BIRLA INSTITUTE OF TECHNOLOGY, MESRA, RANCHI
(END SEMESTER EXAMINATION)

CLASS: BTECH — **SEMESTER : V/ADD**
BRANCH: CHEMICAL ENGINEERING — **SESSION : MO/2025**

SUBJECT: CL325 CHEMICAL REACTION ENGINEERING-II

TIME: 3 Hours — **FULL MARKS: 50**

INSTRUCTIONS:
1. The question paper contains 5 questions each of 10 marks and total 50 marks.
2. Attempt all questions.
3. The missing data, if any, may be assumed suitably.
4. Before attempting the question paper, be sure that you have got the correct question paper.
5. Tables/Data hand book/Graph paper etc. to be supplied to the candidates in the examination hall.

			CO	BL
Q.1(a)	Explain the mechanism of heterogeneous gas-liquid reaction with an example.	[2]	CO1	2
Q.1(b)	A reaction $\mathrm{A(g)} \xrightarrow{\text{Catalyst}} \mathrm{B(g)}$ is carried out on a solid catalytic surface. Considering both external mass transfer and internal pore diffusions, (i) Identify various steps of the overall reaction rate (ii) Explain the roles of bulk gas velocity (u) and catalyst particle size (d_p) on the overall reaction rate.	[3]	CO3 CO4	3
Q.1(c)	(i) A spherical carbon particle of radius 0.2 cm reacts with oxygen based on the following reaction: $\mathrm{C(s)} + \mathrm{O_2(g)} \rightarrow \mathrm{CO_2(g)}$ under chemical reaction control. If the reaction rate constant is k_s=0.15 cm s^{-1} and gas concentration is C_{Ag}=0.1 mol cm^{-3}, calculate the (1) time required for complete conversion and 80% conversion of the carbon particle, and (2) the core radius. Assume carbon particle molar density, ρ_b is 0.17 gm cm^{-3}. Given: $t = \frac{\rho_B R}{b k_s C_{Ag}}\left(1 - \frac{r_c}{R}\right)$ (ii) For the chemical reaction control, draw the concentration profile of O_2 gas along the radial direction from bulk gas phase to the core of the particle.	[4+1]	CO2	3
Q.2(a)	Define dual-site adsorption mechanism. Specify different types of dual-site adsorption with mechanisms.	[2]	CO1	1,2
Q.2(b)	State the assumptions in Langmuir-Hinshelwood kinetics.	[2]	CO2	1,2
Q.2(c)	Show that the rate laws for irreversibly surface reaction-limited catalytic reaction for the following cases, are given by (i) Single site- $A.S \rightarrow B.S$, $-r_A' = \frac{(p_A)k}{1+K_A p_A + K_B p_B}$ (ii) Eley-Rideal- $A.S + B(g) \rightarrow C.S$, $-r_A' = \frac{(p_A p_B)k}{(1+K_A p_A + K_C p_C)}$	[3×2]	CO2	3
Q.3(a)	A spherical ore particle of diameter d_p reacts with a gas. Determine the effects of d_p on gas phase mass transfer coefficient for (i) Low Reynolds number and (ii) high Reynolds number. Given: $Sh = 2 + 0.6 Re^{1/2} Sc^{1/3}$	[2]	CO2 CO3	3
Q.3(b)	Explain the critical factors that affect the design of Gas-Solid reactors (catalytic and non-catalytic)? Give examples.	[2]	CO2	2

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Q.3(c)	(i) Show that the overall rate of noncatalytic reaction $A(g) + bB(s) \rightarrow Product$ (gas-solid reaction) is $$-r_B = -br_A = \frac{bC_{Ag}}{\left[\frac{1}{k_g} + \frac{R(R-r_c)}{r_c D_e} + \frac{R^2}{k r_c^2}\right]}$$ Here: $-r_B = -br_A = \frac{1}{S_{ex}}\frac{dN_B}{dt} = -\frac{b}{S_{ex}}\frac{dN_A}{dt}$ (ii) Further, show that for ash-free particles, in which particles shrink with reaction, $$-r_A = -\frac{1}{S_{ex}}\frac{dN_A}{dt} = C_{Ag}/\left[\frac{1}{k_g} + \frac{1}{k}\right]$$	[5+1]	CO2 CO3	3
Q.4(a)	Define overall effectiveness factor in a fluid-solid catalytic reaction. Specify the parameters on which the overall effectiveness factor depends.	[2]	CO3	1,2
Q.4(b)	Rate of reaction (intrinsic 1st order) was measured to be 5 mol s–1 m–3 for a catalyst slab (flat plate) at a gas concentration of 0.2 mol m–3. Find the followings: (i) Thiele modulus, (ii) internal effectiveness factor, (iii) observed rate for a catalyst of pellet thickness of 2 mm. Assume De = 2x10– 6 m2 s–1. (iv) Is the catalyst pore diffusion resistant?	[4]	CO3 CO4	3
Q.4(c)	An experimental rate measurement on the first-order decomposition of *A* with a spherical catalyst with bulk density (ρ_b). The following details are known:	[4]	CO3 CO4	3

d_p = 3.5 mm	D_e = 4.2 x 10^{-5} m^2/hr
Catalyst density (ρ)=1.6 g/cm^3 Porosity (ε_p) = 0.45	k_g = 6.2 x 10^4 m^3/hr m^2 cat
C_{Ag} = 18 mol/m^3	-r_{obs} = 10^5 mol/hr. m^3 cat

Using Weisz-Prater (WP) and Mears' criterion (MR), determine if the observed rate is limited by internal pore diffusion or external mass transfer or both.

Given: $WP = \eta\phi^2 = \frac{(-r_{obs})\rho R^2}{9C_{As}D_e}$, $MR = \frac{(-r_{obs})\rho_b R n}{k_g C_{Ab}}$

Q.5(a)	Define the physical significance of enhancement factor.	[1]	CO5	2
Q.5(b)	For Hatta number greater than 2 (*Ha* or M_H>2) draw the possible cases of concentration profiles and locate the reaction zone (front).	[3]	CO5	2
Q.5(c)	The rate of expression of reaction of gas *A* with liquid *B* is given by: $$-r_A = kC_A,\ \ k = 1 \times 10^{-3}\ [m^3/mol.hr]$$ For this system,	[1.5+ 2+ 1.5+ 1 =6]	CO5	3

$k_{Ag} = 1 \times 10^{-4} [mol/hr.m^2.Pa]$	$k_{Al} = 2.5 \times 10^{-4} [m/hr]$
$D_{Al} = 10^{-6}\ [m^2/hr]$	$f_l = 0.75\ [-]$
$\mathcal{H}_A = 2600\ [Pa.m^3/mol]$	$a = 150\ \ [m^2/m^3]$

At a particular point in the reactor, the partial pressure of *A* was measured to be $5\ \times 10^3\ Pa$

(i) Evaluate and comment on the major resistances among – liquid-film, gas-film, and main body.

(ii) Calculate the overall rate for absorption with reaction using the equation:

$$(-r_A)_{overall} = \frac{p_A}{\left[\frac{1}{k_{Ag}a} + \frac{\mathcal{H}_A}{k_{Al}a} + \frac{\mathcal{H}_A}{f_l k}\right]}$$

(iii) Calculate the Hatta Number ($M_H\ or\ Ha = \sqrt{kD}/k_l$) and draw the profile of *A* through *B*.

(iv) Suggest a suitable reactor for the operation.