

GATE PSUs

State Engg. Exams

MADE EASY
WORKBOOK 2024



**Detailed Explanations of
Try Yourself *Questions***

Chemical Engineering
Chemical Reaction Engineering



1

Kinetics of Homogeneous Reactions



Detailed Explanation of Try Yourself Questions

T1 : Solution

(0.227) [0.222 to 0.229]

$$\epsilon_A = y_{A_0} \delta_A$$

$$\delta_A = \frac{1 - \left(\frac{1}{2} + 1\right)}{1} = \left(-\frac{1}{2}\right)$$

$$y_{A_0} = \frac{1}{1 + \frac{1}{2}} = \frac{2}{3}$$

So,

$$\epsilon_A = \left(\frac{2}{3}\right) \left(-\frac{1}{2}\right) = -\frac{1}{3}$$

Now,

$$\frac{C_A}{C_{A_0}} = \frac{(1 - X_A)}{(1 + \epsilon_A X_A) \left(\frac{P_0}{P}\right) \left(\frac{T}{T_0}\right)}$$

$$\frac{C_A}{C_{A_0}} = \frac{1 - 0.8}{\left(1 - \frac{1}{3} \times 0.8\right) \left(\frac{360}{300}\right)} = 0.227$$

T2 : Solution

(d)

Equation of straight line can be written as

$$y = mx + c$$

m = Slope

c = Intercept on y axis

So by putting values from graph

$$\begin{aligned} (-r_A) &= \left(\frac{k_1}{k_2} \right) + \left(-\frac{1}{k_2} \right) \left(\frac{-r_A}{C_A} \right) \\ &= -r_A \left[1 + \frac{1}{k_2 C_A} \right] = \frac{k_1}{k_2} \\ -r_A &= \frac{k_1 C_A}{1 + k_2 C_A} \end{aligned}$$

T3 : Solution

(422 kJ/mol) [420 to 424 kJ/mol]

From Arrhenius law:

$$\begin{aligned} \ln \left(\frac{r_2}{r_1} \right) &= \ln \left(\frac{k_2}{k_1} \right) = \ln \left(\frac{t_1}{t_2} \right) = \frac{E}{R} \left[\frac{1}{T_1} - \frac{1}{T_2} \right] \\ \ln \left(\frac{30 \times 60}{15} \right) &= \frac{E}{8.314} \left[\frac{1}{336} - \frac{1}{347} \right] \\ E &= 422 \text{ kJ/mol} \end{aligned}$$

■■■■

2

Design of Isothermal Ideal Reactors



Detailed Explanation of Try Yourself Questions

T1 : Solution

(148 litre)

$$\begin{aligned} \epsilon_A &= y_{A_0} \delta_A & C_{A_0} &= \frac{P_{A_0}}{RT} \\ &= \frac{7-4}{4} \times 1 = 0.75 & &= \frac{460000}{8.314 \times 922} \\ X_A &= 0.8 & &= 60 \text{ mol/m}^3 \end{aligned}$$

For variable volume first order reaction for PFR following equation can be used.

$$\begin{aligned} k\tau &= -(1 + \epsilon_A) \ln(1 - X_A) - \epsilon_A X_A \\ \frac{10 \times V \times 60}{40} &= -(1 + 0.75) \ln(1 - 0.8) - 0.75 \times 0.8 \\ &= 0.148 \text{ m}^3 = 148 \text{ litre} \end{aligned}$$

■■■■

3

Design of Non-Isothermal Reactors



Detailed Explanation of Try Yourself Questions

T1 : Solution

(300 K)

$$k_1 = \exp\left(10 - \frac{5000}{T}\right)$$

$$k_2 = \exp\left(40 - \frac{15000}{T}\right)$$

As we know that

$$k = k_0 e^{-E/RT}$$

Taking in both side

$$\ln k = \ln k_0 - \frac{E}{RT}$$

$$k = \exp\left[\ln k_0 - \frac{E}{RT}\right] \quad \dots(A)$$

On comparing given data with equation (A)

$$\ln k_0 = 10, \quad \ln k_{20} = 40$$

$$\frac{E_1}{R} = 5000, \quad \frac{E_2}{R} = 15000$$

T_{optimum} for reversible exothermic reaction is given by

$$T_{\text{optimum}} = \frac{E_2 - E_1}{R \ln \left(\frac{k_{20}}{k_0} \cdot \frac{E_2}{E_1} \cdot \frac{X_A}{1 - X_A} \right)}$$

$$= \frac{10000}{\ln \left[\frac{e^{40}}{e^{10}} \cdot \frac{15000}{5000} \cdot \frac{0.8}{0.2} \right]}$$

$$T_{\text{optimum}} = 307.86 \text{ K}$$

but in question maximum allowable temperature is 300 K.

So optimum temperature will be 300 K.

T2 : Solution

(318 K)

For adiabatic CSTR

$$T - T_F = \frac{(-\Delta H_R) F_{A_0} X_A}{P_{\text{mix}} C_{P_{\text{mix}}} v_0}$$

$$353 - T_F = \frac{50000 \times 2 \times v_0 \times 0.7}{1000 \times 2 \times v_0}$$

$$T_F = 318 \text{ K}$$

■■■■

4

Concept of Selectivity and Yields



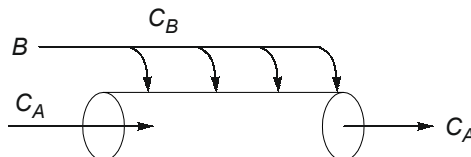
Detailed Explanation of Try Yourself Questions

T1 : Solution

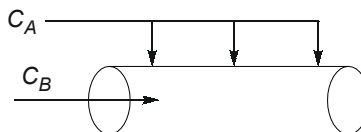
(b, d, a, c)

$$\frac{r_R}{r_S} = \frac{k_1}{k_2} C_A^{1.0} C_B^{-1.5}$$

To minimize formation of desired product. We have to keep C_A high and C_B low. As the concentration dependency of B is more pronounced than that of A , it is more important to have low C_B than high C_A . So most favourable condition is PFR with side stream of B .



Least desirable contacting pattern is which will yield low C_A and high C_B means PFR with side stream of A .



From remaining two schemes (CSTR and PFR) CSTR will yield low C_B , low C_A and PFR will yield high C_A , high C_B .

As concentration of B is more dominant than concentration of A so we should prefer low C_B and low C_A means CSTR.

So from most favourable to least favourable the order is as given following:

Most favourable $\Rightarrow$ PFR with side stream of B

2nd most favourable $\Rightarrow$ CSTR

3rd most favourable $\Rightarrow$ PFR

Least favourable $\Rightarrow$ PFR with side stream of A



5

Design of Non-Ideal Reactors



Detailed Explanation of Try Yourself Questions

T1 : Solution

(c)

In macro fluid each packet contains 10^{12} to 10^{18} molecules which have same residence time and molecules in a packet are bounded, not to interact with molecules of other packets.

T2 : Solution

(0.45)

F -curve stands for fraction of molecules in outlet stream having age less than t . For step input in ideal CSTR of space time τ_m :

$$F(t) = 1 - e^{-t/\tau_m}$$

$$F(t) = 1 - e^{-3/5}$$

$$F(t) = 0.451$$

■ ■ ■ ■

6

Heterogeneous Reaction and Reactor Design



Detailed Explanation of Try Yourself Questions

T1 : Solution

(48.35) [47 to 49]

$$k = k' \times \rho$$

$$k = 0.8 \times 2.8 \text{ sec}^{-1}$$

$$\phi = L_c \sqrt{\frac{k}{D_e}}, \text{ here } L_c = \frac{R}{2}$$

$$= 1 \sqrt{\frac{0.8 \times 2.8}{0.08}} = 0.8819$$

$$\eta = \frac{1}{0.8819} \left[\frac{1}{\tanh 3 \times 0.8819} - \frac{1}{3 \times 0.8819} \right]$$

$$\eta = 0.7168$$

Not for packed bed reactor

$$\frac{W}{F_{A_0}} = \int_0^{X_A} \frac{dX_A}{(-r_A)_{\text{obs}}}$$

where,

$$(-r_A)_{\text{obs}} = \eta(-r_A)$$

$$\frac{W}{v_0 \times C_{A_0}} = \frac{1}{k' C_{A_0} \eta} \int_0^{X_A} \frac{dX_A}{(1 - X_A)}$$

$$W = \frac{v_0}{k' \cdot \eta} [-\ln(1 - X_A)]$$

$$W = \frac{20}{0.8 \times 0.7168} [-\ln(1 - 0.75)]$$

$$W = 48.35 \text{ kg}$$

T2 : Solution

On writing the corresponding rate equations:

$$\begin{aligned}r_1 &= k_1 p_A C_V - k_2 C_{A.S} \\r_2 &= k_3 p_B C_V - k_4 C_{B.S} \\r_3 &= k_5 C_{A.S} C_{B.S} - k_6 C_{CS} \cdot C_{DS} \\r_4 &= k_7 C_{C.S} - k_8 p_C C_V \\r_5 &= k_9 C_{D.S} - k_{10} p_D C_V\end{aligned}$$

Since reaction rate is rate controlling

So,

$$r_1 = 0 \Rightarrow C_{AS} = K_1 p_A C_V \left(K_1 = \frac{k_1}{k_2} \right)$$

■ ■ ■ ■