UNIVERSITI MALAYSIA PERLIS

Peperiksaan Akhir Semester Pertama
Sidang Akademik 2025/2026

Februari 2026

KMJ32003 – Reaction Engineering
[Kejuruteraan Tindakbalas]

Masa: 3 jam

Please make sure that this question paper has **FOURTEEN (14)** printed pages including this front page before you start the examination.
*[Sila pastikan kertas soalan ini mengandungi **EMPAT BELAS (14)** muka surat yang bercetak termasuk muka hadapan sebelum anda memulakan peperiksaan ini.]*

This question paper has **TWO** parts that consist of **SIX (6)** questions. Answer **ALL FOUR (4)** questions in **PART A** and **ANY ONE (1)** question in **PART B**. Each question contributes 20 marks.
*[Kertas soalan ini mengandungi **DUA** bahagian yang terdiri daripada **ENAM (6)** soalan. Jawab **SEMUA EMPAT (4)** soalan di **BAHAGIAN A** dan **MANA-MANA SATU (1)** soalan di **BAHAGIAN B**. Markah bagi tiap-tiap soalan adalah 20 markah.]*

PART A
[BAHAGIAN A]

Answer ALL FOUR (4) questions in PART A.
[Jawab SEMUA EMPAT (4) soalan di BAHAGIAN A.]

Question 1
[Soalan 1]

(a) Reactors can be divided into two broad categories, which are batch reactors and continuous reactors. In continuous reactors, there are three common types such as Continuous Stirred Tank Reactor (CSTR), Plug Flow Reactor (PFR) and Packed Bed Reactor (PBR). Differentiate between these three reactors.
[Reaktor boleh dibahagikan kepada dua kategori besar, iaitu reaktor kelompok dan reaktor selanjar. Dalam reaktor selanjar, terdapat tiga jenis yang biasa seperti Reaktor Tangki Teraduk Selanjar (CSTR), Reaktor Palam Aliran (PFR) dan Reaktor Lapisan Terpadat (PBR). Bezakan antara ketiga-tiga reaktor ini.]

(3 Marks/ *Markah*)

(b) The following elementary liquid reaction is to be carried out in a flow reaction system. Given k = 1 min^{-1}
[Tindak balas asas cecair berikut akan dijalankan dalam sistem tindak balas aliran. Diberikan k = 1 min^{-1}.]

$$A \rightarrow B$$

The reaction data, shown in **Table Q1** were obtained.
*[Data tindak balas, yang ditunjukkan dalam **Jadual Q1** diperolehi.]*

Table Q1 Reaction data
***[Jadual Q1** Data tindakbalas]*

Conversion, X (%) *[Penukaran, X (%)]*	10	20	30	40	50	60	70	80
C_A (mol/ dm^3)	1.8	1.6	1.4	1.2	1	0.8	0.6	0.4

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(i) Decide the most suitable combination of reactors that would have the smallest volume to achieve these conversions. You are required to sketch any diagram used to solve this.
[Tentukan gabungan reaktor yang paling sesuai yang mempunyai isipadu terkecil untuk mencapai penukaran-penukaran ini. Anda dikehendaki melakar sebarang rajah yang digunakan untuk menyelesaikannya.]

(14 Marks/ *Markah*)

(ii) If you are asked by the top management of your company to opt for using only one CSTR, justify your selection in part (i) by comparing the volumes.
[Jika anda diminta oleh pengurusan atasan syarikat anda untuk memilih menggunakan hanya satu CSTR, justifikasikan pilihan anda di bahagian (i) dengan membandingkan isipadu.]

(3 Marks/ *Markah*)

Question 2
[Soalan 2]

(a) The irreversible elementary gas phase reaction in **Equation Q2** is currently carried out in a packed bed reactor containing 100 kg of catalyst. The entering pressure is 20 atm. The flow rate and temperature remain unchanged. The reactor was assumed to has no pressure drop.
*[Tindak balas fasa gas asas tidak berbalik dalam **Persamaan Q2** sedang dijalankan dalam reaktor lapisan terpadat yang mengandungi 100 kg pemangkin. Tekanan masuk ialah 20 atm. Kadar aliran dan suhu kekal tidak berubah. Reaktor tersebut diandaikan tidak mempunyai penurunan tekanan.]*

$$2A \rightarrow B + C \qquad \textbf{(Equation Q2)}$$

(i) Formulate the design equation, W in terms of conversion, X and C_{AO}. You can construct a stoichiometric table to assist your answer.
[Formulasikan persamaan reka bentuk, W dari segi penukaran, X dan C_{AO}. Anda boleh membina jadual stoikiometri untuk membantu jawapan anda.]

(12 Marks/ *Markah*)

(ii) Evaluate the conversion. Given that the entering flowrate of A is 8 m^3/h, the concentration of A is 0.5 $kmol/m^3$ and the specific reaction rate is 15 $m^6/$ kmol kg catalyst h.
[Nilaikan penukaran. Diberi kadar alir masuk A ialah 8 m^3/j, kepekatan A ialah 0.5 $kmol/m^3$ dan kadar tindak balas tentu ialah 15 $m^6/$ kmol kg pemangkin j.]

(5 Marks/ *Markah*)

(b) For the irreversible gas-phase reaction:
[Bagi tindak balas fasa-gas tidak berbalik:]

$$A \rightarrow 2B$$

The following correlation was determined from laboratory data (the initial concentration of A is 0.5 mol/L):
[Hubungan berikut telah ditentukan daripada data makmal (kepekatan awal A adalah 0.5 mol/L):]

$$For\ X \leq 0.5: \frac{1}{-r_A} = 3.0 \frac{m^3 min}{mol}$$

$$For\ X \geq 0.5: \frac{1}{-r_A} = 3.0 + 10(X - 0.5) \frac{m^3 min}{mol}$$

The volumetric flow rate was 12 L/min.
[Kadar aliran isipadu adalah 12 L/min.]

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Determine over what range of conversions are the plug-flow reactor (PFR) and continuous stirred tank reactor (CSTR) volumes identical?
[Tentukan dalam lingkungan apa penukaran reaktor aliran palam (PFR) dan reaktor tangki-teraduk berterusan (CSTR) mempunyai isipadu yang sama?]

(3 Marks/ *Markah*)

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Question 3
[Soalan 3]

(a) State the steps involved in a reaction taking place in a presence of solid catalyst.
[Nyatakan langkah-langkah yang terlibat di dalam tindakbalas yang berlaku dengan kehadiran mangkin pepejal.]

(7 Marks/ *Markah*)

(b) t-Butyl alcohol (TBA) is an important octane enhancer that is used to replace lead additives in gasoline. t-Butyl alcohol was produced by the liquid-phase hydration (W) of isobutene (I) over an Amberlyst-15 catalyst. The system is normally a multiphase mixture of hydrocarbon, water and solid catalysts. However, the use of cosolvents or excess TBA can achieve reasonable miscibility. The reaction mechanism is believed to be:
[Alkohol t-Butil (TBA) adalah suatu penggalak oktana penting yang digunakan untuk menggantikan bahan tambahan plumbum di dalam gasolin. Alkohol t-Butil dihasilkan dengan penghidratan (W) fasa cecair untuk isobutena (I) melalui pemangkin Amberlyst-15. Sistem ini pada kebiasaannya adalah campuran multi-fasa hidrokarbon, air dan mangkin pepejal. Namun, penggunaan sepelarut atau lebihan TBA dapat menghasilkan kelarutcampuran berpatutan. Mekanisme tindak balas dipercayai seperti berikut:]

$$I + S \rightleftharpoons I \cdot S$$

$$W + S \rightleftharpoons W \cdot S$$

$$W \cdot S + I \cdot S \rightleftharpoons TBA \cdot S + S$$

$$TBA \cdot S \rightleftharpoons TBA + S$$

Derive a rate law assuming:
[Terbitkan hukum kadar dengan menganggap:]

(i) The surface reaction is rate-limiting.
[Tindakbalas permukaan sebagai penghad-kadar.]

(5 Marks/ *Markah*)

(ii) The adsorption of isobutene is limiting.
[Penjerapan isobutena sebagai penghad.]

(5 Marks/ *Markah*)

(iii) The reaction follows Eley-Rideal kinetics and that the surface reaction is limiting.
[Tindakbalas mematuhi kinetik Eley-Rideal dan tindakbalas permukaan sebagai penghad.]

$$I \cdot S + W \longrightarrow TBA \cdot S$$

(3 Marks/ *Markah*)

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Question 4
[Soalan 4]

The residence time distribution (RTD) of a chemical reactor is a probability distribution function that describes the amount of time a fluid element could spend inside the reactor. The theory of residence time distributions generally begins with three assumptions.
[Taburan sela masa (TSM) bagi reaktor kimia adalah fungsi taburan kebarangkalian yang menerangkan jumlah masa bagi elemen cecair berada di dalam reaktor. Teori taburan sela masa secara amnya bermula dengan tiga andaian.]

(a) State the assumptions considered for the theory of RTD.
[Nyatakan andaian-andaian yang dipertimbangkan bagi teori RTD.]

(3 Marks/ *Markah*)

(b) The following data were obtained from a tracer test to a reactor. Based on the data in **Table Q4**:
*[Data berikut diperolehi daripada ujian pengesanan untuk reaktor. Berdasarkan data dalam **Jadual Q4**:]*

Table Q4: Tracer test data
*[**Jadual Q4**: Data ujian pengesanan]*

t (s)	0	5	10	15	20	25	30	35
C_t (mg/dm^3)	0	0	0	5	10	5	0	0

(i) Plot $C_t(t)$.
[Lakarkan Ct(t).]

(2 Marks/ *Markah*)

(ii) Calculate $E(t)$.
[Kirakan E(t).]

(4 Marks/ *Markah*)

(iii) Calculate the fraction of material that spends between 15 and 20 seconds in the reactor by plotting $E(t)$.
[Kirakan bahagian pecahan bahan yang digunakan antara 15 dan 20 saat dalam reaktor dengan melakar E(t).]

(5 Marks/*Markah*)

(iv) Evaluate $F(t)$, and the fraction of material that spends 25 seconds or less in the reactor.
[Anggarkan F(t), dan bahagian pecahan daripada bahan yang digunakan pada 25 saat atau kurang dalam reaktor.]

(6 Marks/ *Markah*)

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PART B
[BAHAGIAN B]

Answer any ONE (1) question in PART B.
[Jawab mana-mana SATU (1) soalan di BAHAGIAN B.]

Question 5
[Soalan 5]

(a) To study the photochemical decay of aqueous bromine in bright sunlight, a small quantity of liquid bromine was dissolved in water contained in a glass battery jar and placed in direct sunlight. The reaction involved is shown below.
[Untuk mengkaji pereputan fotokimia bromin berair dalam cahaya matahari yang terang, sejumlah kecil cecair bromin telah dilarutkan dalam air yang terkandung dalam balang bateri kaca dan diletakkan di bawah cahaya matahari langsung. Tindak balas yang terlibat ditunjukkan di bawah.]

$$Br \xrightarrow{\text{Sunlight}} \text{Products}$$

The following reaction data were obtained:
[Data tindak balas berikut diperolehi:]

Table Q5 Reaction data
***[Jadual Q5** Data tindak balas]*

Time (min) *[Masa (min)]*	10	20	30	40	50	60
Concentration of Br (mg/L) *[Kepekatan Br (mg/L)]*	2.45	1.74	1.25	0.88	0.62	0.44

Prove that the order of reaction in bromine is first order using graphical differentiation method. You are required to plot the histogram.
[Buktikan bahawa tertib tindak balas dalam bromin ialah tertib pertama menggunakan kaedah pembezaan bergraf. Anda dikehendaki memplot histogram.]

(8 Marks/ *Markah*)

(b) The following elementary gas-phase reaction is carried out isothermally in a flow reactor with no pressure drop. The specific reaction rate at 50 °C is 0.0001 min^{-1} and the activation energy is 85 kJ/mol. Pure di-tert-butyl peroxide ($(CH_3)_3COOC(CH_3)_3$) enters the reactor at 10 atm and 127 °C and at a molar flow rate of 2.5 mol/min.
[Tindak balas asas fasa gas berikut dijalankan secara isoterma dalam reaktor aliran tanpa penurunan tekanan. Kadar tindak balas spesifik pada 50 °C ialah 0.0001 min^{-1} dan tenaga pengaktifan ialah 85 kJ/mol. Di-tert-butil peroksida ($(CH_3)_3COOC(CH_3)_3$) tulen memasuki reaktor pada 10 atm dan 127 °C dan pada kadar aliran molar 2.5 mol/min.]

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$$(CH_3)_3COOC(CH_3)_3 \rightarrow C_2H_6 + 2CH_3COCH_3$$

(i) Construct a stoichiometric table for the reaction.
[Binakan jadual stoikiometri untuk tindak balas.]

(5 Marks/ *Markah*)

(ii) Derive the equation for concentration of all species in terms of the initial concentration of $(CH_3)_3COOC(CH_3)_3$ and the conversion.
[Terbitkan persamaan bagi kepekatan semua spesies dari segi kepekatan awal $(CH_3)_3COOC(CH_3)_3$ dan penukaran.]

(5 Marks/ *Markah*)

(iii) Calculate the concentration of C_2H_6 and CH_3COCH_3, when the conversion of di-tert-butyl peroxide is 80%.
[Kirakan kepekatan C_2H_6 and CH_3COCH_3, apabila penukaran di-tert-butyl peroxide ialah 80%.]

(2 Marks/ *Markah*)

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Question 6
[Soalan 6]

(a) State **FOUR (4)** types of multiple reactions. Describe these types of multiple reactions by giving appropriate equations.
*[Nyatakan **EMPAT (4)** jenis tindakbalas berbilang. Terangkan jenis-jenis tindakbalas berbilang ini dengan memberikan persamaan-persamaan yang bersesuaian.]*

(4 Marks/ *Markah*)

(b) In a chemical industry, liquid reactant A decomposes as follows:
[Dalam satu industri kimia, bahan tindakbalas cecair A terurai seperti berikut:]

$A \longrightarrow R$ $\quad r_R = k_1$ $\quad , k_1=1.5\ mol/m^3.min$

$A \xrightarrow{k_2} D$ $\quad r_D = k_2C_A$ $\quad , k_2=2\ min^{-1}$

$A \xrightarrow{k_3} T$ $\quad r_T = k_3C_A^2$ $\quad , k_3=0.4\ m^3/mol.min$

A feed of aqueous A (C_{A0}=40 mol/m^3) enters a continuous stirred tank reactor, decomposes and a mixture of A, R, D and T leaves the reactor. D is the desired product while R and T are the undesired products.
[Suatu suapan akues A (C_{A0}=40 mol/m^3) memasuki reaktor tangki teraduk berterusan, terurai dan campuran A, R, D dan T meninggalkan reaktor. D adalah produk yang diingini manakala R dan T adalah produk-produk yang tidak diingini.]

(i) Calculate the optimum concentration of A, C_A and mean residence time, τ which maximized the selectivity of D in the reactor.
[Kirakan kepekatan optimum A,C_A dan masa mastautin purata, τ yang memaksimakan kememilihan D di dalam reaktor.]

(8 Marks/ *Markah*)

(ii) Calculate the optimum concentration of A, C_A which maximizes the yield of D in the reactor
[Kirakan kepekatan optimum A,C_A yang memaksimakan keluaran D di dalam reaktor.]

(4 Marks/ *Markah*)

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(c) The following elementary liquid phase reactions are to be carried out:
[Tindakbalas fasa cecair asas berikut akan dijalankan:]

$$A + B \xrightarrow{k_1} R$$

$$R + B \xrightarrow{k_2} S$$

Species R is the desired product.
[Spesis R merupakan produk yang diingini.]

Derive the instantaneous selectivity of R with respect to S, ($S_{R/S}$) in terms of concentration of A, (C_A), concentration of B, (C_B), concentration of R, (C_R), k_1 and k_2.
[Terbitkan kememilihan serta merta bagi R terhadap S, ($S_{R/S}$) dalam sebutan-sebutan kepekatan A, (C_A), kepekatan B, (C_B), kepekatan R, (C_R), k_1 dan k_2.]

(4 Marks/ *Markah*)

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APPENDIX

Useful Equations:

1. $r_A V = \frac{dN_A}{dt}$

2. $V = \frac{F_{AO}X}{-r_A}$

3. $V = F_{AO}\int_0^X \frac{dX}{-r_A}$

4. $W = F_{AO}\int_0^X \frac{dX}{-r'_A}$

5. $V = V_0(1+\varepsilon X)\frac{P_0}{P}\frac{T}{T_0}$

6. $ln\left(\frac{-dC_A}{dt}\right) = \alpha lnC_A + \ln k$

7. $E(t) = \frac{C(t)}{\int_0^\infty C(t)dt}$

8. $E(t) = \int_0^\infty E(t)\,dt = 1$

9. $F(t) = \frac{C(t)}{C_0}$

10. $F(t) = \int_0^t E(t)\,dt$

11. $F(t_1) = \int_0^{t_1} E(t)dt$

12. $1 - F(t_1) = 1 - \int_0^{t_1} E(t)dt = \int_{t_1}^\infty E(t)\,dt$

13. $S_{DU} = S_{D/U} = \frac{r_D}{r_U}$

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14. $Y_D = \dfrac{r_D}{-r_A}$

15. $S_{B/XY} = \dfrac{r_B}{r_X + r_Y}$

Constant

$R = 8.314\ kPa.dm^3/mol.\ K$
$R = 0.082\ L.atm/mol.\ K$

Numerical Evaluation of Integrals:

1. **Trapezoidal rule** (two-point).

$$\int_{X_0}^{X_1} f(X)dX = \frac{h}{2}[f(X_0)+f(X_1)]$$

$$where \quad h = X_1 - X_0$$

2. **Simpson's one third rule** (three-point).

$$\int_{X_0}^{X_2} f(X)dX = \frac{h}{3}[f(X_0)+4f(X_1)+f(X_2)]$$

$$where \quad h = \frac{X_2 - X_0}{2} \quad X_1 = X_0 + h$$

3. **Simpson's three-eighths rule** (four-point).

$$\int_{X_0}^{X_3} f(X)dX = \frac{3}{8}h[f(X_0)+3f(X_1)+3f(X_2)+f(X_3)]$$

$$where \quad h = \frac{X_3 - X_0}{3} \quad X_1 = X_0 + h \quad X_2 = X_0 + 2h$$

4. **Five-point quadrature formula** (five-point).

$$\int_{X_0}^{X_4} f(X)dX = \frac{h}{3}[f(X_0)+4f(X_1)+2f(X_2)+4f(X_3)+f(X_4)]$$

$$where \quad h = \frac{X_4 - X_0}{4}$$

Useful Graphical Formula:

1. Initial point: $\left[\frac{dC_A}{dt}\right]_{t_0} = \frac{-3C_{A0} + 4C_{A1} - C_{A2}}{2\Delta t}$

2. Interior point: $\left[\frac{dC_A}{dt}\right]_{t_i} = \frac{1}{2\Delta t}(C_{A(i+1)} - C_{A(i-1)})$

3. Final point: $\left[\frac{dC_A}{dt}\right]_{t_5} = \frac{1}{2\Delta t}(C_{A3} - 4C_{A4} + 3C_{A5})$

Useful Integrals Formula:

1. $\int_0^X \frac{dX}{1-X} = \ln\frac{1}{1-X}$

2. $\int_0^X \frac{dX}{(1-X)^2} = \frac{X}{1-X}$

3. $\int_0^X \frac{dX}{(1+\varepsilon X)} = \frac{1}{\varepsilon}\ln(1+\varepsilon X)$

4. $\int_0^X \frac{(1+\varepsilon X)}{(1-X)} dX = (1+\varepsilon)\ln\frac{1}{1-X} - \varepsilon X$

5. $\int_0^X \frac{(1+\varepsilon X)}{(1-X)^2} dX = \frac{(1+\varepsilon)X}{(1-X)} - \varepsilon\ln\frac{1}{1-X}$

6. $\int_0^X \frac{(1+\varepsilon X)^2}{(1-X)^2} dX = 2\varepsilon(1+\varepsilon)\ln(1-X) + \varepsilon^2 X + \frac{(1+\varepsilon)^2 X}{(1-X)}$

7. $\int_0^X \frac{dX}{(1-X)(\theta_B - X)} = \frac{1}{\theta_B - 1}\ln\frac{\theta_B - X}{\theta_B(1-X)} \qquad \theta_B \neq 1$

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