



**SCHOOL OF ENGINEERING
DISCIPLINE OF CHEMICAL ENGINEERING
HOWARD COLLEGE CAMPUS**

TEST: OCTOBER 2025

COURSE AND CODE: EXPERIMENTAL TECHNIQUES AND MEASUREMENTS
(ENCH2ET)

DURATION: 13:30 – 16:30 (3 HOURS)

TOTAL MARKS: 100

INTERNAL EXAMINERS:

MR E. M. OBWAKA
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INTERNAL MODERATOR:

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INSTRUCTIONS:

1. This question paper consists of three sections: Section A (Questions 1 – 2); Section B (Questions 3 - 4); and Section C (Question 5). One 12-page booklet has been provided. Please clearly label your solutions as Solution 1, Solution 2, etc.
2. You should attempt all 5 questions.
3. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the test.
4. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
5. Factors for unit conversions and the gas constant in various units are provided at the end of the question paper.

SECTION A**QUESTION 1**

- (a) Figure 1.1 below shows a liquid column manometer connected at opposite ends to two gas reservoirs. The pressures of the gas reservoirs are $p_1 = 123.3 \text{ kPa}$ and $p_2 = 110.1 \text{ kPa}$. The U-shaped tube contains an oil with a density of 1080 kg/m^3 . What is the vertical distance h between the tops of the oil columns?

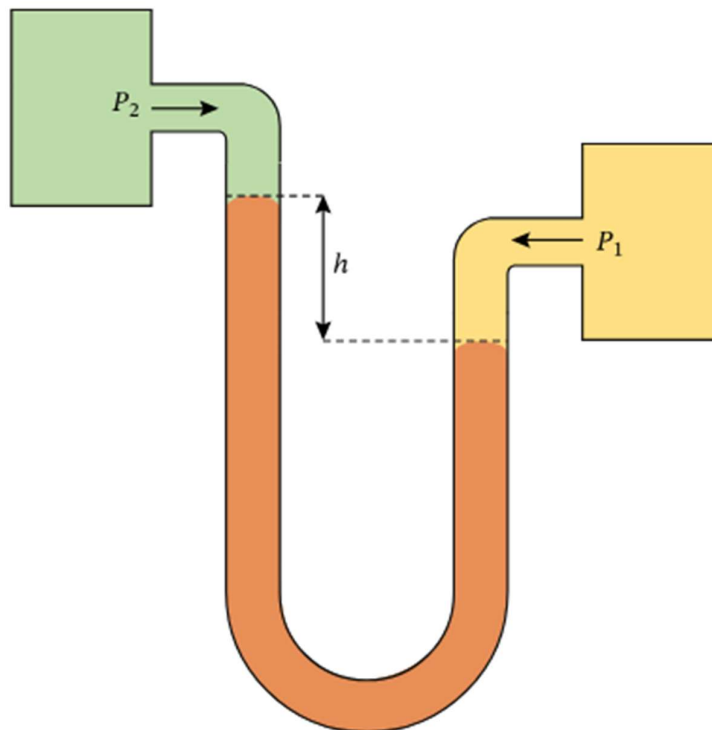


Figure 1.1: A differential manometer

- (b) Figure 1.2 below shows a liquid column manometer connected at one end to a gas reservoir and at the opposite end to the atmosphere. The U-shaped tube contains mercury that has a density of 13595 kg/m^3 . The top of the mercury column in contact with the atmosphere is vertically below the top of the mercury column in contact with the gas reservoir. The vertical distance between the column tops is $h = 25 \text{ cm}$. Find the pressure of the gas in the reservoir, p_2 . Use a value of $p_1 = 101.3 \text{ kPa}$ for atmospheric pressure.

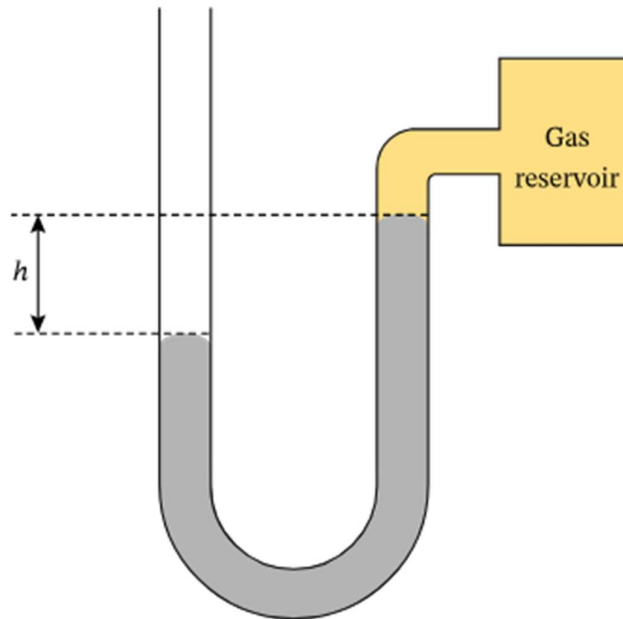


Figure 1.2: An open-ended manometer

(6)

- (c) List 4 advantages of U-tube manometers over other pressure sensors

(4)

- (d) List 4 disadvantages of U-tube manometers over other pressure sensors

(4)

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QUESTION 2

Given a horizontal liquid storage tank with flat heads as shown in Figure 2.1, given a tank diameter, Φ , of 0.6 m, tank length, L , of 1 m, and liquid level (dipstick reading), h , of 0.2 m, determine the volume, V , of fuel in the tank.

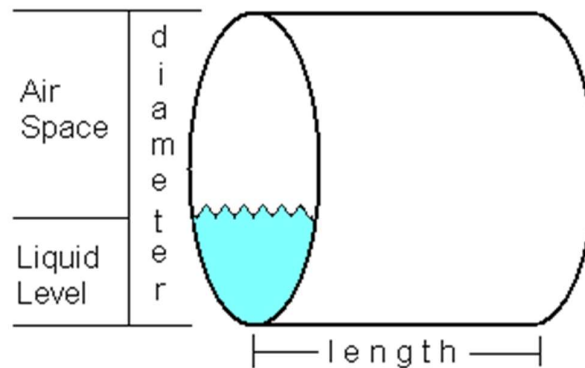


Figure 2.1: A horizontal liquid storage tank with flat heads

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SECTION B**QUESTION 3**

An evaporator is required to concentrate a glycerol-water solution from 10 to 30 % at the rate of 250 kg of feed per hour. The pressure in the evaporator is absolute 77 kPa, and steam is available at 200 kPa (gauge). The temperature of the feed is 18 °C and the boiling point of the solution at 77 kPa (absolute) is 91 °C. The specific heat of the solution is the same as that for water, which is 4186 J/kg.°C, and the condensing temperature of steam at 200 kPa (gauge) is 134 °C with latent heat of 2164 kJ/kg. The condensing temperature of the solution at 77 kPa (absolute) is 91 °C with latent heat of 2281 kJ/kg.

- (a) Calculate the mass of water evaporated in kg/h. (7)
- (b) Determine the quantity of steam required per hour. (10)
- (c) How can the energy requirements of the unit be reduced? (3)

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QUESTION 4

(a) A drain water pipeline is normally installed in a new building. The flowrate of drain water off the main pipe having diameter of 0.25 m, is to be displayed in the hall to indicate to the residents whether the building is exceeding the maximum usage of recommended water. A **Venturi meter**, having pressure transducers in the pipe and the throat, has been included, with throat diameter of 0.2 m. It has a nominal coefficient of discharge of 0.95.

- i. Derive an expression for the velocity of water within the pipe in terms of the pressure drop across the Venturi meter and the diameters of the pipe and Venturi meter. Bernoulli equation and the continuity equation are expressed as,

$$\text{Bernoulli Equation: } \frac{v_1^2}{2} + \frac{p_1}{\rho} + gz_1 = \frac{v_2^2}{2} + \frac{p_2}{\rho} + gz_2$$

$$\text{Continuity Equation: } v_1 A_1 = v_2 A_2 \quad (6)$$

- ii. Determine the volumetric flowrate of the waste water off the building by incorporating the coefficient of discharge (C_d) into the calculation. The pressure drop is 1520 Pa. (4)

(b)

- i. A Venturi meter having a diameter of 50 mm at the inlet and there is 10 mm at the throat. The density of oil is 900 kg/m^3 and dynamic viscosity as $1 \times 10^{-3} \text{ Pa.s}$. The differential pressure head of 80 mm is produced. The discharge coefficient (C_d) is 0.92. Determine the flow rate in kg/s.

Given:
$$Q = C_d A_1 \sqrt{\frac{2\Delta P}{\rho \left(\frac{A_1}{A_2} - 1 \right)}}$$

$$\Delta P = \rho g \Delta h \quad (7)$$

- ii. Determine the Reynolds number at the inlet and classify the flow regime. (3)

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SECTION C**QUESTION 5**

A vapour-compression refrigeration system uses a commercial refrigerant. The following state enthalpies are given (kJ/kg):

State 1 (compressor inlet, superheated vapour): $h_1 = 250$ kJ/kg

State 2s (compressor outlet if isentropic): $h_{2s} = 290$ kJ/kg

Compressor isentropic efficiency: $\eta_c = 0.82$

State 3 (condenser outlet, liquid before sub cooler): $h_3 = 110$ kJ/kg

After a liquid line sub-cooler, liquid entering the expansion valve: $h_4 = 100$ kJ/kg

Expansion through the valve is isenthalpic, so $h_5 = h_4$

Assume a steady state and negligible heat losses, except where explicitly stated.

- (a) Using the isentropic efficiency, compute the actual compressor outlet enthalpy h_2 (kJ/kg) and the compressor specific work w_c (kJ/kg). (6)
- (b) Compute the refrigeration effect q_{in} (kJ/kg), condenser heat q_{out} (kJ/kg), and COP. (4)
- (c) For a refrigeration load $\dot{Q}_L = 40$ kW, compute: mass flow $\dot{m}$ (kg/s), compressor power P_c (kW), and condenser heat rejection $\dot{Q}_{out}$ (kW). (6)
- (d) If the sub cooler is removed, so (without sub cooling) $h_{4_no} = h_3 = 110$ kJ/kg, recompute q_{in} and COP. State the percent improvement in COP due to the 10 kJ/kg sub-cooling. (4)

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FACTORS FOR UNIT CONVERSIONS

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb _m = 35.27392 oz 1 lb _m = 16 oz = 5 × 10 ⁻⁴ ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10 ⁶ microns (μm) = 10 ¹⁰ angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m ³ = 1000 liters = 10 ⁶ cm ³ = 10 ⁶ ml = 35.3145 ft ³ = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft ³ = 1728 in. ³ = 7.4805 gal = 0.028317 m ³ = 28.317 liters = 28 317 cm ³
Force	1 N = 1 kg·m/s ² = 10 ⁵ dynes = 10 ⁵ g·cm/s ² = 0.22481 lb _f 1 lb _f = 32.174 lb _m ·ft/s ² = 4.4482 N = 4.4482 × 10 ⁵ dynes
Pressure	1 atm = 1.01325 × 10 ⁵ N/m ² (Pa) = 101.325 kPa = 1.01325 bars = 1.01325 × 10 ⁶ dynes/cm ² = 760 mm Hg at 0°C (torr) = 10.333 m H ₂ O at 4°C = 14.696 lb _f /in. ² (psi) = 33.9 ft H ₂ O at 4°C = 29.921 in Hg at 0°C
Energy	1 J = 1 N·m = 10 ⁷ ergs = 10 ⁷ dyne·cm = 2.778 × 10 ⁻⁷ kW·h = 0.23901 cal = 0.7376 ft·lb _f = 9.486 × 10 ⁻⁴ Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb _f /s = 9.486 × 10 ⁻⁴ Btu/s = 1.341 × 10 ⁻³ hp

THE GAS CONSTANT

$$8.314 \text{ m}^3 \cdot \text{Pa/mol} \cdot \text{K}$$

$$0.08314 \text{ liter} \cdot \text{bar/mol} \cdot \text{K}$$

$$0.08206 \text{ liter} \cdot \text{atm/mol} \cdot \text{K}$$

$$62.36 \text{ liter} \cdot \text{mm Hg/mol} \cdot \text{K}$$

$$0.7302 \text{ ft}^3 \cdot \text{atm/lb-mole} \cdot ^\circ\text{R}$$

$$10.73 \text{ ft}^3 \cdot \text{psia/lb-mole} \cdot ^\circ\text{R}$$

$$8.314 \text{ J/mol} \cdot \text{K}$$

$$1.987 \text{ cal/mol} \cdot \text{K}$$

$$1.987 \text{ Btu/lb-mole} \cdot ^\circ\text{R}$$

$$T(^{\circ}\text{K}) = T(^{\circ}\text{C}) + 273.15$$

$$T(^{\circ}\text{R}) = T(^{\circ}\text{F}) + 459.67$$

$$T(^{\circ}\text{F}) = 1.8 (T(^{\circ}\text{C}) + 32)$$

$$T(^{\circ}\text{R}) = 1.8 T(^{\circ}\text{K})$$

$$\frac{1.8^{\circ}\text{F}}{1^{\circ}\text{C}}, \frac{1.8^{\circ}\text{R}}{1\text{K}}, \frac{1^{\circ}\text{F}}{1^{\circ}\text{R}}, \frac{1^{\circ}\text{C}}{1\text{K}}$$