MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION
(Autonomous)
(ISO/IEC - 27001 - 2005 Certified)

SUMMER-18 EXAMINATION

Model Answer

Subject Title: Chemical Reaction Engineering Subject code 17562

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

<table>
<tr><th>Q No.</th><th>Answer</th><th>Marks</th></tr>
<tr><td>1A</td><td>Attempt any THREE of the following</td><td>12</td></tr>
<tr><td>1A-a</td><td>Rate constant: Rate constant of a chemical reaction is a measure of the rate of the reaction when all the reactants are at unit concentration.
Unit of rate constant = $(\text{time})^{-1} (\text{concentration})^{1-n}$
Given concentration in mole / l and time in seconds,
Unit of rate constant for second order reaction is $(\text{second})^{-1} (\text{moles/l})^{1-2}$
= l / (mole. second)</td><td>2

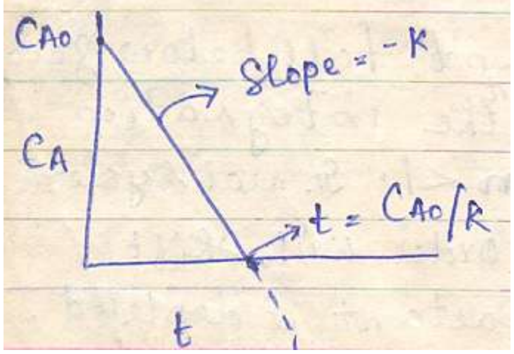
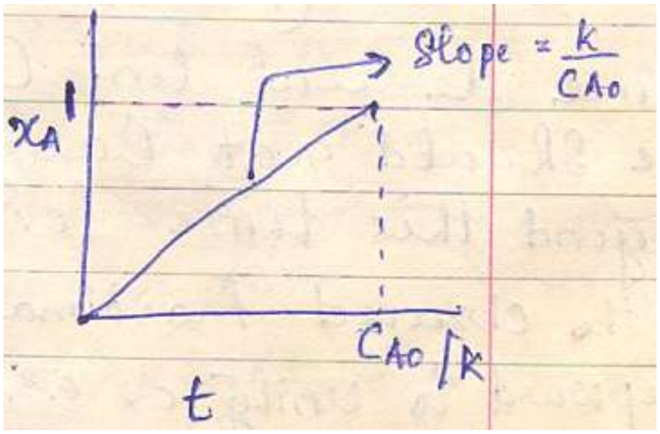
2</td></tr>
<tr><td>1A-b</td><td>Definition:
Entropy: Entropy(s) is the measure of the total disorder or randomness of the system or it is a measure of the unavailable energy to perform useful work.
Unit: J/ K
Gibb’s free energy: It is the energy actually available to do useful work. It predicts the feasibility and equilibrium conditions for chemical reactions at constant temperature and pressure.
Unit: Joules, calories</td><td>
1

1
1

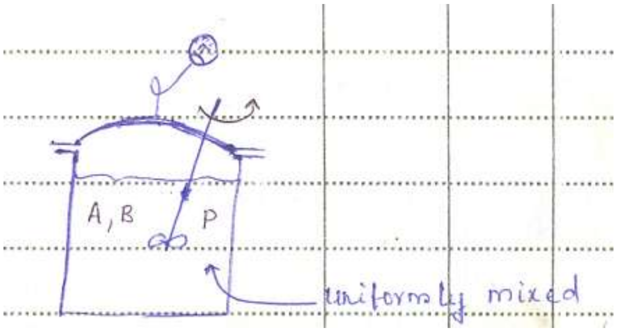
1</td></tr>
<tr><td>1A-c</td><td>Fractional change in volume ϵ_A : It is the fractional change in volume of the system between no conversion and complete conversion of reactant A
$\epsilon_A = (V_{XA=1} - V_{XA=0}) / V_{XA=0}$
$A \rightarrow 3R$ Initially the reaction mixture contains 50 mole % A and 50 mole% inerts. Ie along with 1 mole A, there will be 1 mole inerts
Inerts will not take part in the reaction.
<table>
<tr><th>Moles at no conversion</th><th>Moles after conversion</th></tr>
<tr><td>A= 1 mole
Inert= 1 mole</td><td>R= 3 moles
Inert=1 mole</td></tr>
</table>
</td><td>
2

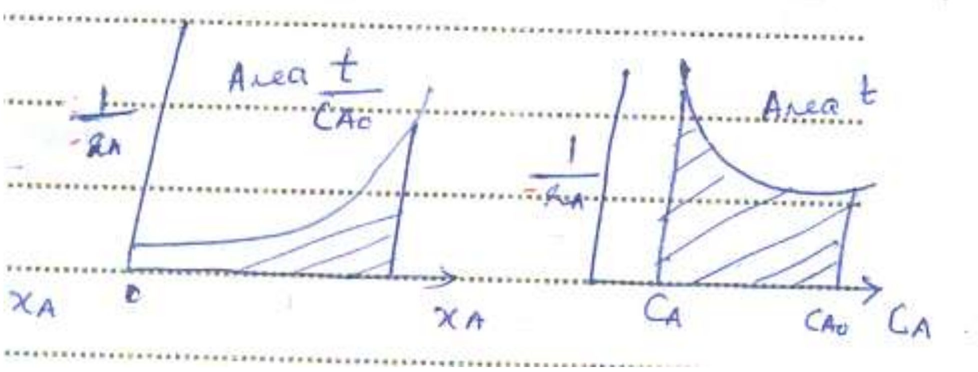
2</td></tr>
</table>

	$\epsilon_A = (V_{XA=1} - V_{XA=0}) / V_{XA=0} = [(3+1) - (1+1)] / (1+1) = \mathbf{1}$	
1A-d	**Space time:** It is the time required to process one reactor volume of feed measured at specified condition. **Mathematical expression and unit** $\tau = \frac{1}{s} = \frac{C_{A0}V}{F_{A0}}$ Unit is unit of time (seconds, minute, etc) **Space velocity** It is the number of reactor volume of feed at specified conditions which can be treated in unit time. **Mathematical expression and unit** **S** = $\boldsymbol{\frac{1}{\tau} = \frac{F_{A0}}{C_{A0}V}}$ Unit is $time^{-1}$ ($second^{-1}$, $minute^{-1}$ etc)	1 1 1 1
1B	**Attempt any ONE of the following**	6
1B-a	**Integrated form of rate expression for zero order reaction** Rate equation is $-r_A = -\frac{dC_A}{dt} = C_{A0}\frac{d_{xA}}{dt} = k$ **In terms of concentration** $-\frac{dC_A}{dt} = k$ Integrating between appropriate limits $\int_{CA_0}^{CA} -dCA = k\int_0^t dt$ $C_{A0} - C_A = kt$ for $t < \frac{C_{A0}}{k}$	2

	 **In terms of fractional conversion** $C_{A0}\frac{dx_A}{dt} = k$ Integrating between appropriate limits $C_{A0}\int_0^{xA} dx_A = k\int_0^t dt$ $C_{A0} X_A = kt$ for $t < \frac{C_{A0}}{k}$ 	1 2 1
1B-b	$T_1 = 500^0C = 773$ K $T_2 = 650^0C = 923$ K $E = 300$ KJ/ mole $= 300\times10^3$ J /mole From Arrhenius law $\ln\frac{k_2}{k_1} = \frac{-E}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) = (-300\times10^3 / 8.314) \times \left(\frac{1}{923} - \frac{1}{773}\right)$	2

	$\ln\frac{k_2}{k_1} = 7.586$ $\frac{k_2}{k_1}$ = **1970.4** **The reaction at 650^{0}C is 1970 times faster than the reaction at 500^{0}C.**	2 2
2	**Attempt any TWO of the following**	**16**
2-a	**Temperature dependency of rate constant from transition state theory**: Reactants combine to form unstable intermediates called activated complex which then decompose spontaneously into products. An equilibrium exists between the concentration of reactants and activated complex at all times and the rate of decomposition of the complex is the same for all reactions and is given by kT / h where k is Boltzmann constant and h is Planck constant. Consider the reversible reaction $A + B \leftrightarrow AB$, k_1 is the rate constant for forward reaction and k_2 is the rate constant for backward reaction According to transition theory, $A + B \underset{k_4}{\overset{k_3}{\leftrightarrow}} AB^* \xrightarrow[k_5]{} AB$ $K_c = k_3 / k_4 = C_{AB}^* / C_A.C_B$ $K_5 = kT/h$ $r_{AB,forward}$= (concentration of activated complex) . (rate of decomposition of activated complex) $= C_{AB}^* . (kT / h)$ $= (kT / h) . K_c. C_A. C_B$ From thermodynamics, $\Delta G = \Delta H - T\Delta S = - RT \ln K_c$ $\ln K_c = - (\Delta G / RT)$ $K_c = e^{-(\Delta G / RT)} = e^{-(\Delta H/ RT) + \Delta S/ R}$ $r_{AB,forward} = (kT / h).C_A. C_B . e^{-(\Delta H/ RT) + \Delta S/ R}$ $= \text{a constant} . T. e^{-(\Delta H/ RT)} C_A. C_B = k C_A. C_B$	2 3

	where k = a constant . T. $e^{-(\Delta H/RT)}$ $e^{\Delta S/R}$ is less temperature sensitive compared to the other terms so that it can be taken as constant. For forward reaction, $k_1 \alpha T e^{-(\Delta H_1/RT)}$ For backward reaction, $k_2 \alpha T e^{-(\Delta H_2/RT)}$ For relating ΔH and Arrhenius activation energy, analogy from thermodynamics is used. $E = \Delta H - RT$ for liquids and solids $E = \Delta H - (\text{molecularity} - 1) RT$ for gases The difference between E and ΔH is small and of the order RT. Hence transition theory predicts that $K \alpha T e^{-(E/RT)}$	3
2-b	**Performance equation for constant volume batch reactor with first order kinetics**  Writing the material balance for any component A. Rate of reactant A in = Rate of reactant A out + Rate of loss of reactant A due to chemical reaction + Rate of accumulation of reactant A within the reactor. In a batch reactor, no fluid enters or leaves the reaction mixture during the reaction. Therefore Rate of reactant A in = Rate of reactant A out = 0 Material balance equation then becomes	

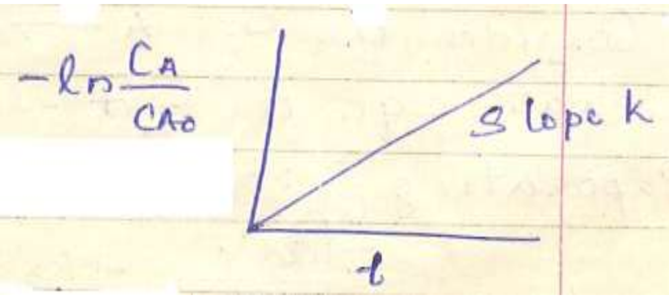
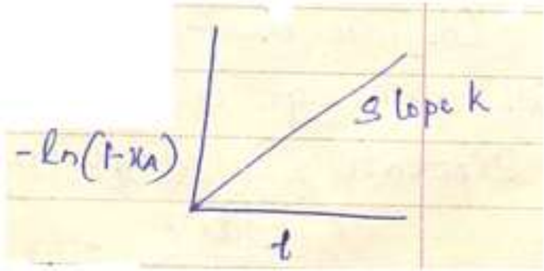
	Rate of loss of reactant A due to chemical reaction = - Rate of accumulation of reactant A within the reactor-------(1) Rate of loss of reactant A due to chemical reaction = $-r_AV$	2
	Rate of accumulation of reactant A within the reactor = $\frac{dN_A}{dt}$ = - $N_{A0}\frac{dX_A}{dt}$ Substituting in equation (1) $-r_AV = N_{A0}\frac{dX_A}{dt}$ Rearranging and integrating $\int_0^t dt = N_{A0}\int_0^{x_A}\frac{dx_A}{V\,(-r_{A})}$ $t = N_{A0}\int_0^{x_A}\frac{dx_A}{V\,(-r_{A})}$	2
	For constant volume system, the equation becomes $t = \frac{N_{A0}}{V}\int_0^{x_A}\frac{dx_A}{(-r_{A})} = C_{A0}\int_0^{x_A}\frac{dx_A}{(-r_{A})} = -\int_{CA0}^{C_A}\frac{dC_A}{(-r_{A})}$	2
	Graphical representation for constant volume batch reactor 	2
2-c	**Methods of catalyst Preparation:** 1. Precipitation 2. Gel formation 3. Simple mixing 4. Impregnation method **1.Precipitation method** :	

	This method produces catalyst in porous form. It consists of adding a precipitating agent to the solution of the desired component. The precipitation is followed by washing, drying, calcinations & activation(or pretreatment) Eg. Magnesium oxide catalyst is prepared by this method. It is prepared by precipitating $MgCO_3$ from magnesium nitrate solution by adding sodium carbonate. The magnesium carbonate precipitate is washed, dried & calcined to obtain magnesium oxide. **2.Gel formation:** If the precipitate formed in the above method is colloidal, then gel is formed. Eg Catalyst containing silica and alumina are suitable for gel formation because their precipitates are colloidal in nature. **3. Simple mixing:** Some porous materials are obtained by mixing the components with water, milling to the desired grain size, drying and calcining. Such materials may be ground and sieved to obtain the particle size. Eg Mixed Mg and Ca oxide catalyst is prepared by this method **4. Impregnation method:** This method is used for the preparation of expensive catalysts like platinum, palladium, silver etc. A catalyst carrier provides a means of obtaining a large surface area with a small amount of catalyst. The steps in the preparation of a catalyst impregnated on a carrier include evacuating the carrier, contacting the carrier with the impregnating solution, removing the excess solution, drying, calcining and activation. Eg Nickel catalyst is prepared on alumina by soaking the evacuated alumina particles with nickel nitrate solution, draining to remove the excess solution and heating in an oven to decompose the nitrate to nickel oxide. The final step is activation in which nickel oxide is reduced to nickel. ***Any other appropriate preparation method should also be given due***	2 marks each for explaining the methods with eg

	consideration	
3	**Attempt any FOUR of the following**	**16**
3-a	Number of moles (n)= 10 / 4 =2.5 P_1 = 3 atm P_2 15 atm T = 100^0C $\Delta S = nC_p \ln\frac{T_2}{T_1} + nR\ln\frac{P_1}{P_2}$ For isothermal operation, $\Delta S = nR\ln\frac{P_1}{P_2}$ ΔS = 2.5 x 1.987 x ln (3/ 15) = **-7.994 cal / K**	2 2
3-b	A → Products Rate equation is $-r_A = -\frac{dC_A}{dt} = k\, C_A^n$ Rearranging $\frac{-dC_A}{C_A^n} = k\,dt$ Integrating between appropriate limits $-\int_{C_{Ao}}^{C_A}\frac{dC_A}{C_A^n} = k\int_0^t dt$ $C_A^{1-n} - C_{Ao}^{1-n}$ = (n-1) kt where n is not equal to 1	2 2
3-c	**Temperature increase is not desirable for exothermic reaction.** Van't Hoff equation is $\frac{d\ln K}{dT} = \frac{\Delta H}{RT^2}$ For exothermic reaction, ΔH is negative. When temperature is increased, dT is positive; the overall equation is negative, which means ln K is negative. When ln K is negative, the value of K is low which denotes lower concentration of products. Therefore temperature increase is not desirable for exothermic reaction.	4

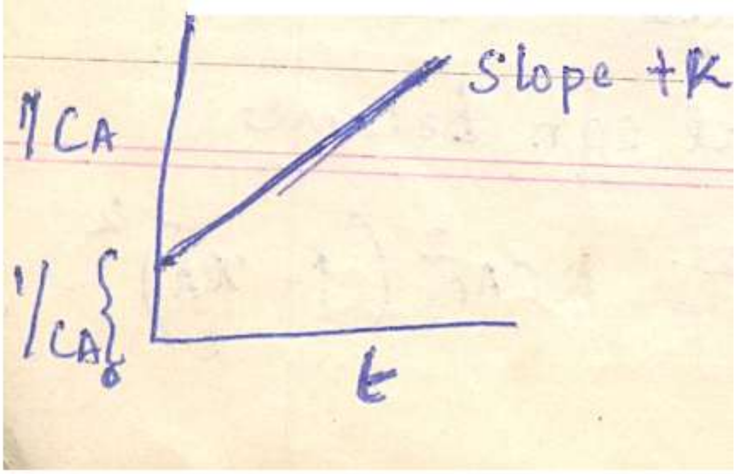
<table>
<tr><td>3-d</td><td>Difference between order and molecularity of reaction.(4 points)
<table>
<tr><th>Sr.No.</th><th>Molecularity</th><th>Order of reaction</th></tr>
<tr><td>1</td><td>Molecularity is the number of molecules, atoms or ions in a chemical reaction.</td><td>Order of reaction is the sum of exponents of the concentration terms involved in the rate equation.</td></tr>
<tr><td>2</td><td>Molecularity always have an integer value 1,2,3…</td><td>Order of reaction can have a fractional value.</td></tr>
<tr><td>3</td><td>Shows the elementary mechanism or separate steps of a complicated process</td><td>Shows the kinetic dependence of the rate on the concentration of the reactants.</td></tr>
<tr><td>4</td><td>Depending upon the value of molecularity, reaction can be unimolecular ,bimolecular etc.</td><td>Depending upon the value of order, the reactions are termed as first order, second order reactions</td></tr>
<tr><td>5</td><td>Molecularity is a theoretical quantity</td><td>Order of reaction is entirely an experimental value.</td></tr>
</table></td><td>1 mark each</td></tr>
<tr><td>3-e</td><td>Types of catalyst deactivation
1. Deactivation by Fouling
2. Chemical Deactivation - Poisoning
3. Deactivation by Thermal Degradation and Sintering</td><td>1</td></tr>
</table>

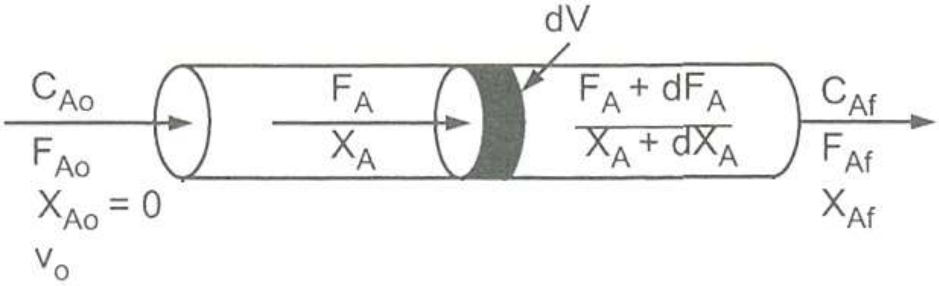
	Description: **Deactivation by Fouling** Generally fouling covers all phenomena where the surface is covered with a deposit. The most widely known form of fouling of catalysts is coke formation. Most of coke formation arises as a result of carbonaceous residues covering the active sites of a heterogeneous catalyst surface, subsequently decreasing the active surface area of the catalyst. In addition the deposition of rust and scale from elsewhere in the catalytic system is not uncommon. Coke-forming processes also involve chemisorption of different kinds of carbons or condensed hydrocarbons that may act as catalyst poisons causing the chemical deactivation of the catalyst. Eg. The fouling of zeolite catalysts occurs in the form of coke molecules limiting the access of the reactant hexane to the active sites of catalyst. ***Due consideration should be given to any other method of catalyst deactivation***	3
4A	**Attempt any THREE of the following**	**12**
4-A-a	For second order reaction: $k = \frac{1}{t}\left[\frac{1}{C_A} - \frac{1}{C_{A0}}\right]$ t = 50 min $C_{A0} = 5*10^{-4}$ mol/l $X_A = 40\% = 0.4$ $C_A = C_{A0}(1 - X_A) = 5x10^{-4}$ x(1- 0.4) = $3*10^{-4}$ mol/l $k = \frac{1}{50}\left[\frac{1}{3*10^{-4}} - \frac{1}{5*10^{-4}}\right]$ k = **26.67 l / (mol.min)**	2 2
4A-b	**Fluidized bed reactor:** **Merits:**	1 mark

	1. Good temperature control 2. Can use small size catalyst particles 3. Regeneration is easily done without shut down of the reactor. **Demerits:** 1. Effective contacting require large amount of catalyst for high gas conversion 2. Catalyst loss is there. So recovery units are required.	each for any two points 1 mark each
4A-c	**Graphical representation of integrated rate equation for first order reaction** **(i) In terms of concentration**  **(i) In terms of conversion** 	2 2
4A-d	**Relation between Gibb's free energy (ΔG^0) and equilibrium constant** K_p Consider the reaction $aA + bB \rightarrow rR + sS$ ΔG reaction = ΔG product - Δ G reactant.	

	$= (r\,\mu_R + s\,\mu_S) - (a\,\mu_A + b\,\mu_B)$. At equilibrium there is no Gibb's free energy change, $\Delta G = 0$ $(r\,\mu_R + s\,\mu_S) - (a\,\mu_A + b\,\mu_B) = 0$ $(r\,\mu_R + s\,\mu_S) = (a\,\mu_A + b\,\mu_B)$ But $\mu_i = \mu_i^0 + RT\ln p_i$ Therefore $r(\mu_R^0 + RT\ln p_R) + s(\mu_S^0 + RT\ln p_S) = a(\mu_A^0 + RT\ln p_A) + b(\mu_B^0 + RT\ln p_B)$ $RT\ln\left(\frac{p_R^r\,p_S^s}{p_A^a\,p_B^b}\right) = (a\,\mu_A^0 + b\,\mu_B^0) - (r\,\mu_R^0 + s\,\mu_S^0)$ $= -(\Delta G \text{ product} - \Delta G \text{ reactant})$ $= -\Delta G \text{ reaction}$. $\ln\left(\frac{p_R^r\,p_S^s}{p_A^a\,p_B^b}\right) = \frac{-\Delta G \text{ reaction}}{RT}$ But $\left(\frac{p_R^r\,p_S^s}{p_A^a\,p_B^b}\right) = K_p$ Therefore $\Delta G = -RT\ln K_p$	2 2
4B	**Attempt any ONE of the following**	**6**
4B-a	$-r_A = 0.005C_A^2$ (mol / cm^3.min) Ie $-r_A = kC_A^2$ In the above equation, concentration is expressed in mol / cm^3 and time in minutes Unit of k = unit of $-r_A$ / Unit of C_A^2 When concentration is expressed in mol /l and time in hours, Value of rate constant is 0.005 x 60 / 1000 = **3 x 10^{-4}** Unit of rate constant is **l / (mol.hr)**	3 3
4B-b	**Van't Hoff equation:** Consider the reaction $aA + bB \rightarrow rR + sS$ $\Delta G^0 = -RT\ln K$….. (1) $\Delta G^0 = (r\mu R + s\,\mu s) - (a\,\mu A + b\,\mu B)$……(2)	2

	From 1 and 2 $-RT\ln K = (r\mu R + s\,\mu s) - (a\,\mu A + b\,\mu B)$ Differentiating with respect to T at constant pressure $\frac{d}{dT}\ln k = -(1/R)\left(\left(r\,\frac{\partial}{\partial T}\,\mu R/T + s\,\frac{\partial}{\partial T}\,\mu s/T\right) - \left(a\,\frac{\partial}{\partial T}\,\mu A/T + b\,\frac{\partial}{\partial T}\,\mu b/T\right)\right)$ Gibb's Helmholtz equation is a $\frac{\partial}{\partial T}(\mu i/T) = -Hi/RT^2$ ie $\frac{d}{dT}\ln k = (1/RT^2)\{[rH_R + sH_s] - [aH_A + bH_B]\}$ $= (1/RT^2)(\Sigma H^0_{product} - \Sigma H^0_{reactant})$ $\frac{d}{dT}\ln k = \Delta H^0/RT^2$ is the Van't Hoff equation where ΔH^0 is molal enthalpy	2 2
5	**Attempt any TWO of the following**	**16**
5-a	**Derivation:** 2A → product **In terms of concentration** The rate of reaction is expressed in terms of rate of disappearance of reactant A. $-r_A = -dC_A/dt = kC_A^2$ Rearranging $\frac{-dC_A}{C_A^2} = kdt$ Integrating between appropriate limits $-\int_{C_{A0}}^{C_A}\frac{dC_A}{C_A^2} = k\int_0^t dt$ $-[-C_A^{-1}]_{C_{A0}}^{C_A} = kt$ $\left[\frac{1}{C_A} - \frac{1}{C_{A0}}\right] = kt$ The above equation is the integrated rate equation for second order reaction in terms of concentration. **Graphical representation:**	2 3

	 The plot of $\frac{1}{C_A}$ Vs time t yields a straight line with a slope equal to value of rate constant k and an intercept equal to $\frac{1}{C_{A0}}$	3
5-b	**Given:** X_A =0.70 ,t = 13 min For batch reactor, in which first order chemical reaction is taking place $-r_A = k.C_A$ $-\ln(1 - X_A) = kt$ $-\ln(1-0.70) = k * 13$ $k = 0.0926\ min^{-1}$ **For Plug flow reactor** (constant –density system): $\frac{V}{F_{A0}} = \int_0^{X_A} \frac{dX_A}{-r_A} = \frac{\tau}{C_{A0}}$ $\tau = C_{A0} \int_0^{X_A} \frac{dX_A}{k.C_{A0}.(1-X_A)}$ $\tau = \int_0^{X_A} \frac{dX_A}{k.(1-X_A)}$ Space time $\tau = \frac{1}{k}(-\ln(1-X_A))$ = $\frac{1}{0.0926}(-\ln(1-0.7))$ = **13 *min*.** Space velocity = s = 1/ τ **= 1/13 = 0.07692 min^{-1}** **For Mixed flow reactor** :	2 1 1

	$\tau = \frac{C_{A0}.X_A}{(-r_A)}$ $\tau = \frac{C_{A0}.X_A}{-r_A} = \frac{C_{A0}.X_A}{kC_{A0}(1-X_A)}$ **Space time** $\tau = \frac{0.70}{0.0926(1-0.7)}$ **= 25.2 min.** **Space velocity = s = 1/** τ **= 1/25.2 = 0.03968 min**$^{-1}$	2 1 1
5-c	**Derivation of performance equation for PFR** In PFR, the composition of the fluid varies from point to point along the flow path. So the material balance for a reaction component must be made for a differential element of volume dV.  Taking material balance of reactant A over the reactor, Input of A to reactor = Output of A from reactor + Disappearance of A due to chemical reaction + Accumulation of A within the reactor. For plug flow reactor, the last term is zero. Input of A to reactor = Output of A from reactor + Disappearance of A due to chemical reaction …………….(1) Let, F_{A0} = Molar feed rate to the reactor. C_{A0} = Molar concentration of A in stream entering the reactor (moles/volume)	1

X_A = Fractional conversion of A

$F_A = F_{A0}(1 - X_A) = F_{A0} - F_{A0}.X_A$

$dF_A = - F_{A0}.dX_A$

For the differential volume dV

Input of A in moles/time = F_A

Output of A from reactor in moles/time = $F_A + dF_A$ 2

Disappearance of A due to chemical reaction in moles/ time = $(-r_A)\,dV$

Substituting all the terms in the material balance equation (1)

$F_A = F_A + dF_A + (-r_A).dV$

$- dF_A = (-r_A)\,dV$

$F_{A0}.dX_A = (-r_A)\,dV$

$$\frac{dV}{F_{A0}} = \frac{dX_A}{-r_A}$$

This is the equation accounting for A in the differential section of the reactor of volume dV. For the whole reactor, the equation must be integrated.

$$\int_0^V \frac{dV}{F_{A0}} = \int_0^{x_A} \frac{dX_A}{-r_A}$$ 3

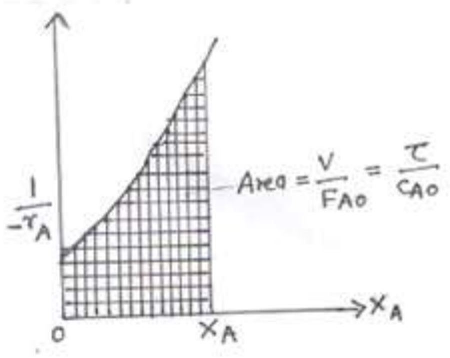
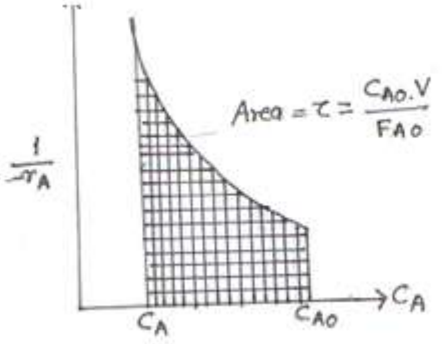
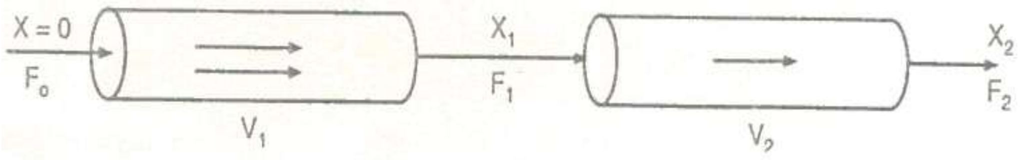
$$\frac{V}{F_{A0}} = \int_0^{x_A} \frac{dX_A}{-r_A} = \frac{\tau}{C_{A0}}$$

Where X_A and $(-r_A)$ are evaluated at the exit conditions

For constant volume system :

$$\frac{V}{F_{A0}} = \int_0^{x_A} \frac{dX_A}{-r_A} = \frac{\tau}{C_{A0}} = \frac{-1}{C_{AO}} \int_{C_{Ao}}^{C_A} \frac{dC_A}{-r_A}$$

Graphicalrepresentation

	 	2
6	**Attempt any FOUR of the following**	**16**
6-a	**Plug flow reactors are not connected in series** : Assume two PFRs are placed in series as shown below Let X_1 & X_2 be the fractional conversions of a component A leaving reactors 1 &2 .  X_1 : conversion of A from first reactor X_2 : overall conversion of A from entire system The performance equation for PFR1 is $\frac{V_1}{F_0} = \int_0^{X_1} \frac{dX}{(-r)}$ The performance equation for PFR2 is $\frac{V_2}{F_0} = \int_{X_1}^{X_2} \frac{dX}{(-r)}$ Two PFRS in series $\frac{V}{F_0} = \frac{V_1}{F_0} + \frac{V_2}{F_0} = \int_0^{X_1} \frac{dX}{(-r)} + \int_{X_1}^{X_2} \frac{dX}{(-r)}$ EqI From eqI, it is clear that the total volume of two PFRs in series is identical to that of one PFR (single reactor) for the same conversion. If the total volume of two PFRs in series is V= $V_1 + V_2$ for X_2,then the same conversion (X_2) can be	2 2

	achieved using one PFR of volume Thus it makes no difference if two PFRs are connected in series or one PFR of same reactor volume.	
6-b	**Relation between K_p and K_c** Consider the reaction aA +bB + …. → rR + sS……. $K_c = (C_R^r \,.\, C_S^s) / (C_A^a \,.\, C_B^b)$ For ideal gas $C_i = p_i / RT$ Therefore $K_c = \{(p_R / RT)^r \,.\, (p_S / RT)^s\} / \{ (p_A / RT)^a \,.\, (p_B / RT)^b\}$ $= (p_R^r \,.\, p_S^s) / (p_A^a \,.\, p_B^b) \,.\, (1 / RT)^{(r + s + \ldots -(a+b=\ldots))}$ R is the ideal gas constant T the absolute temperature in K P is the pressure in atm ie$K_c = K_p \,.\, (1 / RT)^{\Delta n}$ where $K_p = (p_R^r \,.\, p_S^s) / (p_A^a \,.\, p_B^b)$ $\Delta n = (r + s + \ldots -(a + b +\ldots))$is the difference in the number of moles of product and reactant **Or $K_p = K_c \times (RT)^{\Delta n}$**	2 2
6-c	**Factors affecting the rate of a chemical reaction** : 1. In **homogeneous system** temperature, pressure and composition are the variables. 2. In **heterogeneous system**, since more than one phase is involved, material have to move from phase to phase during reaction, hence the rate of mass transfer is important. 1. rate of heat transfer 2. Catalyst 3. Nature of reactants 4. Surface area available. 5. Intensity of light if reaction is light sensitive.	1 mark each for any 4 points.
6-d	**General procedure for analysis of complete rate equation by integral**	

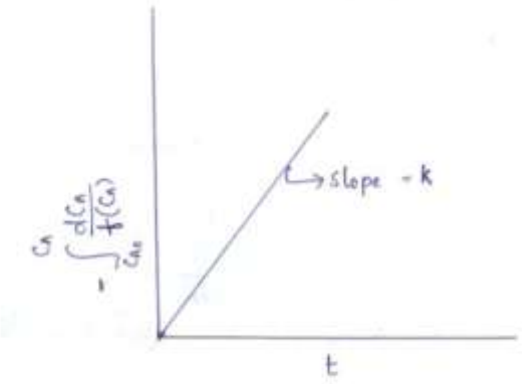
method

The procedure for integral method of analysis is as follows :

1. In a constant volume system , the rate expression for the disappearance of reactant A will be of the following form
   $-r_A = -dC_A / dt = kf(c)$
2. Rate equation is rearranged as
   $-dC_A / f(c) = kdt$
   f(c) involves the concentration of materials which may be expressed in terms of C_A
3. Above equation is integrated with appropriate limits
   $$-\int_{C_{A0}}^{C_A} (dC_A / f(c)) = k \int_{0}^{t} dt$$
4. The concentration function is proportional to time, so a plot of concentration vs time gives a straight line of slope k for this particular rate equation.
5. From experiment, determine the numerical value for the above integral and plot these at the corresponding time.
6. If the data fall on a reasonable straight line, then it may said that the particular rate equation being tested satisfactorily fits the data. If the data are being fitted by a curve, the rate equation and mechanism are rejected and another rate equation is tried.

3

Graph:

		1
6-e	**Batch reactor** **Advantages:** 1. Simple in construction & operation 2. Low equipment cost 3. Gives highest conversion by leaving the reactants for longer periods in reactor. 4. Requires small instrumentation & less supporting equipment. **Disadvantages:** 1. High labor costs per unit volume of production. 2. Requires considerable time to empty, clean out & refill. 3. Poorer quality control of product. 4. Large scale production is difficult.	1 mark each for any two points 1 mark each for any two points