MANICALAND STATE UNIVERSITY

OF APPLIED SCIENCES

FACULTY OF ENGINEERING, SCIENCE AND TECHNOLOGY

DEPARTMENT: CHEMICAL AND PROCESSING ENGINEERING

REACTOR ANALYSIS AND DESIGN II/CHEMICAL REACTION ENGINEERING II

CODE: CHEP 224/HCHE 312

SESSIONAL EXAMINATIONS

JUNE 2023

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) Explain the following in terms of the gas-liquid reactions:

- i. *gas film resistance*
- ii. *bulk liquid resistance*
- iii. *behaviour in the liquid film*
- iv. *locating the resistance to reaction.* [4]

(b) i. What is meant by *fluid-fluid reactions*? [2]

ii. Give an industrial example of a fluid-fluid reaction. [1]

iii. State **three** reasons why such reactions are made to take place? [3]

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

$A(l \rightarrow g) + B(l) \rightarrow R(l)$, $r_A = kC_A\, C_B$ in a packed column

i. Determine the behavior in the liquid film (pseudo first-order reaction, instantaneous, second-order reaction, physical transport. [5]

ii. Describe the following characteristics of the kinetics: location of the major resistance (gas film, liquid film, main body of liquid. [6]

iii. Calculate the rate of the reaction [2]

Given that:

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

$k = 10^8$ m^3/mol^2.h

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

$a = 20$ m^2/m^3 of reactor

$k_{Al}a = 20$ m^3 liquid / (m^{3}reactor h)

$H_A = 1$ (Pa m^3 liquid)/mol

$f_l = \quad 0.098$ m^3 liquid/m^3 reactor

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

(a) What is the role of the Hatta's modulus, M_H in fluid-fluid reactions? [2]

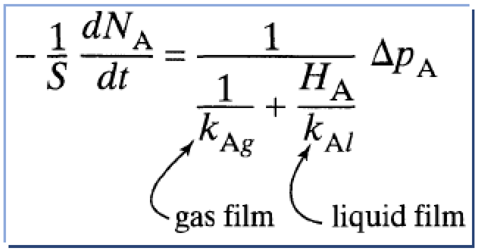
QUESTION TWO

(b) State any **five** factors to consider in selecting a contactor. [5]

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

- i. When M_H is large,
- ii. if M_H is very small [2]

(d) For reactions which occur in the film, the phase distribution coefficient H_A can suggest whether the gas-phase resistance is likely to be important or not.



$$-\frac{1}{S}\frac{dN_A}{dt} = \frac{1}{\underset{\text{gas film}}{\frac{1}{k_{Ag}}} + \underset{\text{liquid film}}{\frac{H_A}{k_{Al}}}}\Delta p_A$$

Copy and complete Table 1

Table 1

Gas solubility	**H_A small or large**	**Rate controlling factor**	**Type of contactor**
Slightly soluble gases			
Highly soluble gases			

[6]

(e) An engineering process is planned to remove 80 % of reactant present in a gas stream by absorption in water. Find the volume of the tower for a countercurrent absorption operation.

Given the following data:

$F_g = 9000$ mol/h at $\pi = 10^5$ Pa

$P_A = 1000$ Pa, $p_{Aout} = 100$ Pa

$F_l = 90000$ mpl/h, $k_{Ag}a = 0.36$ mol /hm^3.Pa

$k_{Al}\,a = 72$/h, $C_T = 50000$ mol/h

$H_A = 2.0$ Pa m^3/mol, $k = 0$ m^3/mol h [12]

QUESTION THREE

(a) i. What is roll of enhancement factor in fluid-fluid reactions? [2]

ii. What is maximum and minimum value of E? [2]

(b) Illustrate the shrinking core model in fluid-particle reactions. [8]

(c) State the **five** successive steps in the *shrinking core model.* [5]

(d) Spherical solid particles containing B are roasted isothermally in an oven with gas of constant composition. Solids are converted to a firm nonflaking product according to the SCM as follows:

$A(s) + B(g) \rightarrow R(g) + S(s)$, $C_A = 0.01$ kmol/m^{3,} $\acute{\rho}_B = 20$ kmol/m^3

From the following conversion data (by chemical analysis) or core size data (by slicing and measuring) determine the rate controlling mechanism for the transformation of solid.

d_p, mm	X_B	t, min

1	1	200
1.5	1	450

[6]

(e) State two limitations of the *shrinking core model* [2]

QUESTION FOUR

(a) State **three** factors controlling the design of a fluid-solid reactor. [3]

(b) Give two example of two industrial reactors for solids and gas both in plug flow [2]

(c) Explain the following terms

i. *ash diffusion control*,

ii. *gas diffusion control*

iii. *chemical reaction control* [3]

(d) The equations (1.1) and (1.2) show how the unreacted core shrinks with time in gas film control systems of solid-fluid reactions.

$$-\frac{\rho_B}{R^2}\int_R^{r_c} r_c^2\,dr_c = bk_gC_{Ag}\int_0^t dt \tag{1.1}$$

$$t = \frac{\rho_B R}{3bk_gC_{Ag}}\left[1-\left(\frac{r_c}{R}\right)^3\right] \tag{1.2}$$

Define each symbol these equations. [6]

(e) A feed consisting: 25% of 25-pm-radius particles

30% of 50-pm-radius particles

25% of 100-pm-radius particles

is to be fed continuously in a thin layer onto a moving grate crosscurrent to a flow of reactant gas. For the planned operating conditions, the time required for complete conversion is 5, 10, and 20 min for the three sizes of particles. Find the conversion of solids on the grate for a residence time of 8 min in the reactor. [5]

(f) Name the three types of contacting patterns in gas-solid operation and give an example of such an industrial contactor which shows each of the stated contacting patterns. [6]

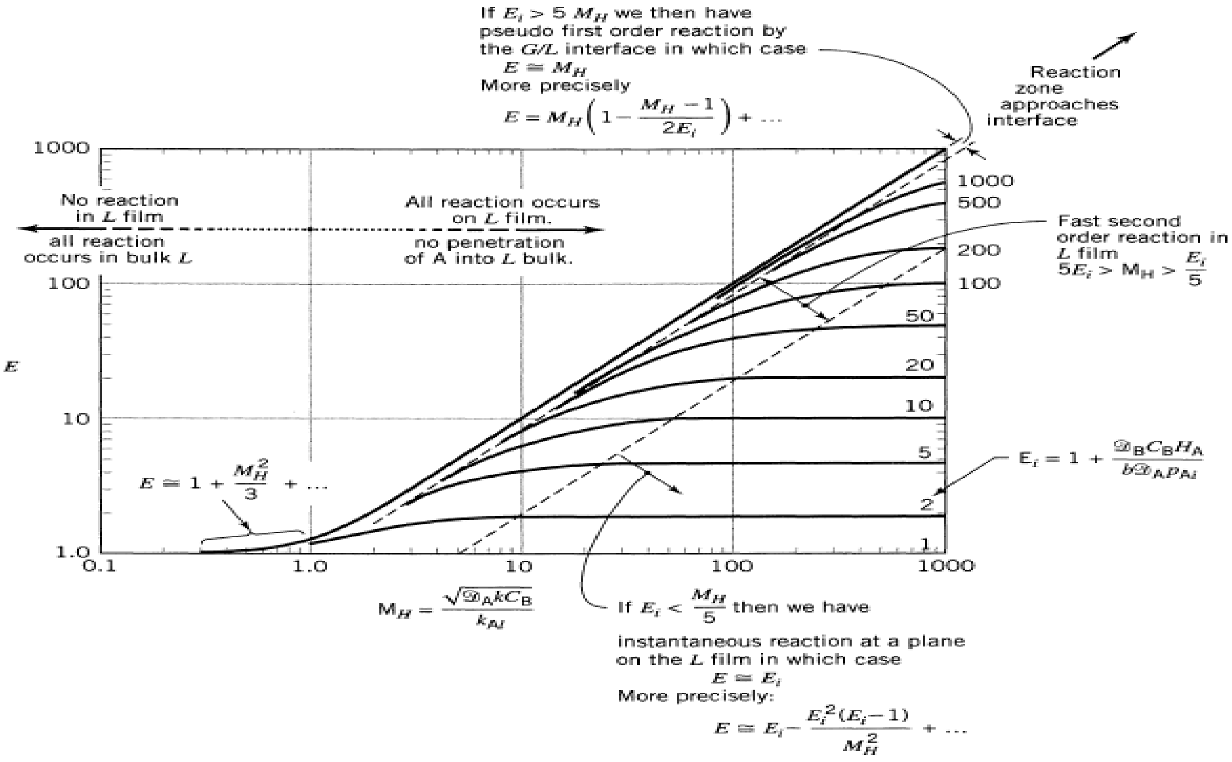
END OF EXAMINATION

LIST OF FORMULAE

Fluid-fluid overall reaction equation:

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

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



Fluid-fluid reactor design:

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 contactor:

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

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

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

$$\frac{1}{K_{Al}} = \frac{1}{H_A k_{Ag}} + \frac{1}{k_{Al}}$$

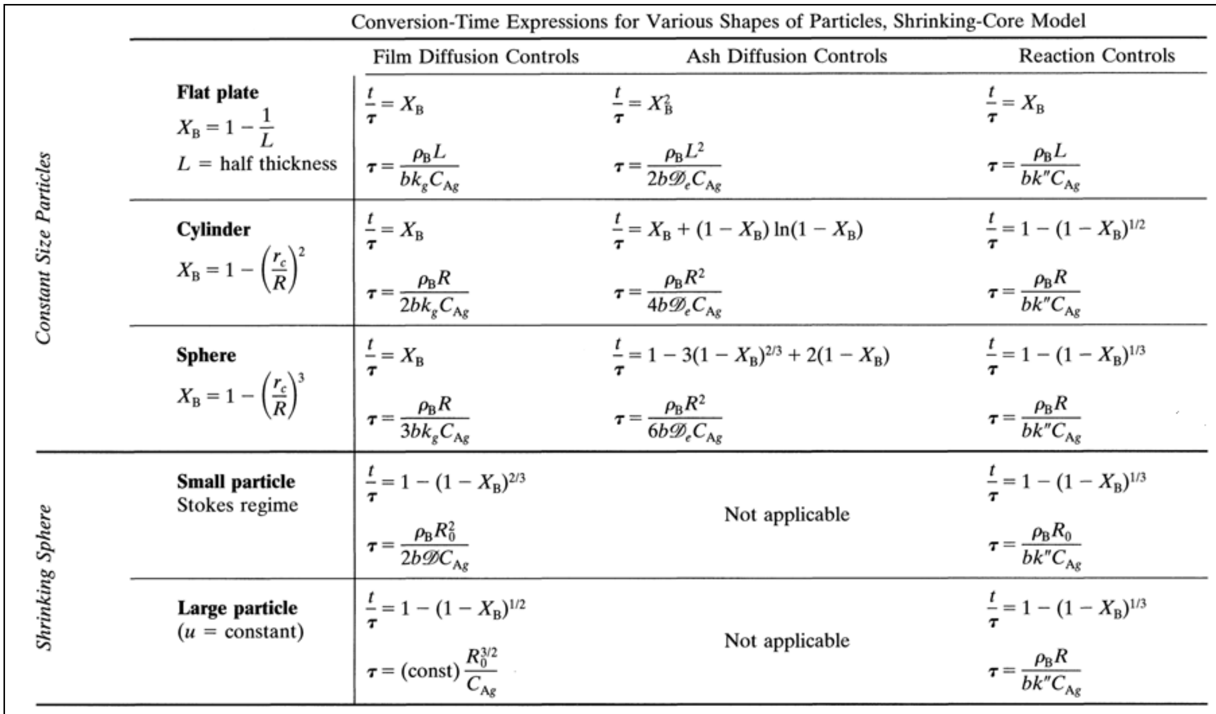
liquid in equilibrium with gas p_A, or

$$C_A^* = p_A / H_A$$

Fluid-particle reactor design:

Conversion-Time Expressions for Various Shapes of Particles, Shrinking-Core Model

		Film Diffusion Controls	Ash Diffusion Controls	Reaction Controls
Constant Size Particles	**Flat plate** $X_B = 1 - \frac{1}{L}$ L = half thickness	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B L}{b k_g C_{Ag}}$	$\frac{t}{\tau} = X_B^2$ $\tau = \frac{\rho_B L^2}{2b\mathscr{D}_e C_{Ag}}$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B L}{b k'' C_{Ag}}$
	Cylinder $X_B = 1 - \left(\frac{r_c}{R}\right)^2$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B R}{2b k_g C_{Ag}}$	$\frac{t}{\tau} = X_B + (1 - X_B)\ln(1 - X_B)$ $\tau = \frac{\rho_B R^2}{4b\mathscr{D}_e C_{Ag}}$	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/2}$ $\tau = \frac{\rho_B R}{b k'' C_{Ag}}$
	Sphere $X_B = 1 - \left(\frac{r_c}{R}\right)^3$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B R}{3b k_g C_{Ag}}$	$\frac{t}{\tau} = 1 - 3(1 - X_B)^{2/3} + 2(1 - X_B)$ $\tau = \frac{\rho_B R^2}{6b\mathscr{D}_e C_{Ag}}$	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ $\tau = \frac{\rho_B R}{b k'' C_{Ag}}$
Shrinking Sphere	**Small particle** Stokes regime	$\frac{t}{\tau} = 1 - (1 - X_B)^{2/3}$ $\tau = \frac{\rho_B R_0^2}{2b\mathscr{D} C_{Ag}}$	Not applicable	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ $\tau = \frac{\rho_B R_0}{b k'' C_{Ag}}$
	Large particle (u = constant)	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/2}$ $\tau = (\text{const})\frac{R_0^{3/2}}{C_{Ag}}$	Not applicable	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ $\tau = \frac{\rho_B R}{b k'' C_{Ag}}$



Conversion-Time Expressions for Various Shapes of Particles, Shrinking-Core Model

		Film Diffusion Controls	Ash Diffusion Controls	Reaction Controls
Constant Size Particles	**Flat plate** $X_B = 1 - \frac{l}{L}$ L = half thickness	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B L}{b k_g C_{Ag}}$	$\frac{t}{\tau} = X_B^2$ $\tau = \frac{\rho_B L^2}{2b\mathscr{D}_e C_{Ag}}$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B L}{b k'' C_{Ag}}$
	Cylinder $X_B = 1 - \left(\frac{r_c}{R}\right)^2$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B R}{2b k_g C_{Ag}}$	$\frac{t}{\tau} = X_B + (1 - X_B)\ln(1 - X_B)$ $\tau = \frac{\rho_B R^2}{4b\mathscr{D}_e C_{Ag}}$	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/2}$ $\tau = \frac{\rho_B R}{b k'' C_{Ag}}$
	Sphere $X_B = 1 - \left(\frac{r_c}{R}\right)^3$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B R}{3b k_g C_{Ag}}$	$\frac{t}{\tau} = 1 - 3(1 - X_B)^{2/3} + 2(1 - X_B)$ $\tau = \frac{\rho_B R^2}{6b\mathscr{D}_e C_{Ag}}$	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ $\tau = \frac{\rho_B R}{b k'' C_{Ag}}$
Shrinking Sphere	**Small particle** Stokes regime	$\frac{t}{\tau} = 1 - (1 - X_B)^{2/3}$ $\tau = \frac{\rho_B R_0^2}{2b\mathscr{D} C_{Ag}}$	Not applicable	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ $\tau = \frac{\rho_B R_0}{b k'' C_{Ag}}$
	Large particle (u = constant)	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/2}$ $\tau = (\text{const})\frac{R_0^{3/2}}{C_{Ag}}$	Not applicable	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ $\tau = \frac{\rho_B R}{b k'' C_{Ag}}$

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:

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