UNIVERSITI SAINS MALAYSIA

First Semester Examination
2015/2016 Academic Session

December 2015 / January 2016

EKC 314 – Transport Phenomena
[Fenomena Pengangkutan]

Duration : 3 hours
[Masa : 3 jam]

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

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

Instruction: Answer **ALL** (4) questions.

*[**Arahan:** Jawab **SEMUA** (4) soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

Answer ALL questions.

1. A fluid with density ρ is flowing upwards in the direction opposing the gravity in between two coaxial cylinders of radii ξR and R for the inner cylinder and outer cylinder, respectively. Assuming that the flow is at a steady-state condition.

[a] Draw a schematic diagram of the boundary condition, show and label the velocity distribution (boundary layer) of the flow.

[5 marks]

[b] Prove that the velocity distribution of the flow upwards the annulus is given by;

$$v_z = \frac{(P_0 - P_L)R^2}{4\mu L}\left[1-\left(\frac{r}{R}\right)^2 - \frac{1-\xi^2}{\ln 1/\xi}\ln\left(\frac{R}{r}\right)\right]$$

[10 marks]

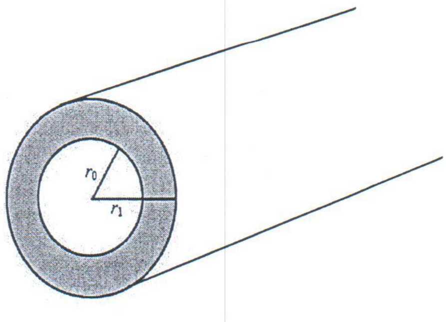
[c] According to the drawn boundary condition in part [a], when does the maximum velocity of the flow occur and find $v_{z,max}$ at the particular condition.

[5 marks]

[d] From the result obtained in part [b], find the average velocity, $\langle v_z \rangle$ of the flow upward in between the two cylindrical walls.

[5 marks]

2. In a study of heat loss in a pipe with length L, it is required to obtain radial temperature profile across the inner wall and the outer wall of the pipe. This problem can be described as steady-state heat flux in radial direction through annular wall having inside radius r_0 and outside radius r_1, as shown in the Figure Q.2.



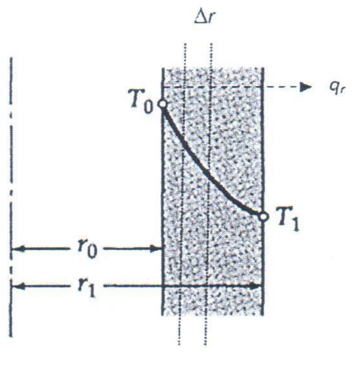


Figure Q.2: Pipe with length L and the schematic diagram showing the direction of heat flux

Given the thermal conductivity k of the wall varies linearly with temperature T and the dimensionless temperature θ is defined as:

$$\theta = \frac{T - T_0}{T_1 - T_0} = \frac{k - k_0}{k_1 - k_0}$$

Note: the subscripts 0 and 1 are used for the inner and outer boundaries, respectively.

...3/-

Jawab SEMUA soalan.

1. *Satu bendalir dengan ketumpatan ρ mengalir ke arah atas melawan graviti di antara dua silinder sepaksi pada jejari-jejari ξR dan R masing-masing untuk silinder dalam dan silinder luar. Dengan mengandaikan bahawa aliran adalah pada keadaan mantap;*

[a] *Lukiskan satu gambarajah skematik keadaan sempadan, dan seterusnya tunjuk dan labelkan agihan halaju (lapisan sempadan) aliran tersebut.*

[5 markah]

[b] *Buktikan bahawa agihan halaju aliran ke arah atas melalui anulus diberi sebagai;*

$$v_z = \frac{(P_0 - P_L)R^2}{4\mu L}\left[1 - \left(\frac{r}{R}\right)^2 - \frac{1-\xi^2}{\ln 1/\xi}\ln\left(\frac{R}{r}\right)\right]$$

[10 markah]

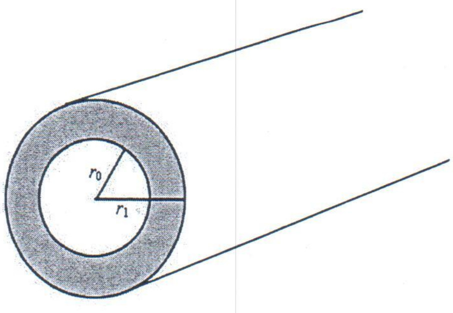
[c] *Berdasarkan keadaan sempadan yang dilukis pada bahagian [a], bilakah berlakunya halaju aliran maksimum dan carikan $v_{z,max}$ pada keadaan tersebut.*

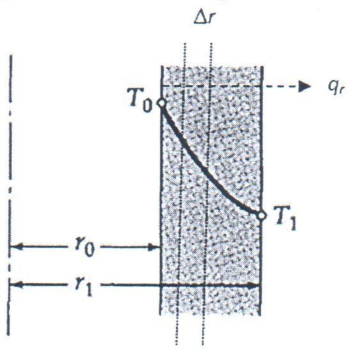
[5 markah]

[d] *Daripada keputusan yang diperolehi di bahagian [b], carikan halaju aliran purata ke atas $\langle v_z \rangle$ di antara dua dinding silinder-silinder tersebut.*

[5 markah]

2. *Dalam satu kajian kehilangan haba dalam satu paip dengan panjang L, adalah diperlukan untuk mendapatkan profil suhu jejarian merentasi dinding dalam dan dinding luar paip tersebut. Masalah ini boleh diterangkan sebagai fluks haba berkeadaan mantap dalam arah jejarian menerusi dinding anulus yang mempunyai jejari dalam r_0 dan jejari luar r_1, seperti yang ditunjukkan dalam Rajah S.2.*





Rajah S.2 Gambarajah skematik menunjukkan arah fluks tenaga

Diberi kekonduksian haba k *bagi dinding berubah secara linear dengan suhu* T *dan suhu tak berdimensi* θ *ditakrifkan sebagai:*

$$\theta = \frac{T - T_0}{T_1 - T_0} = \frac{k - k_0}{k_1 - k_0}$$

Nota: Subskrip 0 dan 1 masing-masing digunakan untuk sempadan dalam dan luar.

[a] By applying energy balance on a cylindrical shell of thickness Δr and length L, show that:

$$\frac{d}{dr}(rq_r) = 0$$

where q_r is the heat flux in radial direction and r representing radial position in the wall.

[8 marks]

[b] Write an algebraic expression showing the variation of temperature in the wall in terms of θ and r.

[7 marks]

[c] Use boundary conditions to solve for constant of integration in [b] and develop expression for the heat flow Q through the wall.

[10 marks]

3. [a] A mathematic expression of Fick's first law is written as:

$$J_A = -D_A \frac{dC_A}{dx}$$

where, J_A is the molecular flux of species A in x-direction, D_A is the diffusivity of species A and C_A is the concentration of species A.

[i] Why negative sign is used in this equation?

[1 mark]

[ii] What is the physical meaning of dC_A/dx?

[2 marks]

[iii] Physically, the analogies of Fick's Law to other common law (such as Fourier's Law) can be defined by recognizing J_A as the current and dx as the resistance. Under this context what is dC_A?

[2 marks]

[b] A solid sphere mainly composed of A with diameter of 10 μm is placed in a large body of unstirred, aqueous solution in Figure Q.3.[b]. The solubility of 'A' is 0.0005 g/cm^3 and the molecular size of A is 5 nm. If the flux of A going into the surrounding media obey Fick's first law:

$$J_A = -D_A \frac{dC_A}{dr}$$

[i] Calculate D_A at room temperature by using Stokes-Einstein Equation.

[2 marks]

[a] *Dengan menggunakan imbangan tenaga pada kerangka silinder berketebalan* Δr *dan panjang* L, *tunjukkan:*

$$\frac{d}{dr}(rq_r) = 0$$

di mana q_r *ialah fluks tenaga dalam arah jejarian dan* r *mewakili kedudukan jejarian dalam dinding.*

[8 markah]

[b] *Tuliskan ungkapan algebra yang menunjukkan perubahan suhu dalam dinding dalam sebutan* θ *dan* r.

[7 markah]

[c] *Gunakan keadaan sempadan untuk menyelesaikan pemalar pengamiran dalam [b] dan bangunkan ungkapan bagi aliran haba Q melalui dinding.*

[10 markah]

3. [a] *Persamaan matematik untuk Hukum Fick pertama adalah seperti berikut:*

$$J_A = -D_A \frac{dC_A}{dx}$$

dimana, J_A *ialah fluks molekul spesis* A *dalam arah-*x, D_A *adalah kemeresapan spesis* A *dan* C_A *adalah kepekatan spesis* A.

[i] *Mengapa tanda negatif digunakan dalam persamaan ini?*

[1 markah]

[ii] *Apakah maksud fizikal untuk* dC_A/dx*?*

[2 markah]

[iii] *Secara fizikal, analogi Hukum Fick kepada hukum-hukum am yang lain (seperti hukum Fourier) boleh ditakrifkan dengan mengambil* J_A *sebagai arus dan* dx *sebagai rintangan. Di bawah konteks ini apakah definisi* dC_A*?*

[2 markah]

[b] *Satu sfera pepejal yang terdiri daripada* A *diletakkan dalam satu bendalir tanpa dikacau di Rajah S.3. Kebolehlarutan* A *adalah 0.0005 g/sm*^{3} *dan saiz molekulnya ialah 5 nm. Sekiranya fluks* A *yang memasuki ke dalam media disekitarnya mematuhi Hukum Fick pertama:*

$$J_A = -D_A \frac{dC_A}{dr}$$

[i] *Kirakan* D_A *pada suhu bilik dengan menggunakan persamaan Stokes-Einstein.*

[2 markah]

[ii] Derive an equation to determine the relationship between C_A and r. Please remember that for dissolution of A, at $\delta r \rightarrow 0$,
$-\frac{1}{r^2}\frac{d}{dr}(r^2 J_A) = 0.$

[4 marks]

[iii] Determine the unknown of the equation you have derived in part [ii] if the diffusion is super slow, hence, at $r = \infty$, $C_A = 0$. Calculate the value of C_A at $r = 10 \cdot R_s$.

[4 marks]

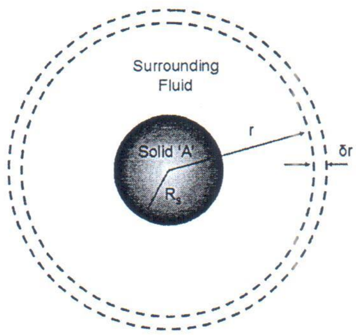


Figure Q.3.[b] Sphere A immersed in an aqueous environment.

[c] [i] Diffusion is a process which depending on temperature of the diffusing system. Discuss why temperature is important for this process.

[2 marks]

[ii] According to Penetration theory developed by Higbie in 1935 suggested that the flux N across an interface into a thin film is $N = k(C_1 - C_2)$, in which k is the mass transfer coefficient of this process. With this definition, Sherwood number (Sh) can be defined as $Sh = k \cdot L/D$, where L is the characteristic length and D is the diffusivity. Explain why the film thickness is normally used as characteristic length L under Penetration theory?

[3 marks]

[iii] A diffusion-reaction process happened within a catalyst pellet, at zero-order reaction. Thiele modulus Φ is defined as $\Phi = \frac{kL^2}{2D_A C_A}$, where k is the mass transfer coefficient, D_A is the diffusivity of species A, L is the characteristic length and C_A is the concentration of species A. What is the physical significance of Thiele modulus? From transport phenomena perspective, what it means if (a) $\Phi \gg 1$, and (b) $\Phi \ll 1$? If you are given a cylindrical shaped catalyst, will you choose its diameter or length to define the characteristic length L? Justify your answer.

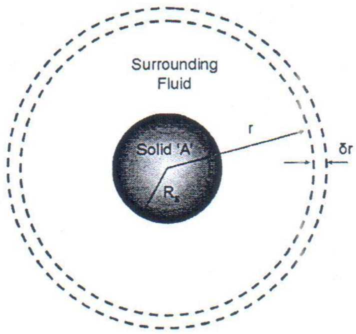
[5 marks]

[ii] *Terbitkan persamaan untuk menentukan hubungan di antara* C_A *dengan r. Diingatkan bahawa untuk pelarutan* A, *pada* $\delta r \rightarrow 0$, $-\frac{1}{r^2}\frac{d}{dr}(r^2 J_A) = 0$.

[4 markah]

[iii] *Tentukan istilah-istilah tidak diketahui dalam persamaan yang diterbitkan dalam [ii] sekiranya resapan berlaku dengan perlahan, oleh demikian, pada* $r = \infty$, $C_A = 0$. *Kirakan nilai untuk* C_A *bagi* $r = 10 \cdot R_s$.

[4 markah]



Rajah S.3. Sfera pepejal A *berada dalam bendalir.*

[c] [i] *Resapan adalah satu proses yang bergantung kepada suhu sistem. Bincangkan mengapa suhu adalah penting untuk proses ini.*

[2 markah]

[ii] *Menurut teori Penembusan yang dibangunkan oleh Higbie pada tahun 1935, fluks* N *melintasi antara muka ke dalam filamen nipis boleh diterbitkan sebagai* $N = k(C_1 - C_2)$, *di mana* k *adalah pekali pemindahan jisim proses ini. Dengan definisi ini, kita boleh menentukan Nombor Sherwood (*Sh*) sebagai* $Sh = k \cdot L/D$, *di mana* L *ialah panjang ciri* D *adalah kemeresapan. Jelaskan mengapa ketebalan filem nipis biasanya digunakan sebagai panjang ciri* L *di bawah teori Penembusan?*

[3 markah]

[iii] *Untuk proses resapan-tindak balas yang berlaku dalam pelet pemangkin, pada tindak balas tertib sifar, Thiele modulus* Φ *ditakrifkan sebagai* $\Phi = \frac{kL^2}{2D_A C_A}$, *di mana* k *adalah pekali pemindahan jisim,* D_A *merupakan kemeresapan* A, L *ialah panjang ciri dan* C_A *ialah kepekatan* A. *Apakah maksud fizikal Thiele modulus? Dari perspektif fenomena pengangkutan, apakah maksud untuk (a)* $\Phi \gg 1$, *dan (b)* $\Phi \ll 1$? *Jika anda dibekalkan pemangkin yang berbentuk silinder, anda akan memilih garis pusat atau panjangnya sebagai panjang ciri? Jelaskan jawapan anda.*

[5 markah]

4. [a] In the near wall region, where pressure gradients and gravitational forces are negligible, the Reynolds averaged form of the Navier-Stokes Equation reduces, for a 1-dimensional flow to;

$$(\mu + \mu_t)\frac{\partial^2 \overline{v_x}}{\partial y^2} \approx 0 \qquad (1)$$

where μ and μ_t are the molecular and turbulent viscosities, $\overline{v_x}$ the mean velocity in the x-direction (parallel to the wall) and y is the distance from the wall. The turbulent viscosity is defined as:

$$\mu_t = -\frac{\rho\overline{v_x' v_y'}}{\partial \overline{v_x} / \partial y} \qquad (2)$$

where v_x' and v_y' are the instantaneous fluctuations in the velocity components in the x- and y-direction, respectively.

[i] Show that for the region immediately adjacent to the wall (where $\mu >> \mu_t$), equation (2) leads to expression:

$$u^+ = y^+$$

where u^+ and y^+ are given by;

$$u^+ = \frac{\overline{v_x}}{u^*} \quad \text{and} \quad y^+ = \frac{u^* \rho y}{\mu}$$

where u^* is the friction velocity defined as

$$u^* = \sqrt{\tau_0 / \rho}$$

where τ_0 is the wall shear stress.

[5 marks]

4. [a] *Pada kawasan berdekatan dinding, di mana kecerunan tekanan dan daya graviti diabaikan, bentuk purata Reynolds bagi persamaan Navier-Stokes diringkaskan kepada aliran 1-dimensi;*

$$(\mu + \mu_t)\frac{\partial^2 \overline{v_x}}{\partial y^2} \approx 0 \qquad (1)$$

di mana μ *dan* μ_t *adalah masing-masing kepekatan molekul dan gelora,* $\overline{v_x}$ *adalah purata halaju pada arah-x (selari dengan dinding) dan y adalah jarak dari dinding. Halaju gelora diberikan oleh;*

$$\mu_t = -\frac{\rho\overline{v'_x v'_y}}{\partial\overline{v_x}/\partial y} \qquad (2)$$

di mana v'_x *dan* v'_y *adalah masing-masing perubahan ketika pada komponen-komponen halaju arah-x dan y.*

[i] *Tunjukkan bagi kawasan hampir serta-merta pada dinding (di mana* $\mu >> \mu_t$*), persamaan (2) diringkaskan kepada persamaan;*

$$u^+ = y^+$$

di mana u^+ *dan* y^+ *diberi sebagai;*

$$u^+ = \frac{\overline{v_x}}{u^*} \quad dan \quad y^+ = \frac{u^* \rho y}{\mu}$$

di mana u^* *adalah halaju geseran yang diberikan oleh*

$$u^* = \sqrt{\tau_0/\rho}$$

di mana τ_0 *adalah tegasan ricih pada dinding.*

[5 markah]

[ii] For the case of fluid further away from the wall, where $\mu_t >> \mu$, the Prandtl mixing length hypothesis may be invoked;

$$\overline{v_x' v_y'} = l^2 \left| \frac{\partial \bar{v}_x}{\partial y} \right| \frac{\partial \bar{v}_x}{\partial y}$$

where the mixing length l is given by;

$$l = \kappa y$$

where κ, is the von Karman constant. Show that it follows from equation (2) and from the above mixing length hypothesis that;

$$u^+ = \frac{1}{\kappa} \ln y^+ + C \qquad (3)$$

where C is a constant.

[4 marks]

[b] A schematic representation in Figure Q.4.[b] shows a phenomenon where heat is being constantly dissipated through a rectangular fin. The effectiveness of the fin surface for heat transfer is defined as parameter η with a condition that the wall is maintained at constant temperature (isothermal). Given:

$$\eta = \frac{\text{Rate of heat loss from the fin to the air}}{\text{Rate of heat loss from the wall to the air}}$$

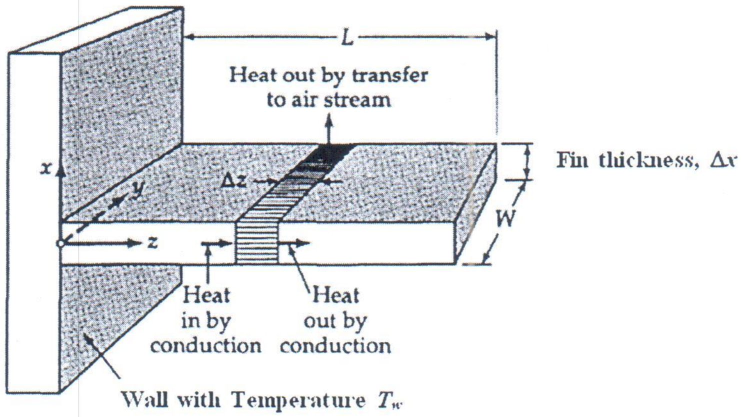


Figure Q.4.[b].

[ii] *Bagi kes bendalir yang berada jauh dari dinding, di mana $\mu_t >> \mu$, hipotesis panjang campuran Prandtl dapat diterbitkan sebagai;*

$$\overline{v_x' v_y'} = l^2 \left| \frac{\partial \overline{v_x}}{\partial y} \right| \frac{\partial \overline{v}_x}{\partial y}$$

di mana panjang campuran, l diberi oleh;

$$l = \kappa y$$

di mana κ, adalah pemalar von Karman. Tunjukkan bahawa daripada persamaan (2) serta hipotesis campuran panjang adalah;

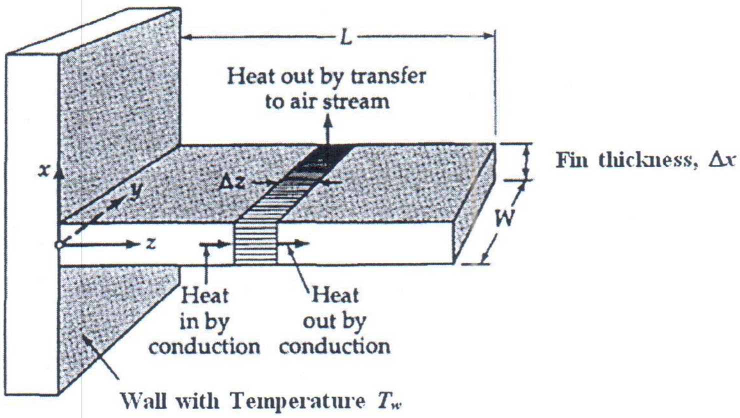
$$u^+ = \frac{1}{\kappa} \ln y^+ + C \qquad (3)$$

di mana C adalah pemalar.

[4 markah]

[b] *Gambarajah skematik dalam Rajah S.4.[b] menunjukkan suatu fenomena di mana haba dipindahkan secara malar melalui sirip segiempat. Keberkesanan permukaan sirip untuk pemindahan haba ditakrifkan sebagai parameter η dengan syarat suhu pada dinding dikekalkan secara malar (isoterma). Diberi:*

$$\eta = \frac{\textit{Kadar kehilangan haba dari sirip ke udara}}{\textit{Kadar kehilangan haba dari dinding ke udara}}$$



Rajah S.4.[b]

The numerical value of the effectiveness of the fin surface for the heat transfer can be estimated through the following correlation:

$$\eta = \frac{\tanh N}{N}$$

where

$$N = \sqrt{\frac{2hL^2}{k(\Delta x)}}$$

h = heat transfer coefficient
k = thermal conductivity
L = length protruding from the wall
Δx = thickness of the fin

with the following assumptions:

- as $\Delta x << L$, heat loss through the edge of the fin is negligible.
- the shaded area maintained at uniform temperature T_w.

[i] Obtain an expression for the rate of heat loss (Q) from a rectangular fin through the definition of effectiveness of the fin surface.

[5 marks]

[ii] If temperature of the surrounding air is found to be 20°C and the temperature of the wall maintained at 70°C, calculate the heat loss from a rectangular fin having width 30 cm, length 6 cm and thickness 4 mm.

k = 105 W/(m K)
h = 680 W/(m^2K)

[3 marks]

[c] Cyclohexane (A) is diffusing through a 1.5 mm thick stagnant benzene (B) film at 25°C as shown in Figure Q.4.[c]. If x_{A0} = 0.15 and x_{AL} = 0.05, determine the molar flux of cyclyhexane (N_{AB}) under steady condition. Take $D_{AB} = 2.09 \times 10^{-5}$ cm²/s. Given:

Component	Density, g/cm³	Molar Mass, gmol
Cyclohexane (A)	0.779	84
Benzene (B)	0.879	78

$c = \frac{1}{\tilde{V}_{mix}} = \frac{1}{x_A\tilde{V}_A + x_B\tilde{V}_B}$; $N_{AB} = \frac{D_{AB}}{L\tilde{V}_A} ln\left(\frac{c_{BL}}{c_{B0}}\right)$, where $\tilde{V}$ is molar volume.

[8 marks]

Nilai berangka keberkesanan permukaan sirip boleh dianggarkan melalui korelasi berikut:

$$\eta = \frac{\tanh N}{N}$$

di mana

$$N = \sqrt{\frac{2hL^2}{k(\Delta x)}}$$

h = *pekali pemindahan haba*
k = *kekonduksian haba*
L = *panjang terjulur dari dinding*
Δx = *tebal sirip*

dengan andaian berikut:

- *apabila* $\Delta x \ll L$, *kehilangan haba melalui pinggir sirip diabaikan*
- *kawasan berlorek dikekalkan pada suhu seragam* T_w.

[i] Dapatkan ungkapan bagi kadar kehilangan haba (Q) dari sirip segiempat melalui definisi keberkesanan permukaan sirip.

[5 markah]

[ii] Jika suhu udara sekeliling didapati 20°C dan suhu dinding dikekalkan pada 70°C, kira kehilangan haba dari sirip segiempat yang mempunyai lebar 30 sm, panjang 6 sm dan tebal 4 mm.

k = 105 W/(m K)
h = 680 W/(m^2K)

[3 markah]

[c] Sikloheksana (A) meresap melalui selapis filamen benzena (B) yang memiliki ketebalan 1.5 mm pada 25°C seperti ditunjukan dalam Rajah S.4.[c]. Sekiranya $x_{A0} = 0.15$ *dan* $x_{AL} = 0.05$, *tentukan fluks molar sikloheksana* (N_{AB}) *dibawah keadaan mantap. Diambil kira* $D_{AB} = 2.09 \times 10^{-5}$ sm^2/s. *Diberikan:*

Komponen	*Ketumpatan, g/sm³*	*Jisim molar, gmol*
Sikloheksana (A)	*0.779*	*84*
Benzena (B)	*0.879*	*78*

$c = \frac{1}{\tilde{V}_{mix}} = \frac{1}{x_A\tilde{V}_A + x_B\tilde{V}_B}$; $N_{AB} = \frac{D_{AB}}{L\tilde{V}_A} \ln\left(\frac{c_{BL}}{c_{B0}}\right)$, *dimana* $\tilde{V}$ *ialah isipadu molar.*

[8 markah]

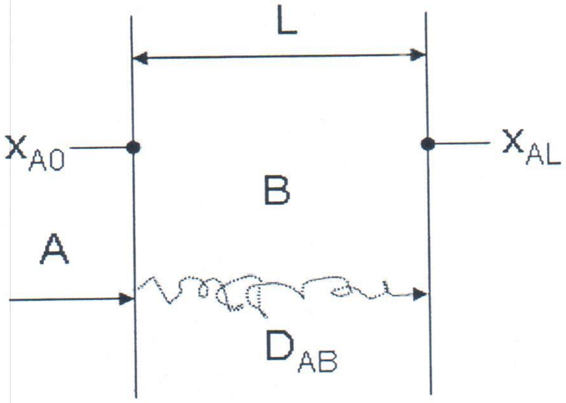
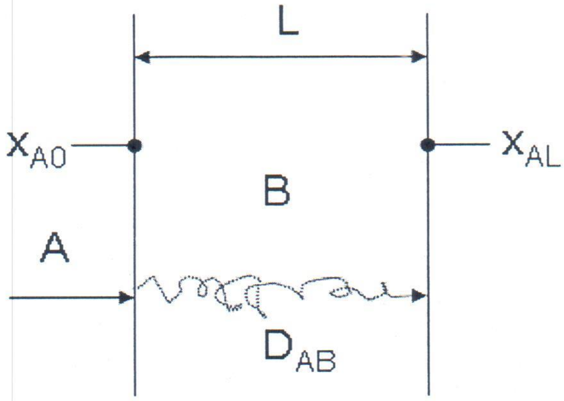


Figure Q.4.[c].



Rajah S.4.[c].

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