, and that the reaction is 1st order with respect to A.

For the mixer: $k\tau_m = \frac{C_{A0} - C_{A1}}{C_{A1}} = \frac{0.010 - 0.008}{0.008} = \frac{1}{4}$

For the reactor: $k\tau_p = 4(k\tau_m) = 4\left(\frac{1}{4}\right) = -\int_{0.008}^{C_{A2}} \frac{dC_A}{C_A} = \ln \frac{0.008}{C_{A2}}$ ... or $C_{A2} = 0.00293$

$\therefore X_A = 0.707$ & $C_{R2} = 0.00793$