



UNIVERSITI
TEKNOLOGI
PETRONAS

FINAL EXAMINATION JANUARY 2025 SEMESTER

COURSE : CEB2093 - REACTION ENGINEERING II
DATE : 15 APRIL 2025 (TUESDAY)
TIME : 2.30 PM - 5.30 PM (3 HOURS)

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

- i. There are **SIX (6)** pages in this Question Booklet including the cover page and appendix.
- ii. **DOUBLE-SIDED** Question Booklet.
- iii. **Graph papers and Engineering Data & Formulae Booklet will be provided.**

1. A new type of amorphous aluminosilicate catalyst was prepared by a sol-gel method using poly(ethylene glycol) (PEG) template, for hydrocracking purposes. Nitrogen physisorption isotherm was carried out at 77 K using 3.4 g of the catalyst. The data for the adsorption of nitrogen on the amorphous aluminosilicate catalyst is available in **TABLE Q1**, where P/P_0 refers to the relative pressure and V is the volume of nitrogen gas absorbed, $\text{cm}^3(\text{STP}) \cdot \text{g}^{-1}$.

TABLE Q1: Nitrogen absorption on the amorphous aluminosilicate catalyst

| P/P_0 | $V, \text{cm}^3(\text{STP}) \cdot \text{g}^{-1}$ |
|---------|--|
| 0.10 | 3.0 |
| 0.20 | 5.5 |
| 0.30 | 7.0 |
| 0.55 | 10.5 |
| 0.60 | 15.5 |

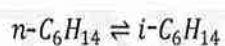
- a. Determine the volume of gas (V_m) required to fit into Langmuir adsorption isotherm model.

[19 marks]

- b. Explain and calculate the BET surface area of the catalyst at STP.

[6 marks]

2. a. Derive a rate of expression of the hydroisomerisation of n-hexane to iso-hexane over a Pt/Al₂O₃ catalyst, assuming that the reaction is a dual site surface reaction-controlled mechanism.



[17 marks]

- b. Compare the differences between Langmuir-Hinselwood model and Eley-Rideal mechanism in terms of adsorption taking place and reaction pathway.

[8 marks]

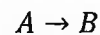
3. a. Explain the importance of high porosity and low tortuosity preferred in a catalyst.

[4 marks]

- b. Describe a graph of the relationship between diffusion flux and pore size of a catalyst. Identify and explain different diffusion regimes in the graph.

[8 marks]

- c. A porous cylindrical catalyst pellet is used in a first-order gas-phase reaction:



The pellet has a radius, $R = 2.5 \text{ mm}$, and the reaction occurs with an intrinsic rate constant of $k = 0.02 \text{ s}^{-1}$. Species A within the catalyst pores has effective diffusivity of $D_e = 5.0 \times 10^{-6} \text{ m}^2 \cdot \text{s}^{-1}$. Assume that the reaction occurs only inside the catalyst, and external mass transfer resistance is negligible.

- i. Calculate the Thiele Modulus for the catalyst pellet and discuss **TWO (2)** significance in relation to internal diffusion resistance.

[7 marks]

- ii. Given that effectiveness factor of the catalyst, $\eta = 1$. Propose a strategy to enhance catalyst efficiency based on design modification or operating conditions.

[6 marks]

4. a. Dry reforming of methane (CH_4) is a catalytic process for syngas production. A 10% $\text{Ni}/\text{Al}_2\text{O}_3$ catalyst was synthesized via sol-gel method and tested in a fixed-bed reactor. After 30 minutes and 70 minutes on stream, CH_4 conversion of 85% and 60% were obtained respectively.

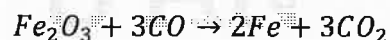
i. Describe if the catalyst has undergone deactivation with justifications.

[4 marks]

ii. The $\text{Ni}/\text{Al}_2\text{O}_3$ catalyst may undergo different types of catalyst deactivation. Provide **THREE (3)** types of deactivation mechanism and explain each of them using appropriate illustrations.

[12 marks]

- b. In a blast furnace, hematite (Fe_2O_3) is reduced to iron (Fe) in carbon monoxide (CO) according to the following reaction:



A spherical Fe_2O_3 pellet with an initial radius of 125 μm is placed in a high temperature CO stream at 1000°C and 3 atmospheric pressures. The reduction process follows the shrinking core model with chemical reaction control. Assume that the rate of reaction constant at this temperature, $k = 3.0 \times 10^{-6} \text{ cm} \cdot \text{s}^{-1}$, molecular weight of Fe_2O_3 is $159.7 \text{ g} \cdot \text{mol}^{-1}$ with density $7.24 \text{ g} \cdot \text{cm}^{-3}$. Calculate the minimum time required for complete reduction of the Fe_2O_3 pellet into iron. State your assumptions.

[9 marks]

-END OF PAPER-

APPENDIX I: FORMULAS

$$\frac{x}{v(1-x)} = \frac{1}{v_m c} + \frac{(c-1)}{v_m c} x$$

$$S = 4.35 v_m$$

$$C_t = C_v + C_{R,S} + C_{P,S}$$

$$\phi = R \sqrt{\frac{k}{D_e}}$$

$$t = \frac{\rho_B R}{3bk_g C_{Ag}} \left\{ 1 - \left(\frac{r_c}{R} \right)^3 \right\}$$

$$t = \frac{\rho_B R^2}{6bD_e C_{Ag}} \left\{ 1 - 3 \left(\frac{r_c}{R} \right)^2 + 2 \left(\frac{r_c}{R} \right)^3 \right\}$$

$$t = \frac{\rho_B R}{bk_g C_{Ag}} \left(1 - \frac{r_c}{R} \right)$$

$$S_a = \frac{S_o}{1 + k_d t}$$