THERMAL SCIENCE & 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 answer 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) What is a thermodynamic system? Differentiate between open system, closed system and isolated system. 8

   (b) Explain the first law of thermodynamics for a change of state and prove that energy is a property. What is the difference between the standard symbols of E and U? 6

   (c) 3 kg of an ideal gas is expanded from a pressure 7 bar and volume 1.5 m^3 to a pressure 1.4 bar and volume 4.5 m^3. The change in internal energy is 525 kJ. The specific heat at constant volume for the gas is 1.047 kJ/kg-K. Calculate (i) gas constant; (ii) change in enthalpy; and (iii) initial and final temperatures. 6

2. (a) State and prove the Clausius inequality 8

   (i) $\oint \frac{\delta Q}{T} < 0$ for a irreversible process

   (ii) $\oint \frac{\delta Q}{T} = 0$ for a reversible process.

   (b) An inventor claims to have designed a heat engine which absorbs 260 kJ of energy as heat from a reservoir at 52 ^{0}C and delivers 72 kJ work. He also states that the engine rejects 100 kJ and 88 kJ of energy to the reservoirs at 27 ^{0}C and 2 °C, respectively. State with justification whether his claim is 6 acceptable or not.

(c) Derive Clapeyron's equation. What is its use and limitations? What is its practical utility? 6

3. (a) Explain the working of an actual gas turbine with p-v and T-s diagrams. 8

(b) It is desired to compress 10 kg of gas from 1.5 m^3 to 0.3 m^3 at a constant pressure of 1.5 bar. During this compression process, the temperature rises from 20^0C to 150^0C and the increase in internal energy is 3250 kJ. Calculate the work done, heat interaction and change in enthalpy during the process. Also work out the average value of specific heat at constant pressure. 6

(c) Derive an expression for the efficiency of diesel cycle. 6

4. (a) 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. 6

(b) Prove that tor the same compression ratio, the efficiency of the Diesel cycle in less than that of the Otto cycle. 6

(c) Define the following items: DBT, WBT, DPT, RH and specific humidity used in air-conditioning. A room contains air at 25°C and 100 kPa at a relative humidity of 85%. Determine the (i) partial pressure of dry air. (ii) specific humidity, and (iii) enthalpy per unit mass of dry air. 8

Group B

5. (a) Prove that, for a cylindrical body as shown in figure, the heat transfer by conduction is given by 8

$$q = \frac{2\pi l(T_1 - T_2)}{\frac{\log(r_2/r_1)}{K_A} + \frac{\log(r_1/r_2)}{K_B} + \frac{\log(r_4/r_3)}{K_C}}$$

(b) Starting from fundamentals, deduce an expression for temperature distribution in a sphere of radius R, generating heat at a constant rate of q per unit volume. 6

(c) Derive an expression for the heat transfer per unit time through a composite wall 6

$$Q = \frac{(t_1 - t_{n+1})}{\sum_1^n \frac{l}{kA}}$$

6. (a) (a) What is Dittus Boelter equation? Where and when does it apply? (b) Define Grashof number and explain its significance in free convection heat transfer. 6

   (b) Derive the momentum equation for hydrodynamic boundary layer over a flat plate. 8

   (c) A vertical cylinder 1.5 m high and 180 mm in diameter is maintained at 100^0C in an atmospheric environment of 20^0C. Calculate heat lost by free convection from the surface of the cylinder. Assume properties of air at mean temperature as , $\rho = 1.06$ kg/m^3, $\nu = 18.97 \times 10^{-6}$ m^2/s, $C_p = 0.24$ kcal/kg^{0}C and K = 0.0249 kcal/m-h-^{0}C. 6

7. (a) Explain the following: 7
   - (i) black body radiation
   - (ii) reflectivity
   - (iii) transmissivity
   - (iv) absorptivity
   - (v) Kirchhoff's law
   - (vi) gray body
   - (vii) emissivity

   (b) Define radiation intensity. Prove that the intensity of radiation is given by $I_b = E_b/\pi$. 8

   (c) State Stephen-Boltzmann law and Kirchhoff law for radiation heat transfer with proper units of measurements. 5

8. (a) What are the two separate processes of nucleate boiling? Explain them. 6

   (b) Derive an expression for LMTD for a parallel flow heat exchanger. Oil (Cp = 3.6 kJ/kg^{0}C) at 100^0C flows at a rate of 30,000 kg/hr and enters into a parallel How heat exchanger Cooling water (C_p = 4.2 kJ/kg^{0}C) enters the exchanger at 10^0C at a rate of 50,000 kg/hr. The heat transfer area is 10 m^2 8 and u = 1000 $W/m^{2\,0}C$. Calculate the following:

(i) Outlet temperature of oil and water; and

(ii) Maximum possible outlet temperature of water.

(c) An oil cooler for a lubrication system has to cool 1000 kg/hr of oil (C_p = 2.09 kJ/kg°C) from 80 ^0C 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

Group C

9. Answer the following in brief: 20

(i) The refrigerant in a house hold refrigerator can be viewed as

(a) an open system
(b) a closed system
(c) an isolated system
(d) partly open and partly closed system

(ii) Rankine cycle comprises

(a) 2 isotherms and 2 adiabatics
(b) 2 isobars and 2 isotherms
(c) 2 isobars and 2 isentropics
(d) 2 isotherms and 2 isentropics

(iii) An Otto cycle consists of

(a) two quasistatic isothetmals and two quasistatic adiabatic processes
(b) two quasistatic adiabatics and two quasistatic constant volume processes
(c) two quasistatic adiabatics and two quasistatic constant pressure processes
(d) two quasistatic constant pressure and two quasistatic constant volume processes

(iv) A person claims to have designed a heat engine with maximum possible thermal efficiency. If the engine operates between 30^0C and 5^0C and it receives 500 kJ of heat energy, the work produced cannot be more than

(a) 10 kJ
(b) 20.15 kJ
(c) 35.00 kJ
(d) 41.25 kJ

(v) If neither mass nor energy is allowed to cross the boundary of a system, then it is called

(a) closed system
(b) open system
(c) isolated system
(d) homogeneous

(vi) If the system is carried through a cycle, than the summation of work delivered is equal to the

(a) product of pressure and volume
(b) summation of internal energy
(c) summation of net heat transfer
(d) summation of entropy

(vii) The actual cycle efficiency of a heat engine operating between 1000 K and T_2 K, is 30%. If the Carnot efficiency for the same temperature range is 50%, the value of T_2 will be

(a) 500 K
(b) 150 K
(c) 300 K
(d) 450 K

(viii) If a hot and cold reservoirs are connected by a thermal conductor, the entropy change of

(a) hot reservoir is positive
(b) cold reservoir is positive
(c) universe is zero
(d) universe is negative

(ix) The cycle efficiency of Diesel cycle will be greater than that of the Otto cycle when

(a) compression ratios are same

(b) maximum pressures are same
(c) max. temperatures are same
(d) never does it happen

(x) The statement that theoretically, a 2-stroke engine develops twice the power of a 4-stroke engine at the same speed, is derived from the fact that

(a) the working cycle is completed in one revolution of the crank shaft in a 2-stroke engine, whereas it takes two revolutions in a 4-stroke engine.
(b) a 2-stroke engine runs at twice engine speed compared with a 4-stroke engine
(c) a 2-stroke engine has a set of two cylinders and pistons

(Refer our course material for answers)