Part A – Short knowledge based questions

1. Explain what is meant by the following terms:
   (i) System and surroundings
   (ii) Specific Heat
   (iii) adiabatic process
   (iv) isothermal process
   (v) Absolute temperature scale
   (vi) Enthalpy
   (vii) State
   (viii) Irreversible process
   (ix) Thermodynamic system
   (x) Thermodynamic cycle
   (xi) Reversible process
   (xii) Intrinsic property
   (xiii) Extrinsic property
   (xiv) Heat engine
   (xv) work
   (xvi) Open and closed systems

2. What is the difference between Heat and Temperature?

3. State the Zeroth Law of Thermodynamics

4. Describe the first law of thermodynamics and the forms of energy that may be involved.

5. Write an expression for the first law for a closed system, clearly stating any assumptions made and describing each term in detail.

6. Give and expression for the Total Head, clearly explain each term. Further define what is meant by a siphon with the aid of a diagram.

7. Give two equivalent statements of the Second law of Thermodynamics?

8. Describe the Carnot cycle, including a pressure-volume diagram and fully describe each process in the cycle.

9. Explain why absolute zero can never be reached

10. Define the following terms for fluids and give typical values for water where appropriate:
    (i) Mass density
    (ii) Dynamic viscosity
    (iii) Continuity
    (iv) Knudsen number
    (v) Incompressibility
    (vi) Specific weight
    (vii) Specific gravity
    (viii) Dynamic viscosity
    (ix) Kinematic viscosity
    (x) Gauge pressure
    (xi) Absolute pressure
    (xii) Centre of pressure
    (xiii) discharge

11. Explain using an equation, Newton’s law of viscosity

12. What is a non-Newtonian fluid?

13. Briefly describe the meaning of capillarity

14. Describe what is meant by pressure in a fluid

15. What is a hydrostatic system?

16. State Pascal’s Law for pressure at a point.
17. What is the Hydrostatic Paradox?

18. Explain what is meant by relative equilibrium

19. Explain the Resultant Force on an object immersed in water

20. What is piezometric head?

21. Explain what is meant by buoyancy.

22. What is the Centre of Buoyancy?

23. Explain the stability of floating objects and outline the definition of the Metacentre.

24. Outline the four distinct types of fluid flow that can possibly occur.

25. Explain what is meant by substantive acceleration.

26. What is the difference between Laminar and Turbulent flow?

27. Describe how the Reynold’s number is defined, give an expression and explain its significance.

28. State and briefly explain the continuity equation for a fluid flow.

29. Explain the concept of a streamline and a streamtube

30. What is the momentum correction factor?

31. State and explain Bernoulli’s equation for steady flow of a frictionless fluid.
Part B – Longer questions

1. A gas in a piston cylinder arrangement is compressed from an initial condition of 200 kPa, \(v=0.6 \text{ m}^3/\text{kg}\). During the process the pressure is related to the volume through the equation: \(pv^2=\text{constant}\). Calculate the work \([-240 \text{kJ/kg}]\)

2. A sealed rigid vessel contains 1 kg of fluid that is being heated and stirred. Heat transfer is 400 kJ/kg and stirring work is 50 kJ/kg. If the specific internal energy at the start of the process is 400 kJ/kg, find the final value. \([850 \text{kJ/kg}]\)

3. A constant volume closed system contains 1 kg of perfect gas. During a reversible process 75 kJ heat is transferred to the system raising its temperature from 20 to 120°C. Calculate the change in \(u\), the value of \(C_v\), and the ratio of final to initial pressures. \([75 \text{kJ/kg}; 0.75 \text{kJ/kgK}; 1.34]\)

4. A closed system consisting of a cylinder and a frictionless piston, containing 1 kg of gas with a molecular weight of 26. The gas is maintained at a pressure of 200 kPa. Find the heat transferred when the volume changes from 0.5 to 1.0 m\(^3\). \((R_o=8.314 \text{kJ/KmolK}, C_p=1.08 \text{kJ/kgK})\) \([337.5 \text{kJ/kg}]\)

5. Air undergoes a reversible adiabatic expansion from 500 kPa, 800 K to 200 kPa. Assuming it behaves as a perfect gas with \(C_p = 0.718 \text{kJ/kgK}\) and \(R = 0.287 \text{kJ/kgK}\), find the temperature at the end of expansion. \([615.7 \text{K}]\)

6. A room of 4 x 5 x 7 m is heated by a radiator transferring 10 000 kJ/hr. The air is circulated in this room by a 100 W fan. The heat loss from the room is estimated as 5000 J/hr. If the initial room temperature is 10°C, determine how long it will take to heat the room air to 20°C. Use constant specific heat. \([831 \text{seconds}]\)

7. A closed system containing air undergoes a cycle consisting of the following processes:
   
   1 \(\rightarrow\) 2 Isothermal compression
   2 \(\rightarrow\) 3 Heating at constant pressure
   3 \(\rightarrow\) 1 Adiabatic expansion

   \(p_1 = 175 \text{kPa}, T_1 = 20^\circ \text{C}, p_2 = 650 \text{kPa}\); For air, \(R = 0.287 \text{kJ/kgK}, C_v = 0.718 \text{kJ/kgK}\).

   Draw the cycle on a \(p-v\) diagram. Clearly stating all assumptions made, calculate \(q\) and \(w\) for each process. Demonstrate that the first law of Thermodynamics holds for the cycle. \([-110.3 \text{kJ/kg}; -110.3 \text{kJ/kg}; 131.8 \text{kJ/kg}; 37.7 \text{kJ/kg}; 0 \text{kJ/kg}; 95.1 \text{kJ/kg}]\)

8. A heat engine operating on a Carnot cycle has an efficiency of 55%. The waste heat is rejected to a nearby lake at 15°C at a rate of 800 kJ/min. find (a) the power input in kW, and (b) the temperature of the source. \([16.3 \text{kJW}; 640 \text{K}]\)

9. Define the efficiency of an engine based on a Carnot cycle and derive an expression for this efficiency in terms of the temperatures of the heat reservoirs. Discuss what your expression says about the efficiency of such engines and the second law of thermodynamics. A manufacturer of a heat engine claims that when connected to a source at 540 K and rejecting waste heat to a sink at 250 K, the engine receives 450 kJ of heat and produces a net work of 300 kJ. Discuss whether or not this claim is reasonable, giving reasons for your arguments. \([\text{No – efficiency too high}]\)

10. Use a triangular fluid element model to derive Pascal’s law for pressure at a point.

11. Derive, with the aid of a diagram, a simple expression for the change in pressure with height in a fluid, including the effect of gravity. Use this to explain the concept of head.
12. Use a diagram to explain the operation of a piezometer

13. Use a diagram to explain the operation of a u-tube manometer in measuring the pressure between two points in a pipe. Outline any problems with this type of measurement.

14. A trapezoidal door PQ in the vertical wall of a tank filled with water is hinged along its top edge as shown with the top of the tank open to atmosphere and the free surface at O. Calculate: The resultant force, the location of the centre of pressure and the moment about the hinge necessary to hold the door closed. \([50.33\text{kN}, 1.86\text{m}, 38\text{kNm}]\)

![Diagram of trapezoidal door](image)

15. The tank shown in the diagram has a rectangular window (shown separately) at an angle of 45°. The tank contains water and the centroid G of the window is 1.25m below the surface. Determine the resultant force on the window and the location of the centre of pressure. \([6.13\text{kN}; 1.1\text{cm below centroid}]\)

![Diagram of rectangular window](image)

16. A closed rectangular tank with vertical sides is 1.8m deep and contains water to a depth of 1.2m. Air is pumped into the space above the water until the air pressure is 35kNm-2. If the length of one wall of the tank is 3m, draw a pressure diagram for this system, hence determining the resultant force on the wall and the height of the centre of pressure above the base. \([210.2\text{kN}, 0.84\text{m}]\)
17. A sluice gate is constructed as a circular arc of radius 6m and angle 60° and is filled to the top with water. Calculate the magnitude and direction of the resultant force on the gate and the location with respect to O of a point on its line of action. [179.5kN/m, passes through O at an angle of -10.3°]

18. Explain what is meant by conservation of mass and use this fundamental law to derive the continuity equation using a rectangular fluid element.

19. For a simple expanding pipe, derive the one-dimensional momentum equation:

![Diagram of a simple expanding pipe]

\[
\text{area} - A_1, \quad \text{velocity} - u_1, \quad \text{density} - \rho_1
\]

\[
\text{area} - A_2
\]

20. A jet of water of diameter 40mm issues with average velocity 4.5 m/s from a hole in the side of a water filled tank, which is 2m below the surface of the water. The tank is kept filled to the same height and assume that gravity and pressure gradient effects can be ignored. Determine the force on the tank and its contents when it is (i) stationary and (ii) moving with a velocity of 1.2m/s in the direction opposite to the jet, with the velocity of the jet relative to the tank unchanged. In the latter case, determine the rate of work. [(i) 25.4kN; (ii) 25.4kN; 30.5W]

21. Consider a jet of water of velocity 5ms\(^{-1}\) from a nozzle of diameter 10cm, striking a stationary flat plate perpendicularly. Assuming that the surface is frictionless, calculate the change in force if (a) the angle of the plate is changed to 30° and (b) if the plate is moved at a speed of 1ms\(^{-1}\) towards the nozzle.

22. Explain the difference between laminar and turbulent flow in a pipe of circular cross section and state Prandlt’s one seventh power law. For fully developed turbulent flow, use this law to determine the relationship between the maximum velocity and the average velocity and calculate the momentum correction factor. [1.02]

23. Use a streamtube model to derive Euler’s equation of motion for a fluid.

24. State the Navier-Stokes equations and use them to define the Reynolds’ number. Clearly define each term and variable in all expressions.
25. Use the Navier-Stokes equations or Newton’s law of viscosity to derive an expression for the fluid flow in a pipe of circular cross-section at low Reynolds’ numbers. Further derive an expression for the mass flow rate and use this to explain an inherent problem with fluid networks.

26. Derive an expression for steady flow down an inclined cylindrical pipe of fixed cross-section using conservation of momentum and Newton’s law of viscosity. Estimate the maximum velocity of water in a pipe of diameter 22mm and 10m long, raised at an angle of 45 degrees to the horizontal and under a back-pressure of 25kN.

27. A car radiator cools 1kg/s of water from 98°C to 80°C using air cooling. The air enters the radiator at 20°C with a velocity of 10m/s. The effective surface area of the radiator is 0.25m². Find the air temperature as it leaves the radiator. [45.1°C]

28. Derive the Steady Flow Energy equation for an open system. Clearly describe each term in the equation. A steady flow machine operates on a flow of gas which enters at 650kPa, 300°C and a velocity of 50 m/s. It leaves at 150 kPa, 150°C and 200 m/s. Assuming the machine is well insulated and that the gas behaviour is perfect, calculate the net work, stating also the direction. Note that \( C_p = 1.05 \text{kJ/kgK} \) [138.75kJ/kg]

29. The intake of a jet engine acts as a diffuser. Air enters at 70kPa, -3°C and 200 m/s. The air leaves at 100 m/s. Find the exit temperature and pressure. Assume a reversible adiabatic process. [284.9K;84.5kPa]

30. Write down Bernouilli’s equation, clearly explain each term. Explain with the aid of diagrams, the operation of a Pitot tube and a Venturi meter and, using Benouilli’s equation, derive operating equations relating flow velocity to height measurement in each case.