$$A + D \longrightarrow R, \quad (-r_A) = 21\, C_A C_D$$
$$B + D \longrightarrow S, \quad (-r_B) = 147\, C_B C_D$$

Assuming that the reactions go to completion, how much D need be added to a batch of mixture to bring about the desired quality.

(b) For the elementary reactions

$$\begin{tikzcd} A \arrow[r, "k_1"] \arrow[d] & R \arrow[r, "k_2"] & S \\ T & & \end{tikzcd}$$

Show for plug flow that

$$\frac{C_{R\max}}{C_{A0}} = \frac{k_1}{k_1+k_3}\left(\frac{k_2}{k_1+k_3}\right)^{k_2/(k_1-k_2+k_3)} \text{ at } \tau_{opt} = \ln[(k_1+k_3)/k_2]/(k_1-k_2+k_3).$$

6 + 6=12

7. (a) The catalytic reaction $A \rightarrow 4R$ is run at 3.2 atm and 117°C in a plug flow reactor which contains 0.01 kg of catalyst and uses a feed consisting of the partially converted product of 20 liters/hr of pure unreacted A. The results are as follows:

Run	1	2	3	4
C_{Ain}, mol/liter	0.100	0.080	0.060	0.040
C_{Aout}, mol/liter	0.084	0.070	0.055	0.038

Find a rate equation to represent this reaction.

(b) Show that for a chemical reaction under strong pore diffusion regime the observed activation energy is half of the actual value.

6 + 6 = 12

Group – E

8. (a) What do you mean by dead zone of a reactor?

(b) Determine mean conversion in a PFR following Segregation model.

3 + 9 = 12

9. (a) A sample of the tracer hytane at 320K was injected as a pulse to a reactor, and the effluent concentration was measured as a function of time, as per the data shown in the following table.

t (min)	0	1	2	3	4	5	6	7	8	9	10	12	14	17	20	23
C (g/m³)	0	1	5	8	10	12	11	9	8	6.5	5	3.0	2.2	1.5	0.6	0

(b) Construct figures showing C(t) and E(t) as functions of time. Determine the fraction of material leaving the reactor that has resided between 8 and 17 minutes.

8 + 4 = 12

CHEMICAL REACTION ENGINEERING (CHEN 3102)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and <u>any 5 (five)</u> from Group B to E, taking <u>at least one</u> from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) For the reaction SO_2 + ½ O_2 = SO_3 carried out in presence of V_2O_5 catalyst, the reaction:
(a) is considered as homogeneous
(b) is considered as heterogeneous
(c) may be either homogeneous or heterogeneous
(d) none of the above.

(ii) For a reaction rate $(-r_A) = kC^n$, the units of k are
(a) time $^{-1}$ (b) (concentration)$^{(1-n)}$(time)$^{-1}$
(c) (concentration)$^{(1-n)}$(time) (d) (concentration)$^{(n-1)}$(time)$^{-1}$

(iii) A catalyst
(a) initiates a reaction
(b) lowers the activation energy of reacting molecules
(c) is capable of reacting with any one of the reactants
(d) cannot be recovered at the end of a chemical reaction.

(iv) Identify the name of the Dimensionless group which is not associated with Residence Time Distribution Studies
(a) Bodenstein number (b) Mach Number
(c) Damköhler number (d) Peclet Number.

(v) Under strong pore diffusion regime a nth-order reaction behaves like a
(a) $(n + 1)$ order reaction (b) $\frac{(n+1)}{2}$ order reaction
(c) $\frac{(n-1)}{2}$ order reaction (d) none of the above.

(vi) For reaction under pore diffusion regime, the reaction rate:
(a) varies directly with catalyst particle size
(b) varies inversely with catalyst particle size
(c) is independent of catalyst particle size
(d) none of the above.

(vii) The third moment of RTD refers to
(a) mean residence time (b) variance
(c) skewness (d) space time.

(viii) For a gaseous reaction A + B = R with 30% A,60% B and 10% inert, the volume expansion factor (ε_A) is equal to
(a) -1 (b) 1 (c) -0.3 (d) -0.7.

(ix) A second order reaction requires two equal sized mixed flow reactors. The conversion is
(a) less when they are connected in series.
(b) more when they are connected in series
(c) more when they are connected in parallel
(d) same whether they are connected in series or parallel.

(x) For RTD in Open-open system, when the extent of dispersion becomes same as mean residence time, the value of Peclet number would be close to order of
(a) zero (b) infinity (c) unity (d) two.

Group – B

2. (a) At 500 K the rate of a bimolecular reaction is ten times the rate at 400 K. Find the activation energy of this reaction:
(i) From Arrhenius' law
(ii) From collision theory
(iii) What is the percentage difference in rate of reaction at 600 K predicted by these two methods?

(b) Show that the following scheme

$N_2O_5 \rightleftharpoons NO_2 + NO_3^*$
$NO_3^* \rightarrow NO^* + O_2$
$NO^* + NO_3^* \rightarrow 2\,NO_2$

is consistent with and can explain the observed first order decomposition of N_2O_5.

8 + 4 = 12

3. (a) Prove that for a 2nd order irreversible bimolecular reaction, $A+2B \rightarrow$ Products $\ln\left(\frac{M-2X_A}{M(1-X_A)}\right) = C_{A0}(M-2)kt$ where, $M = C_{B0}/C_{A0}$ & M# 2
(Symbols stand for usual notations).

(b) For the reactions in series, $A \xrightarrow{k_1} R \xrightarrow{k_2} S$, $k_1 = k_2$ (batch reactor)
Find the maximum concentration of R and the time when it is reached.

6 + 6 = 12

Group – C

4. (a) Deduce the performance equation of a recycle reactor.

(b) A daily production of 50 tonnes of ethyl acetate from alcohol and acetic acid is required. The reaction proceeds according to

$C_2H_5OH\ (A) + CH_3COOH\ (B) \rightleftharpoons CH_3COOC_2H_5\ (P) + H_2O\ (Q)$

The reaction rate in the liquid phase at 100^{0}C is
$(-r_A) = k\,(C_AC_B - C_PC_Q / K)$, where, $k = 7.93 \times 10^{-6}$ m^3/ kmol.s and K = 2.93
The feed solution contains 23 wt% of acid, 46 wt% of alcohol and no ester. The required conversion of acid is 35%. The density may be assumed to have a constant value 1020 kg / m^3. The plant must be operated day and night and times for filling, emptying and cleaning operation of a reactor is 1 hour. What would be the required reactor volume if one batch reactor vessel is used?

7 + 5 = 12

5. (a) The elementary irreversible aqueous-phase reaction A + B → 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 rnol 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.

(b) Styrene (A) and butadiene (B) are to be reacted in a series of MFRs each 26.5 m^3 capacity. The initial concentrations are C_{A0} = 0.795 and C_{B0} = 3.55 kmol /m^3. Feed rate is 20 m^3/ hr. The rate equation is $(-r_A) = 0.036C_AC_B$ kmol /m^3 hr. Find the number of tanks needed to effect 90% conversion of the limiting reactant. The reaction is A + B → product.

6 + 6 = 12

Group – D

6. (a) We have a mixture consisting of 90 mol% A (45 mol/liter) and 10 mol% impurity B (5 mol/liter). To be of satisfactory quality the mol ratio of A to B in the mixture must be 100 to 1 or higher. D reacts with both A and B as follows: