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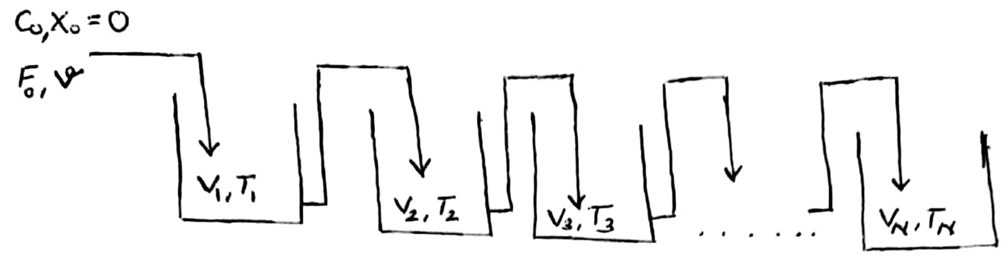
CHEMICAL REACTION ENGINEERING

QUIZ

1.



In first order reaction (where $\epsilon = 0$), for the i^{th} reactor

$$\tau_i = \frac{C_{i-1} V_i}{F_{i-1}} = \frac{C_0 V_i}{F_0} = \frac{V_i}{v} = \frac{C_0 (X_i - X_{i-1})}{-r_{A_i}}$$

as $\epsilon = 0$ we have $\frac{C_i}{C_0} = (1 - x_i)$

thus $\tau_i = \frac{C_0\left(\left(1 - C_i/C_0\right) - \left(1 - C_{i-1}/C_0\right)\right)}{kC_i}$ $[\because -r_{A_i} = kC_i$ in I^{st} order$]$

Now as volume of all the reactors are same, so $\tau_i = \frac{V_i}{v} = \frac{V_{reactor}}{v}$ is same for all reactors.

$$\frac{C_0}{C_N} = \frac{1}{1 - X_N} = \frac{C_0}{C_1} \times \frac{C_1}{C_2} \times \frac{C_2}{C_3} \times \cdots \times \frac{C_{N-1}}{C_N} = (1 + k\tau_i)^N$$

$$\Rightarrow \tau_i = \frac{1}{k}\left[\left(\frac{C_0}{C_N}\right)^{1/N} - 1\right]$$

where N is the no. of reactors.

Hence $$\tau_{N\,reactor} = N\tau_i = \frac{N}{K}\left[\left(\frac{C_0}{C_N}\right)^{1/N} - 1\right] \quad \text{—— (1)}$$

if $N \to \infty$ then ~~rea~~ eqn (1) ~~redo~~ reduces to

$$\tau_{\infty\,reactors} = \frac{1}{K}\ln\left(\frac{C_0}{C}\right)$$; which is $\tau_{Plug\,Flow}$

So we can say that when no. of MFR in series approaches to ∞ then space time (total) of MFRs approaches to space time of single PFR

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2.

For Batch reactor :-

Let the batch reactor be filled with a macrofluid containing reactant 'A'. Since each aggregate/packet of macrofluid acts as its own little batch reactor, conversion is same in all aggregates and is infact identical to what would be obtained with a microfluid, thus for batch operation degree of ~~freedom~~ segregation doesn't effect conversion.

For plug flow reactor :-

Since plug flow can be visualized as a flow of small batch reactors passing in succession through the vessel, macro and microfluids act alike. So degree of segregation doesn't effect conversion.

For Mixed flow reactor :-

Microfluid :-

In MFR the reactant concentration everywhere drops to the low ~~volume~~ value prevailing the reactor. No clump of molecules retain its high initial concn of 'A'. We may characterize this by saying that each molecule loses ~~its~~ its identity and has no determinable past history. In other words by examining its neighbors we can't tell whether a molecule is new comer or an old timer in the reactor. For this system

$$X_A = \frac{(-r_A)V}{F_{A_0}}$$

as $\epsilon = 0$ we have $\frac{C_A}{C_{A_0}} = (1 - X_A)$

$$\Rightarrow \frac{C_A}{C_{A_0}} = 1 - \frac{(-r_A)\bar{t}}{C_{A_0}}$$

where $\bar{t}$ is the mean residence time of fluid in reactor.

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Macrofluid :- When a macrofluid enters a MFR, the reactant concⁿ in an aggregate does not drop immediately to a low value but decreases in the same way as it would be in batch reactor. Thus a molecule in a macrofluid doesn't lose its identity. Its age can be estimated by examining its neighboring molecules.

The performance eqⁿ for a macrofluid in a MFR is given by

$$1-\bar{X}_A = \frac{\bar{C}_A}{C_{A_0}} = \int_0^\infty \left(\frac{C_A}{C_{A_0}}\right)_{Batch} E\,dt$$

where $E\,dt = \frac{\nu}{V} e^{-\nu t/V} dt = \frac{e^{-t/\bar{t}}}{\bar{t}} dt$

thus $1-\bar{X}_A = \frac{\bar{C}_A}{C_{A_0}} = \int_0^\infty \left(\frac{C_A}{C_{A_0}}\right)_{Batch} \frac{e^{-t/\bar{t}}}{\bar{t}} dt$

for Iˢᵗ order reaction

$$\left(\frac{C_A}{C_{A_0}}\right)_{Batch} = e^{-kt}$$

$\rightarrow 1-\bar{X}_A = \frac{\bar{C}_A}{C_{A_0}} = \frac{1}{\bar{t}} \int_0^\infty e^{-kt} e^{-t/\bar{t}} dt$

$\rightarrow \frac{\bar{C}_A}{C_{A_0}} = \frac{1}{1+k\bar{t}}$

for microfluid

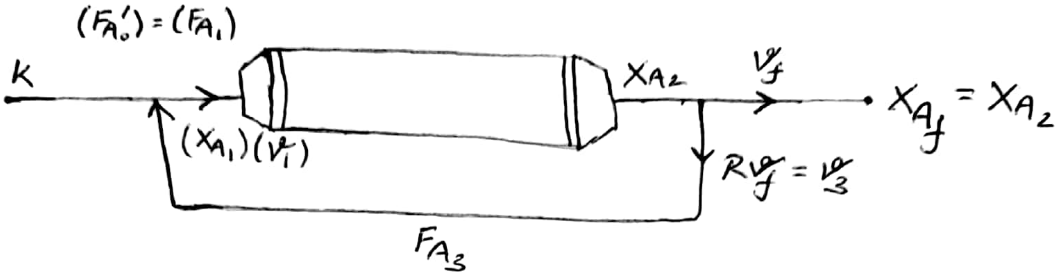
$-r_A = kC_A$ [$\because$ Iˢᵗ order]

$\Rightarrow \frac{C_A}{C_{A_0}} = 1 - \frac{(-r_A)\bar{t}}{C_{A_0}} = 1 - \frac{kC_A\bar{t}}{C_{A_0}}$

or $\frac{C_A}{C_{A_0}} = \frac{1}{1+k\bar{t}}$

as the equations for macro and micro fluids are same thus we conclude that the degree of segregation has no effect on conversion for Ist order reac^n.

3.



Across the reactor plug flow gives

$$\frac{V}{F_{A_0}'} = \int_{X_{A_1}}^{X_{A_2}=X_{A_f}} \frac{dX_A}{-r_A}$$

where F_{A_0}' would be the feed rate of 'A' if the stream entering the reactor (fresh feed plus recycle) were unconverted

$\rightarrow F_{A_0}' =$ fresh feed + Recycle stream

$= F_{A_0} + R F_{A_0}$

$= (1+R) F_{A_0}$

$R = \dfrac{\text{volume recycled}}{\text{volume leaving the reactor}}$

$R \in [0, \infty)$

$$X_{A_1} = \frac{1 - C_{A_1}/C_{A_0}}{1 + \epsilon_A C_{A_1}/C_{A_0}} \quad \text{——} \; (1)$$

as $\epsilon = 0$ we have $X_{A_1} = (1 - C_{A_1}/C_{A_0})$

$$C_{A_1} = \frac{F_{A_1}}{v_1} = \frac{F_{A_0} + F_{A_3}}{v_0 + R v_f} = \frac{F_{A_0} + R F_{A_0}(1 - X_{AF})}{v_0 + R v_0}$$

thus $C_{A_1} = C_{A_0}\left(\dfrac{1 + R - R X_{AF}}{1+R}\right)$ —— (2) $\left\{ \text{where } \dfrac{F_{A_0}}{v_0} = C_{A_0} \right\}$

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for eq^n ① & ②

$$X_{A_1} = \frac{R}{R+1} \cdot X_{A_f}$$

$$\rightarrow \frac{V}{F'_{A_0}} = \int_{X_{A_1}=\frac{R}{R+1}X_{A_f}}^{X_{A_f}} \frac{dX_A}{-r_A}$$

$$\rightarrow \frac{V}{F_{A_0}} = (R+1) \int_{\frac{R}{R+1}X_{A_f}}^{X_{A_f}} \frac{dX_A}{-r_A}$$

$$\tau = \frac{C_{A_0} V}{F_{A_0}} = -(R+1) \int_{\frac{C_{A_0}+RC_{A_F}}{R+1}}^{C_{A_F}} \frac{dC_A}{-r_A}$$

$\left\{ \text{as } \varepsilon_A = 0 \text{ and } dC_A = -C_{A_0} dX_A \right\}$

and also $-r_A = kC_A$ [$\because$ Ist order reac^n]

$-r_A = kC_A$

$$\rightarrow \tau = -(R+1) \int_{\frac{C_{A_0}+RC_{A_f}}{R+1}}^{C_{A_f}} \frac{dC_A}{kC_A} \quad \text{—— ③}$$

$$\rightarrow k\tau = -(R+1) \ln\left(\frac{C_{A_f}(R+1)}{C_{A_0} + RC_{A_f}} \right)$$

$$\rightarrow \frac{k\tau}{R+1} = \ln\left[\frac{C_{A_0}+RC_{A_f}}{(R+1)C_{A_f}} \right]$$

Putting $R = 0$ in eq^n ③ $\Rightarrow \tau = \frac{1}{k} \ln\left(\frac{C_{A_0}}{C_{A_f}}\right)$ (Plug Flow)

Putting $R = \infty$ in eq^n ③ $\Rightarrow \tau = \frac{1}{k} \int_{X_{A_0}}^{X_{A_f}} \frac{dX_A}{1-X_A}$ (MFR)