# CHEMICAL REACTION ENGINEERING I
## (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 any 5 (five) from Group B to E, taking at least one 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 a homogeneous reaction, when the reactant at start is diluted ten times, the fractional conversion increases by a factor of ten at the same batch time under otherwise uniform conditions. What can you say about the order of the reaction?
(a) Zero order (b) First order
(c) Second Order (d) Third order

(ii) For a homogeneous irreversible reaction, the rate constant is inversely proportional to the half-life period. The order of the reaction is
(a) Zero (b) Half
(c) One (d) Two

(iii) A rule of thumb in Chemical Kinetics is that the rate of reaction doubles for 10K rise in temperature. At 300K, what value of activation energy does it imply? R = 8.314 $JK^{-1}$ $mol^{-1}$
(a) 8.2 KJ/mol (b) 18.9 KJ/mol
(c) 31.3 KJ/mol (d) 53.6 KJ/ mol

(iv) For the liquid phase zero order irreversible reaction A → B, the conversion of A in a CSTR is found to be 0.3 at a space velocity of 0.1min-1. What will be the conversion for a PFR with a space velocity of 0.2 min-1 ? Assume that all the other operating conditions are the same for CSTR and PFR
(a) 0.15 (b) 0.
(c) 0.60 (d) 0.30

(v) The gas phase reaction 2A → B is carried out in an isothermal plug flow reactor. The feed consists of 80 mole % A and 20 mole % inserts. If the conversion of *A* at the reactor exit is 50%, then $C_A$ / $C_{A0}$ at the outlet of the reactor is:
(a) 3/8 (b) 5/8
(c) 2/3 (d) 1/3

(vi) For identical flow rate, feed composition and for elementary first order reactions, 'n' equal sized MFR in series with a total volume of 'V' gives the same conversion as a single PFR of volume 'V' for constant density systems. This is true when the value of 'n' is

(a) 1 (b) 2

(c) 3 (d) Infinity

(vii) A space velocity 5 $hr^{-1}$ means

(a) Five reactor volumes of feed (at specified conditions) are being fed into the reactor per hour

(b) After every 5 hours, reactor is being filled with the feed

(c) Cent per cent conversion can be achieved in at least 5 hours

(d) A fixed conversion of a given batch of feed takes 5 hours

(viii) A batch reactor is characterised by

(a) Variation in extent of reaction with time

(b) Variation of composition at different position of the reactor

(c) non variation in extent of reaction with time

(d) none of the above

(ix) Stimulus-response techniques are commonly used to characterize the extent of non-ideal flow in vessels. Tracer input signal is used as stimulus. Any material can be used

(a) as tracer if it can disturb the flow pattern in the vessel

(b) as tracer if it does not disturb the flow pattern in the vessel and it can be detected.

(c) as tracer if it follows ideal flow patterns

(d) none of the above

(x) Reactor design

(a) Invariably relies on experimental determined rates

(b) Invariably relies on theoretical predicted rates

(c) Does not rely on theoretically predicted rates

(d) Both (a) and (c).

## Group- B

2\. (a) Define the terms Molecularity and Order in respect of a chemical reaction, citing appropriate example. [(CO1) (Remember/LOCQ)]

(b) A consecutive reaction $A \rightarrow B \rightarrow C$, both steps being first order with rate constants, k and k', respectively, in appropriate units, occurs in a batch reactor. Initially there is only A in the reactor. Write down the rate equations for reaction of A and for formation of B and solve the equations. [(CO1) (Remember/LOCQ)]

(c) Find the optimum batch time when the concentration of B becomes maximum. Interpret the result. [(CO1)(Remember/LOCQ)]

**4 + 4 + 4 = 12**

3. (a) Why is Arrhenius Law important in Chemical Kinetics? What is its form? Explain the usual notations in the Arrhenius Law and state their units.
[(CO1) (Understand/LOCQ)]

(b) In a gas-phase dissociation reaction, A → R + S taking place at constant temperature and pressure, the following data are reported:

| Time in second | 0 | 30 | 90 | 120 | 180 | 240 | 360 |
|---|---|---|---|---|---|---|---|
| Volume $dm^3$ | 47 | 61 | 68 | 72 | 75 | 78.5 | 84 |

Find the order of the reaction and the rate constant. [(CO1) (Evaluate /HOCQ)]

**4 + 8 = 12**

## Group - C

4. (a) We are planning to operate a batch reactor to convert A into R. This is a liquid reaction, the stoichiometry is A = R, and the rate of reaction is given in the following table. How long must we react each batch for the concentration to drop from $C_A$ = 1.3 mol /liter to $C_{Af}$ = 0.3 mol / liter?
Data:

| $C_A$ mol /liter | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 1.0 | 1.3 |
|---|---|---|---|---|---|---|---|---|---|---|
| $-r_A$, mol / liter. min | 0.1 | 0.3 | 0.5 | 0.6 | 0.5 | 0.25 | 0.10 | 0.06 | 0.05 | 0.045 |

[(CO2) Evaluate(HOCQ]

(b) A high molecular weight hydrocarbon gas A is fed continuously to a heated high temperature mixed flow reactor where it thermally cracks (homogeneous gas reaction) into lower molecular weight materials, collectively called R, by a stoichiometry approximated by A -5R. By changing the feed rate different extents of cracking are obtained as follows:

| $F_{A0}$, millimol/hr | 300 | 1000 | 3000 | 5000 |
|---|---|---|---|---|
| $C_{Aout.}$ Millimol / liter | 16 | 30 | 50 | 60 |

The internal void volume of the reactor is V = 0.1 liter, and at the temperature of the reactor the feed concentration is $C_{A0}$ = 100 millimol/liter. Find a rate equation to represent the cracking reaction. [(CO2) (Analyze/IOCQ)]

**6 + 6 = 12**

5. (a) Deduce the performance equation of a plug flow reactor.
[(CO2) (Understand/LOCQ)]

(b) Show that the performance equation of a recycle reactor changes to that of a mixed flow reactor if the recycle ratio (R) tend to infinity.
(CO2) (Analyze/IOCQ)]

(c) The kinetics of the aqueous-phase decomposition of A is investigated in two mixed flow reactors in series, the second having twice the volume of the first reactor. At steady state with a feed concentration of 1 mol A/liter and mean residence time of 96 sec in the first reactor, the concentration in the first reactor is 0.5 rnol A/liter and in the second is 0.25 rnol A/liter. Find the kinetic equation for the decomposition. [(CO2)( Evaluate/HOCQ)]

**3 + 4 + 5 = 12**

## Group - D

6. (a) Substance A in a liquid reacts to produce R and S as follows:

$$A \nearrow R \text{ first order}$$
$$A \searrow S \text{ first order}$$

A feed ($C_{A0}$ = 1, $C_{R0}$ = 0, $C_{S0}$, = 0) enters two mixed flow reactors in series, ($\tau$, = *2.5* min, $\tau$, = *5* min). Knowing the composition in the first reactor ($C_{A1}$ = 0.4, $C_{R1}$ = 0.4, $C_{S1}$ = 0.2), find the composition leaving the second reactor.

[(CO3) (Analyze/IOCQ)]

(b) A and B react with each other as follows:

$2A \rightarrow R, \quad r_R = k_1 C_A^2$

$A + B \rightarrow S, \quad r_S = k_2 C_A C_B$

$2B \rightarrow T, \quad r_T = k_3 C_B^2$

What ratio of A and B should be maintained in a mixed flow reactor so as to maximize the fractional yield of desired product S?

[(CO3) (Evaluate/HOCQ)]

**6 + 6 = 12**

7. Chemical R is to be produced by the decomposition of A in a given mixed reactor. The reaction proceeds as follows:

$$A \rightarrow R, \quad r_R = k_1 C_A$$
$$2A \rightarrow S, \quad r_S = k_2 C_A^2$$

Let the molar cost ratio $\$_R/\$_A$ = M (S is waste material of no value), and for convenience let $k_1 = N k_2 C_{A0}$. In the feed $C_{A0}$ is fixed.

(a) Ignoring operating costs, find what conversion of A should be maintained in the reactor to maximize the gross earnings and therefore the profits.

(b) Repeat part (a) with the hourly operating cost dependent on feed rate and given by $\alpha + \beta F_{A0}$. [(CO3) (Analyze/IOCQ)] [(CO3) (Evaluate/HOCQ)]

**(6 + 6) = 12**

## Group – E

8. The concentration reading in the following table represents a continuous response to a delta function input into a closed vessel which is used as a chemical reactor.

| Time (t), min | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
|---|---|---|---|---|---|---|---|---|
| Tracer concentration, gm/L | 0 | 3 | 5 | 5 | 4 | 2 | 1 | 0 |

The vessel is to be used to carry out a first order liquid phase reaction A → R having rate constant (k) = 0.307 min-1. Find the fraction of reactant unconverted in this real reactor. [(CO4) (Analyze/IOCQ)]

**12**

9. (a) Define residence time, distribution function and discuss in detail how RTD can be determined from tracer experiment.

[(CO5) (Remember/LOCQ)]

(b) Derive the second order ordinary differential equation relating a nth. order chemical reaction with dispersion'. [(CO4) (Evaluate/HOCQ)]

**6 + 6= 12**

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| Cognition Level | LOCQ | IOCQ | HOCQ |
|---|---|---|---|
| Percentage distribution | 26.04 | 29.17 | 44.79 |

**Course Outcome (CO):**

After the completion of the course students will be able to

1. Determine rate equation of a chemical reaction from its kinetic experimental data.
2. Design a suitable reactor for a given chemical reaction.
3. Optimize the size and combination of chemical reactors in view to maximize yield and productivity of a material.
4. Compare the performance of ideal and non-ideal reactors using E(t) and F(t) curves.
5. Analyse a non-ideal reactor and predict conversion of a given chemical reaction.

*LOCQ: Lower Order Cognitive Question; IOCQ: Intermediate Order Cognitive Question; HOCQ: Higher Order Cognitive Question

| Department & Section | Submission Link |
|---|---|
| CHE | https://classroom.google.com/c/NDA0ODk0MTMzNTgz/a/NDYzODM2OTIxNTk2/details |