UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2007/2008

April 2008

EBB 338/3 - Process Control
[Kawalan Proses]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains TWELVE printed pages and THREE pages APPENDIX before you begin the examination.
[Sila pastikan bahawa kertas peperiksaan ini mengandungi DUA BELAS muka surat beserta TIGA muka surat LAMPIRAN yang bercetak sebelum anda memulakan peperiksaan ini.]

This paper contains SEVEN questions. THREE questions in PART A, TWO questions in PART B and TWO questions in PART C.
[Kertas soalan ini mengandungi TUJUH soalan. TIGA soalan di BAHAGIAN A, DUA soalan di BAHAGIAN B dan DUA soalan di BAHAGIAN C.]

Instructions: Answer **FIVE** questions : **ONE** from PART A, **ONE** from PART B, **ONE** from PART C and **TWO** questions from any sections. If a candidate answers more than five questions only the first five questions in the answer sheet will be graded.
*[**Arahan:** Jawab **LIMA** soalan : **SATU** dari BAHAGIAN A, **SATU** dari BAHAGIAN B, **SATU** dari BAHAGIAN C dan **DUA** dari mana-mana bahagian. Jika calon menjawab lebih daripada lima soalan hanya lima soalan pertama mengikut susunan dalam skrip jawapan akan diberi markah.]*

Answer to any question must start on a new page.
[Mulakan jawapan anda untuk setiap soalan pada muka surat yang baru.]

You may answer a question either in Bahasa Malaysia or in English.
[Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]

PART A

BAHAGIAN A

1. The thermal conductivity of a material varies with temperature as

$$\ln k = 0.01T + 0.5$$

where k has the units W·m^{-1}·K^{-1} and T has the units degrees Celsius. Heat flows by conduction through a plane slab of this material of thickness 0.1 m, the left face of which is at 100°C and the right face of which is at 0°C. Calculate:

(a) The mean thermal conductivity of the material in the range 0 to 100°C if the definition of a mean value of the thermal conductivity, k_m, in the temperature range $T_1 - T_2$ is

$$k_m(T_2 - T_1) = \int_{T_1}^{T_2} k(T)dT$$

(b) The heat flux through the slab.

(c) The actual variation of T with distance through the slab.

(d) The temperature at $x = 0.05\,\text{m}$.

(e) The temperature at $x = 0.05\,\text{m}$ calculated using the mean thermal conductivity.

(f) The actual temperature gradient in the slab at $x = 0.05\,\text{m}$.

(g) The temperature gradient at $x = 0.05\,\text{m}$ calculated using the mean thermal conductivity.

Konduktiviti terma sesuatu bahan berbeza dengan suhu seperti

$$\ln k = 0.01T + 0.5$$

di mana k *adalah unit* $W{\cdot}m^{-1}{\cdot}K^{1}$ *dan* T *adalah unit* ^{o}C. *Aliran haba oleh konduksi melalui kepingan bahan yang mempunyai ketebalan 0.1 m, permukaan kini menghadapi* $100^{o}C$ *dan permukaan kanan menghadapi* $0^{o}C$. *Kirakan*

(a) *Purata konduktiviti terma sesuatu bahan pada jarak 0 hingga* $100^{o}C$ *jika definisi bagi nilai purata konduktiviti terma,* k_m, *dalam julat suhu* $T_1 - T_2$ *ialah*

$$k_m(T_2 - T_1) = \int_{T_1}^{T_2} k(T)dT$$

(b) *Fluks haba melalui kepingan tersebut.*

(c) *Perbezaan sebenar* T *dengan jarak melalui kepingan tersebut.*

(d) *Suhu pada* $x = 0.05$ m.

(e) *Suhu pada* $x = 0.05$ m, *kirakan dengan menggunakan purata pengaliran haba.*

(f) *Perubahan sebenar suhu di dalam kepingan tersebut pada* $x = 0.05$ m.

(g) *Perubahan suhu pada* $x = 0.05$ m, *kirakan dengan menggunakan purata konduktiviti terma.*

(100 marks/*markah*)

2. Helium is separated from natural gas by a method based on the fact that Pyrex glass is permeable to helium but impermeable to natural gas. In one method a cylindrical Pyrex glass tube is used with the natural gas inside the tube and the helium diffusing radially through the walls of the tube. Let the inside radius of the Pyrex tube be R_1, the outside radius be R_2, and the length be L. Let the concentration of He at the inside be C_{A1} and at the outside be C_{A2}. It is desired to find the total transport of helium in moles per hour through the glass.

   (a) Make an incremental molar balance over an element of thickness Δr. Draw a diagram showing mass flow into and out of the increment.
   (b) Obtain a differential equation for the molar flux.
   (c) Obtain the flux distribution.
   (d) Write the flux law for this case.
   (e) Write the boundary conditions.
   (f) Solve for the concentration distribution $C_A(r)$ in terms of R_1 and R_2.
   (g) Find the total molar transport of He through the wall of the tube.
   (h) Show that this problem is analogous to that of heat transport in the wall of a metal pipe.

Gas Helium telah diasingkan daripada gas asli melalui cara berdasarkan kepada fakta yang menyatakan gelas Pyrex yang boleh ditelapi kepada Helium tetapi tidak boleh ditelapi kepada gas asli. Di dalam satu kaedah yang lain tiub selinder gelas Pyrex telah digunakan bersama dengan gas asli di dalam tiub berkenaan dan gas Helium telah meresap secara sekata melalui dinding tiub. Andaikan jejari dalaman tiub Pyrex ialah R_1 jejari luar R_2 dan panjang L. Anggapkan kepekatan Helium di sebelah dalam sebagai C_{A1} dan luarannya C_{A2}. Keadaan ini amat diperlukan untuk menentukan jumlah pengangkutan Helium di dalam mol/jam melalui gelas.

(a) *Tentukan penambahan persamaan molar terhadap ketebalan unsur Δr. Lukiskan gambarajah yang menunjukkan aliran jisim keluar masuk terhadap tokokan tersebut.*

(b) *Dapatkan persamaan perbezaan untuk aliran molar.*

(c) *Dapatkan taburan aliran.*

(d) *Tuliskan hukum aliran untuk kes ini.*

(e) *Tuliskan keadaan persempadanan.*

(f) *Selesaikan untuk taburan kepekatan $C_A(r)$ di dalam sebutan R_1 dan R_2.*

(g) *Tentukan jumlah pengangkutan molar Helium yang melalui dinding tiub.*

(h) *Tunjukkan bahawa masalah ini beranalog kepada pengangkutan haba di dalam dinding paip logam.*

(100 marks/*markah*)

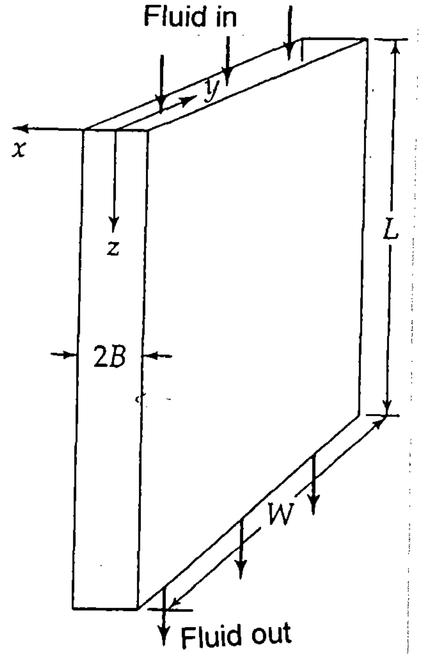


Figure 1 - Flow through a slit, with $B << W << L$

3. A Newtonian fluid is in laminar flow in a narrow slit formed by two parallel walls a distance 2B apart. It is understood that $B << W$, so that "edge effect" are unimportant. Make a differential momentum balance, and obtain the following expressions for the momentum-flux and velocity distributions:

$$\tau_{xz} = \left(\frac{P_0 - P_L}{L}\right)x$$

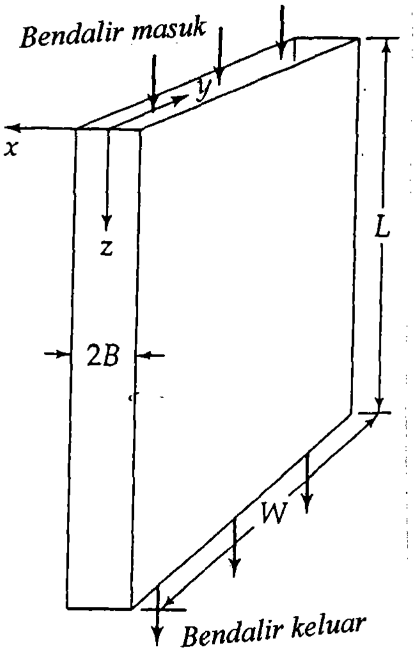
$$\upsilon_z = \frac{(P_0 - P_L)B^2}{2\mu L}\left[1 - \left(\frac{x}{B}\right)^2\right]$$

In these expressions $P = p + pgh = p - \rho gz$

(a) Write incremental momentum balances, giving the physical meaning of all terms and including terms for the bulk flow of momentum into and out of the increment.

(b) Derive an equation for the momentum-flux distribution and draw a sketch showing how it varies across the slit.

(c) Derive an equation for the velocity profile.



Rajah 1 – Aliran melalui aliran sempit, dengan $B << W << L$

Satu bendalir Newtonian beraliran lamina telah melalui satu laluan sempit yang terbentuk daripada dua dinding selari yang berketebalan 2B. Difahamkan bahawa $B << W$ *, supaya "kesan pinggir" dapat diabaikan. Buatkan satu keseimbangan perbezaan momentum dan dapat ungkapan berikut bagi aliran momentum dan taburan halaju:*

$$\tau_{xz} = \left(\frac{P_0 - P_L}{L}\right)x$$

$$\upsilon_z = \frac{(P_0 - P_L)B^2}{2\mu L}\left[1 - \left(\frac{x}{B}\right)^2\right]$$

Di dalam ungkapan $P = p + pgh = p - \rho gz$

(a) *Tuliskan penokokan keseimbangan momentum dengan memberikan maksud fizikal untuk kesemua sebutan dan termasuk sebutan-sebutan untuk aliran pukal bagi momentum yang keluar dan masuk tokokan.*

(b) *Terbitkan satu persamaan untuk taburan aliran momentum dan lukiskan satu lakaran yang menunjukkan bagaimana ia berubah melintasi laluan.*

(c) *Terbitkan satu persamaan bagi profil halaju.*

(100 marks/*markah*)

PART B

BAHAGIAN B

4. [a] Describe the importance of heat transfer in polymer processing operation with the assistance of a suitable diagram.

Jelaskan kepentingan pemindahan haba dalam operasi pemprosesan polimer dengan bantuan gambarajah yang sesuai.

(60 marks/*markah*)

[b] What is Brinkman number, B_r, and how it is used to explain viscous dissipation in polymer processing?

Apakah nombor Brinkman, B_r, *dan bagaimanakah ia digunakan untuk menerangkan kejadian pelesapan likat dalam pemprosesan polimer?*

(40 marks/*markah*)

5. [a] List and explain factors that could contribute to the complexity in describing heat flow analyses in polymer processing. For each factor give specific examples to support their existence in actual processing activities.

Senarai dan terangkan faktor-faktor yang boleh menyumbang kepada kesulitan dalam menjelaskan analisa aliran haba dalam pemprosesan polimer. Untuk setiap faktor, berikan contoh-contoh spesifik bagi menyokong kewujudan mereka dalam aktiviti pemprosesan sebenar.

(40 marks/*markah*)

[b] Low density polyethylene (LDPE) is injection moulded into a rectangular cavity having dimension of 10 cm by 10 cm and 0.40 cm thickness (b). Two experiments were conducted where molten LDPE with a temperature of 160°C is fed into the mould cavity which is set 30°C and 50°C for each respective experiment.

Given,

No flow temperature of LDPE = 85.03°C

Thermal diffusivity (α) = 1 x 10^{-7} m^2s^{-1}

Useful equations for non-steady heat transfer in one dimension:

$$\frac{\delta^2 T}{\delta x^2} = \frac{1}{\alpha}\frac{\delta T}{\delta t} \qquad \alpha = \frac{k}{\rho C_p} \qquad F_o = \frac{\alpha t}{(0.5b)^2}$$

Determine the dimensionless temperature gradient, θ and Fourier number, F_o.

Also, with the aid of the following Figure 2 (refer the Appendix 1), calculate the freeze time (t) for the LDPE component in both experiments.

Polietilena berketumpatan rendah (LDPE) disediakan melalui pengacuanan suntikan kepada bentuk segiempat dengan dimensi 10 cm × 10 cm dan berketebalan (b) 0.40 cm. Dua eksperimen dijalankan iaitu leburan LDPE dengan suhu 160°C disuntik ke dalam kaviti acuan yang masing-masing ditetapkan pada suhu 30°C dan 50°C untuk setiap eksperimen.

Diberi,

Suhu tiada aliran LDPE = 85.03°C

Pekali kemeresapan haba (α) = $1 \times 10^{-7}\ m^2 s^{-1}$

Persamaan-persamaan berguna untuk pemindahan haba tak-mantap dalam satu dimensi:

$$\frac{\delta^2 T}{\delta x^2} = \frac{1}{\alpha}\frac{\delta T}{\delta t} \qquad \alpha = \frac{k}{\rho C_p} \qquad F_o = \frac{\alpha t}{(0.5b)^2}$$

Tentukan kecerunan suhu nir-dimens, θ *dan nombor Fourier,* F_o.

Juga, dengan bantuan Rajah 2 (sila lihat Lampiran 1), kirakan masa penyejukan (t) bagi komponen LDPE dalam kedua-dua eksperimen tersebut.

(60 marks/*markah*)

PART C

BAHAGIAN C

6. [a] Based on the Fick's Law of diffusion formula derive the units of diffusion coefficient. Calculate the diffusion coefficient for CO_2-air pair at atmospheric pressure and 30°C temperature. The atomic volumes are provided in Table 1.

Berdasarkan kepada formulasi Hukum Penyerapan Fick's terbitkan unit pekali peresapan. Kirakan pekali peresapan untuk pasangan CO_2-air pada suhu 30°C dan tekanan atmosphera. Isipadu atom telah disediakan di dalam Jadual 1.

Table 1

Jadual 1

Air	29.9	Oxygen (O_2)	7.4
Bromine	27	Couped	
Carbon	14.8	In aldehydes and ketones	7.4
Carbon dioxide	34	In methyl esters	9.1
Chlorine			
As in R-Cl	21.6	In ethyl esters	9.9
As in R-CHCl-R	24.6	In higher esters and ethers	11
Fluorine	8.7	In acids	12
Hydrogen (H_2)	14.3	In union with S, P, N	8.3
In compounds	3.7	Phosphorous	27
Iodine	37	Sulphur	25.6
Nitrogen (N_2)	15.6	Water	18.8
In primary amines	10.5		
In secondary amines	1.2		

(20 marks/*markah*)

[b] Calculate the rate of burning of a pulverized carbon particle of 0.25 cm diameter, in an atmosphere of pure oxygen at 1000 K and 1 atm pressure, assuming a very large blanketing layer of CO_2 has formed around the particle.

Kirakan kadar pembakaran pemecahan partikel karbon yang bergarispusat 0.25 cm, di dalam 1 tekanan atmosphera yang berisi gas oksigen tulen pada 1000 K, anggarkan suatu liputan lapisan gas CO_2 telah terhasil menyelaputi partikel.

(80 marks/*markah*)

7. Air at 35°C and 1 atm flows at a velocity of 60 m/s over:

(a) a flat plate 0.5 m long

(b) a sphere 5 cm in diameter

Calculate the mass transfer coefficient of water vapour in air. Assume concentration of vapour in air as very small. (Diffusion coefficient of water vapour in air, D = 0.256 x 10^{-4} m^2 s^{-1})

Udara pada suhu 35°C dan aliran kelajuan pada 60 m/s tekanan 1 atmosphera melalui:

(a) kepingan rata panjangnya 0.5 m

(b) bulatan yang bergarispusat 5 cm

Kirakan pekali pemindahan haba pemeruapan air di udara. Anggarkan kepekatan pemeruapan di dalam air terlalu kecil. (Pekali peresapan pemeruapan air di udara, D = 0.256 x 10^{-4} m^2 s^{-1})

(100 marks/*markah*)

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APPENDIX 1

LAMPIRAN 1

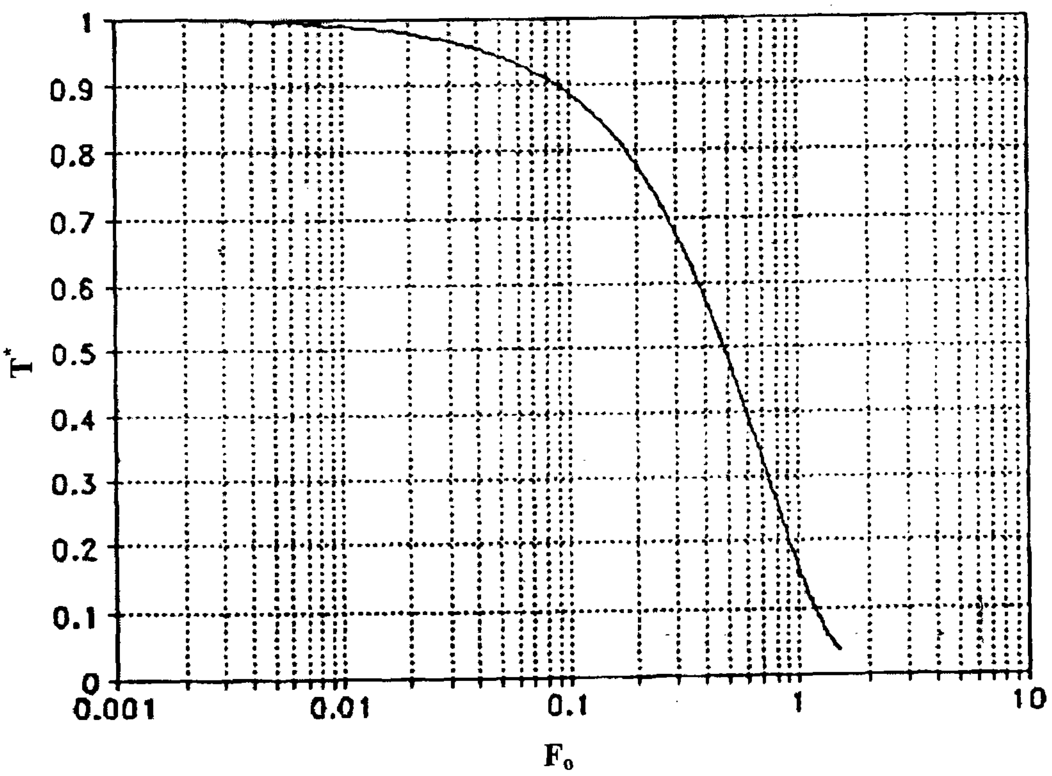

Figure 2 - A plot of T^* versus F_o

Rajah 2 - A plot of T^* versus F_o

APPENDIX 2

LAMPIRAN 2

Physical Constants

Universal Gas Constant:

$\mathcal{R} = 8.205 \times 10^{-2}\ m^3 \cdot atm/kmol \cdot K$

$= 8.314 \times 10^{-2}\ m^3 \cdot bar/kmol \cdot K$

$= 8.315\ kJ/kmol \cdot K$

$= 1545\ ft \cdot lb_f/lbmole \cdot {}^{\circ}R$

$= 1.986\ Btu/lbmole \cdot {}^{\circ}R$

Avogadro's Number:

$\mathcal{N} = 6.024 \times 10^{23}$ molecules/mol

Planck's Constant:

$h = 6.625 \times 10^{-34}\ J \cdot s/molecule$

Boltzmann's Constant:

$k = 1.380 \times 10^{-23}\ J/K \cdot molecule$

Speed of Light in Vacuum:

$c_o = 2.998 \times 10^8\ m/s$

Stefan-Boltzmann Constant:

$\sigma = 5.670 \times 10^{-8}\ W/m^2 \cdot K^4$

$= 0.1714 \times 10^{-8}\ Btu/h \cdot ft^2 \cdot {}^{\circ}R^4$

Blackbody Radiation Constants:

$C_1 = 3.7420 \times 10^8\ W \cdot \mu m^4/m^2$

$= 1.187 \times 10^8\ Btu \cdot \mu m^4/h \cdot ft^2$

$C_2 = 1.4388 \times 10^4\ \mu m \cdot K$

$= 2.5897 \times 10^4\ \mu m \cdot {}^{\circ}R$

$C_3 = 2897.8\ \mu m \cdot K$

$= 5215.6\ \mu m \cdot {}^{\circ}R$

Gravitational Acceleration (Sea Level):

$g = 9.807\ m/s^2 = 32.174\ ft/s^2$

Standard Atmospheric Pressure:

$p = 101{,}325\ N/m^2 = 101.3\ kPa$

Heat of Fusion of Water at Atmospheric Pressure:

$h_{sf} = 333.7\ kJ/kg$

Heat of Vaporization of Water at Atmospheric Pressure:

$h_{fg} = 2257\ kJ/kg$

APPENDIX 3

LAMPIRAN 3

Periodic Table

Key: 29 — Atomic number; Cu — Symbol; 63.54 — Atomic weight

Metal | Nonmetal | Intermediate

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1 H 1.0080																	2 He 4.0026
3 Li 6.939	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.183
11 Na 22.990	12 Mg 24.312											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.91	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.34	Rare earth series	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.98	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	Acti-nide series															

Rare earth series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
Actinide series	89 Ac (227)	90 Th 232.04	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lw (257)