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*) Show that energy is a property of a system. What are the modes in which energy is stored in a system ? What is the difference between the standard symbols of E and U ? 6

(*b*) A gas of mass 1.5 kg undergoes a quasi-static expansion which follows a relationship $p = a + bv$, where a and b are constants. The initial and final pressures are 1000 kPa and 200 kPa, respectively and the corresponding volumes are 0.20 m^3 and 1.20 m^3. The specific internal energy of the gas is given by

$$u = 1.5\,pv - 85\ \text{kJ/kg}$$

where p is in kPa and v is in m^3/kg.

Calculate the net heat transfer and the maximum internal energy of the gas attained during expansion 10 (*c*) How does the current flowing through a resistor represent work transfer? 2

(*d*) Does heat transfer inevitably cause a temperature rise? 2

2. (*a*) What is a steady flow process? What is steady state? Write the steady flow energy equation for a single stream entering and a single stream leaving a control volume and explain the various terms in it. 5

(*b*) What will be the velocity of a fluid leaving a nozzle, if the velocity at inlet to it is negligibly small? 3

(*c*) Show that the enthalpy of a fluid before throttling is equal to that after throttling. 2

(*d*) In a steady flow apparatus, 135 kJ of work is done by each kg of fluid. The specific volume of the fluid, pressure, and velocity at the inlet are 0.37 m^3/kg, 600 kPa and 16 m/s. The inlet is 32 m above the floor, and the discharge pipe is at floor level. The discharge conditions are 0.62 m^3/kg, 100 kPa and 270 m/s. The total heat loss between the inlet and discharge is 9 kJ/kg of fluid. In flowing through the apparatus, does the specific internal energy increase or decrease, and by how much? 10

3. (*a*) Explain the following statements:

(*i*) To produce net work in a thermodynamic cycle, a heat engine has to exchange heat with two thermal reservoirs.

(*b*) What do you understand by dissipative effects? When is work said to be dissipated? 3

(*c*) Show that the efficiency of a reversible engine operating between two given temperatures is the maximum. 5

(*d*) Two reversible heat engines A and B are arranged in series A rejecting heat directly to B. Engine A receives 200 kJ at a temperature of 421 °C from a hot source, while engine B is in communication with a cold sink at a temperature of 4.4 °C. If the work output of A is twice that of B, find the (*i*) intermediate temperature between A and B, (*ii*) efficiency of each engine, and (*iii*) heat rejected to the cold sink. 7

4. (*a*) How is the entropy change of a reversible process estimated? Will it be different for an irreversible process between the same end states? 3

(*b*) Give the criteria of reversibility, irreversibility and impossibility of a thermodynamic cycle. 2

(*c*) What do you understand by the entropy principle? Why is the entropy increase of an isolated system a measure of the extent of irreversibility of the process undergone by a system? 6

(*d*) One kg of water at 273 K is brought into contact with a heat reservoir at 373 K. When the water has reached 373 K, find the entropy change of the universe. If water is heated from 273 K to 373 K by first bringing it in contact with a reservoir at 323 K and then with a reservoir at 373 K, what will be the entropy change of the universe? Explain how water might be heated from 273 K to 373 K with no change in entropy of the universe. 9

Group B

5. (*a*) An aluminium (k = 185 W/mK) pipe carries steam at 110 °C. The pipe has an inner diameter of 10 cm and an outer diameter of 12 cm. The pipe is located in a room where the ambient air temperature is 30 °C and the convective heat transfer coefficient is 15 W/m^{2}K. Determine the heat transfer rate per unit length of pipe.

To reduce the heat loss from the pipe, it is covered with 5 cm thick layer of insulation (k = 0.2 W/mK). Determine the rate of heat loss per unit length and the percentage reduction in heat loss by the insulation. Neglect the convector resistance of the steam. 10

(*b*) A 50 mm × 50 mm iron bar 0.4 m long is connected to the walls of two heated reservoirs, each at 120 °C. The ambient air temperature is 35 °C and the convective heat transfer coefficient is 17.4 W/m^{2}K. Calculate the rate of heat loss from the bar and the temperature of the far midway between the reservoirs. The thermal conductivity of iron is 52 W/mK. 10

6. (*a*) Water flows over a flat plate measuring 1 m × 1 m with a velocity of 2 m/s. The plate is at a uniform temperature of 90 °C and the water temperature is 10 °C. Estimate the length of plate over which the flow is laminar and the rate of heat transfer from the entire plate. The properties of water at 50 °C are : $\varrho = 988.1$ kg/m^3, $\nu = 0{\cdot}556 \times 10^{-6}$ m^2/s, Pr = 3.54 and $k = 0.648$ W/mK. 8

(*b*) State and explain the Hagen–Poiseiulle flow through a tube and show that for laminar flow, $f = 64/\mathrm{Re}_d$. 4

(*c*) Water flows at a velocity of 12 m/s in a straight tube of 60 mm diameter. The tube surface temperature is maintained at 70 °C and the flowing water is heated from the inlet temperature of 15 °C to an outlet temperature of 45 °C. Taking the physical properties of water at the mean bulk temperature of 30 °C as $\varrho = 995.7$ kg/m^3, $C_p = 4.174$ kJ/kgK, $k = 0.617$ W/mK, $\nu = 0.805 \times 10^{-6}$ m^2/s and Pr = 5.42. Calculate the (*i*) heat transfer coefficient from the tube surface to the water, (*ii*) heat transferred, and (*iii*) length of the tube. 8

7. (*a*) On what factors does the radiant heat exchange between two bodies depend ? What is shape factor ? Show that

$$A_1 F_{12} = \frac{1}{\pi} \int_{A_1} \int_{A_2} \frac{\cos\phi_1 \cdot \cos\phi_2}{r^2}\, dA_1\, dA_2$$

The symbols have their usual meanings. 10

(*b*) A small sphere (outside radius = 60 mm) with a surface temperature of 300 °C is located at the geometric centre of a large sphere (inside diameter = 360 mm) with an inner surface temperature of 15 °C. Calculate how much of heat emitted from the large sphere inner surface is incident upon the outer surface of the small sphere, assuming that both surfaces approach black body behaviour. What is the heat exchange of heat between the two spheres ? 10

8. (*a*) For a balanced heat exchanger of counterflow operation, where $\dot{m}_h c_h = \dot{m}_c c_c$, show that the temperature profiles of two fluids along the heat exchanger are linear and parallel. 5

(*b*) What is the limitation of LMTD method in heat exchanger calculations ? How is ε-NTU method superior to correction factor— LMTD method ? 7

(*c*) A coaxial tube counterflow heat exchanger is to cool 0.03 kg/s of benzene from 360K to 310K with a counterflow of 0.02 kg/s of water at 290K. If the inner tube outside diameter is 20m and $U_0 = 650$ W/m^{2}K, determine the required length of the exchanger. Take the specific heats of benzene and water as 1880 J/kg.K and 4175 J/kg.K, respectively. 8

Group C

9. Choose the *correct* answer for the following: 20 × 1

(*i*) Which property of a system increases when heat is transferred to it at constant pressure ?

(*a*) Internal energy

(*b*) Enthalpy

(*c*) Volume

(*d*) Gibbs function

(*ii*) The Kelvin temperature of a system can be measured by a

(*a*) mercury-in-glass thermometer

(*b*) thermocouple

(*c*) constant volume gas thermometer

(*d*) resistance thermometer

(*iii*) If the thermal efficiency of a Carnot engine is 1/5, the COP of the corresponding Carnot refrigerator is

(*a*) 5

(*b*) 4

(*c*) 6

(*d*) 3

(*iv*) When air is adiabatically saturated, the temperature attained is

(*a*) dry bulb temperature.

(*b*) wet bulb temperature.

(*c*) dew point temperature.

(*d*) triple point temperature.

(*v*) Specific heats of an ideal gas C_p and C_v

(*a*) vary with temperature.

(*b*) vary with pressure.

(*c*) vary with both pressure and temperature.

(*d*) are constant.

(*vi*) When a system is in equilibrium, any conceivable change in entropy would be

(*a*) zero.

(*b*) maximum.

(*c*) positive.

(*d*) negative.

(*vii*) The efficiency of a reversible cycle depends upon the

(*a*) nature of the working substance.

(*b*) amount of the working substance.

(*c*) temperatures of two reservoirs between which the cycle operates.

(*d*) type of cycle followed.

(*viii*) Reversible steady flow work interaction is equal to

(*a*) $\int pdv$

(*b*) $-\int vdp$

(*c*) $u_1 - u_2$

(*d*) $p_1 v_1 - p_2 v_2$

(*ix*) For a system undergoing phase change like melting or vaporization, —— remains constant.

(*a*) enthalpy

(*b*) entropy

(*c*) specific volume

(*d*) Gibbs function

(*x*) Torr is a unit of

(*a*) temperature

(*b*) pressure

(*c*) volume

(*d*) energy

(*xi*) A thermodynamic cycle is impossible if

(*a*) $\oint \frac{dQ}{T} < 0$

(*b*) $\oint \frac{dQ}{T} > 0$

(*c*) $\oint \frac{dQ}{T} = 0$

(*d*) $\oint ds > 0$

(*xii*) The critical radius of insulation for a spherical shell is

(*a*) h/k

(*b*) $2h/k$

(*c*) k/h

(*d*) $2k/h$

(*xiii*) If A_1 and A_2 are the inside and outside surface areas of a hollow cylinder, the logarithmic mean area is given by

(*a*) $(A_1 + A_2)/\ln A_2/A_1$

(*b*) $(A_2 - A_1)/\ln A_2/A_1$

(*c*) $\ln A_2/A_1/(A_1 + A_2)$

(*d*) $(A_1 + A_2)/2$

(*xiv*) Prandtl number is defined as

(*a*) $K/\mu C_p$

(*b*) α/ν

(*c*) $\mu C_p/k$

(*d*) KC_p/μ

(*xv*) Gases have poor

(*a*) transmissivity.

(*b*) absorptivity.

(*c*) reflectivity.

(*d*) emissivity.

(*xvi*) The intensity of radiation is obtained by multiplying the emissive power by a factor

(*a*) π

(*b*) $1/\pi$

(*c*) $\frac{1}{\sqrt{2}}\pi$

(*d*) $\frac{\sqrt{2}}{\pi}$

(*xvii*) Which one of the following dimensionless number is relevant in transient heat conduction?

(*a*) Reynolds number

(*b*) Fourier number

(*c*) Grashof number

(*d*) Prandtl number

(*xviii*) Ice is very close to a

(*a*) gray body.

(*b*) white body.

(*c*) black body.

(*d*) specular body.

(*xix*) The reciprocity theorem states that

(*a*) $A_1F_{12} = A_2F_{21}$

(*b*) $A_2F_{12} = A_1F_{21}$

(*c*) $F_{12} = F_{21}$

(*d*) $\alpha_1F_{12} = \alpha_2F_{21}$

(*xx*) Which one of the following has the least value of thermal conductivity:

(*a*) Rubber

(*b*) Air

(*c*) Water

(*d*) Plastic