UTHM
Universiti Tun Hussein Onn Malaysia

# UNIVERSITI TUN HUSSEIN ONN MALAYSIA

## FINAL EXAMINATION
## SEMESTER II
## SESSION 2016/2017

| | | |
|---|---|---|
| COURSE NAME | : | REACTOR TECHNOLOGY |
| COURSE CODE | : | DAK 30403 |
| PROGRAMME | : | 3 DAK |
| EXAMINATION DATE | : | JUNE 2017 |
| DURATION | : | 3 HOURS |
| INSTRUCTION | : | SECTION A) ANSWER **ALL** QUESTIONS<br>SECTION B) ANSWER **TWO (2)** QUESTIONS |



THIS QUESTION PAPER CONSISTS OF **TEN (10)** PAGES

**SECTION A**

**Q1** (a) (i) Explain what is a reactor and what is normally happens inside it.
(4 marks)

(ii) State **TWO (2)** importance to learn chemical reaction engineering.
(4 marks)

(iii) State **THREE (3)** variables that may affect the rate of reaction.
(3 marks)

(b) **Figure Q1 (b)** shows a hydrolysis process which is carried out in a square-shaped container with 50 cm high and 0.09 $m^2$ of cross-sectional area. If 1.3 kg/s of oxygen gas were produced, calculate the rate of reaction, $-r_A$ of water, hydrogen gas and oxygen gas. The overall reaction of the process is $2H_2O \rightarrow 2H_2 + O_2$.
[Molecular weight for H = 1 g/mol, O = 16 g/mol]
(8 marks)

(c) Copy and fill in the blanks in the **Table Q1 (b)** in your answer script.
(6 marks)

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**Q2** (a) A simplified chemical reaction is given as 2A + B → C.

(i) Define the term $N_{A0}$, $N_A$ and $N_{C0}$.

(6 marks)

(ii) Show an equation to relate the value of $N_{A0}$ and $N_{B0}$ based on the simplified chemical equation above.

(2 marks)

(b) A series reactor used in a chemical industry was shown in **Figure Q2 (b)**. The first reactor, $V_1$ is a CSTR, $V_2$ is a PFR and $V_3$ is a CSTR. In an annual maintenance, $V_3$ is found to be heavily damaged and is permanently taken out for a major service. The current operations now only use $V_1$ and $V_2$. However, the conversion of $V_1$ remains the same but the new conversion of $V_2$ is 45%. The molar flow rate, $F_{A0}$ is 100 mol/s.

(i) Use the reaction data in **Table Q2 (b)** and calculate the volume of $V_1$ and $V_2$ in $m^3$.

(8 marks)

(ii) In the following month, it is found out that $V_2$ is also require major maintenance and has to be taken out permanently. If the total desired conversion remains 65%, calculate the size of reactor if only $V_1$ is used for the entire operation.

(3 marks)

(c) (i) State **FOUR (4)** possible arrangements for series reactor.

(4 marks)

(ii) Explain why batch reactor cannot be used in the series reactor.

(2 marks)

**SECTION B**

**Q3** (a) (i) Define the term $-r_A$ and $k$.

(4 marks)

(ii) Explain *the order of reaction* and *the overall order of reaction* based on the simplified chemical equation below.

$$0.5A + 3B \rightarrow 2C$$

(4 marks)

(iii) Write the elementary rate law equation and the reversible rate law equation for the chemical equation in **Q3 (a)(ii)**.

(6 marks)

(iv) If the actual reaction order for the chemical equation in **Q3 (a)(ii)** is given as below, write its non-elementary rate law equation.

The reaction order for component A = $1^{st}$ order.
The reaction order for component B = $2^{nd}$ order.

(2 marks)

(b) Show the unit of $k$ for a reaction rate law of $-r_A = k_A C_A^2$.

(3 marks)

(c) A reaction is carried out in a constant-volume batch reactor with the equation below;

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

Copy and complete the full stoichiometric **Table Q3 (c)** in your answer script, assuming that there are no inert components involved in the oxidation process.

(6 marks)

**Q4** (a) There are **TWO (2)** major problems studied in the reactor design besides. If the first problem is to find the reactor volume, state the other problem.

(3 marks)

(b) The liquid phase reaction of sodium thiosulfate and hydrogen proxide is carried out in a **constant-volume** batch reactor. The reaction equation is given as below.

$Na_2S_2O_3 + 2H_2O_2 \rightarrow$ Product

$k = 6.85 \times 10^{11} \exp(-E/RT)$
R = 8.31 J / mol.K
E = 76.48 kJ/mol A
$C_{A0} = 0.12$ kmol/m$^3$
$C_{B0} = 0.22$ kmol/m$^3$
T = 60°C

(i) Calculate the value of $k$.

(3 marks)

(ii) Write the simplified chemical equation for this process.

(3 marks)

(iii) Assuming first order kinetics with respect to A and first order with respect to B, derive the rate law equation, $-r_A$ for 80% conversion. Apply the technique used in the stoichiometry table to simplify your works.
[Hint: do not insert the value of $k$, $C_{A0}$ and $C_{B0}$ in your equation]

(6 marks)

(iv) Compare the reaction times, $t$ needed for reaction temperatures of 60°C and 120°C, assuming second order kinetics with respect to A and zero order with respect to B, and constant conversion at 80%.
[Hint: derive the rate law equation first before inserting any value]

(10 marks)

**Q5** (a) (i) Define the term series reactions and parallel reactions.

(4 marks)

(ii) Explain the differences between the two set of reactions below.

Set 1:

$$D + E \rightarrow F + G$$
$$H + E \rightarrow J + K$$

Set 2:

$$D + E \rightarrow F + G$$
$$H + I \rightarrow J + K$$

(4 marks)

(b) Write the net rate law equations, $-r_A$ for the reactions below.

(i) Reaction of A to produce desired product C.

$$\alpha_1 A \overset{k_C}{\rightarrow} C$$

$$\alpha_2 A \overset{k_U}{\rightarrow} U$$

(3 marks)

(ii) Reaction of A to produce desired product C.

$$A \overset{k_A}{\rightarrow} B \overset{k_B}{\rightarrow} C$$

(3 marks)

(c) (i) For the reaction in **Q6 (a) (i)**, state **TWO (2)** ways to maximize the desired product (based on its instantaneous selectivity, $S_{D/U}$).

(6 marks)

(ii) For the reaction in **Q6 (a) (ii)**, state **ONE (1)** way to maximize the desired product (based on its instantaneous selectivity, $S_{D/U}$).

(2 marks)

(d) State **ONE (1)** general factor to maximize the product in the parallel reactions, and **ONE (1)** general factor to maximize the product in the series reactions.

(3 marks)

**Q6** (a) (i) Define the term catalyst.

(3 marks)

(ii) State few examples of commercial catalyst exist in the market.

(4 marks)

(b) Based on the statements below, state whether they are homogeneous or heterogeneous catalytic reaction.

(i) Dehydrogenation process of liquid cyclohexane using platinum-on-alumina as the catalyst.

(ii) "Fisher esterification" process occurs when a liquid alcohol and liquid acid react to form ester, using sulphuric acid solution as a catalyst.

(iii) "Haber process" occurs when hydrogen gas and nitrogen gas react to form ammonia, using metal iron as a catalyst.

(6 marks)

(c) (i) Some of the commonly found catalyst are porous catalyst, molecular sieves and monolithic. Briefly explain those **THREE (3)** catalysts.

(6 marks)

(ii) State **THREE (3)** ways to deactivate a catalyst.

(3 marks)

(d) State the **THREE (3)** steps involved in the catalytic reaction based on the **Figure Q6 (d)** below. Take note that at the bottom of each image sequence below is the catalyst surface (the lined surface).

(3 marks)

**– END OF QUESTION –**

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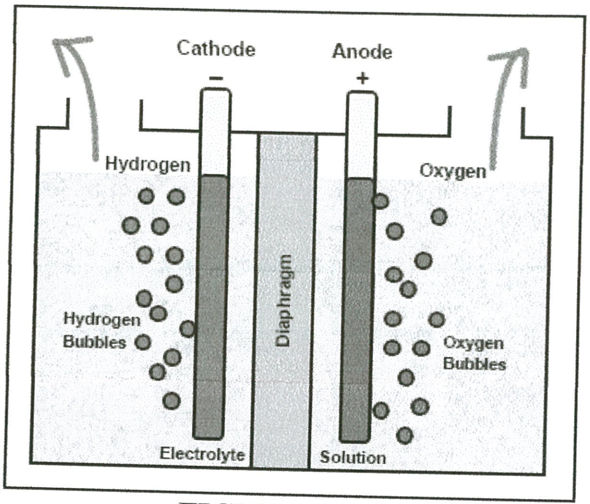


**FIGURE Q1 (b)**

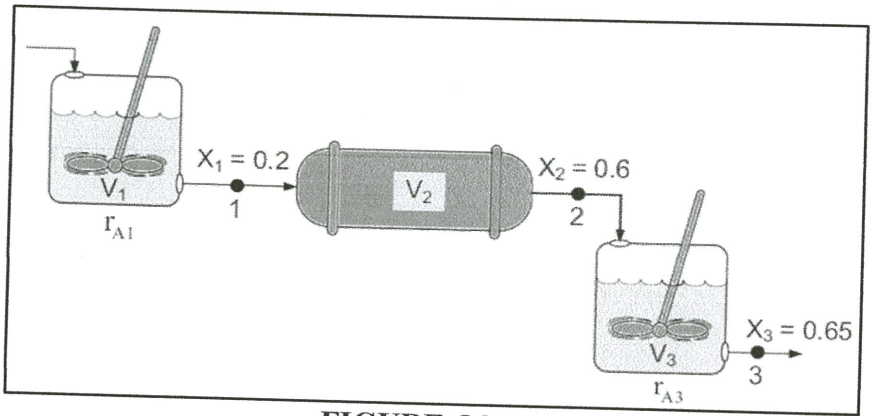


**FIGURE Q2 (b)**

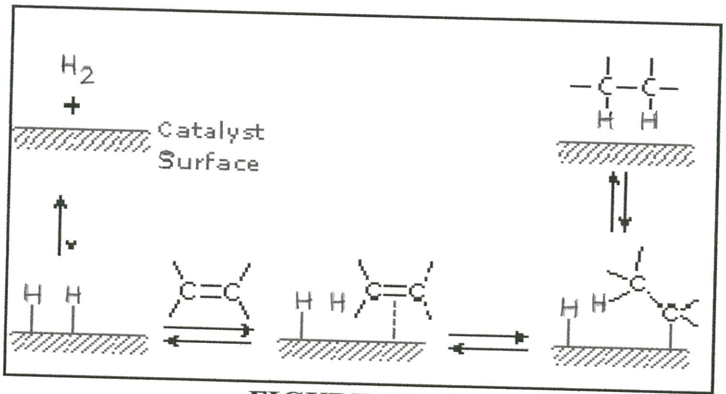


**FIGURE Q6 (d)**

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**TABLE Q1 (b)**

| The differences between Batch Reactor, CSTR and PFR. | Batch Reactor | CSTR | PFR |
|---|---|---|---|
| 1. Inlet and outlet molar flow rate. | | | |
| 2. Conversion per volume | | | |
| 3. Suitability with liquid and gaseous phase | | | |

**TABLE Q2 (b)**

| $X$ | $-r_A\ (mol/m^3.s)$ |
|---|---|
| 0.00 | 4.3 |
| 0.20 | 4.0 |
| 0.45 | 3.0 |
| 0.65 | 1.5 |
| 0.80 | 0.25 |

**TABLE Q3 (c)**

| Species Name | Symbol | Concentration of component, $C_i\ (mol/m^3)$ | | |
|---|---|---|---|---|
| | | Initial $(mol/m^3)$ | Change $(mol/m^3)$ | Remaining $(mol/m^3)$ |
| | A | | | $C_A =$ |
| | B | | | $C_B =$ |
| | C | | | $C_C =$ |
| | D | | | $C_D =$ |

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List of Formula

$-r_A\ (mol/m^3.s)$

Design equation for batch reactor: $V = \frac{N_{A0}}{t}\int_{X(0)}^{X(t)} \frac{dX}{-r_A}$

Reaction time for batch reactor: $t = C_{A0}\int_{X(0)}^{X(t)} \frac{dX}{-r_A}$

Design equation for CSTR: $V = \frac{(F_{A0}X)}{-r_A}$

Design equation for PFR: $V = F_{A0}\int_{X(0)}^{X(t)} \frac{dX}{-r_A}$

Simpson's trapezoidal rule (two-point rule),

$$\int_{X0}^{X1} f(X)\,dX = \frac{h}{2}[f(X_0) + f(X_1)]$$

Simpson's one third rule (three point rule),

$$\int_{X0}^{X2} f(X)\,dX = \frac{h}{6}[f(X_0) + 4f(X_1) + f(X_2)]$$

Where, $f(X_0)$ is the value of $1 / (-r_A)$ at point $X_0$ and $h$ is the distance between conversion points. For example, $(X_0 = 0.0)$, $(X_1 = 0.2)$, $(X_3 = 0.4)$ gives $h = 0.2$.

$V = A \times H$

$C_{A0} = N_{A0} \div V$

$k = Ae^{-\frac{E}{RT}}$

$C_A = C_{A0} - C_{A0}X$ or $C_A = C_{A0}(1 - X)$

$F_A = F_{A0}(1 - X)$

$$\int \frac{1}{(1-X)^2}\,dX = \frac{1}{(1-X)}$$

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