UNIVERSITI TEKNOLOGI PETRONAS

# FINAL EXAMINATION
# MAY 2024 SEMESTER

**COURSE** : **CFB1053 - CHEMICAL ENGINEERING FLUID MECHANICS**

**DATE** : **12 AUGUST 2024 (MONDAY)**

**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** :

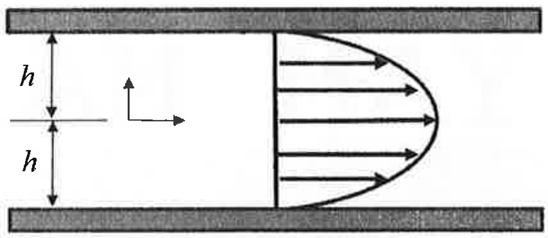
i. There are **THIRTEEN (13)** pages in this Question Booklet including the cover page and appendices.

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

1. a. Explain how the viscosity of liquids and gases varies with temperature.

[4 marks]

b. A Newtonian fluid flows between two wide, parallel plates as shown in **FIGURE Q1**. The velocity distribution for the flow is given by the equation below where, $v_{max}$ is the maximum velocity.




$$v = v_{max}\left[1 - \left(\frac{2y}{h}\right)^2\right]$$

**FIGURE Q1:** Velocity distribution profile between two parallel plates

The fluid has a viscosity of 1.9 Pa.s. Given, $v_{max}$ = 0.4 m/s and $h$ = 0.5 mm, determine the:

i. shearing stress acting on the bottom plate.

[5 marks]

ii. shearing stress acting on a plane parallel to both plates and passing through the centerline (midline).

[3 marks]

c. A block of wood has a mass of 4 kg and a density of 600 $kg/m^3$. The wood is to be loaded with polytetrafluoroethylene plastic (PTFE) so that it will float on water with 90% of its volume submerged. The density of PTFE plastic is 2300 $kg/m^3$.

i. Calculate the mass of PTFE plastic needed if it is attached to the top of the wood.

[4 marks]

ii. Calculate the mass of PTFE plastic needed if it is attached to the bottom of the wood and discuss the difference with the value obtained in **part (c)(i)**.

[8 marks]

2. a. Two containers, A and B contain oil at the respective pressures of 280 kPag and 140 kPag. A manometer is placed between those two containers as shown in **FIGURE Q2a**. Calculate the height difference, $h$ of mercury inside the manometer. Given: $x + y = 2\ m$, $SG_{mercury}$ = 13.6 and $SG_{oil}$ = 0.8.

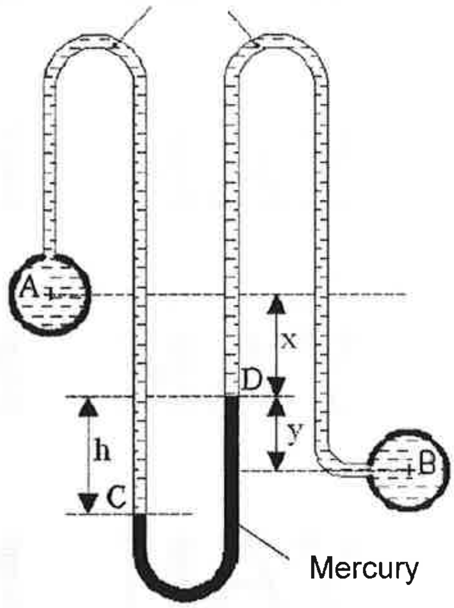



**FIGURE Q2a**: Two tanks connected to a U-tube manometer

[7 marks]

b. A siphon has a uniform circular bore of 80 mm diameter and consists of a bent pipe with its crest 1.9 m above gas condensate level discharging into the atmosphere at a level 4.5 m below gas condensate level as shown in **FIGURE Q2b**. Neglect all energy loss. Take $SG_{oil}$=0.85, $SG_{condensate}$=0.7 and $P_{atm}$ = 101.325 kPa.

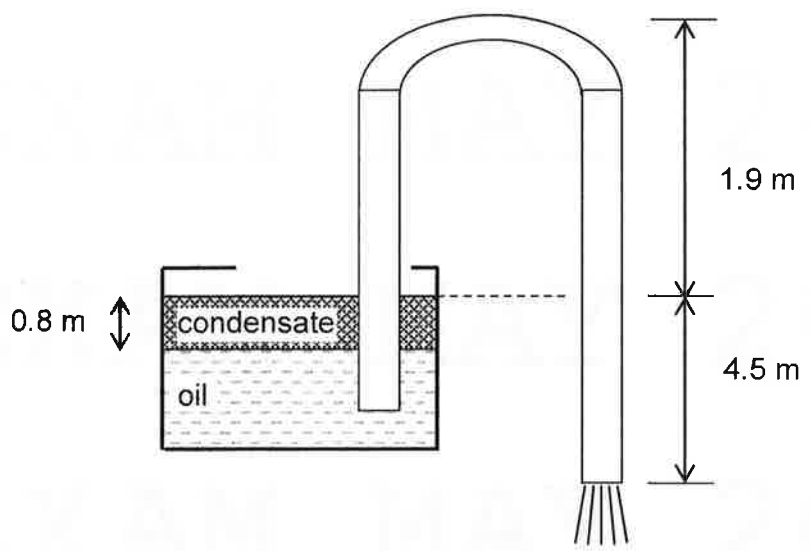



**FIGURE Q2b**: Siphon used to empty a tank

i. Determine the initial mass flowrate of oil.

[7 marks]

ii. Calculate the initial absolute pressure at crest level.

[5 marks]

iii. Determine the maximum height of the crest above the gas condensate level where beyond that maximum height, the siphon ceases to function.

[4 marks]

iv. Discuss what would happen if gas condensate was replaced with another liquid with the same exact quantity but having lower SG value than gas condensate.

[3 marks]

3. Water from a river is to be transferred into a big tank as shown in **FIGURE Q3**. The tank is open to atmospheric pressure. A pipeline system is constructed using 3-in Schedule 40 commercial steel pipes. The pipes are partially immersed 3 m below the river water surface. Along the pipeline there are three 90° standard elbows, a globe valve, and a pump. The energy cost is RM 0.35 per kilowatt-hour (kW.h) and the efficiency of the pump is 0.75.

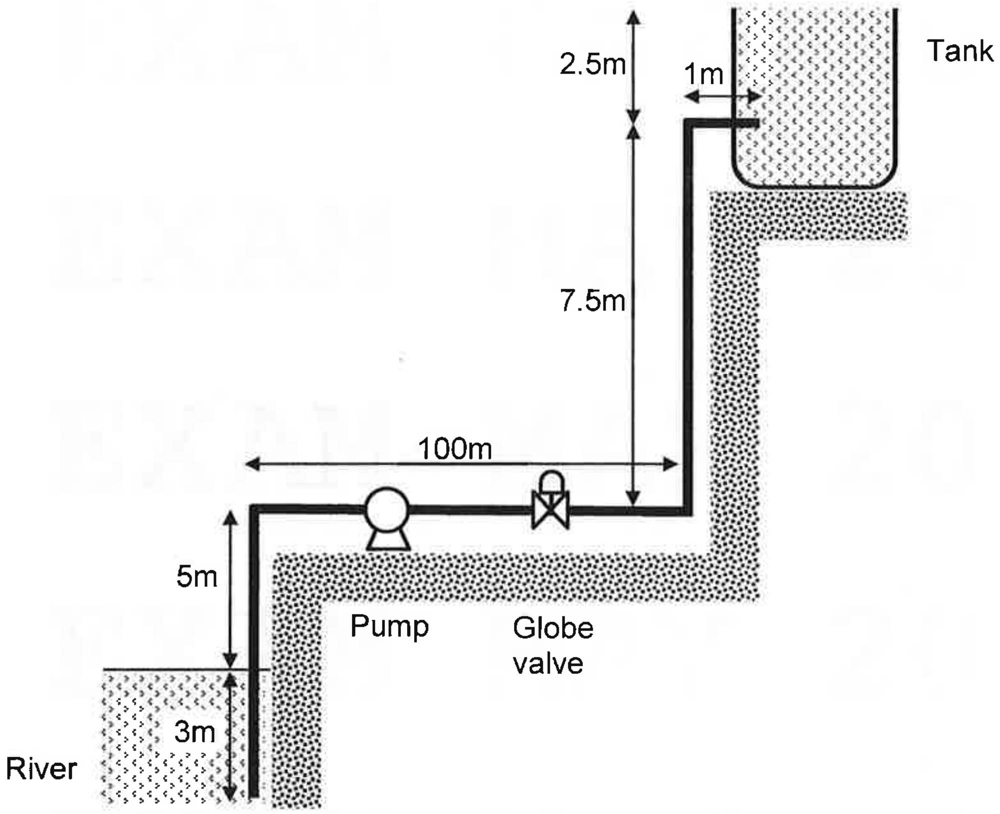



**FIGURE Q3:** Water from a river is being pumped into a tank

a. Identify **THREE (3)** types of energy losses experienced in the pipeline system.

[3 marks]

b. Characterize the flow if the maximum flow rate that can be pumped from the river is 50 L/min.

[4 marks]

c. Calculate the maximum energy loss of the pipeline system if the flowrate is the same as **part (b)**.

[6 marks]

d. Estimate the pump continuous operating cost per week.

[8 marks]

e. If the pipeline system is changed with plastic pipe, evaluate the energy loss with suitable calculation while the other parameters remain constant.

[5 marks]

4. a. Nitrogen enters the nozzle at a temperature of 500 K and a pressure of 2000 kPa (abs). Nitrogen is discharged at the divergent section at 300 K. Assume that the specific heat ratio and gas constant for nitrogen are 1.4 and 297 J/kg.K, respectively. Based on the reservoir conditions, determine the pressure, Mach number and velocity of the gas.

[6 marks]

b. A 4500 kg airplane has wings 20 m long (tip to tip) and 2.5 m wide. The airplane is going to take-off at lift coefficient of 0.8. After the take-off, the airplane is steadily cruising at a constant altitude. The drag coefficient of the airplane during cruising is 0.08.

i. Determine the velocity required for the airplane to take-off. Take density of air as 1.23 kg/m$^3$.

[5 marks]

ii. Calculate the required power to keep the plane cruising at 300 km/h. Take density of air as 0.8 kg/m$^3$.

[4 marks]

iii. Does the airplane need to fly as high as possible to reduce the cost of fuel per km? Justify your answer.

[3 marks]

c. A bed of spherical ion-exchange resin particles with a diameter of 760 μm are placed in a 3 cm-diameter cylinder which has a height of 35 cm as shown in **FIGURE Q4c**.

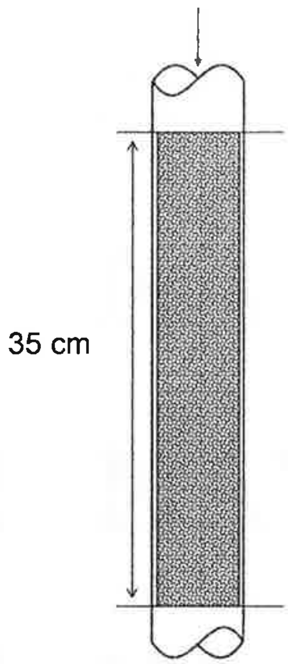



**FIGURE Q4c:** Ion-exchange resin inside a cylinder

In an experiment water trickles down the bed with superficial velocity of 24 cm/min. Given the bed porosity is 0.4, determine the volumetric flow rate of water and pressure gradient required in the system.

[6 marks]

-END OF PAPER-

**APPENDIX I**

a. **Properties of water at room temperature:**

- Density, $\rho$ = 1000 kg/m$^3$
- Dynamic viscosity, $\mu$ = 1 cP = $10^{-3}$ kg/m·s

b. **Properties for air**

- Molar mass, MW = 29 kg/kmol
- Specific heat constant, k = 1.4
- Gas constant of air = 287 J/kg.K

c. **Conversion factors:**

- 1 m = 3.281 ft = 39.37 in = 100 cm = $10^{-3}$ km
- 1 atm = 101.3 kPa = 1.013 bar = 12.7 lbf/in$^2$
  = 10.33 m of water = 760 mm mercury = 760 torr
- 1 cp = 0.01 poise = 0.001 kg/m·s = 0.001 N·s/m$^2$
- 1 cSt = $10^{-6}$ m$^2$/s
- 1 J/kg = 1 m$^2$/s$^2$
- 1 ft$^3$ = 0.02831 m$^3$ = 28.31 L = 7.48 gal

d. **Other useful information**

- Universal gas constant, $Ru$ = 8.314 kJ/kmol·K
  = 8.314 kPa·m$^3$/ kmol·K
- Gravitational acceleration, $g$ = 9.81 m/s$^2$

e. **Piping and fitting system**

- $K$ values for various kinds of valves and fittings

| Type of fitting | Constant, K, dimensionless |
|---|---|
| Globe valve, wide open | 6.30 |
| 90° standard elbow | 0.74 |

**APPENDIX I (CONT'D)**

- Schedule 40 Steel pipe:

| Nominal pipe size, in | Outside diameter, in | Inside diameter, in |
|---|---|---|
| 3 | 3.500 | 3.068 |
| 4 | 4.500 | 4.026 |

- Resistance due to sudden contractions, $K_c$ = 0.5
- Resistance due to sudden expansion, $K_e$ = 1.0
- Surface roughness commercial steel pipe, $\varepsilon$ = 0.045 mm
- Surface roughness for plastic pipe, $\varepsilon$ = 0.0015 mm

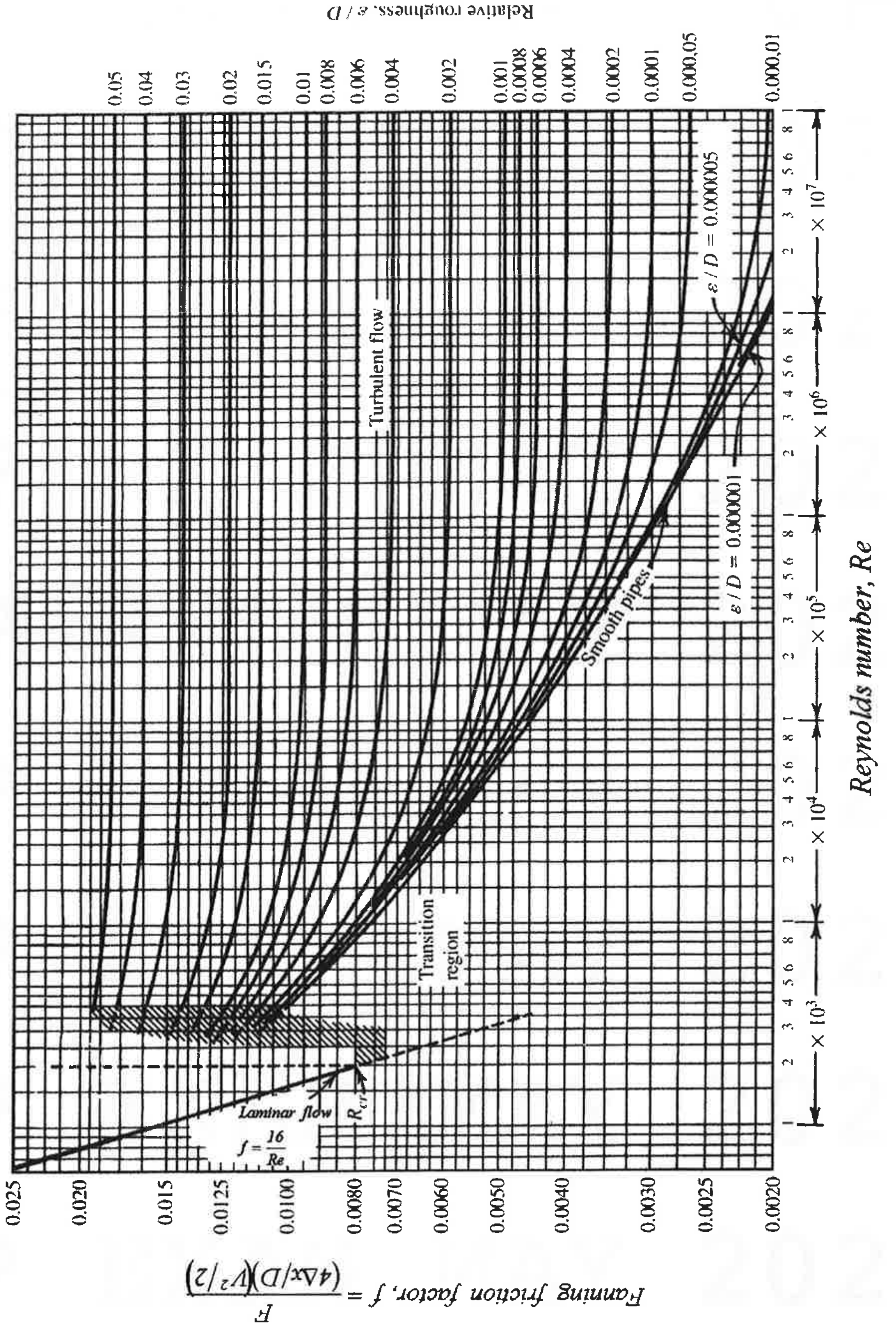
f. **Useful formulas**

- $\tau = \mu \frac{du}{dy}$
- $\tau = \frac{F}{A}$
- $\gamma = \rho g$
- $\upsilon = \frac{\mu}{\rho}$
- Buoyancy force, $F_B$ = weight of displaced fluid $= mg = \rho g V_{displaced\,fluid}$
- For floating bodies, buoyancy force, $F_B = W_{total\,weight\,of\,the\,body}$
- $\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 + \frac{W_P}{g} = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + \frac{W_T}{g} + \frac{F}{g}$ $[m]$
- $Re = \frac{\rho v D_h}{\mu}$
- $D_h = \frac{4\,A_{cros-sectional\,of\,flow}}{P_{wetted\,perimeter}}$
- $F = \left(\frac{4fL}{D} + \sum K_{fitting} + K_e + K_c\right)\frac{v^2}{2}$
- $f = 0.001375\left[1 + \left(20000\frac{\varepsilon}{D} + \frac{10^6}{Re}\right)^{\frac{1}{3}}\right]$

**APPENDIX I (CONT'D)**

- $c = \sqrt{kRT}$
- $Ma = \frac{V}{c}$
- $\frac{P_R}{P_1} = \left(\frac{{Ma_1}^2(k-1)}{2} + 1\right)^{\frac{k}{k-1}}$
- $\frac{T_R}{T_1} = \frac{{Ma_1}^2(k-1)}{2} + 1$
- $\frac{\rho_R}{\rho_1} = \left(\frac{{Ma_1}^2(k-1)}{2} + 1\right)^{\frac{1}{k-1}}$
- $F_D = C_D A \frac{\rho v_0^2}{2}$
- $F_L = C_L A \frac{\rho v_0^2}{2}$
- $P = F_D v \quad or \quad P = F_L v$
- $v_{0,t} = \frac{1}{18} \frac{gD^2(\rho_s - \rho_f)}{\mu}$
- $Re_P = \frac{\rho v D_p}{\mu}$
- $Re_{PM} = \frac{\rho v_s D_p}{\mu(1-\varepsilon)}$
- $F = \left(1.75 \frac{v_s^2 L}{D_p} \frac{(1-\varepsilon)}{\varepsilon^3}\right) + \left(150 \frac{v_s \mu L}{\rho_f D_p^2} \frac{(1-\varepsilon)^2}{\varepsilon^3}\right)$

## APPENDIX II




Moody's Diagram