UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE	**:**	**CFB1053 - CHEMICAL ENGINEERING FLUID MECHANICS**
DATE	**:**	**12 APRIL 2025 (SATURDAY)**
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. Identify and briefly explain three fundamental types of mechanical stress encountered in materials. Give **ONE (1)** example for each.

[6 marks]

b. If 3 m^3 of certain oil weighs 27 kN calculate the specific weight, specific gravity and density of the oil.

[3 marks]

c. Two flat, rectangular pieces of glass are held parallel and vertically, about 2 m apart as shown in **FIGURE Q1**. Their lower edges are immersed in water. The water rises in the space between them because of surface tension and the plates pull together.

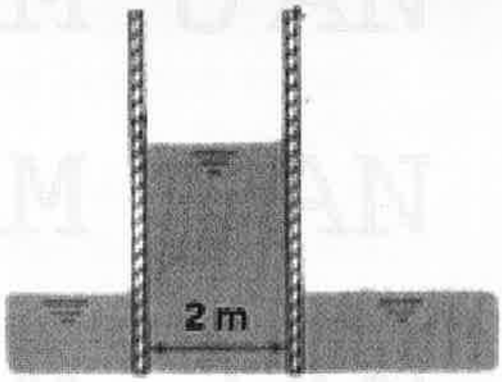


FIGURE Q1: Two plates parallel to each other

i. After they have pulled together, they can be easily separated by being slid parallel to their surface, but they are very difficult to separate by being pulled perpendicular to the surface. Explain why this phenomenon occurs.

[4 marks]

ii. What is the magnitude of the force pulling them together?

[3 marks]

d. In 225 BC, King of Syracuse in Sicily asked Archimedes to determine whether his crown was made of pure gold. At that time no chemical means were known for settling the question without destroying the crown. Suppose that in his own testing of the crown, Archimedes found that in air it had a weight of 5.0 N and a weight of 4.725 N in water. The densities of gold and silver are 19.3 and 10.5 g/cm^3, respectively. Assume that the density of gold-silver alloys is

$$\rho_{alloy} = \rho_{silver} + \frac{(vol.\%gold)}{100}(\rho_{gold} - \rho_{silver})$$

If the crown was made of an alloy of both, determine percentage by volume of the gold

[8 marks]

2. a. The deepest point in the oceans of the world is believed to be in the Marianas Trench, southeast of Japan; there the depth is about 11,000 m. What is the gauge pressure and absolute pressure at that point? Assume the density of seawater as 1025 kg/m^3.

[6 marks]

b. An inverted U-tube manometer is used to measure the difference of water pressure between two points in a pipe as shown in **FIGURE Q2a**.

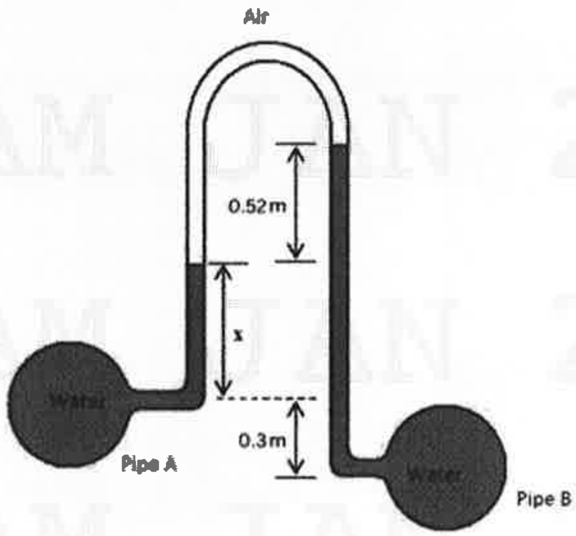


FIGURE Q2a: Inverted U-tube manometer.

Find the difference of pressure between the points. If the pressure at one point is reduced by 3 kPa, what will be the new differences of levels of water in the manometer?

[7 marks]

c. Water flows through a tapered pipe and inclined at the angle of 35° as described in **FIGURE Q2b**. The pipe tapers uniformly from an inlet diameter of 0.1 m to an outlet diameter of 0.2 m over a length of 3 m. The pressures recorded at the inlet and outlet are 200 kPa and 230 kPa, respectively.

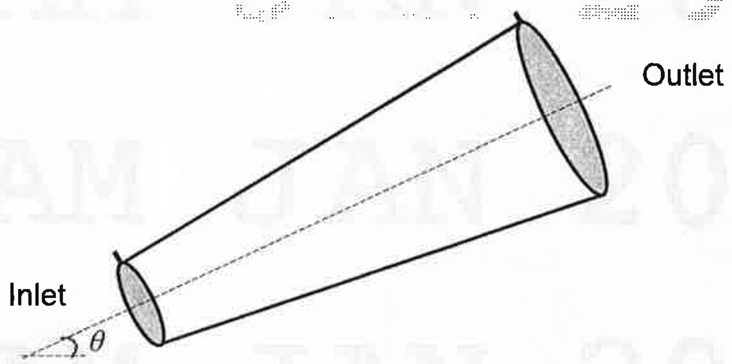


FIGURE Q2b: 2-dimensional diagram of tapered pipe

i. Develop expression of Bernoulli's equation for inlet and outlet of the pipe. State **ALL** assumptions.

[5 marks]

ii. Determine the flow rate of water.

[8 marks]

3. A diaphragm pump with an efficiency of 65% takes brine from the bottom of a supply tank and delivers it to the bottom of a discharge tank as shown in **FIGURE Q3**. The tops of both tanks are exposed to the atmosphere. The brine level in the discharge tank is 65 m higher than that in the supply tank. The total line between the tanks is 150 m of 4-in Schedule 40 commercial steel pipe. The brine flow rate is 1000 L/min. The line has two gate valves, four standard tees flow through run and four 90° standard elbows. Specific gravity, SG and dynamic viscosity, μ of the brine are 1.18 and 1.2 cP, respectively.

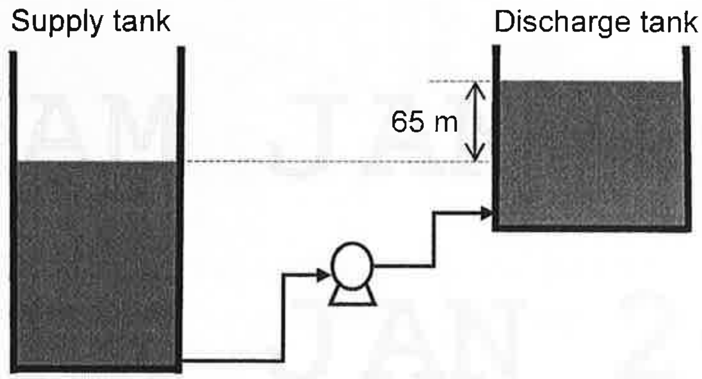


FIGURE Q3: Brine transfer between supply and discharge tank

a. Develop expression of the overall energy balance and state any **TWO (2)** assumptions made.

[4 marks]

b. Determine the Reynolds number of the flow.

[4 marks]

c. Determine the total friction losses in the pipeline.

[6 marks]

d. Calculate the cost for running the pump for a 24-hour day if the energy cost is RM 400 per kilowatt-year on a basis of 300 days per year.

[8 marks]

e. The diaphragm pump is replaced with a centrifugal pump due to its higher efficiency. Determine and discuss the cost of running the centrifugal pump for a 24-hour period if its efficiency is 20% higher than that of the diaphragm pump.

[4 marks]

4. a. Air is being discharged from a tank to a receiver through frictionless convergent nozzle. The tank's absolute pressure & temperature are 150 kPa and 40°C, respectively. By taking specific heat ratio, *k* for air as 1.4, determine the pressure and temperature in the receiver tank for a maximum mass flow rate.

[5 marks]

b. A car has a frontal projected area of 1.6 m^2 and travels at 60 km/h. It has a drag coefficient of 0.45 based on frontal area. Take ρ_{air} = 1.24 kg/m^3.

i. Calculate the power required to overcome wind resistance by the car.

[3 marks]

ii. Determine the speed of the car if the drag coefficient is reduced to 0.35 by streamlining for the same power in overcoming air resistance

[4 marks]

c. A bed of spherical ion-exchange resin particles with a diameter of 60 μm are placed in a 2 cm-diameter cylinder which has a height of 25 cm as shown in **FIGURE Q4**. With the bed porosity of 0.35, in an experiment water trickles down the bed with superficial velocity of 20 cm/min.

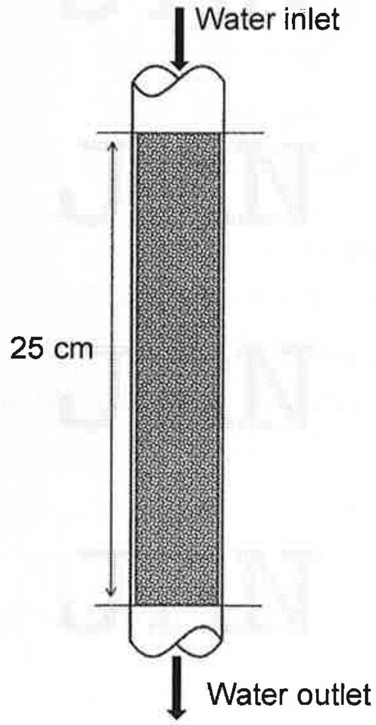


FIGURE Q4: Ion-exchange resin inside a cylinder

i. Determine the volumetric flow rate of water and pressure gradient required in the system.

[8 marks]

ii. Discuss what would happen if larger sphere particles were used inside the column.

[4 marks]

-END OF PAPER-

APPENDIX I

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

- Density, ρ = 1000 kg/m^3
- Dynamic viscosity, μ = 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
Gate valve, wide open	0.13
90° standard elbow	0.74
Standard tee, flow-through run	0.4

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, ε = 0.045 mm
- Surface roughness for plastic pipe, ε = 0.0015 mm

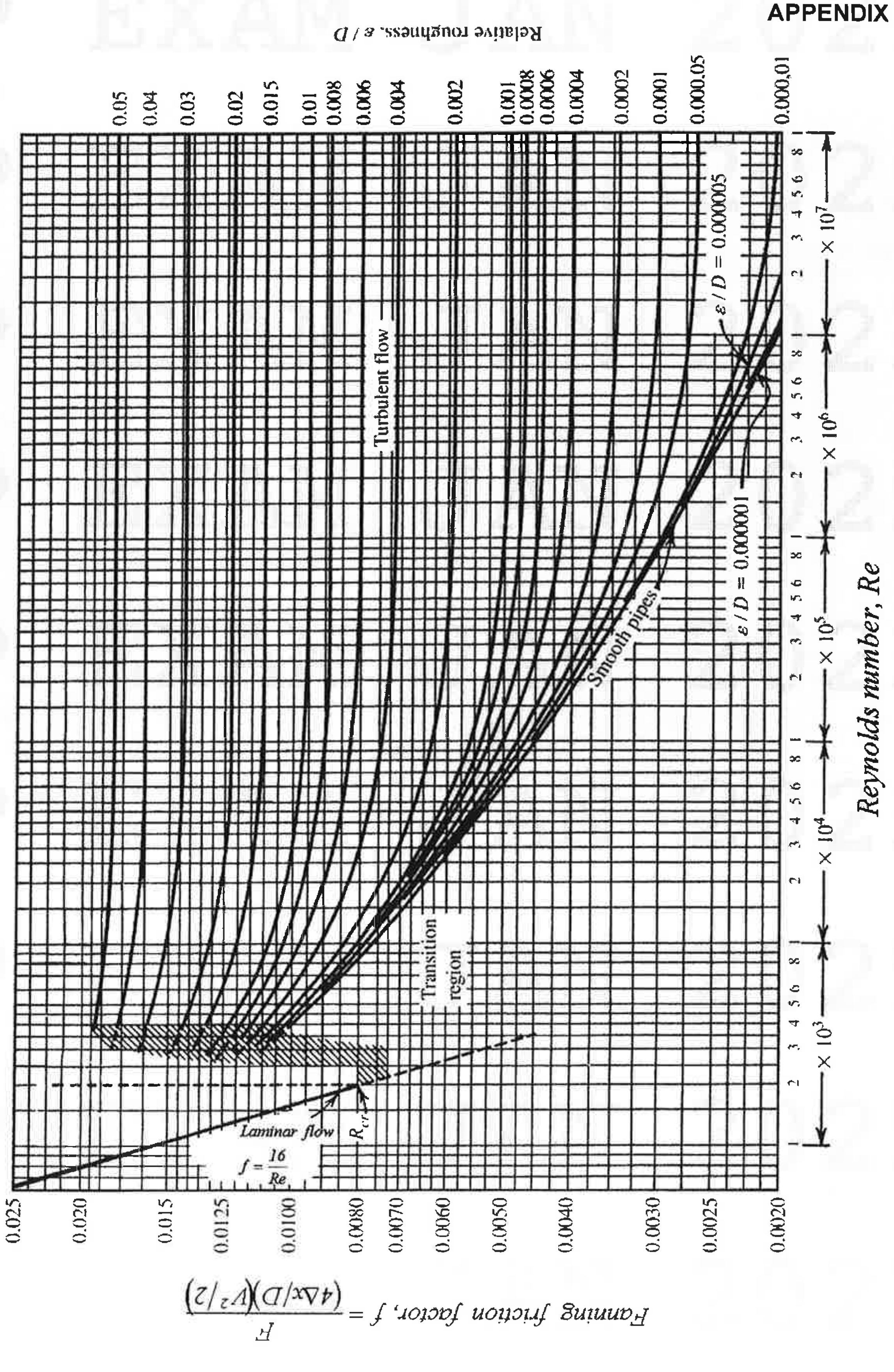
f. **Useful formulas**

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

APPENDIX I (CONT'D)

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

APPENDIX II



Moody's Diagram