UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2008/2009

April/May 2009

EKC 337 – Reactor Design and Analysis
[Rekabentuk dan Analisis Reaktor]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of EIGHT pages of printed material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi LAPAN muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

Instructions: Answer **FOUR** (4) questions. Answer **ONE** (1) questions from Section A. Answer **THREE** (3) questions from Section B.

*[**Arahan**: Jawab **EMPAT** (4) soalan. Jawab **SATU** (1) soalan dari Bahagian A. Jawab **SEMUA** (3) soalan dari Bahagian B.]*

You may answer the question either in Bahasa Malaysia or in English.

[Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]

Section A : Answer any ONE question.
Bahagian A : Jawab mana-mana SATU soalan.

1. [a] For some cell populations, a minimum level of substrate may be required to achieve a nontrivial steady-state. As an example, consider the system with kinetics of the form given by;

$$r_s = \frac{\mu_{max} sx}{K_s + s} - k_e x \qquad r_s = -\frac{1}{Y}\frac{\mu_{max} sx}{K_s + s}$$

in a continuous-stirred-tank (bio) reactor (CSTbR);

1. [a] Bagi satu populasi sel, aras minima bagi substrat mungkin diperlukan untuk mncapai keadaan mantap mudah. Sebagai contoh, pertimbangkan penghasilan sistem dengan kinetik seperti yang diberi;

$$r_s = \frac{\mu_{mak} sx}{K_s + s} - k_e x \qquad r_s = -\frac{1}{Y}\frac{\mu_{mak} sx}{K_s + s}$$

dalam sebuah (bio) reaktor tangki teraduk berterusan (CSTbR);

[i] Show that at substrate level below;

$$\frac{k_e K_s}{(\mu_{max} - k_e)}$$

The only steady-state in a CSTbR system is when $x = 0$.

[i] Tunjukkan pada peringkat substrat seperti di bawah;

$$\frac{k_e K_s}{(\mu_{mak} - k_e)}$$

Keadaan mantap di dalam sistem CSTbR hanya berlaku apabila $x = 0$.

[4 marks/markah]

[ii] If $\mu_{max} = 0.5\ h^{-1}$, $K_s = 0.2$ g/L, $k_e = 0.1\ h^{-1}$ and $Y_s = 0.6\ g_{cell}/g_{substrate}$, sketch a graph of $(^{dx}/_{dt})_{batch}$ versus x and prove by direct solution of the above equations that when $(^{dx}/_{dt}) = 0$ for low s and for $D > D_{washout}$.

[ii] Jika $\mu_{mak} = 0.5\ jam^{-1}$, $K_s = 0.2$ g/L, $k_e = 0.1\ h^{-1}$ dan $Y_s = 0.6\ g_{sel}/g_{substrat}$, lakar graf $(^{dx}/_{dt})_{kelompok}$ melawan x dan buktikan secara penyelesaian terus bagi persamaan di atas apabila $(^{dx}/_{dt}) = 0$ untuk nilai s yang rendah dan untuk $D > D_{basuh\ habis}$.

[8 marks/markah]

[b] [i] Multiphase reactions can be run in a number of ways. Sketch various ways of running G/L reactions catalyzed by solids in a packed or fixed-bed reactor.

[b] [i] Tindakbalas berbilang fasa boleh dijalankan menurut pelbagai kaedah. Lakarkan pelbagai kaedah bagi menjalankan tindakbalas G/L bermangkinkan pepejal dalam sebuah reaktor lapisan terpadat atau tetap.

[3 marks/markah]

[ii] List three commonly used catalyst pre-treatment methods and briefly state the purpose of each method.

[ii] Senaraikan tiga kaedah pra-rawatan mangkin yang lazim digunakan dan nyatakan secara ringkas matlamat bagi setiap kaedah.

[3 marks/markah]

[c] [i] A very fast reaction occurs on a spherical catalyst pellet 1.2 cm in diameter suspended in a large body of dilute liquid reactant A. Given that the bulk concentration of the reactant is 1.4 M and the free-system liquid velocity is 0.08 m/s, kinematic viscosity is 0.6 centistoke (1 centistoke = 10^{-6} m^2/s) and the liquid diffusivity of A is 1.2 x 10^{-10} m^2/s. Calculate the reaction rate per unit surface area of the catalyst.

[c] [i] Suatu tindakbalas yang sangat pantas berlaku pada pelet mangkin sfera 1.2 sm garispusat yang terapung dalam bahan tindakbalas cecair A yang berkepekatan rendah. Diberi bahawa kepekatan pukal bahan tindakbalas tersebut ialah 1.4 M dan halaju cecair sistem bebas ialah 0.08 m/s, kelikatan kinematik sebanyak 0.6 sentistoke (1 sentistoke = 10^{-6} m^2/s) dan kemeresapan cecair bagi A ialah 1.2 x 10^{-10} m^2/s. Kirakan kadar tindakbalas per unit luas permukaan bagi mangkin tersebut.

[4 marks/markah]

[ii] Curves I, II and III in Figure Q.1. [c][ii] show the variation in reaction rate for three different reactions catalyzed by solid catalyst pellets. Give comment on each reaction curve based on either external diffusion, internal diffusion or reaction rate controlling.

[ii] Keluk I, II dan III dalam Rajah S.1. [c][ii] menunjukkan variasi kadar tindakbalas untuk tiga tindakbalas berlainan yang dimangkinkan oleh pelet mangkin pepejal. Berikan komen bagi setiap kelok tindakbalas tersebut samaada ianya dipengaruhi oleh resapan luaran, resapan dalaman atau kadar tindakbalas.

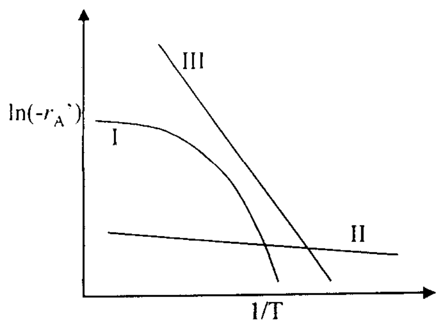

Figure Q.1. [c][ii]
Rajah S.1. [c][ii]

[3 marks/markah]

...4/-

2. [a] [i] A correlation to represent the mass transfer around a spherical catalyst pellet is commonly written as;

$$Sh = 2 + 0.6Re^{1/2}Sc^{1/3}$$

where Sh is the Sherwood number, Re is the Reynolds number and Sc is Schmidt number. For a liquid reaction system with very large values of Sc and Re, how much the mass transfer coefficient will change if the temperature of the system is increased so that the diffusivity of A (D_{AB}) increases by 15 % and the kinematic viscosity (v) decreases by 12 %. Assume that the free-system velocity is fixed and the same sample of catalyst is used in both cases.

2. [a] [i] Suatu hubungkait yang mewakili pemindahan jisim di sekeliling pelet mangkin berbentuk sfera selalunya ditulis sebagai;

$$Sh = 2 + 0.6Re^{1/2}Sc^{1/3}$$

di mana Sh ialah nombor Sherwood, Re ialah nombor Reynolds dan Sc ialah nombor Schmidt. Bagi suatu sistem tindakbalas cecair dengan nilai Sc dan Re yang sangat besar, berapa banyakkah pekali pemindahan jisim akan berubah sekiranya suhu sistem dinaikkan menyebabkan kemeresapan A (D_{AB}) meningkat sebanyak 15 % dan kelikatan kinematik menurun sebanyak (v) 12 %. Anggapkan bahawa halaju sistem bebas ditetapkan dan sampel mangkin yang sama digunakan dalam kedua-dua kes.

[5 marks/markah]

Note / *Nota*:

$Sh = k_c d_p / D_{AB}$

$Re = U d_p / v$

$Sc = v / D_{AB}$

[ii] Based on Figure Q. 2.[a][ii] that shows the diffusivity of molecules (D) in porous catalyst versus pore diameter (d_p), name and briefly explain characteristics of different pore diffusion categories as observed in the figure.

[ii] Berdasarkan Rajah S. 2.[a][ii] yang menunjukkan kemeresapan molekul (D) dalam mangkin berliang melawan garispusat liang (d_p), namakan dan terangkan secara ringkas ciri kategori resapan liang yang berlainan sebagaimana yang ditunjukkan dalam rajah tersebut.

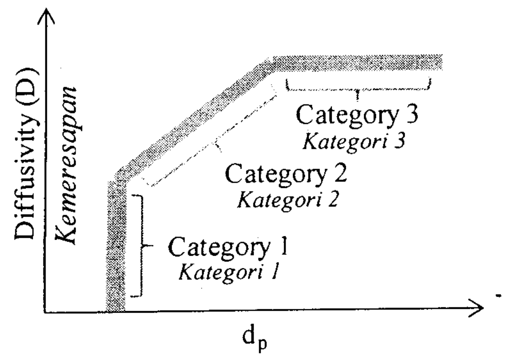

Figure Q. 2.[a][ii]
Rajah S. 2.[a][ii]

[3 marks/markah]

...5/-

[b] [i] The adsorption or ion-exchange method of catalyst preparation involves many steps. Briefly write these steps.

[b] [i] Kaedah penjerapan atau penukaran ion bagi penyediaan mangkin melibatkan banyak langkah. Nyatakan langkah-langkah tersebut secara ringkas.

[4 marks/markah]

[ii] Because of their unique porous properties, zeolites are used in a variety of applications with a global market of several million tonnes per annum.

(a) What are zeolites?
(b) How can their acidity and thermal stability increase?

[ii] Sifat berliangnya yang unik menyebabkan zeolit digunakan dalam pelbagai aplikasi yang mempunyai pasaran global beberapa juta tan setahun.

(a) Apakah zeolit?
(b) Bagaimanakah keasidan dan kestabilan haba zeolit ditingkatkan?

[4 marks/markah]

[c] Baby hamster kidney cells are immobilised in alginate beads. The average particle diameter is 5 mm. Rate of oxygen consumption at bulk concentration of 8×10^{-3} kg is 8.4×10^{-5} kg s^{-1} m^{-3} catalyst. The effective diffusivity of oxygen in the beads is 1.88×10^{-9} m^2 s^{-1}. Assuming that the oxygen concentration at the surface of the catalyst is equal to the bulk concentration, and that oxygen uptake follows zeroth order kinetics:

[i] Are the internal mass transfer effects significant?
[ii] What reaction rate would be observed if diffusional resistance were eliminated?

[c] Sel buah pinggang seekor anak hamster disekat-gerak di atas manik algenat. Purata garispusat partikel adalah 5 mm. Kadar penggunaan oksigen pada kepekatan pukal adalah 8×10^{-3} kg manik 8.4×10^{-5} kg s^{-1} m^{-3} pemangkin. Resapan berkesan oksigen di dalam manik adalah 1.88×10^{-9} m^2 s^{-1}. Menganggap bahawa kepekatan oksigen pada permukaan pemangkin adalah sama dengan kepekatan pukal, dan penggunaan oksigen adalah menurut kinetik tertib sifar:

[i] Adakah pemindahan jisim dalaman berkesan?
[ii] Apakah kadar tindakbalas yang akan diperolehi jika rintangan resapan diabaikan?

[9 marks/markah]

...6/-

Section B : Answer ALL questions.
Bahagian B : Jawab SEMUA soalan.

3. [a] List common disadvantages of homogeneous catalytic processes over heterogeneous ones.

3. [a] Senaraikan kekurangan umum bagi proses bermangkin homogen berbanding proses heterogen.

[5 marks/markah]

[b] A plug flow reactor is used to determine the rate expression of a first order chemical reaction represented as,

$$A \rightarrow 4R$$

where, A and R are the reactant and product, respectively. Various amounts of catalyst are packed into the reactor and the reaction is carried out at 117°C and 3.2 atm with 20 L/h of pure A. 4 different experimental runs are performed and the concentration of A in the product stream is recorded.

[b] Suatu reaktor aliran palam digunakan untuk menentukan hubungan kadar bagi suatu tindakbalas kimia tertib pertama yang diwakili oleh,

$$A \rightarrow 4R$$

di mana, A dan R adalah masing-masing bahan dan hasil tindakbalas. Amaun mangkin yang berlainan dimasukkan ke dalam reaktor dan tindakbalas tersebut dijalankan pada suhu 117°C dan 3.2 atm dengan 20 L/jam A tulen. 4 larian eksperimen dilakukan dan kepekatan A dalam aliran produk direkodkan.

Run *Larian*	1	2	3	4
W_{cat} (g) $W_{mangkin}$ *(g)*	20.0	40.0	80.0	160.0
$C_{A,\,out}$ (mol/L) $C_{A,\,keluar}$ *(mol/L)*	0.074	0.060	0.044	0.029

[i] Find the rate expression to represent this reaction.

[i] Carikan persamaan kadar bagi mewakili tindakbalas ini.

[15 marks/markah]

[ii] Determine the amount of the same catalyst to be charged into the reactor to achieve 60 % conversion of A at a rate of 1,500 mol/h if the reaction is carried out under the same conditions.

[ii] Tentukan amaun mangkin yang sama yang perlu dimasukkan ke dalam reaktor tersebut untuk mencapai penukaran 60 % bagi A pada kadar 1,500 mol/jam sekiranya tindakbalas tersebut dilakukan dalam keadaan yang sama.

[5 marks/markah]

...7/-

4. [a] Dilute aqueous ethanol (about 2-3%) is oxidized to acetic acid by the action of pure oxygen at 10 atm in a trickle bed reactor packed with palladium-alumina catalyst pellets and kept at 30°C. The reaction proceeds as follows:

$$\underbrace{O_2(g \rightarrow l)}_{(A)} + \underbrace{CH_3CH_2OH(l)}_{(B)} \xrightarrow{\text{on Catalyst}} CH_3COOH(l) + H_2O$$

with rate

$-r'_A = k'C_A \qquad k' = 1.77x10^{-5}\ m^3/kg.s$

Find the fractional conversion of ethanol to acetic acid if gas and liquid are fed to the top of a reactor in the following system:

4. [a] Etanol akues cair (lebih kurang 2-3%) dioksidakan kepada asid asetik melalui tindakan oksigen tulen pada 10 atm dalam sebuah reaktor lapisan cucur yang dipadatkan dengan pelet mangkin 'palladium-alumina' yang dikekalkan pada 30°C. Tindakbalas berlaku seperti yang berikut:

$$\underbrace{O_2(g \rightarrow l)}_{(A)} + \underbrace{CH_3CH_2OH(l)}_{(B)} \xrightarrow{\text{atas mangkin}} CH_3COOH(l) + H_2O$$

dengan kadar

$-r'_A = k'C_A \qquad k' = 1.77x10^{-5}\ m^3/kg.s$

Carikan penukaran pecahan etanol kepada asid asetik jika gas dan cecair disuapkan ke bahagian atas sebuah reaktor dalam sistem yang berikut:

Gas stream: / *Aliran gas:*	$v_g = 0.01\ m^3/s$, $H_A = 86{,}000\ Pa.m^3/mol$
Liquid stream: / *Aliran cecair:*	$v_l = 2x10^{-4}\ m^3/s$, $C_{Bo} = 400\ mol/m^3$
Reactor: / *Reaktor:*	5 m height, 0.1 m^2 cross section, $f_s = 0.58$
	Tinggi 5 m, keratan rentas 0.1 m^2, $f_s = 0.58$
Catalyst: / *Mangkin:*	$d_p = 5$ mm, $\rho_s = 1800\ kg/m^3$
	$D_e = 4.16x10^{-10}\ m^3/m$ cat. s
	$D_e = 4.16x10^{-10}\ m^3/m$ bermangkin. s
Kinetics: / *Kinetik:*	$k_{Ag}a_i = 3x10^{-4}\ mol/m^3.Pa.\ s$, $k_{Al}a_i = 0.02\ s^{-1}$
	$k_{Ac} = 3.86x10^{-4}\ m/s$

[16 marks/markah]

[b] What are the three main components of a supported catalyst? State the role of each component.

[b] Apakah tiga komponen utama suatu mangkin tersokong? Nyatakan peranan setiap komponen.

[5 marks/markah]

[c] What are the objectives of catalyst characterization?

[c] Apakah objektif pencirian mangkin?

[4 marks/markah]

5. Consider a 1000 L continuous-stirred-tank (bio) reactor (CSTbR) in which biomass is being produced with glucose as the substrate. The microbial system follows a Monod model with $\mu_{max} = 0.4\ h^{-1}$, $K_S = 1.5$ g/L and $Y_{X/S} = 0.5\ g_{biomass}/g_{substrate}$. If the normal operation with a sterile feed containing 10 g/L glucose at a rate of 100 L/h.

5. Pertimbangkan suatu 1000 L tangki (bio) reaktor-teraduk berterusan (CSTbR) di mana biomas dihasilkan dengan glukos sebagai substrat. Sistem mikrobial menuruti model Monod dengan $\mu_{mak} = 0.4\ j^{-1}$, $K_S = 1.5$ g/L dan $Y_{X/S} = 0.5\ g_{biomas}/g_{substrat}$. Jika operasi berlaku secara normal dengan suapan steril yang mengandungi 10 g/L glukosa pada kadar 100 L/j.

[a] What is the specific biomass production rate in g/L·h at steady-state?

[a] Apakah kadar penghasilan biomas spesifik di dalam g/L·j pada keadaan mantap?

[10 marks/markah]

[b] Show that for a CSTR system with a recycle stream, the external dilution rate, D_{ex} is given by;

$$D_{ex} = \frac{\mu}{1 - \alpha(c-1)}$$

with the recycle ratio, α is given by;

$$\alpha = \frac{\text{Recycle flowrate}}{\text{Flowrate leaving the stream}}$$

and c is defined as the ratio of the recycled cell and the amount of cell within the reactor. If recycle is used with a recycle stream of 10 L/h and a recycle biomass concentration five times as large as that in the reactor exit, what would be the new specific biomass production rate?

[b] Tunjukkan untuk sistem CSTR dengan aliran kitar semula, kadar pencairan luaran, D_{luaran} diberi oleh;

$$D_{luaran} = \frac{\mu}{1 - \alpha(c-1)}$$

dengan nisbah kitar semula, α diberi oleh;

$$\alpha = \frac{\text{Kadar alir kitar semula}}{\text{Kadar alir yang keluar}}$$

dan c ditakrifkan sebagai nisbah kitar semula sel dengan amaun sel di dalam reaktor. Jika kitar semula digunakan dengan aliran kitar semula 10 L/j dan kepekatan edar semula biomas adalah 5 kali banyaknya berbanding dengan aliran keluar daripada reaktor, apakah kadar penghasilan biomas spesifik yang baru?

[10 marks/markah]

[c] Explain the differences between the values found in parts [a] and [b] above.

[c] Terangkan perbezaan di antara nilai yang diperolehi dalam bahagian [a] dan [b] di atas.

[5 marks/markah]

- ooo O ooo -