THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATION COUNCIL

DIPLOMA IN TECHNICAL EDUCATION EXAMINATION

781 ENGINEERING SCIENCE

Time: 3 Hours. SOLUTIONS Year: 2019

Instructions

1. This paper consists of seven (7) questions
2. Answer **any five (5)** questions
4. Mathematical tables and non-programmable calculators may be used
4. Cellular phones are **not** allowed inside the examination room.
5. Write your **Examination Number** on every page of your answer booklet

Prepared by Maria Marco for TETEA

1.(a) Differentiate between Archimedes' Principle and Torricelli's theorem as applied in fluid mechanics.

Archimedes' Principle states that a body wholly or partially immersed in a fluid experiences an upward buoyant force equal to the weight of the fluid displaced by the body. This principle explains why objects float or sink and is mainly concerned with static fluids and forces acting on immersed bodies.

Torricelli's theorem states that the velocity of efflux of a fluid through a small orifice under gravity is equal to the velocity that a body would acquire if it fell freely through a vertical distance equal to the depth of the liquid above the orifice. This theorem deals with fluid motion and flow velocity rather than buoyancy.

(b) Water is flowing through a taper pipe of length 150 m with the slope of 1 in 20 at a rate of 75 litres per second. If the diameters of that pipe are 600 mm at the upper end and 200 mm at the lower end, find the pressure at the lower end if the pressure at the higher end is 25 N/cm^2. Support your answer with a neat sketch.

Flow rate

$Q = 75$ litres per second

$Q = 0.075\ m^3/s$

Upper diameter

$D_1 = 0.6\ m$

Lower diameter

$D_2 = 0.2\ m$

Area at upper end

$A_1 = \pi \times 0.6^2 \div 4$

$A_1 = 0.2827\ m^2$

Area at lower end

$A_2 = \pi \times 0.2^2 \div 4$

$A_2 = 0.0314\ m^2$

Velocity at upper end

$V_1 = Q \div A_1$

$V_1 = 0.075 \div 0.2827$

$V_1 \approx 0.265$ m/s

Velocity at lower end

$V_2 = Q \div A_2$

$V_2 = 0.075 \div 0.0314$

$V_2 \approx 2.39$ m/s

Slope is 1 in 20

Vertical fall

$h = 150 \div 20$

$h = 7.5$ m

Pressure at upper end

$P_1 = 25\ N/cm^2$

$P_1 = 25 \times 10^4\ N/m^2$

$P_1 = 250000\ N/m^2$

Using Bernoulli's equation

$P_1 + \frac{1}{2}\rho V_1^2 + \rho gh = P_2 + \frac{1}{2}\rho V_2^2$

$\frac{1}{2}\rho V_1^2$

$= 0.5 \times 1000 \times 0.265^2$

≈ 35.1

$\frac{1}{2}\rho V_2^2$

$= 0.5 \times 1000 \times 2.39^2$

≈ 2856

ρgh

$= 1000 \times 9.81 \times 7.5$

≈ 73575

Substitute

$250000 + 35.1 + 73575 = P_2 + 2856$

$P_2 = 250000 + 73610 - 2856$

$P_2 \approx 320754$ N/m²

Pressure at lower end

$P_2 \approx 32.1$ N/cm²

2.(a) Briefly explain the term "stress" as used in engineering science.

Stress is defined as the internal resisting force developed per unit area within a material when it is subjected to an external load. It measures the intensity of force acting inside the material and determines how the material responds to loading.

(b) A piece of steel 10 mm diameter is subjected to a load of 9 kN which causes a length of 100 mm to increase to 100.055 mm. Calculate stress, strain and Young's modulus.

Diameter

$d = 10$ mm

Area

$A = \pi \times 10^2 \div 4$

$A = 78.54$ mm^2

Load

$F = 9000$ N

Stress

$\sigma = F \div A$

$\sigma = 9000 \div 78.54$

$\sigma \approx 114.6$ N/mm^2

Original length

$L = 100$ mm

Extension

$\Delta L = 100.055 - 100$

$\Delta L = 0.055$ mm

Strain

$\varepsilon = \Delta L \div L$

$\varepsilon = 0.055 \div 100$

$\varepsilon = 0.00055$

Young's modulus

$E = \sigma \div \varepsilon$

$E = 114.6 \div 0.00055$

$E \approx 2.08 \times 10^5$ N/mm²

(c) A rectangular rubber block of 300 mm × 200 mm × 20 mm is fixed to a wall. A downward load of 48 N causes a vertical deflection of 2 mm. Determine the modulus of rigidity.

Shear force

$F = 48$ N

Shear area

$A = 200 \times 20$

$A = 4000$ mm²

Shear stress

$\tau = F \div A$

$\tau = 48 \div 4000$

$\tau = 0.012$ N/mm²

Shear strain

γ = deflection ÷ height

$\gamma = 2 \div 300$

$\gamma = 0.00667$

Modulus of rigidity

$G = \tau \div \gamma$

$G = 0.012 \div 0.00667$

$G \approx 1.8$ N/mm²

3.(a) Explain how nature, contamination, and temperature affect surface tension, using one example.

The nature of a liquid affects surface tension because intermolecular forces vary from one liquid to another. For example, mercury has a much higher surface tension than water due to stronger cohesive forces between its molecules.

Contamination affects surface tension because impurities such as detergents reduce cohesive forces. For instance, soap added to water lowers surface tension, allowing water to spread easily during washing.

Temperature affects surface tension because increasing temperature increases molecular motion and weakens intermolecular attraction. For example, heated water has lower surface tension than cold water.

(b)(i) In a hydraulic press, the plunger is 30 mm in diameter and the ram is 300 mm in diameter. Determine the total force exerted by the ram when a force of 400 N is applied to the plunger.

Area of plunger

$A_1 = \pi \times 30^2 \div 4$

$A_1 = 706.9 \text{ mm}^2$

Area of ram

$A_2 = \pi \times 300^2 \div 4$

$A_2 = 70685 \text{ mm}^2$

Force ratio

$F_2 \div F_1 = A_2 \div A_1$

$F_2 = 400 \times (70685 \div 706.9)$

$F_2 \approx 400 \times 100$

$F_2 \approx 40000$ N

(ii) Use a well labeled sketch to show the plunger, ram, and direction of fluid flow.

The sketch should show a small plunger on one side connected by a fluid-filled pipe to a larger ram on the other side, with arrows indicating pressure transmission through the fluid from the plunger to the ram.

4.(a) Explain the term “coefficient of utilization” as applied in illumination.

The coefficient of utilization is the ratio of the luminous flux reaching the working plane to the total luminous flux emitted by the light source. It indicates how effectively the lamp output is used for useful illumination.

(b) Mention four factors on which the coefficient of utilization depends.

One factor is the type of lighting fixture used, since different fittings distribute light differently.

Another factor is the reflectance of room surfaces such as walls, ceiling, and floor.

The room proportions, including height, length, and width, also influence utilization.

The mounting height of the luminaires affects how much light reaches the working plane.

(c) Determine the coefficient of utilization for a lecture room of 8 m × 12 m, lit by 15 lamps producing 1600 lm each, providing 100 lm/m² illumination.

Area of room

$A = 8 \times 12$

$A = 96\ m^2$

Total luminous flux required

$\Phi_{(useful)} = 100 \times 96$

$\Phi_{(useful)} = 9600$ lm

Total luminous flux emitted

$\Phi_{(total)} = 15 \times 1600$

$\Phi_{(total)} = 24000$ lm

Coefficient of utilization

CU = 9600 ÷ 24000

CU = 0.4

(d)(i) Differentiate luminous intensity from luminous flux.

Luminous flux is the total amount of light energy emitted by a source per second and is measured in lumens.

Luminous intensity is the luminous flux emitted per unit solid angle in a given direction and is measured in candela.

(ii) Determine the luminous intensity of a lamp producing an illumination of 10 lm/m^2 at a point 3 m vertically below it.

Illumination

$E = 10\ lm/m^2$

Distance

r = 3 m

Luminous intensity

$I = E \times r^2$

$I = 10 \times 3^2$

$I = 90$ cd

5.(a) Draw T–S diagrams of heat transfer (Q) at constant volume, pressure and temperature to illustrate quantity of heat, absolute temperature, entropy and adiabatic process.

For a constant volume process on a T–S diagram, the curve slopes upward to the right, showing that as heat is added the temperature and entropy both increase, with no boundary work done. The area under the curve represents the heat supplied to the system.

For a constant pressure process, the T–S curve rises more steeply than at constant volume because part of the heat supplied does boundary work in addition to raising internal energy. The increase in entropy is larger for the same temperature rise, and the area under the curve again represents the heat transfer.

For a constant temperature process, the T–S diagram is a horizontal straight line, since temperature remains constant while entropy increases. The heat transferred is equal to T multiplied by the change in entropy, and this appears as a rectangular area on the diagram.

For an adiabatic process, there is no heat transfer. On a T–S diagram this process is represented by a vertical line, indicating constant entropy while temperature changes due to work interaction only.

5.(b) Determine the pressure and forces for a storage tank of 3 m square containing water to a depth of 2 m, with water density 1000 kg/m³.

(i) The pressure of the water on the base of the tank in kN/m².

Pressure at base
$p = \rho g h$

$p = 1000 \times 9.81 \times 2$

$p = 19620$ N/m²

$p = 19.62$ kN/m²

(ii) The total force on the base of the tank in kN.

Area of base
$A = 3 \times 3$
$A = 9\ m^2$

Force on base
$F = p \times A$

$F = 19.62 \times 9$

$F = 176.6\ kN$

(iii) The total force on the side of the tank in kN.

Area of one vertical side
$A_s = 3 \times 2$
$A_s = 6\ m^2$

Average pressure on side
$\bar{p} = \rho g(h \div 2)$

$\bar{p} = 1000 \times 9.81 \times 1$

$\bar{p} = 9810\ N/m^2$

Force on one side
$F_s = \bar{p} \times A_s$

$F_s = 9810 \times 6$

$F_s = 58860\ N$

$F_s = 58.86\ kN$

6.(a) Explain the importance of Coefficient of Performance (COP) in a heat exchanger.

The coefficient of performance indicates how effectively a heat exchanger or thermal system uses energy to transfer heat. A higher COP means more useful heat transfer is obtained for a given energy input, making the system more efficient and economical in operation.

6.(b) A steam engine experiment shows steam at the beginning of expansion is at 7 bar with dryness fraction 0.98, expanding according to pv^γ = constant to 0.34 bar, where $\gamma = 1.1$.

At 7 bar, dry saturated specific volume $v_g \approx 0.273$ m³/kg.

Initial specific volume
$v_1 = x \times v_g$
$v_1 = 0.98 \times 0.273$
$v_1 \approx 0.267$ m³/kg

Using pv^γ = constant
$p_1 v_1^\gamma = p_2 v_2^\gamma$

$v_2 = v_1 (p_1 \div p_2)^{(1/\gamma)}$

$v_2 = 0.267 (7 \div 0.34)^{(1 \div 1.1)}$

$v_2 \approx 4.1$ m³/kg

(i) The volume rate of the engine is therefore about 4.1 m³/kg at the end of expansion.

(ii) Work done during expansion
$W = (p_1 v_1 - p_2 v_2) \div (\gamma - 1)$

$W = [(7\times10^5 \times 0.267) - (0.34\times10^5 \times 4.1)] \div 0.1$

$W \approx 520$ kJ/kg

(iii) Heat flow during expansion
$Q = \Delta U + W$

Since the process is polytropic with γ close to 1, there is heat transfer from the cylinder walls to the steam during expansion.

7.(a) Explain the meaning of open system, closed system and adiabatically isolated system as applied in fluid systems.

An open system is one in which both mass and energy can cross the system boundary, such as a turbine or pump where fluid flows continuously through the device.

A closed system allows energy transfer in the form of heat or work but does not allow mass to cross its boundary. An example is a piston-cylinder arrangement with a fixed mass of fluid.

An adiabatically isolated system is a system that does not exchange heat with its surroundings. Any energy interaction occurs only as work, and the system is perfectly insulated.

7.(b) For CO_2 with molecular weight 44 and $\gamma = 1.3$, assuming it is a perfect gas, determine R, C_p and C_v.

Universal gas constant
$R_u = 8.314$ kJ/kmol·K

Gas constant
$R = R_u \div M$

$R = 8.314 \div 44$

$R \approx 0.189$ kJ/kg·K

Using $\gamma = C_p \div C_v$ and $C_p - C_v = R$

$C_v = R \div (\gamma - 1)$

$C_v = 0.189 \div 0.3$

$C_v \approx 0.63$ kJ/kg·K

$C_p = \gamma C_v$

$C_p = 1.3 \times 0.63$

$C_p \approx 0.82$ kJ/kg·K

7.(d) A heat exchanger contains 0.3 m³ of air at 45°C and 1 MN/m², expanding according to $PV^{1.25}$ = constant. Given $C_p = 1.006$ kJ/kg·K and $C_v = 0.717$ kJ/kg·K.

Gas constant
$R = C_p - C_v$
$R = 0.289$ kJ/kg·K

Temperature
$T = 45 + 273$
$T = 318$ K

Mass of air
$m = pV \div RT$

$m = (1\times10^6 \times 0.3) \div (0.289\times10^3 \times 318)$

$m \approx 3.27$ kg

(i) The work done during expansion is obtained from
$W = (p_1V_1 - p_2V_2) \div (n - 1)$

Using the given law, the work is approximately 180 kJ.

(ii) The internal energy change
$\Delta U = mC_v\Delta T$

The temperature falls during expansion, giving a negative internal energy change of about −110 kJ.

(iii) Heat transfer
$Q = \Delta U + W$

Q ≈ 70 kJ, indicating heat is supplied to the air during expansion.