



NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING

DEPARTMENT OF CHEMICAL ENGINEERING

REACTOR DESIGN AND ANALYSIS 2

(Chemical Reaction Engineering II)

ECE /TCE3102

Final Examination Paper

December 2024

This examination paper consists of 5 pages

Time Allowed: 3 hours

Total Marks: 100

Examiner's Name: Dr Liberty Lungisani Mguni

INSTRUCTIONS

1. Answer **Section A** and any other **three (3)** questions
2. Each question carries 25 marks
3. Use of calculators is permissible

MARK ALLOCATION

QUESTION	MARKS
1.A	25
1.B	25
2.B	25
3.B	25
4.B	25
TOTAL ATTAINABLE	100

SECTION A

Answer all questions

- a) Distinguish between Langmuir-Hinshelwood-Hougen-Watson (LHHW) kinetics and Eley-Rideal kinetics. [6]
- b) Give an approach on how to determine LHHW kinetics given the elementary steps and the rate-determining step. [8]
- c) Discuss the effect of tortuosity and porosity on effective diffusivity. [6]
- d) For the equation below, state the assumption necessary to get to this equation. [5]

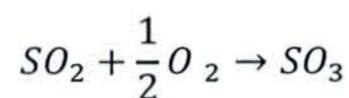
$$\eta = \frac{\tanh\phi}{\phi}$$

SECTION B

Answer any 3 questions

QUESTION B1

- a) What are the assumptions of Langmuir adsorption isotherms? [5]
- b) i) The contact process is used to produce sulphuric acid. The overall reaction and reaction kinetics for the process are given below. Suggest and prove a mechanism that satisfies the rate equation given.



$$r = \frac{kK_A^{0.5}(O)^{0.5}(SO_2)}{1 + K_A^{0.5}(O)^{0.5} + K_C(SO_3)} \quad k = k_s C_T$$

[16]

- ii) With the aid of the rate law equation, discuss how oxygen partial pressure affects the reaction rate. [4]

QUESTION B2

- a) Discuss what you understand by the following terms and their significance

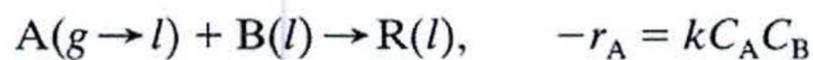
- (i) Knudsen diffusivity [3]
(ii) Thiele modulus [3]
- b) Discuss the need to support catalysts on typical support materials like alumina and silica. Emphasize the advantages and disadvantages of this process. [5]
- c) Find the activation energy of the first-order reaction from the following data:

d_p	C_A	$-r'_A$	T, K	
1	20	1	480	A → R $C_{A0} = 50$
2	40	1	480	
2	40	3	500	

[14]

QUESTION B3

- a) Discuss when the addition of a chemical reaction is useful in fluid-fluid reactions and what contact system is ideal for such a reaction. [6]
- b) Discuss three factors that will determine how we approach the design or reaction analysis for Fluid-Fluid reactions. [6]
- c) We plan to remove about 90% of the A present in a gas stream by absorption in water, which contains reactant B. Chemicals A and B react in the liquid as follows:



- (a) What volume of contactor is needed? [10]
(b) Where does the resistance of the absorption reaction lie? [3]

DATA

	For the packed bed	kinetics
Gas stream	$F_1 = 900\,000 \text{ mol/hr}$	$k = 2.6 \cdot 10^3 \text{ m}^3/\text{mol} \cdot \text{hr}$
$F_g = 90\,000 \text{ mol/hr}$ at $\pi = 10^5 \text{ Pa}$	$K_{Ala} = 72 \text{ hr}^{-1}$	$H_A = 10^3 \text{ Pa} \cdot \text{m}^3/\text{mol}$
$P_{Ain} = 1000 \text{ Pa}$	$K_{Aga} = 0.36 \text{ mol/hr} \cdot \text{m}^3 \cdot \text{Pa}$	
$P_{Aout} = 100 \text{ Pa}$	$C_{Bin} = 55.56 \text{ mol/m}^3$	
Physical data	$a = 100 \text{ m}^2/\text{m}^3$	
$D_A = D_B = 3.6 \cdot 10^{-6} \text{ m}^2/\text{hr}$	$f_l = 0.08$	
$C_U = 55\,556 \text{ H}_2\text{O}/\text{m}^3 \text{ liquid at all } C_B$		

QUESTION B4

a) Give six examples of fluid-particle reactions. [6]

b) Discuss how to determine the rate-controlling step in fluid-particle reactions. [8]

c) A solid feed consisting of

20 wt% of 1-mm particles and smaller

30 wt% of 2-mm particles

50 wt% of 4-mm particles

passes through a rotating tubular reactor somewhat like a cement kiln where it reacts with gas to give a hard, nonfriable solid product (SCM/gas film, $T = 4$ h for 4-mm particles (complete conversion)). If necessary, state relevant assumptions.

i) Find the residence time needed for 100% conversion of solids. [3]

ii) Find the mean conversion of the solids for a residence time of 15 min. [8]

	Film Diffusion Controls	Ash Diffusion Controls	Reaction Controls
Flat plate $X_B = 1 - \frac{1}{L}$ $L = \text{half thickness}$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B L}{bk_g C_{Ag}}$	$\frac{t}{\tau} = X_B^2$ $\tau = \frac{\rho_B L^2}{2b\mathcal{D}_e C_{Ag}}$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B L}{bk^n C_{Ag}}$
Cylinder $X_B = 1 - \left(\frac{r_c}{R}\right)^2$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B R}{2bk_g C_{Ag}}$	$\frac{t}{\tau} = X_B + (1 - X_B) \ln(1 - X_B)$ $\tau = \frac{\rho_B R^2}{4b\mathcal{D}_e C_{Ag}}$	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/2}$ $\tau = \frac{\rho_B R}{bk^n C_{Ag}}$
Sphere $X_B = 1 - \left(\frac{r_c}{R}\right)^3$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B R}{3bk_g C_{Ag}}$	$\frac{t}{\tau} = 1 - 3(1 - X_B)^{2/3} + 2(1 - X_B)$ $\tau = \frac{\rho_B R^2}{6b\mathcal{D}_e C_{Ag}}$	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ $\tau = \frac{\rho_B R}{bk^n C_{Ag}}$

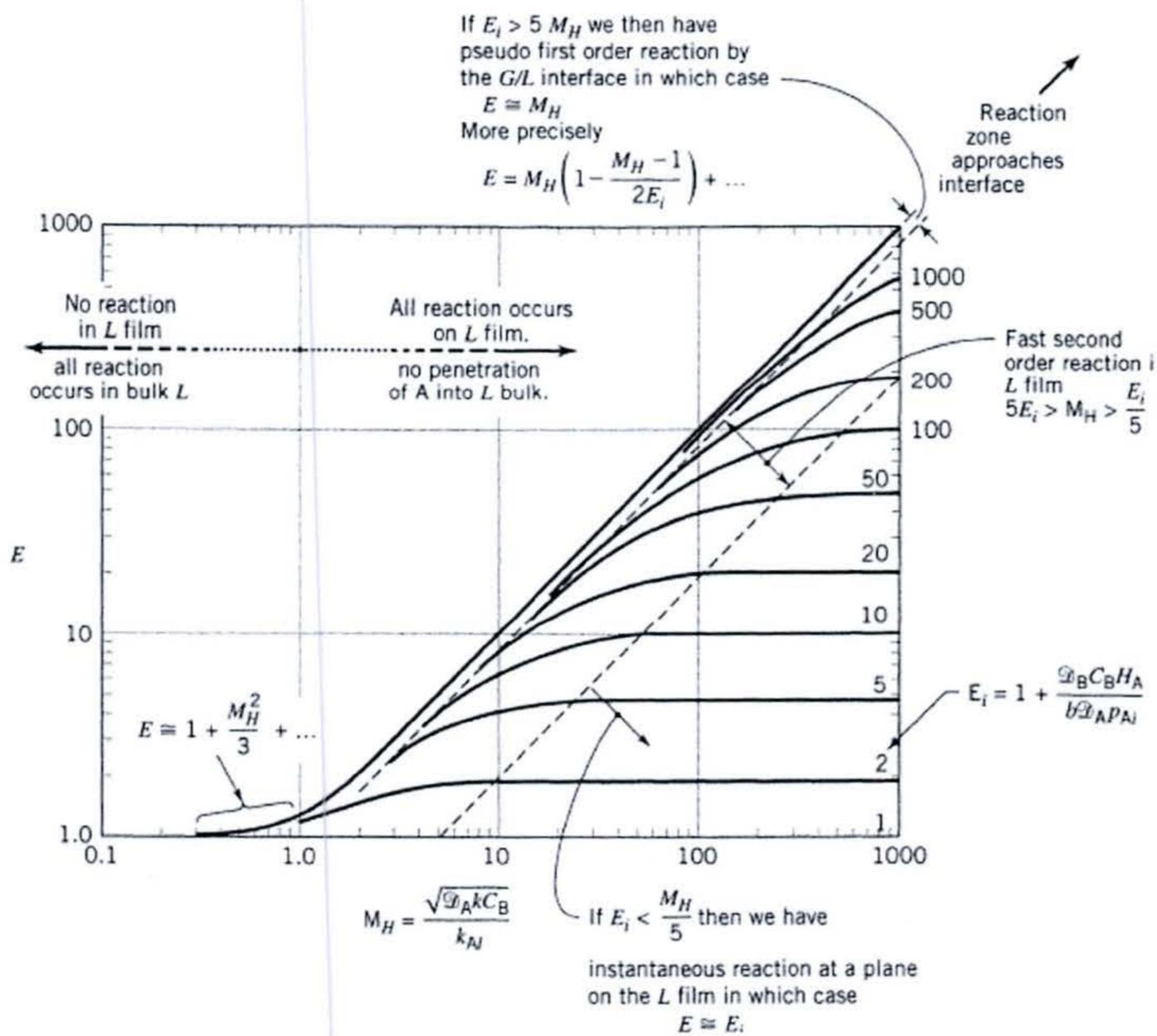


Figure 1: The enhancement factor for fluid-fluid reactions as a function of M_H and E_i ,
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