मोतीलाल नेहरू राष्ट्रीय प्रौद्योगिकी संस्थान इलाहाबाद
प्रयागराज–211004 भारत

Motilal Nehru National Institute of Technology Allahabad
Prayagraj-211004 [India]

DEPARTMENT OF CHEMICAL ENGINEERING
Mid Semester (Even) Examination 2023-24

Programme Name: B. Tech./~~M. Tech./MBA/M. Sc/MCA~~

Course Code: CHN 15111…………….. **Semester:** ….5th……….

Branch: Chemical Engineering……. **Course Name:** Heterogeneous Reaction Engineering……

Duration: 90 Minutes **Student Reg. No.:** 20222068

Max. Marks: 20

Instructions: (Related to Questions)
1. *Attempt all questions*
2. *Figures to the right indicate the full marks.*
3. *Symbols have their usual meanings*
4. *Assume missing data suitably, if any*
5. *Use of non-programmable scientific calculator is permitted*

		Marks	CO No.
Q 1	A first order reaction occurs in a reactor whose RTD is given in Fig. Q1 (c). Calculate the conversion for the flow schemes shown in the Figs. Q1(a & b). For simplicity take $C_0 = 1$, $k = 1$, and $\tau = 1$ for each unit.	(4) 2	1

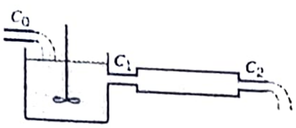

Fig. Q1(a): Microfluid, early mixing at molecular level,

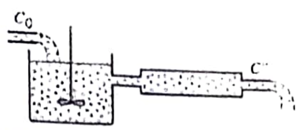

Fig. Q1(b): Macrofluid, early mixing of elements

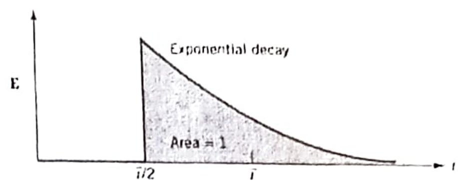

Fig. Q1(c)

		Marks	CO No.
Q 2	Calculate the time needed to burn to completion spherical particles of graphite (radius 12 mm, bulk density 2.4 gm/cm^3, surface reaction rate constant, k" = 20 cm/sec) in 12% oxygen stream at 900 ^{0}C and 1 atm. Assume gas film resistance to be negligible. Also calculate the remaining amount of graphite particles unburned and their radius after 1 hour.	(4) 3	2
Q 3	Hydrogen sulfide is removed from coal gas by passing the gas through a moving bed or iron oxide particles. In the coal gas environment (consider uniform) the solids are converted from Fe_2O_3 to FeS by the SCM/reaction control, $\tau = 2$ hr. Find the fractional conversion of oxide to iron sulfide if the RTD of solids in the reactor is approximated by the E curves of Fig. Q3.	(4)	2

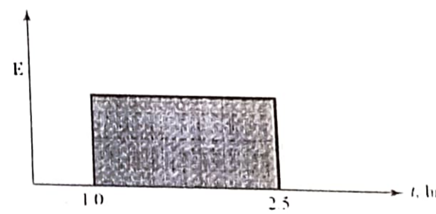

Fig. Q3

		Marks	CO No.
Q 4	Gaseous A absorbs and reacts with liquid phase reactant B in a packed bed according to following reaction:	(4)	2

$$A(g \to l) + B(l) \to R(l), \qquad -r_A = kC_AC_B$$

Calculate the rate of reaction in mol/hr.m^3 in reactor at a point in the reactor where p_A = 100 Pa and C_B = 100 mol/m^3.

Additional data: *$k_{Ag}a$ = 0.1 mol/hr .m^2 of reactor. Pa; $k_{Al}a$ = 100 m^3 liquid/m^3 reactor .hr; $D_{Al} = D_{Bl}$ = 1.0 × 10^{-6} m^2/hr H_A = 1000 Pa. m^3/mol; k = 10 m^3/mol.hr; a = 100 m^2/m^3; f_l = 0.01 m^3 liquid/m^3 reactor.;*

Q 5 Discuss ANY TWO of the following in detail: (2×2)

3

(a) Classification of chemical reactions on the basis of phases with appropriate examples 1

(b) Role of Hatta Number and Solubility data in fluid-fluid reaction system. 2

(c) Factors to Consider in Selecting a Contactor for fluid-fluid reaction system. 2

**** Good Luck ****

Course Outcomes (COs):

1. Ability to interpret and analyze heterogeneous reaction kinetics data.
2. Ability to design reactors for non-catalytic heterogeneous (fluid-particle and fluid-fluid) reactions systems.
3. Ability to identify the kinetics of solid catalyzed reaction systems and to design reactors containing solid catalysts.
4. Ability to identify kinetics of the catalyst deactivation, and to design reactors containing decaying solid catalysts.

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DEPARTMENT OF CHEMICAL ENGINEERING

End Semester (Even) Examination 2024-25

Programme Name: B.Tech./~~M.Tech./MBA/M.Sc/MCA~~ **Semester:**....5th..........

Course Code: CHN 15111................ **Course Name:** Heterogeneous Reaction Engineering ......

Branch: Chemical Engineering....... **Student Reg. No.:** 20222068

Duration: 2½ Hours **Max. Marks:** 40

Instructions: (Related to Questions)

1. *Attempt all questions*
2. *Figures to the right indicate the full marks.*
3. *Symbols have their usual meanings*
4. *Assume missing data suitably, if any*
5. *Use of non-programmable scientific calculator is permitted*

			Marks	COs
Q 1	a	Gas A contacts and reacts with a spherical solid B according to the reaction: $$A(g)+B(s)\rightarrow R(g)+S(s)$$ As reaction progresses, a sharp reaction plane moves forward into the solid leaving behind it a product layer through which gaseous A and R must diffuse. For this situation, three resistances that act in series are gas film, ash layer, and reaction step. Taking into consideration that rate of thickening of ash layer is proportional to rate of reaction at that instant, show that the time to reach any thickness l, is the sum of the time needed if each resistance acted alone or $$t_{actual} = t_{film\_alone} + t_{ash\_alone} + t_{reaction\_alone}$$	(4)	CO2
	b	Two small samples of solids (2 mm and 4 mm diameters) are kept in constant environment oven for a period of 1.0 hour. Under the condition prevailing in the oven 4 mm particles are 57.8% converted and 2 mm particles are 87.5% converted. Find the rate controlling mechanism for the conversion of solids and time required for complete conversion of both size particles in the oven.	(4)	CO2

Q 2 Attempt ANY TWO of the following:

a Air with gaseous A bubbles through a tank containing aqueous B. Reaction occurs as follows: (4) CO2

$$A(g\rightarrow l)+2B(l)\rightarrow R(l),\quad -r_A = kC_AC_B^2,\quad k = 10^6\ \mathrm{m^6/mol^2.hr}$$

For this system

$k_{Ag}a = 0.01\,\mathrm{mol/hr.m^2.Pa}$; $k_{Al}a = 20.0\ \mathrm{m/hr}$; $f_l = 0.98$; $H_A = 10^5\ \mathrm{Pa.m^3/mol}$

$D_{Al} = D_{Al} = 10^{-6}\ \mathrm{m^2/hr}$; $a = 20\,\mathrm{m^2/m^3}$

For a point in the absorber-reactor where $p_A = 5.0\times10^3$ Pa ; $C_B = 1.0\,\mathrm{mol/m^3}$

Determine following for the above system:

(i) locate the resistance to the reaction **(ii)** locate the reaction zone
(iii) determine the behavior in the liquid film **(iv)** calculate the rate of reaction ($\mathrm{mol/m^3.hr}$)

b Researchers studied the rate of CO_2 absorption into an alkaline buffered solution of K_2CO_3 and $KHCO_3$. The resulting reaction can be represented as: (4) CO2

$$\underset{(A)}{CO_2(g\rightarrow l)} + \underset{(B)}{OH^-(l)} \rightarrow HCO_3^- \qquad \text{with} \qquad -r_A = kC_AC_B$$

In the experiment pure CO_2 at 1 atm was bubbled into a packed column irrigated by rapidly recirculating solution kept at 20°C and close to constant C_B. Find the fraction of entering CO_2 absorbed.

Data Given:

Column: $V_r = 0.6041\ m^3$ $\quad f_l = 0.08 \quad a = 120\ m^2/m^3$
Gas: $\pi = 101\,325$ Pa $\quad H_A = 3500\ Pa\cdot m^3/mol \quad v_0 = 0.0363\ m^3/s$
Liquid: $\overline{C}_B = 300\ mol/m^3$ $\quad \mathscr{D}_{Al} = \mathscr{D}_{Bl} = 1.4 \times 10^{-9}\ m^2/s$
Rates: $k = 0.433\ m^3/mol\cdot s$ $\quad k_{Al}a = 0.025\ s^{-1}$

c Consider the following three-phase *(gas-liquid on solid catalysts)* reaction and stoichiometry: (4) CO2 & CO3

$$A(g \to l) + bB(l) \xrightarrow[\text{surface}]{\text{on catalyst}} \text{products} \cdots b = \left(\frac{\text{mol B}}{\text{mol A}}\right)$$

$$\left.\begin{aligned} -r_A''' &= k_A''' C_A C_B \\ -r_B''' &= k_B''' C_A C_B \end{aligned}\right\} \text{where} \left\{\begin{aligned} -r_A''' &= -r_B'''/b \cdots \text{mol A/m}^3\ \text{cat}\cdot\text{s} \\ k_A''' &= k_B'''/b \cdots m_l^6/\text{mol B}\cdot\text{m}^3\ \text{cat}\cdot\text{s} \end{aligned}\right\}$$

Gas reactant must first dissolve in the liquid, then both reactants (A & B) diffuse to the solid catalyst surface for reaction to occur. Develop overall rate equations $(-r_A''')$ and $(-r_B''')$ in terms of measurable concentration or partial pressure. Also, mention all the assumptions required for the same.

Q 3 a Define Non-dissociative and Dessociative Adsorption. Derive Langmuir adsorption isotherm equation with all necesseary assumptions for Dessociative Adsorption. (4) CO3

b The reaction of two noxious automobile exhaust products, CO and NO carried out over a copper catalyst to form environmentally acceptable products, N_2 and CO_2. The main reaction and its mechanism are given below: (4) CO3

Reaction: $$CO + NO \xrightleftharpoons{\text{Copper}} CO_2 + {}^1/_2 N_2$$

Mechanism:

$$\left.\begin{aligned} CO + S &\rightleftarrows CO\cdot S \\ NO + S &\rightleftarrows NO\cdot S \end{aligned}\right\} \quad \text{Rapid}$$

$$NO\cdot S + CO\cdot S \rightleftarrows CO_2 + N\cdot S + S\} \quad \text{Rate-limiting}$$

$$\left.\begin{aligned} N\cdot S + N\cdot S &\rightleftarrows N_2\cdot S \\ N_2\cdot S &\longrightarrow N_2 + S \end{aligned}\right\} \quad \text{Rapid}$$

Derive overall rate equation for the reaction using *Langmuir-Hinshelwood Approach.*

Q 4 a A first-order catalytic reaction $A(l) \rightarrow R(l)$ is run in a long, narrow vertical reactor with up flow of liquid through a fluidized bed of catalyst particles. Conversion is 90% at the start of operations when the catalyst particles are 5 mm in diameter. The catalyst is friable and slowly wears away, particles shrink and the fine powder produced washes out of the reactor. After a few months each of the 5-mm spheres has shrunk to 3-mm spheres. What should be the conversion at this time? Assume plug flow of liquid. (4) CO3

(i) Particles are porous and allow easy access for reactants (no resistance to pore diffusion).
(ii) Particles are porous and at all sizes provide a strong resistance to pore diffusion.

b Consider a single cylindrical pore of length L, with reactant A diffusing into the pore, and reacting on the surface by a first-order reaction taking place at the walls of the pore, and product diffusing out of the pore. The catalyst used is decaying with time. Develop expression for *Effectiveness factor* in terms of *Thiele Modulus* for decaying catalyst (M_{T_d}). (4) CO3 & CO4

Q 5 a Discuss types of deactivation of a solid porous catalyst? Derive the performance equation for *Mixed fluid/batch Solid* system with deactivating catalyst. The reaction taking place in the reactor is of first order and the solid catalyst is decaying as a result of *sintering*. (4) CO4

b The reversible catalytic reaction, $[A \leftrightarrow R,\ \ X_{Ae} = 0.5]$, proceeds with decaying catalyst in a batch reactor (batch-solids, batch fluid). What can you say of the kinetics of reaction and deactivation from the following data: (4) CO4

t, hr	0	0.25	0.5	1	2	(∞)
C_A, mol/liter	1.000	0.901	0.830	0.766	0.711	0.684

**** Good Luck ****

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