

**CHEMICAL REACTION ENGINEERING II  
(CHE3105)**

**Time Allotted : 2½ hrs**

**Full Marks : 60**

*Figures out of the right margin indicate full marks.*

*Candidates are required to answer Group A and  
any 4 (four) from Group B to E, taking one from each group.*

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

**Group – A**

1. Answer any twelve:

**12 × 1 = 12**

*Choose the correct alternative for the following*

- (i) In an autocatalytic reaction  $A + R \rightarrow R + R$ , the rate follows  
(a) a parabola with a maximum where concentration of A and R are equal  
(b) a parabola with a maximum where concentration of A is greater than R  
(c) a parabola with a maximum where concentration of R is greater than A  
(d) none of the above
- (ii) The catalyst  
(a) Can radically alter selectivity (b) Cannot alter selectivity  
(c) Can alter equilibrium conversion (d) None of the above
- (iii) Promoter is added to the catalyst to improve its  
(a) Porosity (b) Sensitivity  
(c) Surface area (d) None of these
- (iv) For the decomposition of cumene to benzene and propylene in the presence of a catalyst, if the adsorption of cumene is rate-limiting, the variation of the initial rate of reaction with the initial partial pressure of cumene is  
(a) linear (b) parabolic  
(c) exponential (d) hyperbolic
- (v) Pore diffusion offers negligible resistance for Thiele modulus  
(a) less than 1 (b) less than 0.4  
(c) greater than 1 (d) greater than 4
- (vi) In the regime of strong pore diffusion, a first order reaction  
(a) changes to 0 order (b) remains 1<sup>st</sup> order  
(c) becomes 1.5 order (d) becomes 2<sup>nd</sup> order
- (vii) The relation between fractional conversion ( $X_B$ ) of a spherical particle B with the radius of the shrinking core ( $r_c$ ) and the particle radius  $R$  is given as  
(a)  $X_B = 1 - \left(\frac{r_c}{R}\right)^3$  (b)  $X_B = 1 - \left(\frac{r_c}{R}\right)$  (c)  $X_B = 1 - \left(\frac{r_c}{R}\right)^2$  (d)  $X_B = \left(\frac{r_c}{R}\right)^3$

- (viii) As per the shrinking core model, the time of complete conversion of a spherical solid particle in reaction- controlled region  
 (a) is inversely proportional to the particle radius  
 (b) is directly proportional to the square of particle radius  
 (c) is inversely proportional to the square of the particle radius  
 (d) is directly proportional to the particle radius
- (ix) The major resistance/s observed in a slurry reactor is/are  
 (a) resistance to gas absorption and resistance to transport to the catalyst surface  
 (b) resistance to diffusion and reaction within the catalyst pellet  
 (c) Either (a) or (b)  
 (d) Both (a) and (b)
- (x) The two parameters in the real CSTR with bypass and dead space are  
 (a) ratio of bypass volumetric flowrate to the flowrate to CSTR, ratio of dead volume to total volume of the CSTR  
 (b) total volumetric flowrate including bypass and main reactor, total deadspace volume  
 (c) ratio of bypass volumetric flowrate to total flowrate, ratio of ideal CSTR volume to total volume of the CSTR  
 (d) bypass volumetric flowrate, ideal CSTR volume

*Fill in the blanks with the correct word*

- (xi) Catalytic action in a catalytic chemical reaction follows from the ability of catalyst to change the \_\_\_\_\_.
- (xii) Catalyst poisons \_\_\_\_\_ the activity of catalyst.
- (xiii) The Fischer-Tropsch synthesis of long-chain hydrocarbons in Sasol plant is carried out in \_\_\_\_\_.
- (xiv) The Thiele modulus in a cylindrical catalyst pore is expressed as \_\_\_\_\_.
- (xv) For particle sizes  $R_1$  and  $R_2$ , the ratio of reaction rates in the regime of strong pore diffusion resistance is \_\_\_\_\_.

### **Group - B**

2. (a) What do you understand by catalyst deactivation? Discuss in details different reasons for catalyst deactivation. [[CO3](Analyse/HOCQ)]  
 (b) Write a brief note on physical adsorption and chemisorptions and compare them in a tabular form. [[CO4](Remember/LOCQ)]
- 6 + 6 = 12**
3. Starting from the first principle, derive the Langmuir adsorption isotherm in terms of concentration. [[CO2](Apply/IOCQ)]

**12**

## Group - C

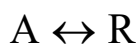
4. (a) Define (i) turnover frequency (ii) dispersion of a catalyst. [[CO2](Remember/LOCQ)]  
(b) The Fischer-Tropsch synthesis was studied using a commercial 0.5 wt% Ru on  $\gamma$ - $\text{Al}_2\text{O}_3$ . The catalyst dispersion percentage of atoms exposed, determined from hydrogen chemisorption, was found to be 49%. At a pressure of 988 kPa and a temperature of 475 K, a turnover frequency of  $0.044 \text{ s}^{-1}$  was reported for methane. What is the rate of formation of methane in mol/s. g of catalyst (metal + support)? Molecular weight of Ruthenium=101.1 g.  
$$\text{CO} + 3\text{H}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O}$$
[[CO2](Evaluate/HOCQ)]  
(c) Explain the different factors affecting the rate of reaction in a porous catalyst particle. [[CO2](Understand/IOCQ)]  
(d) Distinguish between homogenous and heterogeneous catalysis. Give examples of reactions involving both. [[CO2](Analyse/IOCQ)]  
**3 + 4 + 3 + 2 = 12**
5. (a) Consider a catalyst with a cylindrical pore of length L. Reactant A diffuses into the pore and undergoes a first-order reaction on the pore walls. Perform a steady state material balance for the reactant and derive the expression for concentration profile within the pore. Sketch the concentration profile within the pore. [[CO2](Analyse/IOCQ)]  
(b) Explain the significance of internal effectiveness factor. For pores of different geometries, sketch the variation of effectiveness factor with Thiele modulus. What can be concluded from the plot? [[CO4](Remember/LOCQ)]  
**(6 + 1) + (2 + 2 + 1) = 12**

## Group - D

6. (a) Explain the shrinking core model with the aid of a diagram. [[CO3](Remember/LOCQ)]  
(b) Derive the relation between reaction time, conversion and radius of the particle when diffusion through gas film controls in a non-catalytic fluid-solid reaction. [[CO3](Analyse/IOCQ)]  
(c) Discuss the industrially important fluid-solid non-catalytic reactions. Write the relevant reactions. [[CO3](Remember/IOCQ)]  
**4 + 5 + 3 = 12**
7. (a) Derive the relation between reaction time, conversion and radius of the particle when diffusion through ash layer controls in a non-catalytic fluid-solid reaction. [[CO3,CO6](Analyse/IOCQ)]  
(b) Calculate the time needed to burn to completion particles of graphite ( $R_0=5\text{mm}$ ,  $\rho_B=2.2 \text{ g/cc}$ ,  $k''=20 \text{ cm/s}$ ) in an 8%  $\text{O}_2$  stream. For the high gas velocity used assume that film diffusion does not offer any resistance to transfer and reaction. The reaction temperature is  $900^\circ\text{C}$ . [[CO3](Understand/LOCQ)]  
(c) Discuss the Progressive Conversion model (PCM) with a diagram. [[CO3,CO6](Remember/LOCQ)]  
**6 + 3 + 3 = 12**

## Group - E

8. (a) Explain with a diagram the working principle of an industrial slurry reactor used for conversion of syngas to hydrocarbon wax by Fischer-Tropsch synthesis. Discuss the various steps occurring during reaction in a slurry reactor and derive the rate expression. [[CO4,CO6](Understand/LOCQ)]
- (b) Methyl linoleate is to be converted to methyl oleate in a 2 m<sup>3</sup> slurry reactor. The molar feed rate of methyl linoleate to the reactor is 0.7 kmol/min. The partial pressure of H<sub>2</sub> is 6 atm and the reactor is considered to be well-mixed. Calculate the catalyst charge necessary to achieve 30% conversion for a 60 μm particle size if the resistance to gas absorption  $r_b$  is 0.08 min and overall resistance to internal, external diffusion and reaction for 80 μm particle size, is 0.28 min.kg/m<sup>3</sup>. The Henry's constant for hydrogen is 0.00233 mol H<sub>2</sub>/atm. dm<sup>3</sup>. [[CO4](Remember/LOCQ)]
- (3 + 4) + 5 = 12**
9. (a) For the elementary solid-catalyzed liquid phase reaction, plot the equilibrium conversion as a function of temperature. Determine the adiabatic equilibrium temperature and conversion when pure A is fed to the reactor at a temperature 300 K. (graph needed)



Data:  $H_A^0(298\text{ K}) = -40000\text{ cal/mol}$ ,  $H_B^0(298\text{ K}) = -60000\text{ cal/mol}$ ,  $C_{pA} = C_{pB} = 50\text{ cal/mol K}$ ,  $K = 100,000$  at 298 K. [[CO5](Analyse/HOCQ)]

- (b) A step tracer test is carried out in a CSTR with dead space and bypass. The tracer output of the reactor is presented in the Table below. The measured reactor volume is 1 m<sup>3</sup> and the flowrate to the reactor is 0.1 m<sup>3</sup>/min. Represent the CSTR with a schematic diagram and calculate the volumetric flowrate to the well-mixed portion of the reactor and the volume of the well-mixed region. Given: A positive step tracer input of 2000 mg/dm<sup>3</sup> applied to the CSTR (graph needed)

Tracer data

$C_T$ (mg/dm <sup>3</sup> )	1000	1333	1500	1666	1750	1800
t(min)	4	8	10	14	16	18

[[CO6](Apply/IOCQ)]

**7 + 5 = 12**

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	37.5	44.79	17.71