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_o refers to the relative pressure and V is the volume of nitrogen gas absorbed, $cm^3(STP)\cdot g^{-1}$.

TABLE Q1: Nitrogen absorption on the amorphous aluminosilicate catalyst

P/P_0	V, cm^3(STP))$\cdot g^{-1}$
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/Al_2O_3 catalyst, assuming that the reaction is a dual site surface reaction-controlled mechanism.

$$n\text{-}C_6H_{14} \rightleftharpoons i\text{-}C_6H_{14}$$

[17 marks]

b. Compare the differences between Langmuir-Hinselwood model and Eiley-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:

$$A \rightarrow B$$

The pellet has a radius, R = 2.5 mm, and the reaction occurs with an intrinsic rate constant of k = 0.02 s^{-1}. Species A within the catalyst pores has effective diffusivity of D_e = 5.0×10^{-6} m^{2}·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, η = 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% Ni/Al_2O_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 Ni/Al_2O_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:

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

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 = 3.0×10^{-6} $cm\cdot s^{-1}$, molecular weight of Fe_2O_3 is 159.7 $g\cdot mol^{-1}$ with density 7.24 $g\cdot cm^{-3}$. 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

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

$$S = 4.35v_m$$

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

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

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

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

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

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