UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**CEB4053 - TRANSPORT PHENOMENA**
DATE	**:**	**9 AUGUST 2024 (FRIDAY)**
TIME	**:**	**9.00 AM - 12.00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **NINE (9)** pages in this Question Booklet including the cover page and appendix.

ii. **DOUBLE-SIDED** Question Booklet.

1. The speed on how fast a water tank is filled is directly related to how powerful the water pump is to overcome the pressure drop inside the water pipe channel. **FIGURE Q1** shows water flows upwards in a circular tube channel to fill the water tank on top of a household, with its detailed internal dimensions. Assume the channel length, L is considerably larger than the channel radius, R. The liquid flows in the channel under the effect of gravity and pressure difference.

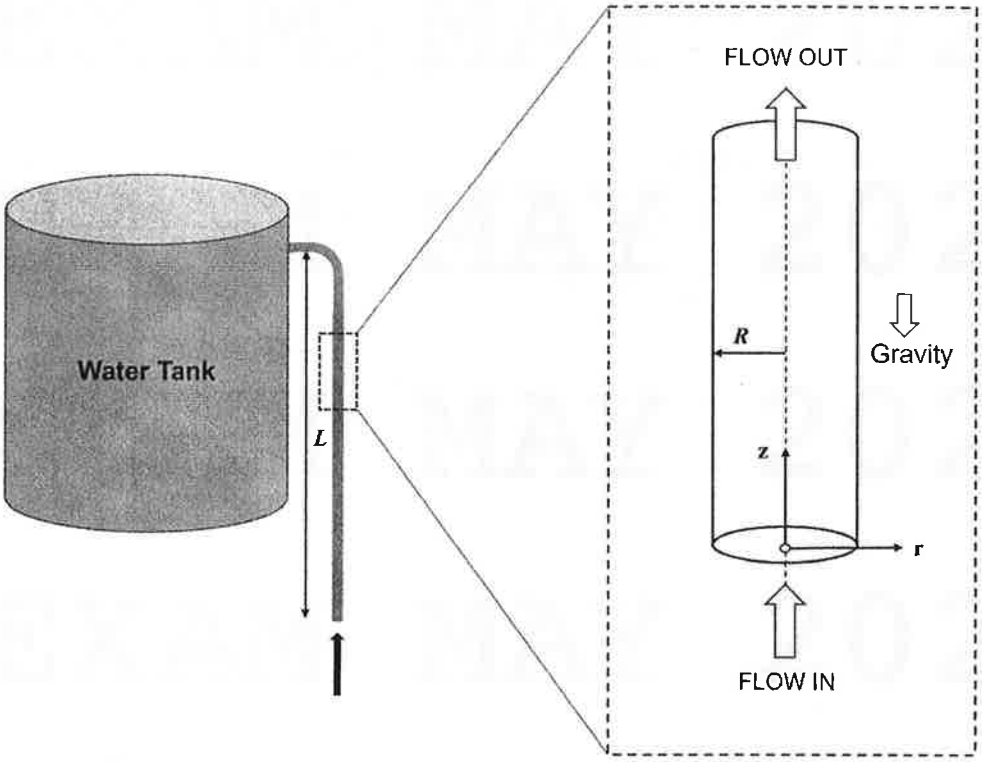

FIGURE Q1: Upward laminar flow of an incompressible Newtonian liquid in a vertical cylindrical water pipe

a. Using the equation of change method and the given coordinate axes, develop the velocity distribution profile and the average velocity for the liquid flows in the circular tube channel.

[17 marks]

b. If the water flows in a constant flowrate, estimate the average time required to fill a 10,000 L water tank with 5 kPa pressure drop pump capacity. The properties of the liquid and the circular tube channel are provided in **TABLE Q1.**

TABLE Q1: Properties of the liquid and the circular channel

Properties of Newtonian liquid	Value
Density of water, ρ (kg/m^3)	1000
Viscosity of water, μ (Pa.s)	1.1×10^{-3}
Channel length, L (m)	5.5
Channel Diameter, D (cm)	2.5
Gravitational acceleration, g (m/s^2)	9.81

[8 marks]

2. Insulation layer is an important design to keep a hot liquid to remain hot for a longer time. **FIGURE Q2** shows a cross-sectional view of a thermal flask with insulator. The insulation materials include the aluminum casing, vacuum insulator and glass container with outer radius of r_A, r_B, and r_C, with each having surface temperature of T_A, T_B, and T_C, respectively. The hot water is kept in a glass container with an internal radius, r_D, with bulk temperature of T_W which is much hotter than the external flask wall temperature, T_A. Assume a steady flow of heat through the flask insulators due to the difference between the bulk fluid and the external aluminum casing temperature.

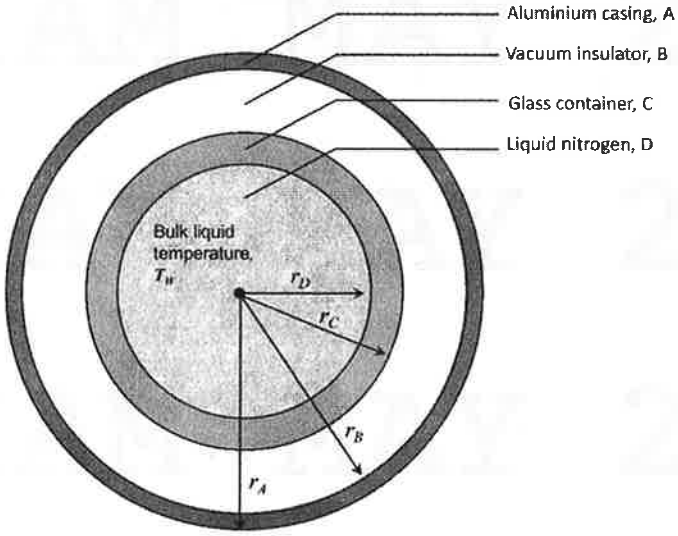

FIGURE Q2: Cross-sectional of an insulated thermal flask.

a. Develop the heat flux and the heat flow at the external surface of the aluminum casing protecting the hot water in the thermal flask.

[15 marks]

b. If the bulk hot water temperature is 98 °C with 500 mL hot water container size, calculate the heat flow (W) to keep the external aluminum casing at temperature of 25 °C. Assume a constant heat flow across the layers and a perfect cylinder container. The thermal properties of the materials and fluids are provided in **TABLE Q2.**

TABLE Q2: Thermal properties of the materials and fluids.

Parameter	Value
Thermal flask length (m)	0.5
Thickness of aluminium casing (mm)	2.3
Thickness of vacuum insulator (mm)	28
Thickness of glass container (mm)	5.5
Heat conductivity of aluminium, k_A ($W.m^{-1}.K^{-1}$)	237
Heat conductivity of vacuum gas, k_B ($W.m^{-1}.K^{-1}$)	2
Heat conductivity of glass, k_C ($W.m^{-1}.K^{-1}$)	0.08
Heat transfer coefficient of hot water, h_W ($W.m^{-2}.K^{-1}$)	21

[10 marks]

3. When there is a flow of lubricant in between two rapidly moving parts, viscous heating will occur. **FIGURE Q3** shows an incompressible Newtonian fluid between two slabs with thickness of δ. The surface temperature of the bottom and upper wall is maintained at T_1 and T_2, respectively. The bottom wall is stationary while the upper wall is moving with a constant velocity of v_{wall} with constant surface area of WL. The combined energy flux for this phenomenon is described as below:

$$e_y = q_y + \tau_{yx} v_x$$

$$\text{where, } v_x = \left(\frac{y}{\delta}\right) v_{wall}$$

With assumptions and boundary conditions, develop the temperature distribution and show that the dimensionless Brinkman number (Br) is defined as

$$Br = \mu \frac{{v_{wall}}^2}{k(T_2 - T_1)}$$

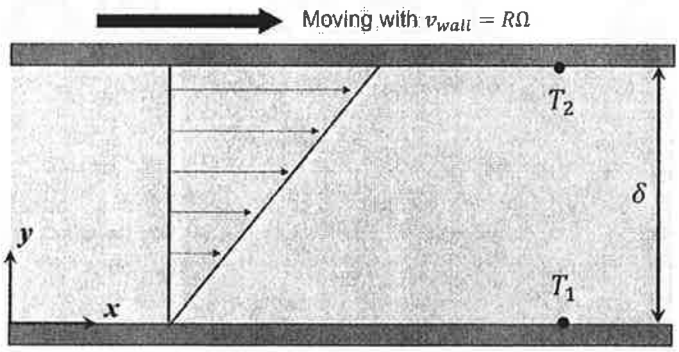

FIGURE Q3: Heat dissipation with viscous heat source between two moving slabs.

[25 marks]

4. **FIGURE Q4** shows a mass diffusion system in which liquid dimethyl ether (DME), D, is evaporating into air, A. At equilibrium, the evaporated gas-phase concentration of DME at the liquid-gas interphase is expressed as x_{D1}. Assume that the solubility of air in liquid DME is negligible and the cross-sectional of the container has square shape with width of W. If the entire system is kept at constant temperature and pressure, and mixture of air and DME gases are assumed to be ideal, derive the concentration profile of DME in terms of partial pressure using the shell mole balance method.

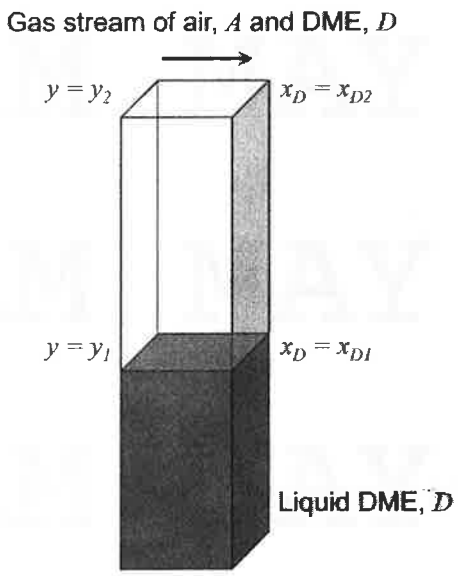

FIGURE Q4 Steady-state diffusion of DME through stagnant A in a rectangular container

[25 marks]

- END OF PAPER -

APPENDIX

LIST OF EQUATION

Equation of Motion for Cylindrical Coordinate

***r*-Momentum Balance**

$$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}+v_z\frac{\partial v_r}{\partial z}-\frac{v_\theta^2}{r}\right)=-\frac{\partial p}{\partial r}-\left[\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rr})+\frac{1}{r}\frac{\partial}{\partial \theta}\tau_{\theta r}+\frac{\partial}{\partial z}\tau_{zr}-\frac{\tau_{\theta\theta}}{r}\right]+\rho g_r$$

***θ*-Momentum Balance**

$$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+v_z\frac{\partial v_\theta}{\partial z}+\frac{v_r v_\theta}{r}\right)=-\frac{1}{r}\frac{\partial p}{\partial \theta}-\left[\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\tau_{r\theta})+\frac{1}{r}\frac{\partial}{\partial \theta}\tau_{\theta\theta}+\frac{\partial}{\partial z}\tau_{z\theta}+\frac{\tau_{\theta r}-\tau_{r\theta}}{r}\right]+\rho g_\theta$$

***z*-Momentum Balance**

$$\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial p}{\partial z}-\left[\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rz})+\frac{1}{r}\frac{\partial}{\partial \theta}\tau_{\theta z}+\frac{\partial}{\partial z}\tau_{zz}\right]+\rho g_z$$

Momentum transport equations

Combined momentum flux

$$\emptyset_{ij}=\pi_{ij}+\rho v_i v_j=p\delta_{ij}+\tau_{ij}+\rho v_i v_j$$

where,

$$\tau_{ij}=-\mu\left(\frac{\partial v_j}{\partial x_i}+\frac{\partial v_i}{\partial x_j}\right)+\left(\frac{2}{3}\mu-\kappa\right)\left(\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}\right)\delta_{ij}$$

Average velocity equation

$$\langle v_z\rangle=\frac{\int_0^{2\pi}\int_0^R v_z r\,dr\,d\theta}{\int_0^{2\pi}\int_0^R r\,dr\,d\theta}$$

Mass flow rate

$$w=\int_0^{2\pi}\int_0^R \rho v_z r\,dr\,d\theta$$

Combined Energy Flux Equation

$$e = q + \left(\frac{1}{2}\rho v^2 + \rho\widehat{H}\right)v + [\tau.v]$$

Combined Molar Flux Equation for Species A in the z-direction

$$N_{Az} = -cD_{AB}\frac{\partial x_A}{\partial z} + x_A(N_{Az} + N_{Bz})$$