W'10 : 6 AN : MC 405 (1498)

THERMAL SCIENCE AND ENGINEERING

Time : Three hours

Maximum Marks : 100

Answer FIVE *questions, taking* ANY TWO *from* **Group A,** ANY TWO *from* **Group B** *and* ALL *from* **Group C.**

All parts of a question (a, b, etc.) should be answered at one place.

Answer should be brief and to-the-point and be supplemented with neat sketches. Unnecessary long answers may result in loss of marks.

Any missing or wrong data may be assumed suitably giving proper justification.

Figures on the right-hand side margin indicate full marks.

Group A

1. (*a*) Explain the concept of macroscopic and microscopic viewpoint as applied to study of thermodynamics. 6

(*b*) Explain the term 'system', 'closed system', 'open system' and 'isolated system'. Also, give a suitable example for each. 6

(*c*) A fluid system undergoes a non-flow frictionless process following the pressure volume relations as $p = (5/v) + 1.5$ where p is in bar and v is in m^3. During the process, the volume changes from $0.15\ m^3$ to $0.05\ m^3$ and the system rejects 45 kJ of heat. Determine (*i*) change in internal energy, and (*ii*) change in enthalpy. 8

2. (a) Prove that the expression for polytropic heat rejection is given by

$$Q_{1-2} = (y-n)/(y-1) \times \text{polytropic work done.}$$ 6

(b) Derive an expression for the first law of thermodynamics of an open system. 6

(c) At the inlet to a certain nozzle, the enthalpy of the fluid passing is 2800 kJ/kg and the velocity is 50 m/s at the discharge end. The enthalpy is 2600 kJ/kg; nozzle is horizontal; and there is a negligible heat loss from it.

(i) Find the velocity at the exit of the nozzle.

(ii) If the inlet area is 900 cm^2 and specific volume at inlet is 0.187 m^3/kg, find the mass flow rate.

(iii) If the specific volume at the nozzle exit is 0.498 m^3/kg, find the exit area of nozzle. 8

3. (a) State and prove the Clausius inequality $\oint \frac{dQ}{T} \leq 0$. 6

(b) The first source can supply energy at the rate of 12,000 kJ/min at 320 °C. The second source can supply energy at the rate of 12,0000 kJ/min at 70 °C. Which source (1 or 2) would you choose to supply energy to an ideal reversible heat engine to produce large amount of power, if the temperature of the surrounding is 35 °C? 6

(c) A heat-pump works on a reversed Carnot cycle takes energy from a reservoir maintained at 5 °C and delivered it to another reservoir at a temperature of 77 °C. The heat-pump derives the power for its operation from a reversible engine operating within high and low temperatures of 1077 °C and 77 °C, respectively. For 100 kJ/kg of energy supplied to reservoir of 77 °C, estimate the energy taken from the reservoir at 1077 °C. 8

4. (a) Prove that the efficiency of diesel cycle is given by

$$\eta_{diesel} = 1 - \frac{1}{r^{y-1}}\left[\frac{\varrho^{y}-1}{y(\varrho-1)}\right]$$ 8

(b) With the help of a neat sketch, explain the working of simple vapour compression refrigeration cycle. 4

(c) In a diesel cycle, air at 0.1 MPa and 300 K is compressed adiabatically until the pressure rises to 5 MPa. If 700 kJ/kg of energy in the form of heat is supplied at a constant pressure, determine the compression ratio, thermal efficiency and mean effective pressure. 8

Group B

5. (a) Derive an expression for the temperature distribution and heat transfer from a fin loosing heat at the tip. 6

(b) Derive an expression for the heat transfer per unit time through a composite wall

$$Q = (t_1 - t_{n+1})/\sum_{1}^{n} l/kA$$ 6

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(c) An insulated steam pipe, having outside diameter of 30 mm, is to be covered with two layers of insulation, each having thickness of 20 mm, thermal conductivity of one material is five times that of the other. Assuming that the inner and outer surface temperatures of the composite insulation are fixed, how much will heat transfer be increased when better insulation material is next to the pipe than it is outer layer? 8

6. (a) Prove that the energy equation for a flow over a flat plate is given by

$$u\frac{\partial t}{\partial x} + v\frac{\partial t}{\partial y} = \alpha \frac{\partial^2 t}{\partial y^2}$$ 6

(b) What is the transient heat conduction? 4

(c) Air at 20°C and at a pressure of 1 bar is flowing over a flat plate at a velocity of 3 m/s. If the plate is 280 mm wide and at 56°C, calculate the following quantities at $x = 280$ mm. Properties of air at mean temperature of 38°C are: $\varrho = 1.1374$ kg/m^3, $k = 0.02732$ W/m°C, $C_p = 1.005$ kJ/kg°K, $\nu = 16.768 \times 10^{-6}$ m^2/sec, Pr = 0.7. 10

(i) Boundary layer thickness, δ

(ii) Local friction coefficient, C_{fx}

(iii) Average friction coefficient, $\bar{C}_f$

(iv) Shear stress due to friction, τ_0

(v) Thickness of thermal boundary layer, δ_{Th}

(vi) Local convective heat transfer coefficient, h_x

(vii) Average convective heat transfer coefficient, $\bar{h}$

(viii) Rate of heat transfer.

7. (a) Prove that the effectiveness for a parallel flow heat exchanger is given by

$$\varepsilon = \frac{1 - C^{-NTU(1+R)}}{1+R}$$ 8

(b) An oil cooler for a lubrication system has to cool 1000 kg/hr of oil (C_p = 2.09 kJ/kg°C) from 80°C to 40°C by using a cooling water flow of 1000 kg/hr at 30°C. Give your choice for parallel flow or counter flow heat exchanger with reasons. Calculate the surface area of the heat exchanger, if the overall heat transfer coefficient is 24 W/m^2°C. Take C_p of water = 4.18 kJ/kg°C. 6

(c) Oil (C_p = 3.6 kJ/kg°C) at 100°C flows at the rate of 30,000 kg/hr and enters into a parallel flow heat exchanger. Cooling water (C_p = 4.2 kJ/kg°C) enters the heat exchanger at 10°C at the rate of 50,000 kg/hr. The heat transfer area is 10 m^2 and U = 1000 W/m^2°C. Calculate the following: 3+3

(i) Outlet temperature of oil and water; and

(i) Maximum possible outlet temperature of water.

8. (a) State and prove the Stefan-Boltzman law of radiation, $E_b = \sigma T^4$.

(*b*) Prove that the reciprocating theorem

$$A_1F_{1-2} = A_2F_{2-1}$$ 6

(*c*) Assuming the sun to radiate as a black body, calculate the temperature of the sun from the given data. The average radiant energy flux incident upon the earth's atmosphere (solar constant) = 1380 W/m^2, radius of the sun = 7.0×10^8 m, distance between the sun and earth = 15×10^{10} m. 7

Group C

9. Choose the *correct* answer for the following: 10×2

(*i*) When two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other. This statement is called

(*a*) Zeroth law of thermodynamics

(*b*) First law of thermodynamics

(*c*) Second law of thermodynamics

(*d*) Kelvin-Plank's law

(*ii*) A system comprising a single phase is called a

(*a*) closed system

(*b*) open system

(*c*) isolated system

(*d*) homogeneous system

(*e*) hetrogeneous system.

(*iii*) With increase in pressure,

(*a*) enthalpy of dry saturated steam increases.

(*b*) enthalpy of dry saturated steam decreases.

(*c*) enthalpy of dry saturated steam remains same.

(*d*) enthalpy of dry saturated steam first increases and then decreases.

(*iv*) Volume of wet steam (per kg) with dryness fraction, x, is given by

(*a*) $x^2 v_g$

(*b*) xv_f

(*c*) $x^2(v_g - v_f)$

(*d*) $x^3 v_g$

(*e*) None of the above.

(*v*) The net work done per kg of gas in a polytropic process is equal to

(*a*) $p_1 v_1 \log v_2/v_1$

(*b*) $p_1(v_1 - v_2)$

(*c*) $p_2[v_2 - (v_1/v_2)]$

(*d*) $(p_1 v_1 - p_2 v_2)/(n-1)$

(*e*) $(p_2 v_1 - p_2 v_2)/(n-1)$

(*vi*) The heat absorbed or rejected during a polytropic process is

(*a*) $[(y-n)/(y-1)] \times$ work done

(*b*) $[(y-n)/(y-1)]^2 \times$ work done

(*c*) $[(y-n)/(y-1)]^{1/2} \times$ work done

(*d*) $[(y-n)/(y-1)]^3 \times$ work done

(*vii*) Isentropic flow is

(*a*) irreversible adiabatic flow.

(*b*) ideal fluid flow.

(*c*) perfect gas flow.

(*d*) frictionless reversible flow.

(*e*) reversible adiabatic flow.

(*viii*) The efficiency of Carnot engine, using an ideal gas as the working substance, is

(*a*) $(T_1 - T_2)/T_1$

(*b*) $T_1/(T_1 - T_2)$

(*c*) $T_1 T_2/(T_1 - T_2)$

(*d*) $(T_1 - T_2)/T_1 T_2$

(*e*) $[T_2(T_1 - T_2)]/T_1(T_1 + T_2)]$

(*ix*) The property of a working substance which increases or decreases as the heat is supplied or removed in a reversible manner is known as

(*a*) enthalpy.

(*b*) internal energy.

(*c*) entropy.

(*d*) external energy.

(*x*) Availability function is expressed as

(*a*) $a = (u + p_0 dv - T_0 ds)$

(*b*) $a = (u + p_0 dv + T_0 ds)$

(*c*) $a = (du + p_0 dv - T_0 ds)$

(*d*) $a = (u + p_0 v + T_0 ds)$

(*xi*) The power available at the shaft of an IC engine is known as brake horse power and is equal to

(*a*) total power produced – frictional horse power

(*b*) Net IHP – frictional horse power

(*c*) Net IHP + frictional horse power

(*d*) Net IHP/frictional horse power

(*xii*) The mechanical efficiency (η_{mech}) of an IC engine is equal to

(*a*) IHP/BHP

(*b*) BHP/IHP

(*c*) BHP/FHP

(*d*) FHP/BHP

(*xiii*) If the working fluid in a plant does not come in contact with the atmospheric air and is used over and over again, the gas turbine is said to work on

(*a*) semi-closed cycle.

(*b*) open cycle.

(*c*) closed cycle.

(*d*) None of the above.

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(*xiv*) In a psychrometric chart, the vertical scale shows

(*a*) wet-bulb temperature.

(*b*) dry-bulb temperature.

(*c*) adiabatic saturation temperature.

(*d*) specific humidity.

(*xv*) In case of sensible heating of air, the by-pass factor is equal to

(*a*) $(t_{d_2} - t_{d_1})/(t_{d_3} - t_{d_1})$

(*b*) $(t_{d_3} - t_{d_2})/(t_{d_3} - t_{d_1})$

(*c*) $(t_{d_3} - t_{d_1})/(t_{d_2} - t_{d_1})$

(*d*) $(t_{d_3} - t_{d_2})/(t_{d_2} - t_{d_1})$

where t_{d_1} = DBT air entering the heating coil; t_{d_2} = DBT of air leaving the heating coil; and t_{d_3} = temperature of heating coil.

(*xvi*) The logarithmic mean temperature difference for a heat exchanger is equal to

(*a*) $(\Delta t_0) + \Delta t_i)/\log(\Delta t_0/\Delta t_i)$

(*b*) $(\Delta t_0) - \Delta t_i)/\log(\Delta t_0/\Delta t_i)$

(*c*) $\log(\Delta t_0 - \Delta t_i)$

(*d*) $\frac{1}{2}\log(\Delta t_0 - \Delta t_i)$

where Δt_0 = temperature difference of hot and cold fluid at outlet and Δt_i = temperature difference of hot and cold fluid at outlet.

(*xvii*) The rate of radial heat flow per unit length through the wall of a hollow cylinder of inner radius r_1, outer radius r_2, inner temperature t_1 and outer temperature t_2 is given by

(*a*) $2\pi k(t_1 + t_2)/\log(r_2/r_1)$

(*b*) $2\pi(t_1 + t_2)/k\log(r_2/r_1)$

(*c*) $2\pi k(t_1 - t_2)/\log(r_2/r_1)$

(*d*) $\log(r_2/r_1)/2\pi k(t_1 - t_2)$

(*xviii*) If *h* is the coefficient of heat trnsfer; *k*, the thermal conductivity; and *l*, the characteristic linear dimension, then the term *hl/k* is called

(*a*) Reynolds number

(*b*) Nusselt number

(*c*) Prandtl number

(*d*) Froude number

(*xix*) A body, which absorbs all the radiation falling on it, is called

(*a*) opaque body.

(*b*) white body.

(*c*) black body.

(*d*) transparent body.

(*xx*) For a free convection, the Nusselt number is a function of

(*a*) Prandtl number and Grashof number.

(*b*) Reynolds number and Grashof number

(*c*) Reynolds number

(*d*) Reynolds number and Prandtl number.