MANICALAND STATE UNIVERSITY OF APPLIED SCIENCES

FACULTY OF ENGINEERING

CHEMICAL AND PROCESSING ENGINEERING DEPARTMENT

REACTOR ANALYSIS AND DESIGN II/CHEMICAL REACTION ENGINEERING II

CODE: CHEP 224/HCHE 312

SESSIONAL EXAMINATIONS

DECEMBER 2022

DURATION: 3 HOURS

EXAMINER: DR M. CHIGONDO

INSTRUCTIONS

1. *Answer **all** questions*
2. *Each question carries 25 marks*
3. *Total marks 100*

Question one

(a) For the gas-liquid reaction: $A(l \rightarrow g) + B(l) \rightarrow R(l)$ with C_{Ai} less than C_{Bi} sketch the concentration profiles of A and B in liquid film and bulk for the following situations, indicating where the reaction takes place

(i) instantaneous reaction

(ii) Fast reaction, such that Hatta 's modulus is greater than 2

(iii) Very slow reaction such that Hatta's modulus is less that 0.02 [10]

(b) Gaseous ammonia (A) is to be absorbed and reacts with nitric acid (B) as follows:

$A(l \rightarrow g) + B(l) \rightarrow R(l)$, $r_{Al} = kC_A C_B$ in a packed such that Hatta's modulus is less than 0.02. For each case state suitable type of conductor.

Given that:

$p_A = 100$ Pa and $C_B = 100$ mol/m^3 liquid

$k = 10^{-2}$ m^3/mol^2.h

$k_{Ag} = 0.01$ mol/h.m^2 of reactor.Pa

$a = 100$ m^2/m^3 of reactor

$k_{Al}\,a = 100$ m^3 liquid / (m^3 reactor h)

$H_A = 10^5$ (Pa m^3 liquid)/mol

$f_l = 0.1$ m^{3}liquid/m^{3}reactor

$$\mathscr{D}_{Al} = \mathscr{D}_{Bl} = 10^{-6}\ \mathrm{m^2/hr}$$

(i) Calculate the resistances in gas and liquid films and in the bulk liquid and locate the major resistance. [10]

(ii) Locate the reaction zone [1]

(iii) Is the reaction pseudo-first order? Explain your answer. [2]

(iv) Calculate the rate of reaction in mol/hr m^3(react). [2]

Question two

(a) Write a brief description of the *shrinking core* and *progressive conversion* models. Draw representative profiles to aid your explanations. [10]

(b) For the gas-liquid reaction, $A(l \rightarrow g) + B(l) \rightarrow R(l)$ and with C_{Ai} comparable with C_{Bl} , sketch the concentration profiles of A and B in the liquid film and bulk for the following situations, indicating where the reaction takes place:

(i) instantaneous reaction [3]

(ii) fast reaction, such that the Hatta modulus > 2 [3]

(iii) very slow reaction such that the Hatta modulus < 0.02 [3]

(iv) for each case, name one type of reactor which would be suitable and explain your choice. [6]

Question three

(a) With the aid of sketch diagrams show **five** contacting patterns in fluid-solid reactors. [5]

(b) State the three rate controlling mechanisms of the shrinking core model for fluid -particle reaction [3]

(c) Spherical particles of graphite of size R = 5 mm are roasted isothermally in a stream of air. The time-conversion data obtained in **Table 1**

Table 1

t, min	15	30	60
X_B	0.334	0.584	0.880

(i)By using three appropriate formulae, find the values of **τ** (the time required for complete conversion) for the three rate controlling mechanisms. [3]

(ii) Using the data in **Table,** find rate mechanism controlling the of the roasting process [9]

(iii) Calculate the time required for complete combustion of graphite particles (pure Carbon), for which the reaction proceeds according to the shrinking particle model, if the graphite particles (radius 5 mm and density of 2200 kg/m^3) are exposed to a high-velocity 10%-oxygen stream at 1173 K and 1 atm. The rate constant is 20 cm/s

[5]

Question four

(a) (i) What is a *contactor*? [1]

(ii) What is the difference between a tank and a tower in fluid -fluid reactor design

[2]

(b) State the type of contactor for the following situations:

(i) If the liquid film dominates

(ii) If the resistance is in the main body of the liquid

(iii) Relative flow rates of about F_l/F_g, is 10 at 1 bar

[3]

(c) State **any three** characteristics a contactor [3]

(d) An engineering process plans to remove 80 % or reactant present in a gas stream by absorption in water. Find the volume of the tower for a countercurrent operation by straight mass transfer.

Given the following data:

F_g/A_{cs} = 1 x 10^5 mol/h m^2 at $\pi = 10^5$ Pa

P_A = 500 Pa, p_{Aout} = 100 Pa

F_l/A_{cs} = 10.6 x 10^5 mol/h m^2, $k_{Ag}a$ = 0.32 mol /hm^3.Pa

$k_{Al}\,a$ = 0.1/h, C_T = 28 000 mol/h

H_A = 15 Pa m^3/mol, k = 0 m^3/mol h [14]

(e) By means of diagrams, illustrate the following types of contactors:

(i) *irrigated bed counter current is tower*

(ii) *staged bubble tower counter current tower.*

[2]

END OF EXAM

LIST OF FORMULAE

Fluid fluid reactions

Fluid-fluid overall reaction equation:

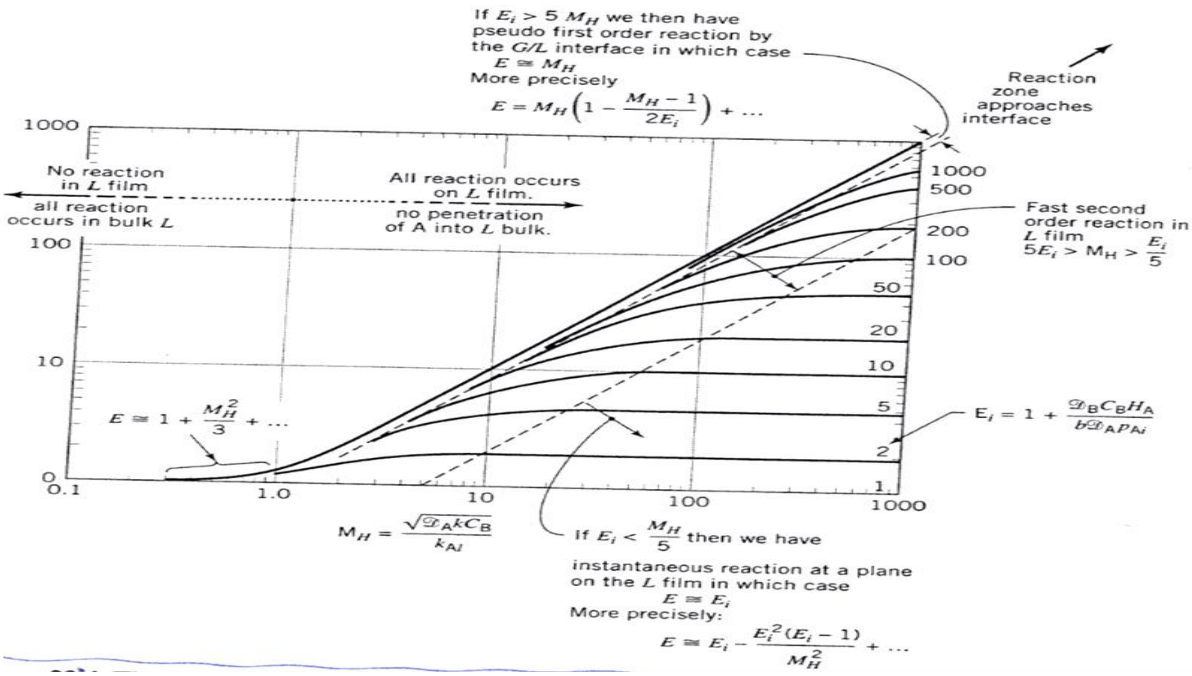
$$-r_A'''' = \frac{1}{\underbrace{\frac{1}{k_{Ag}a}}_{\text{gas film resistance}} + \underbrace{\frac{H_A}{k_{Al}aE}}_{\text{liquid film resistance}} + \underbrace{\frac{H_A}{kC_B f_l}}_{\text{liquid bulk resistance}}} p_A$$

Fluid-fluid overall reaction equation for different cases:

Case	Formula of rate equation
A and B	$\left(k_{Ag}p_A \le \frac{k_{Bl}C_B}{b}\right) \quad -r''_A = -\frac{1}{S}\frac{dN_A}{dt} = k_{Ag}p_A$ **Case A: if $k_{Ag}P_A \ge \frac{k_{Bl}\ C_B}{b}$** **Case B: if $k_{Ag}P_A \le \frac{k_{Bl}\ C_B}{b}$**
C	$-r''''_A = \dfrac{1}{\dfrac{1}{k_{Ag}a} + \dfrac{H_A}{k_{Al}aE}} p_A$
D	$-r''''_A = \dfrac{1}{\dfrac{1}{k_{Ag}a} + \dfrac{H_A}{a\sqrt{\mathscr{D}_A k C_B}}} p_A$
E and F	$-r''''_A = \dfrac{1}{\underbrace{\dfrac{1}{k_{Ag}a}}_{\text{gas film resistance}} + \underbrace{\dfrac{H_A}{k_{Al}aE}}_{\text{liquid film resistance}} + \underbrace{\dfrac{H_A}{kC_B f_l}}_{\text{liquid bulk resistance}}} p_A$
G	$-r''''_A = \dfrac{1}{\dfrac{1}{k_{Ag}a} + \dfrac{H_A}{k_{Al}a} + \dfrac{H_A}{kC_B f_l}} p_A$

H	$$-r'''_A = \frac{kf_l}{H_A} p_A C_B = kf_l C_A C_B$$

Enhancement factor for fluid-fluid reactions as a function of M_H and E_i :



<u>Fluid-fluid reactor design:</u>

For any two points in an absorber:

$$p_{A2} - p_{A1} = \frac{F_l \pi}{F_g C_T}(C_{A2} - C_{A1})$$

Volume of a contractor:

$$V_r = hA_{cs} = \frac{F_g}{\pi}\int_{p_{A1}}^{p_{A2}} \frac{dp_A}{-r_A''''} = \frac{F_l}{C_T}\int_{C_{A1}}^{C_{A2}} \frac{dC_A}{-r_A''''}$$

$$= \frac{F_g}{\pi K_{Ag}a}\int_{p_{A1}}^{p_{A2}} \frac{dp_A}{p_A - p_A^*} = \frac{F_l}{C_T K_{Al}a}\int_{C_{A1}}^{C_{A2}} \frac{dC_A}{C_A^* - C_A}$$

- coefficient on gas basis: $\frac{1}{K_{Ag}} = \frac{1}{k_{Ag}} + \frac{H_A}{k_{Al}}$
- gas in equilibrium with liquid C_A, or $p_A^* = H_A C_A$
- coefficient on liquid basis: $\frac{1}{K_{Al}} = \frac{1}{H_A k_{Ag}} + \frac{1}{k_{Al}}$
- liquid in equilibrium with gas p_A, or $C_A^* = p_A/H_A$

Fluid-particle reactor design:

Conversions-Time Expressions for Various Shapes of Particles, Shrinking core model:

Constant Size Particles

	Film Diffusion Controls	Ash Diffusion Controls	Reaction Controls
Flat plate $X_B = 1 - \frac{1}{L}$, L = half thickness	$\frac{t}{\tau} = X_B$	$\frac{t}{\tau} = X_B^2$	$\frac{t}{\tau} = X_B$
	$\tau = \frac{\rho_B L}{bk_g C_{Ag}}$	$\tau = \frac{\rho_B L^2}{2b\mathscr{D}_e C_{Ag}}$	$\tau = \frac{\rho_B L}{bk'' C_{Ag}}$
Cylinder $X_B = 1 - \left(\frac{r_c}{R}\right)^2$	$\frac{t}{\tau} = X_B$	$\frac{t}{\tau} = X_B + (1 - X_B)\ln(1 - X_B)$	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/2}$
	$\tau = \frac{\rho_B R}{2bk_g C_{Ag}}$	$\tau = \frac{\rho_B R^2}{4b\mathscr{D}_e C_{Ag}}$	$\tau = \frac{\rho_B R}{bk'' C_{Ag}}$
Sphere $X_B = 1 - \left(\frac{r_c}{R}\right)^3$	$\frac{t}{\tau} = X_B$	$\frac{t}{\tau} = 1 - 3(1 - X_B)^{2/3} + 2(1 - X_B)$	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$
	$\tau = \frac{\rho_B R}{3bk_g C_{Ag}}$	$\tau = \frac{\rho_B R^2}{6b\mathscr{D}_e C_{Ag}}$	$\tau = \frac{\rho_B R}{bk'' C_{Ag}}$

Mean conversion of the solids leaving a plug flow reactor:

$$1 - \overline{X}_B = \sum_{R(t_p=\tau)}^{R_m} [1 - X_B(R_i)]\,\frac{F(R_i)}{F}$$

Chemical reaction controls:

$$[1 - X_B(R_i)] = \left(1 - \frac{t_p}{\tau(R_i)}\right)^3$$