RS

W'05 : 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.

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

Use of Mollier Chart and Steam Tables are permitted

Group A

1. (*a*) Define property and mention its main characteristic in relation to a cyclic process. 4

(*b*) In what respects are the heat and work interactions (*i*) similar and (*ii*) dissimilar ? 4

(*Turn Over*)

(*c*) It is desired to compress 10 kg of gas from $1 \cdot 5\, m^3$ to $0 \cdot 3\, m^3$ at a constant pressure of 15 bar. During this compression process, the temperature rises from 20 °C to 150 °C 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. 12

2. (*a*) State and prove Carnot theorem. 6

(*b*) What does the principle of entropy increase, specify? 2

(*c*) A reversible heat engine receives heat from a high temperature reservoir at T_1 K and rejects heat to a low temperature sink of 800 K. A second reversible engine receives the heat rejected by the first engine at 800 K and rejects to a cold reservoir at 280 K. Make calculations for temperature T_1 : (*i*) for equal thermal efficiencies of the two engines, (*ii*) for the two engines to deliver the same amount of work. 12

3. (*a*) Derive Clapeytron's equation. What is its use and limitations? 4

(*b*) How does Rankine cycle differ from Carnot cycle for a vapour? 4

(*c*) A steam turbine working a Rankine cycle is supplied with dry saturated steam at 25 bar and the exhaust takes place at $0 \cdot 2$ bar. For a steam flow rate of 10 kg/s, determine

(*i*) quality of steam at end of expansion

(*ii*) turbine shaft work

(*iii*) power required to drive the pump

(*iv*) work ratio

(*v*) Rankine efficiency

(*vi*) heat flow in the condenser. 12

4. (*a*) Describe a simple vapour compression cycle giving clearly the flow diagram. 4

(*b*) Define dry-bulb temperature and the wet-bulb temperature. When do these become equal to each other? 3

(*c*) What are the two basic types of Internal combustion engines? What are the fundamental differences between the two? 3

(*d*) The steam consumption of a 20 BHP double acting, non-condensing steam engine is 9 kg/BHP/hr. The pressure of the exhaust steam is $1 \cdot 2$ ata and quality is $0 \cdot 85$ dry. If the diameter of the exhaust pipe is 15 cm, what will be the velocity of steam in the exhaust pipe, when the engines develops 18 BHP? 10

Group B

5. (*a*) Write down unsteady state three-dimensional heat conduction equation in rectangular coordinates with heat generator and give the meaning of each term. 5

(*b*) An aluminium ($k = 204$ W/mK) rod 2 cm in diameter and 20 cm long protrudes from a wall which is maintained at 300 °C. The end of the rod is insulated and the surface of the rod is exposed to air at 30 °C. The convective heat transfer coefficient between the rods surface and air is 10 W/m^2 K. Calculate the heat lost by the rod. Also calculate the temperature of the rod at a distance of 10 cm from the wall. 15

6. (*a*) Explain the following : 2×7

(*i*) Black body radiation

(*ii*) Reflectivity

(*iii*) Transmissivity

(*iv*) Absorptivity

(*v*) Kirchoff's law

(*vi*) Gray body

(*vii*) Emissivity.

(*b*) A steel tube, 0·05 m diameter, 4·0 m length, at temperature 600 K is located in (*i*) a large brick room, having wall temperature 300 K, (*ii*) in a brick conduct of size 0·4 m × 0·4 m at 300 K. Estimate the heat loss by radiation in each case. Take emissivity of steel as 0·8, for rough red brick 0·93 respectively. 6

7. (*a*) Define the effectiveness of a heat exchanger. 2

(*b*) Define the Log Mean Temperature Difference (LMTD). 2

(*c*) How can one determine the fouling factor of a heat exchanger ? 2

(*d*) What is Dcttus-Boelter's equation ? Where and when does it apply ? 2

(*e*) Define Grashof number and explain its significance in free convection heat transfer. 2

(*f*) It is desired to cool oil from 120 °C to 50 °C using a double–pipe heat exchanger. The cooling water enters the heat exchanger at 20 °C and leaves it at 40 °C. Calculate the LMTD for

(*i*) a parallel-flow heat exchanger, and

(*ii*) for a countercurrent heat exchanger. 10

8. (*a*) What is meant by film condensation and drop-wise condensation ? 4

(*b*) Distinguish between nucleate boiling and film boiling. 4

(*c*) A tube of 2 m length and 25 mm outside diameter is to be used to condense saturated stream at 100 °C while the tube surface is maintained at 92 °C. Estimate the average heat transfer coefficient and rate of condensation of steam if the tube is kept horizontal. The steam condenses on the outside of the tube. Use the data given below :

At 96 °C :

$k_f = 0 \cdot 08$ W/mK

$\mu_f = 293 \cdot 4 \times 10^{-6}$ Ns/m^2

and $\rho = 961$ kg/m^3

At 100 °C, $h_{fg} = 2257$ kJ/kg. 12

Group C

9. Answer the following questions : 2×10

(*i*) Define internal energy. Is it a function of state or a process ?

(*ii*) What is throttling process ? Point out its salient aspects.

(*iii*) State the difference between the thermodynamic and empirical scale of temperature.

(*iv*) What main conclusions can be drawn with respect to the efficiency of a Carnot engine ?

(*v*) Define the number of heat transfer units (NTU).

(*vi*) What are the factors responsible for fluid motion in natural convection ?

(*vii*) What is meant by lumped heat capacity analysis ?

(*viii*) State the general heat conduction in cartesian coordinates.

(*ix*) What is perpetual motion machine of second kind ? Why such a machine cannot be constructed in actual practice ?

(*x*) State Kirchoff's law for radiation and highlight its significance.

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Group A

1. (*a*) Explain the following terms in the context of thermodynamics: (*i*) System, (*ii*) Surrounding, (*iii*) Universe, (*iv*) State, (*v*) Properties. 5

   (*b*) State and explain the conditions to be satisfied for thermodynamic equilibrium. 5

   (*c*) The two modes of energy transfer are work and heat. Does the mode of energy transfer depend upon the choice of a system? Support your answer with the help of an example. 5

(*Turn Over*)

(*d*) 3 gm of nitrogen gas at 6 atm and 160°C in a frictionless piston-cylinder device is expanded adiabatically to double its initial volume, then compressed at constant pressure to its initial volume and then compressed again at constant volume to its initial state. Calculate the network done on the gas. 5

2. (*a*) An inventor claims to have designed a heat engine which absorbs 260 kJ of energy as heat from a reservoir at 52 °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 °C and 2 °C, respectively. State with justification whether his claim is acceptable or not. 5

(*b*) a reversible engine works between three thermal reservoirs *A, B* and *C*. The engine absorbs an equal amount of heat from the thermal reservoirs *A* and *B* kept at temperatures T_A and T_B, respectively, and rejects heat to the thermal reservoir *C* kept at temperature T_C. The efficiency of the engine is α times the efficiency of the reversible engine, which works between the two reservoirs *A* and *C*. Prove that

$$\frac{T_A}{T_B} = (2\alpha - 1) + 2(1-\alpha)\frac{T_A}{T_C}.$$ 8

(*c*) A Carnot engine receives energy from a reservoir at T_{res} through a heat exchanger where the heat transfer rate $\dot{Q}_H$ is proportional to the temperature difference and is given by $\dot{Q}_H = K(T_{res} - T_H)$. It rejects heat at a given low temperature T_L. To design the heat engine for maximum power, show that the high temperature T_H should be selected as $T_H = \sqrt{T_L T_{res}}$. 7

3. (*a*) Deduce expression for the second Tds equation, given that

$$\left(\frac{\partial S}{\partial p}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P,$$

S, p, T and *V* have usual meanings. Hence, prove that the Joule-Kelvin coefficient of an ideal gas is zero. 4

(*b*) Two moles of an ideal gas at temperature *T* and pressure *p* are contained in a compartment. In an adjacent compartment is one mole of an ideal gas at temperature 2*T* and pressure *p*. The gases mix adiabatically but do not react chemically when a partition separating the compartment is withdrawn. Show that the entropy increase due to mixing process is given by

$$\bar{R}\left(\ln\frac{27}{4} + \frac{\gamma}{\gamma-1} + \ln\frac{32}{27}\right)$$

provided that the gases are different and the ratio of specific heats γ is the same for both gases and remains constant. $\bar{R}$ is the universal gas constant. 8

(*c*) Prove Clausius inequality and hence prove the principle of increase of entropy. 8

4. (*a*) A steam power plant operates between a boiler pressure of 4 MPa and 300 °C and a condenser pressure of 50 kPa. Determine the thermal efficiency of the cycle, the work ratio and the specific steam flow rate, assuming the cycle to be a simple ideal Rankine cycle. 6

(*b*) A gas turbine plant operates on the Brayton cycle between T_{min} = 300 K and T_{max} = 1073 K. Find the maximum work done per kg of air, and the corresponding cycle efficiency. How does this efficiency compare with the Carnot cycle efficiency operating between the same two temperatures? 4

(c) Prove that for the same compression ratio, the efficiency of the Diesel cycle in less than that of the Otto cycle. 5

(d) In an aircraft cooling system, air enters the compressor at 0·1 MPa, 4 °C, and is compressed to 0·3 MPa with an isentropic efficiency of 72%. After being cooled to 55 °C at constant pressure in a heat exchanger, the air expands in a turbine to 0·1 MPa with an isentropic efficiency of 78%. The low temperature air absorbs a cooling load of 3 tonnes of refrigeration at constant pressure before re-entering the compressor which is driven by the turbine. Assuming air to be an ideal gas, determine the C.O.P. of the refrigerator, the driving power required, and the air mass flow rate. 5

Group B

5. (a) State Fourier's law of heat conduction. Derive, in spherical coordinates, the heat conduction equation in three dimension with heat generation using Fourier's law of heat conduction. 2+8

(b) A steam pipe, 170/160 mm in diameters, is covered with two layers of insulation. The thickness δ_1 of the first layer is 30 mm and that of the second layer δ_2 is 50 mm. The thermal conductivities K_1, K_2 and K_3 of the pipe and the insulating layers are 50; 0·15 and 0·08 W/mK, respectively. The temperature of the inner surface of the steam pipe is 300 °C and that of the outer surface of the insulation layer is 50 °C. Determine the quantity of heat lost per metre length of steam pipe and layer contact temperatures. 10

6. (a) Distinguish between fin efficiency and fin effectiveness. 4

(b) A thermocouple in a cylindrical well is inserted in a gas stream (*Fig. 1*). Estimate the true temperature of the gas stream if T_L (the temperature indicated by the thermocouple $= 260\,°C$, T_0 (wall temperature) $= 177\,°C$, $h = 680\ W/m^2K$, $K = 103{\cdot}8\ W/mK$, $t = 2$ mm and $L = 6$ cm. 8

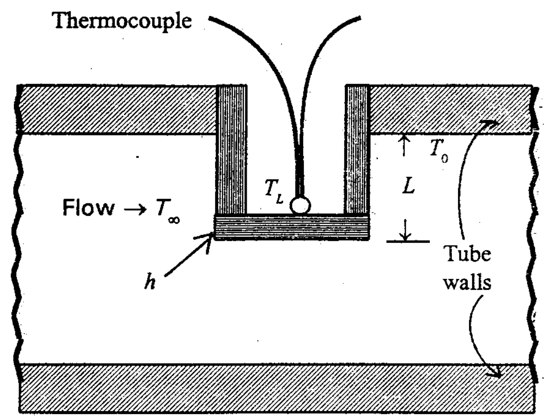

Fig. 1

(c) 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 a 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 $\varrho = 988{\cdot}1\ kg/m^3$, $\nu = 0{\cdot}556 \times 10^{-6}\ m^2/s$, $P_r = 3{\cdot}54$ and $K = 0{\cdot}648$ W/mK. 8

7. (a) What is the effect of inclination of a tube or plate on the average condensation heat transfer coefficient? 3

(b) The maximum allowable surface temperature of an electrically heated vertical plate 15 cm high and 10 cm wide is 140 °C. Estimate the maximum rate of heat dissipation from both sides of the plate in an atmosphere at 20 °C. The radiation heat transfer coefficient is 8·72 W/m^2K. For air at 80 °C, take $\nu = 21{\cdot}09 \times 10^{-6}$ m^2/s, $P_r = 0{\cdot}692$ and $K = 0{\cdot}03$ W/mK. 7

(c) The crank case of an automobile is 80 cm long, 30 cm wide and 10 cm deep. Find the rate of heat flow from the crank case to the atmosphere when the automobile is moving at 90 km/hr. Assume that the vibration of the engine and the chassis induce the transition from laminar to turbulent boundary layer over the entire surface. Also, find the drag force on the total surface of the crank case.

Take the same average convective heat transfer coefficient and average shear stress for front and rear surfaces as for the bottom and the sides. Crank case surface temperature is 75 °C and atmospheric air temperature is 5 °C. At 40 °C for properties of air, take $\rho = 1{\cdot}128$ kg/m^3, $C_p = 1007$ J/kgK, $\mu = 19{\cdot}1 \times 10^{-6}$ kg/ms, $K = 0{\cdot}0285$ W/mK. 10

8. (a) For a balanced counterflow heat exchanger where $\dot{m}_h C_h = \dot{m}_c C_c$, show that the temperature profiles of the two fluids along the heat exchanger are linear and parallel. 6

(b) State and explain the reciprocity theorem in connection with radiation heat transfer. 7

(c) The distance of the sun from the earth is 150×10^6 km. If the radius of the sun is $0{\cdot}7 \times 10^6$ km and its temperature is 6200 K, estimte approximately the mean temperature of the earth. Assume that the rate of radiative transfer from the sun to the earth is equal to the radiant transfer from the earth to the outer space which is at 0 K. Consider the earth and the sun as black bodies. 7

Group C

9. Choose the *correct* answer: 1×20

(i) In the absence of any unbalanced force within the system itself and also between the system and the surroundings, the system is said to be in

(a) thermal equilibrium
(b) mechanical equilibrium
(c) chemical equilibrium
(d) phase equilibrium

(ii) A process, which is defined by the locus of all the equilibrium points passed through by the system, is known as

(a) static process
(b) dynamic process
(c) quasi-static process
(d) none of the above

(iii) The triple point of water is

(a) 273 K
(b) 273·16 K
(c) 273·02 K
(d) none of the above

(*iv*) The internal energy of a system is a

(*a*) point function
(*b*) path function
(*c*) vector function
(*d*) none of the above

(*v*) If h_1 is the enthalpy of a fluid before throttling and h_2 is the enthalpy after throttling, then

(*a*) $h_1 > h_2$
(*b*) $h_1 < h_2$
(*c*) $h_1 \geq h_2$
(*d*) $h_1 = h_2$

(*vi*) A heat reservoir is defined as a body of

(*a*) low heat capacity
(*b*) medium heat capacity
(*c*) large heat capacity
(*d*) infinite heat capacity

(*vii*) If δQ represents the heat transfer at a part of the system boundary b during a portion of the cycle, and T is the absolute temperature at that part of the boundary, then Clausius inequality states that

(*a*) $\oint \left(\frac{\delta Q}{T}\right)_b > 0$

(*b*) $\oint \left(\frac{\delta Q}{T}\right)_b < 0$

(*c*) $\oint \left(\frac{\delta Q}{T}\right)_b \leq 0$

(*d*) $\oint \left(\frac{\delta Q}{T}\right)_b \geq 0$

(*viii*) The second Tds equation is

(*a*) Tds = dH + vdp
(*b*) Tds = du + pdv
(*c*) Tds = dH - vdp
(*d*) none of the above

(*ix*) The entropy balance equation for a closed system, undergoing a change of state from 1 to 2, is given by

(*a*) $S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b + \sigma$

(*b*) $S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b - \sigma$

(*c*) $S_2 - S_1 = \left[\int_1^2 \left(\frac{\delta Q}{T}\right)_b\right] \sigma$

(*d*) $S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b / \sigma$

where σ is entropy production and b is boundary.

(*x*) A simple steam power plant operates in a

(*a*) Carnot cycle
(*b*) Stirling cycle
(*c*) Ranking cycle
(*d*) none of the above

(*xi*) The ratio of partial pressure of water vapour in a mixture to the saturation pressure of pure water at the same temperature of the mixture is called

(*a*) degree of saturation
(*b*) humidity ratio
(*c*) relative humidity
(*d*) none of the above

(*xii*) For a plate of thickness t, area A and thermal conductivity, K, the thermal conductance is given by

(*a*) $\frac{KA}{t}$

(*b*) $\frac{t}{KA}$

(*c*) $\frac{Kt}{A}$

(*d*) $\frac{A}{kT}$

(*xiii*) If α is absorptivity, ϱ, the reflectivity and τ, the transmissibility of a material, the

(*a*) $\alpha = \varrho + \tau$
(*b*) $\alpha = \varrho - \tau$
(*c*) $\alpha = 1 - \varrho - \tau$
(*d*) $\alpha = \varrho + \tau - 1$

(*xiv*) If K is the thermal conductivity of an isulator, h_a is the surface coefficient of heat transfer to the surrounding, then the critical radius of insulation, γ_c is given by

(*a*) $\frac{h_a}{k}$

(*b*) $\frac{k}{h_a}$

(*c*) $h_a + k$

(*d*) none of the above

(*xv*) For a long thin fin with insulated top, the fin efficiency is given by

(*a*) $\frac{\tanh(ml)}{ml}$

(*b*) $\frac{ml}{\tanh(ml)}$

(*c*) $\frac{\tanh ml}{m}$

(*d*) none of the above,

where l is the length of the fin and $m = \sqrt{\frac{hp}{ka}}$.

(*xvi*) The fin effectiveness of a rectangular fin of minimum weight with width b is given by

(*a*) $0{\cdot}005\left(\frac{hb}{2k}\right)^{\frac{1}{2}}$

(*b*) $0.889\left(\frac{2k}{hb}\right)^{\frac{1}{2}}$

(*c*) $0.889\left(\frac{hb}{2k}\right)^{\frac{1}{2}}$

(*d*) none of the above

(*xvii*) If the turbulent boundary layer on a flat plate is assumed to start at the leading edge, the average friction coefficient $\bar{C_f}$ over a length L is given by

(*a*) $\frac{0.005}{(R_{e_L})^{0.5}}$

(*b*) $\frac{0.072}{(R_{e_L})^{0.2}}$

(*c*) $0.09\,(R_{e_L})^{0.2}$

(*d*) none of the above

where R_{e_L} is the Reynolds number

(*xviii*) The ratio of internal thermal resistance of a solid body to its surface thermal resistance is called

(*a*) Biot number

(*b*) Eckert number

(*c*) Fourier number

(*d*) none of the above

(*xix*) The ratio of buoyance to viscous forces is called

(*a*) Reynolds number

(*b*) Prandtl number

(*c*) Grashof number

(*d*) Biot number

(*xx*) Dittu's Boelter equation for Nusselt number in fully developed turbulent flow in smooth tubes for cooling of the fluid is given by

(*a*) $0.023\,R_e^{0.8}\;P_r^{0.4}$

(*b*) $0.023\,R_e^{0.8}\;P_r^{0.2}$

(*c*) $0.023\,R_e^{0.8}\;P_r^{0.3}$

(*d*) $0.023\,R_e^{0.2}\;P_r^{0.4}$

where R_e is the Reynolds number and P_r, the Prandtl number.

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Use of steam tables and Mollier chart are permitted.

Use of Psychrometric chart and Refrigerant tables are permitted.

Group A

1. (*a*) Define the first law of thermodynamics for a closed system. Explain the limitations of the first law. 4

   (*b*) Distinguish clearly between the following, giving examples wherever necessary : 4

   (*i*) Closed system and open system;

   (*ii*) Heat and work;

(*iii*) Point functions and path functions;

(*iv*) Enthalpy and internal energy.

(*c*) $2\,m^3$ of hydrogen at a pressure of 1 bar and 20 °C is compressed isentropically to 4 bar. The same gas is expanded restored to original volume by constant volume heat rejection process. Determine (*i*) pressure volume, temperatures at each end of operation, (*ii*) heat added during the isothermal process, (*iii*) the heat rejection during the constant volume process, and (*iv*) change in internal energy in each process. Assume $R = 4{\cdot}206$ kJ/kg°K, $C_p = 14{\cdot}25$ kJ/kg°K. 12

2. (*a*) State the second law of thermodynamics as stated by Kelvin-Plank and Clausius. Show the equivalence of the above two statements. 8

(*b*) In order to check the validity of the second law, m_1 kg of the fluid at a temperature of T_1 is isentropically and adiabatically mixed with m_2 kg of fluid at temperature T_2 ($T_1 > T_2$). Determine the change in entropy of the universe and find an expression for the same for equal mass of fluid. Also, prove that the change in entropy is necessarily positive and is given by

$$\left[\log \frac{T_1 + T_2}{2\sqrt{T_1 T_2}}\right]$$ 12

3. (*a*) State and prove the Clausius inequality 4

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

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

(*b*) How the Rankine cycle differ from the Carnot cycle for a vapour? 4

(*c*) A steam turbine receives steam at a pressure of 20 bar and superheated to 88·6 °C. The exhaust pressure is 0·07 bar and expansion of steam takes place isentropically. Using the steam table, calculate the following:

(*i*) Heat supplied, assuming that heat pump supplies water to the boiler at 20 bar;

(*ii*) Heat rejected;

(*iii*) Net work done;

(*iv*) Work done by the turbine;

(*v*) Thermal efficiency;

(*vi*) Theoretical steam consumption.

If the actual steam consumption is 5 kg/kWh, what is the efficiency ratio of the turbine? 12

4. (*a*) Define the following terms:

DBT, WBT, DPT, RH and specific humidity ω used in air-conditioning. 4

(*b*) Prove that, for the mixture of gases mole fraction, each constituent in a mixture of perfect gases is the same as its volume fraction and also the ratio of its partial pressure to the total pressure is

$$\frac{n_i}{n} = \frac{v_i}{v} = \frac{p_i}{p}$$ 4

(c) During the test of a single-cylinder oil engine working on the four-stroke cycle and fitted with a rop brake, the following readings are taken:
Effective diameter of a brake wheel = 630 mm, dead load on the brake = 200 N, spring balance reading = 30 N, speed = 450 rpm, area of indicator diagram = 420 mm^2, length of indicator diagram = 60 mm, spring scale = 1·1 bar per mm, diameter of the cylinder = 100 mm, stroke = 150 mm, quantity of oil used = 0·815 kg/hr, calorific value of oil = 42,000 kJ/kg.

Calculate the brake power, indicated power, mechanical efficiency, brake thermal efficiency and brake specific fuel consumption. 12

Group B

5. (a) Derive an expression for the temperature distribution and heat flow from a fin whose one end is insulated. 6

(b) A furnace wall consists of 200 mm layer of refractory bricks, 6 mm layer of steel plate and 100 mm layer of insulation bricks. The maximum temperature of the wall is 1150 °C on the furnace side and the minimum temperature is 40 °C on the outermost side of the wall. An accurate energy balance over the furnace shows that the heat loss from the wall is 400 W/m^2. It is known that there is a thin layer of air between the layers of refractory-bricks and steel plate. Thermal conductivities for three layes are 1·52, 45 and 0·138 W/m °C, respectively. Find

(i) how many mm of insulation brick is the air layer equivalent.

(ii) the temperature of outer layer surface of the steel plate. 14

6. (a) Define the following laws of radiation: 3 × 3

(i) Stefan-Boltzmann law;

(ii) Plank's law; and

(iii) Kirchoff's law.

(b) An enclosure is formed by three surfaces. Details of their shape factors, emissivities and temperatures are as under:

Surface	*Shape*	*Emissivity*	*Temperature*
1	curved cylindrical	0·8	500 °C
2	one end closing disc	0·85	400 °C
3	other end closing disc	0·85	400 °C

Diameters of two closing plate discs and interspacing between the two are 25 mm and 100 mm, respectively. Shape factor between two identical discs is 0·5. Calculate the net rate of radiation heat flow leaving from surface 1 and reacting to each of the surface 2 and 3. 11

7. (a) Derive an expression for the LMTD for a parallel flow heat exchanger. 6

(b) Oil (C_p = 3·6 kJ/kg °C) at 100 °C flows at a 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 exchanger at 10 °C at a rate of 50,000 kg/hr. The heat transfer area is 10 m^2 and u = 1000 W/m^2 °C. Calculate the following: 7 × 2

(i) Outlet temperature of oil and water; and

(ii) Maximum possible outlet temperature of water.

8. (*a*) Define the following:

(*i*) Free and forced convection;

(*ii*) Energy equation for a boundary layer for a flow over a hot flat plate; and

(*iii*) Relationship between thermal boundary layer thickness and hydrodynamic boundary layer thickness.

(*b*) Air is flowing over a flat plate of 5 m long and 2·5 m wide with a velocity of 4 m/sec at 15°C. If $\varrho = 1{\cdot}208\ \text{kg/m}^3$ and $\gamma = 1{\cdot}47 \times 10^{-5}\ \text{m}^2/\text{sec}$, calculate:

(*i*) length of the plate, over which the boundary layer is laminar, and thickness of the boundary layer (laminar);

(*ii*) shear stress at the location where the boundary layer ceases to be laminar; and

(*iii*) total drag force on both sides on that portion of the plate where boundary layer is laminar. 4 × 3

Group C

9. Answer the following questions: 2 × 10

(*i*) Define the zeroth law of thermodynamics.

(*ii*) Define the availability.

(*iii*) Differentiate between IC engine and gas turbine.

(*iv*) Adiabatic mixing of two air-streams.

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(*v*) Efficiency of a Carnot cycle.

(*vi*) Define the unsteady state heat conduction.

(*vii*) Concept of black body.

(*viii*) View factor or shape factor.

(*ix*) Free and forced convection.

(*x*) NTU-method used in heat exchangers.

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Group A

1. (*a*) Which are the characteristics common to both work and heat? 2

(*b*) What is Clausius equation of state and how does it differ from ideal gas law? 2

(*c*) What is an adiabatic process and how does it differ from insentropic process? 2

(*d*) What is entropy generation? Can it be negative? Explain. 2

(e) A cylinder of 0·5 m in diameter, with a functionless piston, contains saturated steam at 500 kPa. The piston is 0·5 m above the base of the cylinder. The piston is held in position by means of latches and energy is added as heat until the pressure of the steam is 1 MPa. Determine the final temperature of the steam and the energy transferred as heat. Now, the piston is released and the energy is added as heat at constant pressure until the steam temperature is 700 °C. Determine the amount of energy added as heat and the final position of the piston. 12

2. (a) How is the COP of a heat pump related to the COP of a refrigerator? 2

(b) State the Carnot theorem. 2

(c) State the Clausius inequality. 2

(d) Define Helmholtz function and Gibbs' free energy. 2

(e) Derive the following relation for the entropy change of an ideal gas

$$\Delta s = C_p \ln (v_2/v_1) + C_v \ln (p_2/p_1)$$ 12

3. (a) What is Clapeyron equation? 2

(b) Differentiate between open-cycle and closed-cycle gas turbines. 2

(c) What is meant by refrigeration? Define a tonne of refrigeration. 2

(d) Does the thermal efficiency of an Otto engine depend on whether the gas or working fluid is monoatomic or diatomic? Explain. 2

(e) By using Maxwell's relations for thermodynamics, show that the Joule-Thomson coefficient, μ, of a gas can be expressed as

$$\mu = \left(\frac{\partial T}{\partial P}\right)_h = \frac{T^2}{C_p}\left[\frac{\partial}{\partial T}\left(\frac{v}{T}\right)\right]_p$$

12

4. (a) Sketch an air standard diesel cycle on p-v and T-s diagrams. How does it differ from Otto cycle? 4

(b) Explain adiabatic saturation and thermodynamic wet-bulb temperature. When are the adiabatic saturation and wet-bulb temperature equivalent for the atmospheric air. What is dew-point temperature?

(c) A house is to be maintained at 25 °C in summer as well as winter. For this purpose, it is proposed to use a reversible device as a refrigerator in summer and a heat pump in winter. The ambient temperature is 40 °C in summer and 3 °C in winter. The energy losses as heat from the roof and the walls are estimated at 5 kW per degree Celsius temperature difference between the room and the ambient conditions. Calculate the power required to operate the device in summer and winter. 12

Group B

5. (a) What is the critical thickness of insulation on a small diameter wire or pipe? Explain its physical significance and derive the expression for the same. 4

(*b*) Differentiate between conductivity and conductance. 2

(*c*) Explain thermal diffusivity and thermal resistance. 2

(*d*) The temperature of air, in an air stream is a tube, is measured by a thermometer placed in a protective well filled with oil. The thermowell is made of steel tube of 1·5 mm thick sheet of length 120 mm. The thermal conductivity of steel = 58·8 W/(mK) and $h_a = 23 \cdot 3\ \text{W/(m}^2\text{-K)}$. If the air temperature recorded was 84°C, estimate the measurement error if the temperature at the base of the well was 40°C. 12

6. (*a*) What is the Dittus-Boelter equation? Where and when does it apply. 2

(*b*) Explain, in detail, the Colburn analogy. 2

(*c*) Explain Nusselt, Prandtl, Reynolds, and Stanton numbers and their significance and forced convection. 4

(*d*) Water at 20°C flows normal to the axis of a circular tube with a velocity of 1·5 m/s. The diameter of the tube is 25 mm. Calculate the average heat transfer coefficient of the tube surface is maintained at a uniform temperature of 80°C. Also, estimate the heat transfer rate per unit length of the tube. Properties of water at $T_f = (20+80)/2 = 50°\text{C}$ are: specific heat, $C_p = 4 \cdot 1813$ kJ/(kg-K), kinematic viscosity, $\nu = 0 \cdot 568 \times 10^{-6}\ \text{m}^2/\text{s}$, Thermal conductivity $k = 0 \cdot 6395$ W/(m-K), Prandtl no., $Pr = 3 \cdot 68$, Density, $\varrho = 990\ \text{kg/m}^3$, Dynamic viscosity of water (μ_w) at $80°\text{C} = 3 \cdot 5456 \times 10^{-4}$ kg/(m-sec), μ_∞ at $20°\text{C} = 1 \cdot 006 \times 10^{-3}$ kg/(m-sec). Use the relation

$$\overline{N}_u = (0 \cdot 4\ R_e^{0 \cdot 5} + 0 \cdot 06\ R_e^{2/3})\ P_2^{0 \cdot 4} \left[\frac{\mu_\infty}{\mu_w}\right]^{1/4}.$$

12

7. (*a*) Discuss briefly various regimes in boiling heat transfer. 4

(*b*) Distinguish between: 4

(*i*) A black body and a gray body

(*ii*) Absorptivity and emissivity of a surface

(*iii*) Specular and diffuse surfaces

(*iv*) Total emissivity and equilibrium emissivity.

(*c*) The configuration of a furnace can be approximated as an equilateral triangular duct which is sufficiently long that the end effects are negligible. The hot wall is maintained (this wall is black) at $T_2 = 1000$ K. The cold wall is at $T_1 = 700$ K and has an emissivity of $\varepsilon_1 = 0 \cdot 8$. The third wall is re-radiating zone for which $Q_3 = 0$. Calculate the net radiation flux leaving the hot wall. 12

8. (*a*) Name the law which establishes a relationship between the emissive power of a surface to its absorptivity. Write the statement. 2

(*b*) A metallic bar at 37°C is placed inside an oven whose interior is maintained at a temperature of 1100 K. The absorptivity of the bar (at 37°C) is a function of the temperature of incident radiation and a few representative values are given below:

Temp (K)	310	700	1100
α	0·8	0·68	0·52

Estimate the rate of absorption and emission by the metallic bar. 6

(c) In a double pipe counterflow heat exchanger, 10,000 kg/h of oil $C_p = 2 \cdot 095$ kJ/(kg-K) is cooled from 80 °C to 50 °C by 8000 kg/h of water entering at 25 °C. Determine the area of heat exchanger for an overall $U = 300$ W/(m^2-K). Take C_p for water as $4 \cdot 18$ kJ/(kg-K). 12

Group C

. Answer the following questions: 2×10

(i) Distinguish between steady state and equilibrium.

(ii) Why Carnot cycle cannot be used for power plants?

(iii) Define availability and irreversibility.

(iv) Define isentropic efficiency of a turbine and a compressor.

(v) How is it possible to assume that the water vapour behaves as an ideal gas in analyzing the mixtures of air and water vapour.

(vi) Differentiate between fin efficiency and the fin effectiveness.

(vii) What are radiation shape factors? Where are they used?

(viii) Why is an analytical solution of a free convection heat transfer problem more difficult than that of a forced convection problem?

(ix) What is meant by a hydrodynamically well developed flow in a pipe line? Explain.

(x) Define Grashof number and its significance in free convection heat transfer.

W'07 : 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 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.

Use of steam tables, heat transfer data/ thermodynamics tables/ psychometric tables may be permitted.

Group A

1. (*a*) Distinguish between steady state and equilibrium. 2

(*b*) A room has 4 persons and have 2 fans and three lamps. Each fan consumes 0·18 kW power and each lamp is of 100 W. Ventilation air at the rate of 80 kg/h enters with an enthalpy of 84 kJ/kg and leaves with an enthalpy of 59 kJ/kg. If each person puts out heat at the rate of 630 kJ/h, determine the rate at which heat is to be removed by a room cooler so that steady state is maintained in the room? 4

(*c*) One kg of ideal gas is heated from 25 °C to 100 °C. Assuming that $R = 0{\cdot}264$ kJ/kg°K, $\gamma = 1{\cdot}18$ for the gas and heat transfer of 200 kJ, find the (*i*) respective specific heats, (*ii*) change in internal energy, (*iii*) change in enthalpy, and (*iv*) work done. 2 × 4 (*d*) An air compressor takes in air at 1 bar and 30 °C raises to 5 bar. Find the work done, internal energy change and heat transfer per kg of fluid compressed if compression process is (*i*) isothermal, and (*ii*) adiabatic. Take $R = 0{\cdot}287$ kJ/kg°K, $\gamma = 1{\cdot}4$. Neglect changes in PE or KE. 6

2. (*a*) Explain the law of corresponding states? 2

(*b*) What is the mass of air contained in a room 6 m × 9 m × 4 m, if the pressure is 101·325 kPa and temperature is 25 °C? 4

(*c*) Derive Maxwell's relations. 5

(*d*) The vapour pressures of ethyl benzene at 347·2 °K and 460 °K are 0·133 bar and 3·325 bar, respectively. Estimate the enthalpy of vaporization of ethyl benzene. 4

(*e*) A mixture of dry air and water vapour is at a temperature of 21 °C under a total pressure of 736 mm of Hg. The dew point temperature is 15 °C. Find

(*i*) partial pressure of water vapour;

(*ii*) relative humidity;

(*iii*) specific humidity; and

(*iv*) specific volume of air/kg of dry air. 5

3. (*a*) Explain why Carnot cycle cannot be realized in practice? 2

(*b*) A Carnot engine operates between two reservoirs at the temperature of T_1 °K and T_2 °K. The work output of the engine is 0·6 times that of heat rejected. Given that difference in temperature between the source and sink is 200 °C. Calculate the source temperature, sink temperature, and thermal efficiency. 6

(*c*) In an oil cooled heat exchanger, the oil is cooled from 90 °C to 40 °C at the rate of 25 kg/min. Water is sent into the heat exchanger with a temperature of 25 °C at the rate of 50 kg/min. Determine the change in availability of the (*i*) water, (*ii*) oil, and (*iii*) irreversibilities.

Given: $C_p$oil = 1·8 kJ/kg°K
$C_p$water = 4·18 kJ/kg°K. 6

(*d*) One kg of air is heated from 27 °C to 127 °C from a heat source at 127 °C. Find the entropy change of air, heat source and of the universe. What will be the change of entropy of the universe, if the air is heated first from a heat source at 77 °C and then with another heat source at 127 °C. Comment on the results. 6

4. (*a*) Explain the thermodynamic variables affecting the efficiency and output of the Rankine cycle. 3

(*b*) A steam power plant produces 200 MW of electricity working on a simple Rankine cycle between pressure limits of 200 bar and 1 bar. Assuming the efficiency of a generator, turbine and boiler as 90%, 80% and 80%, respectively, find (*i*) cycle efficiency, and (*ii*) fuel required to operate the boiler. (C.V. = 25000 kJ/kg). 6

(*c*) An open cycle gas turbine plant consists of a compressor combustion chamber and turbine. The isoentropic efficiency of compressor and turbine are η_c and η_t, the maximum and minimum cycle temperatures are T_3 and T_1, respectively, and r_p is the pressure ratio for both compression and expansion. Neglecting pressure losses and assuming that the necessary condition for positive power output is given by

$$\eta_c \eta_t T_3 > T_1 (r_p)^{\gamma - 1/\gamma}$$

where γ is the ratio of specific heats. 5

(*d*) In an open cycle air refrigeration system, air is drawn from a cold chamber at $-5°C$ and 1 bar and compressed to 6 bar. The air is then cooled to 20 °C and then expanded to 1 bar. The compression and expansion follow the relation $Pv^{1.35} = C$, where C is a constant. To produce to 10 tonnes of refrigeration, find the mass flow rate of air to be circulated. Also, find COP, power required to compress, and rate of heat rejection in the heat exchanger. 6

Group B

5. (*a*) Discuss the mechanism of thermal conduction in gases and solids. 2

(*b*) Calculate the critical radius of insulation for asbestos with $k = 0.17$ W/m °C surrounding a pipe and exposed to a room air at 25 °C with $h = 4.0$ W/m^2 C. Calculate the heat loss from 6.0 cm dia pipe at 200 °C when covered with critical radius of insulation and without insulation. 4

(*c*) An electronic semiconductor device generates 16×10^{-2} kJ/h of heat. To keep the surface temperature at safer limits of 75 °C, it is desired that generated heat should be dissipated to the surrounding which is at 30 °C. This can be achieved by attaching aluminum fins of 0.5 mm^2 and 10 mm to the surface. Estimate the number of fins. Thermal conductivity of fin material is 700 kJ/m h °C. The heat transfer coefficient is 45 kJ/m^2 h °C. Neglect the heat loss from the tip of the fin. 7

(*d*) A copper cylinder of 80 cm dia and 100 cm length is initially at a uniform temperature of 25 °C. The cylinder is suddenly exposed to a hot flue gas. The surface temperature suddenly changes to 450 °C. Estimate the temperature at the centre of the cylinder, 320 sec after the change in surface temperature. Also, calculate time required for the temperature at the centre to attain the value of 375 °C. Given: Thermal diffusivity, $\alpha = 1.12 \times 10^{-4}$ m^2/s. 7

6. (*a*) Enumerate some of the empirical relations being used to compute the convective coefficient for free convection. In the product of Gr and Pr, what group of properties is concerned only with the properties and gravitational field? What is the group of properties called? What are the dimensional units of this group of properties? 5

(*b*) Calculate the heat transfer from 60 W bulb at 120 °C to 30 °C in quiescent air. The bulb can be approximated to 50 mm diameter sphere. Also, calculate the percentage power lost by free convection? The free convection coefficient is as follows: $Nu = 0.60\,(Gr.\,Pr)^{0.25}$. 6

(*c*) Differentiate between filmwise and dropwise condensation. 3

(*d*) A vertical plate of 500 mm high is maintained at 30 °C and is exposed to saturated steam at atmospheric pressure. Calculate the (*i*) rate of heat transfer, and (*ii*) condensate rate per hour/m of plate with film condensation.

Properties of the water film at the mean temperature are:

$\varrho = 980{\cdot}3$ kg/m^3

$K = 66{\cdot}4 \times 10^{-2}$ J/s. m °C

$\mu = 434 \times 10^{-6}$ kg/m.s

$h_{fg} = 2257$ kJ/kg

Assume that the vapour density is small to that of condensate. 6

7. (*a*) Derive an expression for effectiveness in counter flow heat exchangers in terms of NTU and heat capacities of fluids? 5

(*b*) In a counter flow heat exchange, water is heated from 35 °C to 75 °C by an oil with specific heat of 1·45 kJ/kg°K. The oil is cooled from 240 °C to 170 °C. If the overall heat transfer coefficient is 450 W/m^2 °C, calculate the (*i*) rate of heat transfer; (*ii*) mass flow rate of water; and (*iii*) surface area of heat exchanger. 6

(*c*) Oil at 25 °C is forced over a 400 cm^2 square plate at a velocity of 1·18 m/s. The plate is heated to uniform temperature of 55 °C. Calculate the heat lost by the plate. Given: $\varrho = 876$ kg/m^3; $\gamma = 0{\cdot}00024$ m^2/s; $k = 0{\cdot}144$ W/m °C; $C_p = 1{\cdot}97$ kJ/kg °C. 5

(*d*) Explain the terms (*i*) thermal boundary layer, (*ii*) Reynold's analogy and Colburn's analogy. 4

8. (*a*) Explain Lambert's cosine law. 3

(*b*) A small sphere of outside dia 60 mm, with a surface temperature of 400 °C, is located at the centre of a large sphere with the inside diameter of 360 mm. With an inner surface temperature of 25 °C, calculate net interchange of heat between the spheres. Assume that both sides approach black body behaviour. 6

(*c*) The effective temperature of a body having an area of 1 m^2 is 800 °K. Calculate the (*i*) total rate of energy emission; (*ii*) intensity of normal radiation; and (*iii*) wavelength of maximum monochromatic emissive power. 7

(*d*) Explain the terms absorptivity, reflectivity and transmissivity of radiation. Discuss the relationship between each other for a black body and opaque body. 4

Group C

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

(*i*) A cycle is made up of a combination of ——.

- (*a*) properties
- (*b*) states
- (*c*) processes
- (*d*) surroundings

(*ii*) Air standard efficiencies of an Otto cycle —— with increase in compression ratio.

- (*a*) decrease
- (*b*) increase
- (*c*) remains constant

(*iii*) A 10 tonne refrigeration system consumes 10 kW of electrical energy. Its COP will be

(*a*) 10
(*b*) 3·5
(*c*) 0·35
(*d*) 35

(*iv*) Infiltration air in an air-conditioned room

(*a*) reduces heat load.
(*b*) increases heat load.
(*c*) leaks through gaps.
(*d*) Both (*b*) and (*c*) above.

(*v*) The enthalpy of an ideal gas depends on

(*a*) temperature only.
(*b*) pressure only.
(*c*) both pressure and temperature.
(*d*) volume only.

(*vi*) A closed vessel contains equal number of O_2 and H_2 molecules at a total pressure of 760 mm of Hg. If O_2 is removed from the system, the pressure will be

(*a*) 380 mm of Hg
(*b*) 1520 mm of Hg
(*c*) will remain unchanged
(*d*) will initially decrease but soon will reach the original value.

(*vii*) The Joule-Thomson coefficient for an ideal gas is

(*a*) zero
(*b*) positive
(*c*) negative
(*d*) infinity

(*viii*) An apple, with an average mass of 0·15 kg and average specific heat of 3·65 kJ/kg°C, is cooled from 20°C to 5°C. The amount of heat transferred from the apple is

(*a*) 0·55 kJ
(*b*) 15 kJ
(*c*) 8·21 kJ
(*d*) 4·10 kJ

(*ix*) A heat engine receives heat from a source at 1000°C and rejects the waste heat to a sink at 50°C. If the heat is supplied to this engine at a rate of 100 kJ/s, maximum power this heat engine can produce equals

(*a*) 25·4 kW
(*b*) 55·5 kW
(*c*) 74·6 kW
(*d*) 95 kW

(*x*) Heat is lost through a plane wall steadily at a rate of 600 W. If the inner and outer surface temperatures of the wall are 20°C to 5°C, respectively, the rate of entropy generation within the wall is

(*a*) 0·11 W/°K

(*b*) 4·21 W/°K

(*c*) 2·10 W/°K

(*d*) 42·1 W/°K

(*xi*) In which of the following cases most unsteady heat flow occur ?

(*a*) through the walls of a furnace.

(*b*) through lagged pipes carrying steam.

(*c*) through the wall of a refrigerator.

(*d*) during annealing of castings.

(*xii*) If k is the thermal conductivity ; ϱ, the mass density ; and c, the specfic heat, then the thermal diffusivity of a substance is given by

(*a*) $\varrho c/k$

(*b*) $k/\varrho c$

(*c*) kc/ϱ

(*d*) $k\varrho/c$

(*xiii*) Film coefficient is defined as

(*a*) thermal conductivity/equivalent thickness of film.

(*b*) inside diameter of tube/eqivalent thickness of film.

(*c*) specific heat × viscosity/thermal conductivity.

(*d*) None of the above

(*xiv*) The degree of approach in heat exchangers is defined as the difference between temperatures of

(*a*) hot medium outlet and cold water outlet.

(*b*) hot medium outlet and cold water inlet.

(*c*) cold water inlet and outlet.

(*d*) hot medium inlet and outlet.

(*xv*) When metallic surface are oxidized, the emissivity

(*a*) decreases.

(*b*) increases.

(*c*) remain unaltered.

(*d*) unpredictable.

(*xvi*) Dropwise condensation occurs on a —— surface.

(*a*) oily

(*b*) smoothed

(*c*) glazed

(*d*) coated

(*xvii*) A grey body is one whose absorbtivity

(*a*) varies with temperature.

(*b*) varies with wavelength of incident ray.

(*c*) varies with temperature and wavelength of incident ray.

(*d*) does not vary with temperature and wavelength of incident ray.

(*xviii*) The value of convection coefficient in condensation over a vertical surface varies as

(*a*) $k^{0.5}$

(b) $k^{0.55}$

(c) $k^{0.75}$

(d) $k^{0.9}$

where k is the thermal conductivity of the liquid.

(xix) The phenomenon of boiling the milk in an open container, with milk spills over the vessel, is termed as —— boiling.

(a) sub-cooled

(b) pool

(c) film

(d) nucleate

(xx) The temperature gradient in the fluid flowing over a heated plate will be

(a) zero at the top of thermal boundary layer.

(b) very steep at the surface.

(c) zero at the plate surface.

(d) positive at the surface.

S'08 : 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 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.

Steam tables are permitted to use.

Group A

1. (*a*) State and explain the zeroth law of thermodynamics. 4

(*b*) State and explain the various criteria for thermodynamic equilibrium. 6

(*c*) Show that the first law of thermodynamics leads to the conclusion that a 'Perpetual Motion Machine of the First Kind (PMMFK) is impossible'. 5

(*d*) One mol of an ideal gas with $\gamma = 1{\cdot}4$ initially at 300 K and 1 bar is compressed reversibly and adiabatically to 6 bar and then it is cooled at constant pressure to the original temperature. The gas is then restored to its initial state through an isothermal process. Calculate the network and heat interaction. 5

2. (*a*) Prove the equivalence of the Clausius and Kelvin-Plank statements of the second law of thermodynamics. 6

(*b*) Explain the underlying principle for defining the Kelvin temperature scale. 6

(*c*) Water initially a saturated liquid at 100 °C, is contained within a piston-cylinder assembly. Water undergoes a process, during which the piston moves freely in the cylinder, and no heat transfer takes place with the surroundings, but the state is changed to the corresponding vapour state. If the change of state is brought about by the action of a paddle wheel, determine the network per unit mass in kJ/kg, and the amount of entropy produced per unit mass. (Steam tables can be referred.) 8

3. (*a*) What is air standard analysis of reciprocating IC engines? 3

(*b*) An air standard dual cycle, with a compression ratio 15, has the minimum temperature and pressure of 300 K and 0·95 bar, respectively. The cylinder volume is 3 litres and 6 kJ of energy is added as heat, of which one-third is added at constant volume and the rest at constant pressure. Calculate the maximum pressure in the cycle, the temperature of the gas before and after the constant pressure energy addition, the energy rejected as heat, and the thermal efficiency of the cycle. For air, $C_v = 0{\cdot}7175$ kJ/kg.K. 10

(*c*) A gas turbine plant operates on Brayton cycle between $T_{min} = 300$ K and $T_{max} = 1073$ K. Find the maximum work done per kg of air, and the corresponding cycle efficiency. How does this efficiency compare with the Carnot cycle efficiency operating between the same two temperatures? 7

4. (*a*) What is Joule-Kelvin coefficient? 2

(*b*) Using the second *Tds* equation, prove that the Joule-Kelvin coefficient of an ideal gas is zero. 6

(*c*) A mass of 0·25 kg of an ideal gas has a pressure of 300 kPa, a temperature of 80 °C and a volume of 0·07 m^3. The ideal gas undergoes an irreversible adiabatic process 0 to *a*, find pressure of 300 kPa and find volume of 0·10 m^3, during which the work done on the gas is 25 kJ. Evaluate C_p and C_v of the gas and increase in entropy of the gas. 5

(*d*) The atmospheric air at 760 mm of Hg, dry bulb temperature 15 °C and wet belb temperature 11 °C enters a heating coil whose temperature is 41 °C. Assuming by-pass factor of heating coil as 0·5, determine dry bulb temperature, wet bulb temperature and relative humidity of the air leaving the coil. Also, determine the sensible heat added to the air per kg of dry air. 7

Group B

5. (*a*) Consider heat transfer between two identical hot solid bodies and their environments. The first solid is dropped in a large container filled with water, while the second one is allowed to cool naturally in the air. For which case is the lumped system analysis more likely to be applicable and why? 4

(*b*) A solid copper ball of 100 mm diameter and $\varrho = 8954$ kg/m^3, $C_p = 383$ J/kgK, $k = 386$ W/mK is at a uniform temperature of 250 °C. It is suddenly immersed in a well-stirred fluid which is maintained at a uniform temperature of 50 °C. The heat transfer coefficient between the ball and the fluid is $h = 200$ W/m^{2}K. Estimate the temperature of the copper ball after a lapse of 5 min since immersion. 6

(*c*) An aluminium heat sink for electronic components has a base of width 50 mm and length 70 mm. There are eight aluminium ($k = 180$ W/mK) fins of height 12 mm and thickness 3 mm. The fins are cooled by air at 25 °C with a connective heat transfer coefficient of 10 W/m^{2}K. Assuming that the heat transfer coefficient is uniform all along the fin and the lip, determine the (*i*) heat flow through the sink for a base temperature of 50 °C, (*ii*) fin effectiveness, (*iii*) fin efficiency, (*iv*) length of the fin if the heat flow is 95% of the heat flow for an infinite fin. 10

6. (*a*) Determine the maximum current that a 1 mm diameter base aluminium ($k = 204$ W/mK) wire can carry without exceeding a temperature of 200 °C. The wire is suspended in air at temperature of 25 °C and $h = 10$ W/m^{2}K. The electrical resistance of this wire per unit length is 0·037 Ω/m. 8

(*b*) 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 the 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 $\varrho = 988 \cdot 1$ kg/m^3, $\nu = 0 \cdot 556 \times 10^{-6}$ m^2/s, Pr = 3·54 and $k = 0 \cdot 648$ W/mK. 12

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

(*b*) Show that for parallel flow heat exchanger

$$\varepsilon = \frac{1 - \exp[-\mathrm{NTU}(1 - R)]}{1 - R\exp[-\mathrm{NTU}(1 - R)]}$$

where ε is the effectiveness of heat exchanger and R, the heat capacity ratio. 6

(*c*) A two-pass surface condenser is required for 7000 kW turbogenerator which has a steam consumption of 8 kg/kWh. The cooling water inlet and outlet temperatures are 32 °C and 43 °C, respectively. The velocity of water in 2 cm outside diameter and 1·2 mm thick tube is 1·5 m/s. The desired vacuum is 660 mm of Hg and condensate temperature is not to fall below 50 °C. If the dryness fraction of steam at inlet to the condenser is 0·9 and the overall heat transfer coefficient is 3000 W/m^{2}K, find (*i*) cooling surface area required, and (*ii*) number of tubes and the length of each tube. Barometer reads 760 mm of Hg. Assume C_p of water = 4·2 kJ/kgK and $\varrho = 995$ kg/m^3. 8

8. (*a*) Determine the geometric shape factor for a very small disc of surface area dA_1 and a large parallel disc of surface area A_2 located at a distance L directly above the smaller one (both are placed in horizontal planes). 8

(*b*) Determine (in watt) radiation heat loss from each metre of 20 cm diameter heating pipe when it is placed centrally in the brick duct of square section 30 cm side. Given

Temperature of pipe surface	= 200 °C
Brick duct temperature	= 20 °C
Emissivity of pipe surface	= 0·8
Brick duct emissivity	= 0·9

Assume only radiation heat transfer between pipe and brick duct.

If the system is in steady state condition, find the surface heat transfer coefficient of the brick duct assuming the temperature of the surroundings of the duct to be 10°C. Assume $\sigma = 5{\cdot}67 \times 10^{-8}$ J/m^{2}sK^4. 8

(*c*) Two black discs of diameter 50 cm are placed parallel to each other concentrically at a distance of 1 m. The discs are maintained at 727°C and 227°C, respectively. Calculate the heat transfer between the discs per hour when (*i*) no other surfaces are present except the discs; and (*ii*) the discs are connected by cyclindrical black surface. Assume $F_{1-2} = 0{\cdot}06$. 4

Group C

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

(*i*) A closed thermodynamic system is one in which

(*a*) there is no energy or mass transfer across the boundary

(*b*) there is no mass transfer but energy transfer exists

(*c*) there is no energy transfer but mass transfer exists

(*d*) None of the above.

(*ii*) Which one of the following is the extensive property of the system?

(*a*) volume

(*b*) density

(*c*) pressure

(*d*) temperature

(*iii*) The molecular kinetic energy of a gas is proportional to

(*a*) T^2

(*b*) $T^{3/2}$

(*c*) T

(*d*) T^3

(*iv*) At triple point of a pure substance, the following occurs:

(*a*) liquid and vapour phases coexist

(*b*) solid and vapour phases coexist

(*c*) liquid and solid phases coexist

(*d*) solid, liquid and vapour phases coexist

(*v*) For a closed system, the difference between the heat added to and the work done by the system is equal to the change in

(*a*) enthalpy

(*b*) internal energy

(*c*) entropy

(*d*) None of the above

(*vi*) The internal energy of an ideal gas is a function of

(*a*) pressure only

(*b*) temperature only

(*c*) pressure and volume

(*d*) pressure, volume and temperature

(*vii*) The change in enthalpy of a system equals the heat supplied for a

(*a*) constant pressure process

(*b*) constant volume process

(*c*) constant temperature process

(*d*) None of the above.

(*viii*) Isothermal and adiabatic processes are identical at

(*a*) saturation temperature

(*b*) critical temperature

(*c*) absolute zero temperature

(*d*) triple point

(*ix*) For a reversible adiabatic compression in a steady flow process, the work transfer per unit mass is

(*a*) $\int pdv$

(*b*) $\int vdp$

(*c*) $\int Tds$

(*d*) $\int SdT$

(*x*) For a thermodynamic cycle to be irreversible, the following condition will hold good :

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

(*b*) $\int \frac{dQ}{T} < 0$

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

(*d*) $\oint \frac{dQ}{T} \geq 0$

(*xi*) The temperature of air recorded by a thermometer, when it is not effected by the moisture present in it, is called

(*a*) wet bulb temperature

(*b*) dew point temperature

(*c*) dry bulb temperature

(*d*) None of the above.

(*xii*) The difference between dry bulb temperature and wet bulb temperature is called

(*a*) dry bulb depression.

(*b*) wet bulb depression.

(*c*) dew point depression.

(*d*) degree of saturation.

(*xiii*) The curved lines on a psychrometric chart indicates

(*a*) dry bulb temperature

(*b*) wet bulb temperature

(*c*) specific humidity

(*d*) relative humidity

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

(*a*) π

(*b*) $\pi/\sqrt{2}$

(*c*) $1/\pi$

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

(*xv*) The critical radius of insulation of a spherical cell is

(*a*) h/k

(*b*) $2h/k$

(*c*) k/h

(*d*) $2k/h$

(*xvi*) When a liquid flows through a tube with sub-cooled or saturated boiling, the process is called

(*a*) pool boiling

(*b*) bulk boiling

(*c*) convection boiling

(*d*) None of the above.

(*xvii*) For evaporators and condensers, under the given conditions, LMTD for counterflow will be

(*a*) greater than parallel flow.

(*b*) equal to parallel flow.

(*c*) less than parallel flow.

(*d*) None of the above.

(*xviii*) Extended surfaces are used to enhance the rate of heat transfer. When the convective heat transfer coefficient $h = mK$, an addition of extended surface will

(*a*) increase the rate of heat transfer.

(*b*) decrease the rate of heat transfer.

(*c*) not increase the rate of heat transfer.

(*d*) None of the above.

(*xix*) A hollow sphere with uniform temperature and a small hole behaves very nearly as

(*a*) white body

(*b*) opaque body

(*c*) black body

(*d*) gray body

(*xx*) For infinite parallel planes with emissivities ε_1 and ε_2, the interchange view factor for radiation from surface 1 to surface 2 is given by

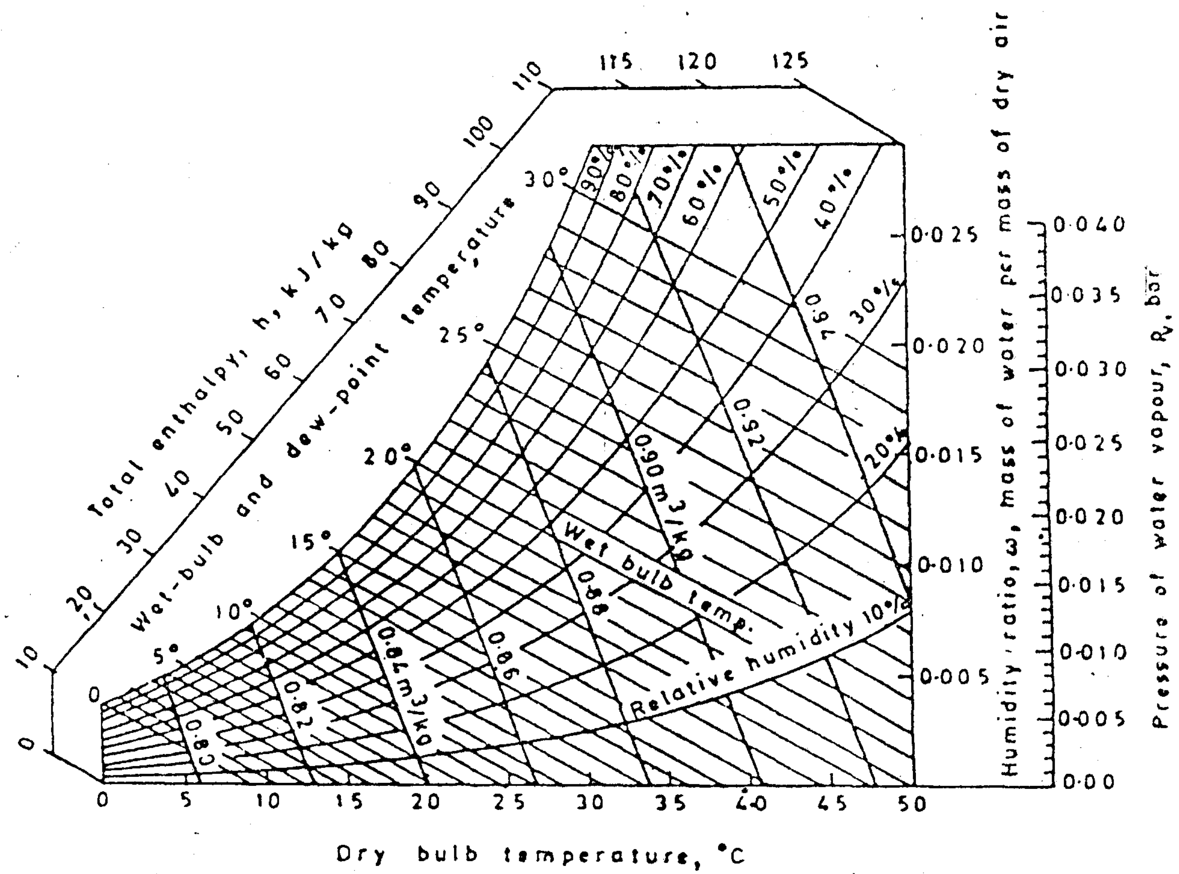
(*a*) $1/(\varepsilon_1 + \varepsilon_2)$

(*b*) $\varepsilon_1\varepsilon_2/(\varepsilon_1 + \varepsilon_2 - \varepsilon_1\varepsilon_2)$

(*c*) $\varepsilon_1 - \varepsilon_2$

(*d*) $\varepsilon_1 + \varepsilon_2$.

S'08 : 6 AN : MC 405 (1498)



Psychometric chart
(Barometric pressure 760 mm Hg)

W'08 : 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 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. 6

(*b*) A cylinder contains 1 kg of a certain fluid at an initial pressure of 20 bar. The fluid is allowed to expand reversibly behind a piston according to pv^2 = constant until the volume is doubled. The fluid is then cooled reversibly at a constant pressure until the piston regain the original position. Heat is then supplied reversibly, with the piston firmly locked in position until the pressure rises to the original value of 20 bar. Calculate the network done by the fluid for an initial volume of 0·05 m^3. 10

(c) Explain the following terms: (i) State, (ii) Process, and (iii) Cycle. 4

2\. (a) What do you mean by the 'perpetual motion machine of first kind (PMM-1)? 4

(b) A centrifugal pump delivers 50 kg of water per sec. The inlet and outlet pressures are 1 bar and 4·2 bar, respectively. The suction is 2·2 m below the centre of the pump and delivery is 8·5 m above the centre of the pump. The suction and delivery pipe diameters are 20 cm and 10 cm, respectively. Determine the capacity of electric motor to run the pump. 9

(c) 90 kJ of heat is supplied to a system at constant volume. The system rejects 95 kJ of heat at constant pressure and 18 kJ of work is done on it. The system is brought to original state by adiabatic process. Determine (i) adiabatic work, and (ii) values of internal energy at all end states if initial, U_1, value is 105 kJ. 7

3\. (a) Show the equivalence of Clausius and Kelvin statement of second law. 5

(b) A Carnot heat engine draws heat from a reservoir at temperature T_1 and rejects the heat to another reservoir at temperature T_3. The Carnot forward cycle engine derives a Carnot reversed cycle engine or Carnot refrigerator which absorbs the heat from reservoir at temperature T_2 and reject the heat to a reservoir at temperature T_3, if the higher temperature $T_1 = 600$ °K and lower temperature $T_2 = 300$ °K. Determine the (i) temperature T_3 such that the heat supplied to engine Q_1 is equal to the heat absorbed by refrigerator Q_2, and (ii) efficiency of Carnot engine and COP of Carnot refrigerator. 10

(c) A cyclic heat engine operates between the source temperature of 1000 °C and a sink temperature of 40 °C. Find the least rate of heat rejection per kW net output of the engine? 5

4\. (a) Derive an expression of availability of a steady flow system. 5

(b) State the Clapeyron equation and its practical utility. 5

(c) Derive the following Tds equations: 10

(i) $Tds = c_v\, dT + \beta T \frac{dv}{k}$

(ii) $Tds = c_p\, dT - v\, \beta T\, dp$

(iii) $Tds = \frac{c_v\, k}{\beta} dp + \frac{c_p}{\beta v} dv$

Group B

5\. (a) Derive an expression for the temperature distribution under one-dimensional steady state heat conduction for a composite cylinder. 6

(b) An aluminium pipe carries a steam at 110 °C. The pipe ($k = 185$ W/m °C) has an inner diameter of 100 mm and outer diameter of 120 mm. The pipe is located in a room where the ambient air temperature is 30 °C and convective heat transfer coefficient between the pipe and air is 15 W/m^2 °C. Determine the heat transfer rate per unit length of the pipe. To reduce the heat loss from the pipe, it is covered with a 50 mm thick layer of insulation ($k = 0{\cdot}2$ W/m °C). Determine the heat transfer rate per unit length from the insulated pipe, assuming that the convective resistance of steam is negligible. 8

(*c*) Aluminium fins of a rectangular profile are attached on a plane wall with 5 mm spacing. The fins have thickness, $b = 1$ mm, length, $l = 10$ mm and thermal conductivity $k = 200$ W/m °K. The wall is maintained at a temperature of 200 °C and fins dissipate heat by convection into the ambient air at 40 °C, with heat transfer coefficient, $h = 50$ W/m^2 °K. Determine the heat loss, assuming the tip to be insulated. 6

6. (*a*) Derive the momentum equation for hydrodynamic boundary layer over a flat plate. 6

(*b*) What is meant by transient heat conduction? 2

(*c*) Air at 20 °C and atmospheric pressure flows at a velocity of 4·5 m/s past a flat plate with a sharp leading edge. The entire plate surface is maintained at a temperature of 60 °C. Assuming that the transition occurs at a critical Reynolds number of 5×10^5, find the distance from the leading edge at which the flow in the boundary layer changes from laminar to turbulent. At the location, calculate the following:

(*i*) Thickness of hydrodynamic layer;

(*ii*) Thickness of thermal boundary layer;

(*iii*) Local and average convective heat transfer coefficient;

(*iv*) Heat transfer rate from both side for unit width of the plate;

(*v*) Strain friction coefficient.

Assume cubic velocity profile and approximate method. Take properties at 40 °C as:
$\rho = 1{\cdot}128$ kg/m^3, $\upsilon = 16{\cdot}96 \times 10^{-6}$ m^2/sec, $K = 0{\cdot}02755$ W/m °C, $P_r = 0{\cdot}699$. 12

7. (*a*) Derive an expression for the LMTD for a counter flow heat exchanger. 8

(*b*) Oil ($c_p = 3{\cdot}6$ kJ/kg °C) at 100 °C flows at a rate of 30,000 kg/h and enters into a parallel flow heat exchanger. Cooling water ($c_p = 4{\cdot}2$ kJ/kg °C) enters the heat exchanger at 10 °C at the rate of 50,000 kg/h. The heat transfer area is 10 m^2 and $W = 1000$ W/m^2 °C. Calculate the following: 12

(*i*) Outlet temperature of oil and water; and

(*ii*) Maximum possible outlet temperature of water.

8. (*a*) Prove that the total emissive power of a diffuse surface is equal to π–times the intensity of radiation. 6

(*b*) State and prove Kirchhoff's law of radiation. 6

(*c*) Calculate the following for an industrial furnace in the form of a black body and emitting radiation at 2500 °C.

(*i*) Monochromatic emissive power at 1·2 μm length.

(*ii*) Wavelength at which the emission is maximum.

(*iii*) Maximum emissive power.

(*iv*) Total emissive power.

(*v*) Total emissive power of the furnace, if it is assumed as a ideal surface with emissivity equal to 0·9. 8

Group C

1. Write the *correct* answer for the following: 20 × 1

(*i*) A perfect gas obeys

(*a*) Boyle's law only.

(*b*) Charle's law only.

(*c*) both Boyle and Charle's laws.

(*d*) None of the above.

(*ii*) Displacement work is equal to

(*a*) $\int Pdv$

(*b*) $\int Vdp$

(*c*) $\int Fdx$

(*d*) None of the above.

(*iii*) For the same expansion ratios, work done by the gas in case of a adiabatic process is

(*a*) more than the work done in case of isothermal process.

(*b*) less than the work done in case of isothermal process.

(*c*) same as in case of isothermal process.

(*d*) None of the above.

(*iv*) The efficiency of a Carnot cycle is equal to (as heat engine)

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

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

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

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

(*v*) The relative efficiency of an engine is equal to

(*a*) Air standard efficiency/Thermal efficiency

(*b*) Thermal efficiency/Air standard efficiency

(*c*) Overall efficiency/Air standard efficiency

(*d*) None of the above

(*vi*) For same compression ratio and same heat input, the thermal efficiency of Otto cycle is

(*a*) less than the diesel cycle.

(*b*) more than the diesel cycle.

(*c*) equal to diesel cycle.

(*d*) None of the above.

(*vii*) The compression ratio for diesel engines lies in the range of

(*a*) 5 to 8

(*b*) 15 to 20

(*c*) 3 to 6

(*d*) 30 to 40

(*viii*) Closed cycle gas turbine works on

(*a*) Rankine cycle

(*b*) Carnot cycle

(*c*) Brayton or Joule cycle

(*d*) Otto cycle.

(*ix*) For maximum output per unit mass flow rate through a closed cycle gas turbine plant, the optimum pressure ratio is given by

(*a*) $r_p = \left(\frac{T_3}{T_1}\right)^{\frac{y-1}{y}}$

(*b*) $r_p = \left(\frac{T_3}{T_1}\right)^{\frac{2y}{y-1}}$

(*c*) $r_p = \left(\frac{T_3}{T_1}\right)^{\frac{y}{2y-1}}$

(*d*) $r_p = \left(\frac{T_3}{T_1}\right)^{\frac{y}{2(y-1)}}$

(*x*) A composite wall of two layers of thickness $\Delta X_1, \Delta X_2$ and thermal conductivities K_1, K_2 is having a cross-section area A, normal to the path of heat flow, if the wall surface temperatures are t_1 and t_3. The rate of heat flow Q, is equal to

(*a*) $A(t_1 - t_3)/[(\Delta x_1/k_1) + (\Delta x_2/k_2)]$

(*b*) $\frac{AK_1K_2(t_1 - t_3)}{\Delta X_1 + \Delta X_2}$

(*c*) $\frac{(AK_1 + AK_2)(t_1 - t_3)}{(\Delta X_1 + \Delta X_2)}$

(*d*) $(t_1 - t_3)/[(\Delta x_1/K_1A) - (\Delta x_2/K_2A)]$

(*xi*) If h = coefficient of heat transfer, k = thermal conductivity, l = characteristic linear dimension, then the term hl/k is called

(*a*) Reynold's number

(*b*) Nusselt number

(*c*) Prandtl number

(*d*) Forde number

(*xii*) A body, which absorbs all the radiations falling on it, is called

(*a*) opaque body.

(*b*) white body

(*c*) black body.

(*d*) transparent body.

(*xiii*) For forced convection, Nusselt number is a function of

(*a*) Prandtl number and Grashoff's number.

(*b*) Grashoff's number only.

(*c*) Reynold and Grashoff's numbers.

(*d*) Reynold and Prandtl numbers.

(*xiv*) The ratio of total emissive power of a body to the total emissive power of a black body is called

(*a*) absorptivity.

(*b*) reflectivity.

(c) transmitivity.

(d) emissivity.

(xv) The process of removing moisture from air at constant dry bulb temperature is known as

(a) sensible heating.

(b) sensible cooling.

(c) humidification.

(d) dehumidification.

(xvi) The dew point temperature is equal to

(a) wet bulb temperature.

(b) dry bulb temperature.

(c) difference of dry bulb and wet bulb temperature.

(d) saturation temperature of water vapour at partial pressure in existing mixture.

(xvii) The ratio of thermal boundary layer and hydro-dynamic boundary layer is given by

(a) $\frac{\delta_{Th}}{\delta} = \frac{1}{(P_r)^{2/3}}$

(b) $\frac{\delta_{Th}}{\delta} = \frac{1}{(P_r)^{1/3}}$

(c) $\frac{\delta_{Th}}{\delta} = (P_r)^{4/3}$

(d) None of the above.

(xviii) The heat dissipated from a infinite long fin is given by

(a) $\sqrt{PhKA}\ (t_s - t_a)$

(b) $Phl\ (t_s - t_a)$

(c) $\sqrt{PhKA}\ (t_s - t_a)\ \tanh ml$

(d) $\sqrt{PhKA}\ (t_s - t_a) \left(\frac{\tanh ml + h/mk}{1 + h/mk^{\tanh ml}}\right)$

(xix) During the process of boiling and condensation, only phase change takes place and one fluid remains at a constant temperature throughout the heat exchanger. In terms of NTU, the effectiveness of such a heat exchanger would be

(a) NTU / (1 + NTU)

(b) $1 - e^{-NTU}$

(c) $(1 - e^{-NTU})/2$

(d) cannot be worked out as the heat capacities are not known.

(xx) The normal automobile radiator is a heat exchanger of the type

(a) direct contact.

(b) parallel flow.

(c) counter flow.

(d) cross-flow.

S'09 : 6 AN : MC 405 (1498)

THERMAL SCIENCE AND ENGINEERING

Time : Three hours

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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.

Thermodynamic tables can be permitted.

Group A

1. (*a*) Explain the principle law of corresponding states. 4

(*b*) Determine the pressure of N_2 gas at $T = 175$ K and $v = 0.00375$ m^3/kg on the basis of (*i*) equation of state, (*ii*) van der Waals' equation of state, if $a = 0.175$ m^{3}kPa/kg^2, and $b = 0.00138$ m^3/kg. 6

(*c*) A mass of 2·4 kg of air at 150 kPa and 12 °C is contained in a gas tight frictionless piston cylinder device. The air is now compressed to a final pressure of 600 kPa. During the process, heat is transferred from the air such that temperature inside the cylinder remains constant. Calculate the work input during this process. 6

(*d*) What is the physical significance of two constants that appear in the van der Waals' equation of state and on what basis they are determined? 4

2\. (*a*) What are the characteristics of all heat engines? 3

(*b*) List three different mechanisms that can cause the entropy of a control volume to change. 3

(*c*) A heat engine receives heat from a source at 1200 K at a rate of 500 kJ/s and rejects the waste heat to a medium at 300 K. The power output of the heat engine in 180 kW. Determine the reversible power and irreversible rate for this process. 6

(*d*) Carbon steel balls ($\varrho = 7833$ kg/m^3) and $C_p = 0{\cdot}465$ kJ/kg°C, 8 mm in diameter, are annealed by heating them first to 900 °C in a furnace first and then allowing them to cool slowly to 100 °C in ambient air at 35°C. If 2500 balls are to be annealed per hour, determine the (*i*) rate of heat transfer from the balls to the air, and (*ii*) rate of entropy generation due to heat loss from the balls to the air. 8

3\. (*a*) Derive Maxwell's relations. 8

(*b*) Water has a vapour pressure of 24 mm Hg at 25°C and a heat of vapourisation of 40·7 kJ/mol. What is the vapour pressure of water at 67°C? 4

(*c*) Air enters the heater at 30 °C and leaves at 70 °C, the pressure being constant at 4 bar. The heat source is at 250 °C and surroundings are at 20 °C. Treating air as perfect gas, find the (*i*) gain in availability of air, and (*ii*) effectiveness of heater. 8

4\. (*a*) Discuss various means of improving the efficiency or specific power output of simple gas turbine cycle. 4

(*b*) A refrigerator uses refrigerant 134 a as the working fluid and operates as ideal vapour compression refrigeration cycle between 0·14 MPa and 0·8 MPa. As the mass flow rate of refrigerant is 0·05 kg/s, determine the (*i*) rate of heat removal from the refrigerator space and power input to the compressor, (*ii*) rate of heat rejection to the environment, and (*iii*) COP of refrigerator. 8

(*c*) 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. 4

(*d*) If there are 2 moles of H_2, 4 moles of O_2 and 6 moles of H_2 in a 5 litre vessel at 27°C, determine partial pressure of each gas and total pressure of the mixture. 4

Group B

5\. (*a*) Explain the Fourier's law of heat conduction. 3

(*b*) Explain (*i*) efficiency of fin, and (*ii*) effectiveness of fin. 5

(*c*) A mild steel tank of wall thickness 12 mm contains water at 100 °C. Calculate the (*i*) rate of heat loss per m^2 of tank surface area when the atmospheric temperature is 20 °C. The thermal conductivity of mild steel is 50 W/mK and the heat transfer coefficients for inside and outside the tank are 2850 W/m^{2}K, and 10 W/m^{2}K, respectively, and (*ii*) temperature of outside surface of the tank. 6

(*d*) The temperature of surfaces of a 25 mm thick steel plate ($k = 48$ W/m°C), having a uniform volumetric heat generation of 30×10^6 W/m^3, are 180°C and 120°C. Neglecting the end effects, determine the following: (*i*) Temperature distribution across the plate, (*ii*) value and position of maximum temperature, and (*iii*) flow of heat from each surface of plate. 6

6. (*a*) Discuss the physical significance of following dimensionless numbers: (*i*) Prandtl no., (*ii*) Stanton no., and (*iii*) Grashoff no. 4

(*b*) Derive an energy equation for thermal boundary layer over a flat plate. 6

(*c*) A steel ball, 60 mm in diameter and at 1000 °C, is placed in a still atmosphere of 30°C. Calculate the initial rate of cooling of the ball (in °C/min). 5

(*d*) In a condenser shell, water flows through 100 thin walled circular tubes (dia = 22·5 mm, length 5 m) which have been arranged in parallel. The mass flow rate of water is 65 kg/s and its inlet and outlet temperature are known to be 22°C and 28°C, respectively. Estimate the average convection coefficient associated with water flow. 5

7. (*a*) What do you mean by fouling in heat exchangers? 4

(*b*) Define heat exchanger effectiveness. 4

(*c*) A counter flow heat exchanger is employed to cool 0·55 kg/s (C_p = 2·45 kJ/kg°C) of oil from 110°C to 35°C by use of water. The inlet and outlet temperatures of cooling water are 20°C and 80°C, respectively. The overall heat transfer coefficient is

expected to be 1500 W/m^2 °C. Using NTU method, calculate the following: (*i*) Mass flow of water, (*ii*) effectiveness of heat exchanger, and (*iii*) surface area required. 8

(*d*) Differentiate between dropwise and filmwise condensation. 4

8. (*a*) Explain how a radiation shield works. 3

(*b*) Define the term 'absorptivity', 'reflectivity' and 'transmissivity' of radiation. 5

(*c*) Describe different types of boiling heat transfer. 4

(*d*) A body at 1000 °C in black surroundings at 500 °C has an emissivity of 0·42 at 1000 °C and an emissivity of 0·72 at 500 °C. Calculate the rate of heat loss by radiation per m^2 (*i*) when the body is assumed to be grey with $\varepsilon = 0{\cdot}42$, (*ii*) when the body is not grey. $\sigma = 5{\cdot}67 \times 10^{-8}$ W/m^{2}K^4. Assume absorptivity is independent of surface temperature. 8

Group C

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

(*i*) First law is based on

(*a*) law of conservation of mass.

(*b*) law of conservation of energy.

(*c*) law of conservation of momentum.

(*d*) None of the above.

(*ii*) Which one of the following is an intensive property ?

(*a*) Internal energy

(*b*) Enthalpy

(*c*) Density

(*d*) Volume

(*iii*) The volume of an ideal gas is 100 cm^3 at 100 °C. If the pressure is held constant, at what temperature will the gas have a volume of 200 cm^3 ?

(*a*) 200°C

(*b*) 473°C

(*c*) 746°C

(*d*) 50°C

(*iv*) A vessel has two compartments, *A* and *B*, containing H_2 and O_2, respectively both at 1 atmospheric pressure. If the wall separating two components is removed,

(*a*) pressure will remain unchanged.

(*b*) pressure will increase in *A*.

(*c*) pressure will increase in *B*.

(*d*) pressure will increase in *A* and *B*.

(*v*) A gas can be liquefied by pressure alone when its temperature is

(*a*) higher than its critical temperature.

(*b*) equal to or higher than its critical temperature.

(*c*) less than or equal to its critical temperature.

(*d*) less than critical temperature.

(*vi*) In an reversible adiabatic compression,

(*a*) pressure remains constant.

(*b*) temperature remains constant.

(*c*) heating takes place.

(*d*) cooling takes place.

(*vii*) The work done in steady flow process is given by

(*a*) $-\int dv$

(*b*) $-\int pdv$

(*c*) $-\int vdp$

(*d*) None of the above.

(*viii*) Throttling process is

(*a*) a reversible and constant entropy process.

(*b*) an reversible and constant enthalpy process.

(*c*) an irreversible and constant enthalpy process.

(*d*) reversible and isothermal process.

(*ix*) The efficiency (η) of an ideal gas turbine is given by

(*a*) $\eta = 1 - (1/r)^Y$

(*b*) $\eta = 1 - (1/r)^{Y-1}$

(*c*) $\eta = (1 - 1/r)^{Y-1/Y}$

(*d*) $\eta = 1 - (1/r)^{1/Y}$

where r = Pr ratio and Y = specific heat ratio.

(*x*) Which one of the following refrigeration cycles has minimum COP ?

(*a*) Carnot cycle.

(*b*) Vapour-compression cycle with a reversible expansion engine.

(*c*) Ordinary vapour compression cycle

(*d*) Air cycle.

(*xi*) Thermal diffusivity of a material is defined as

(*a*) $k/C_p \varrho$

(*b*) $\varrho C_p/k$

(*c*) kC_p/ϱ

(*d*) $k\varrho/C_p$

(*xii*) Biot number is defined as

(*a*) $\alpha t/L^2$

(*b*) $\alpha t^2/L^2$

(*c*) hk/L

(*d*) hL/k

(*xiii*) Heat transfer by convection is described by

(*a*) Fick's law

(*b*) Fourier's law

(*c*) Newton's law of cooling

(*d*) Stefan-Boltzman law

(*xiv*) The Colburn factor for heat transfer is defined as

(*a*) $N_{st} N_{pr}$

(*b*) $N_{st} N_{pr}^{1/3}$

(*c*) $N_{st} N_{pr}^{2/3}$

(*d*) $N_{st} N_{pr}^{3/2}$

(*xv*) The heat flux in the free convection regime of pool boiling varies as

(*a*) ΔT^3

(*b*) $\Delta T^{5/4}$

(*c*) ΔT^2

(*d*) $\Delta T^{1/4}$

(*xvi*) The purpose of floating head in heat exchangers to

(*a*) regulate the flow.

(*b*) increase the pressure drop.

(*c*) decrease the pressure drop.

(*d*) avoid deformation of tubes due to thermal expansion.

(*xvii*) Planck's law of radiation is applicable to —— radiation.

(*a*) monochromatic

(*b*) thermal

(*c*) temperature

(*d*) None of the above

(*xviii*) An increase in convective coefficient over a fin —— effectiveness.

(*a*) decreases

(*b*) increases

(*c*) does not influence

(*d*) None of the above.

(*xix*) For solar collectors, what combination of surface characteristics are required?

(*a*) High absorbtivity and high reflectivity

(*b*) High reflectivity and high emissivity

(*c*) High emissivity and low absorbtivity

(*d*) High absorbtivity and low emissivity

(*xx*) The value of convection coefficient in condensation over a vertical surface varies as

(*a*) $k^{0.5}$

(*b*) $k^{0.35}$

(*c*) $k^{0.75}$

(*d*) $k^{0.9}$

where k is thermal conductivity of liquid.

W'09 : 6 AN : MC 405 (1498)

THERMAL SCIENCE AND ENGINEERING

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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: ϱ = 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, $f = 64/\text{Re}_d$. 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 ϱ = 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 360 K to 310 K with a counterflow of 0.02 kg/s of water at 290 K. If the inner tube outside diameter is 20 m 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

S'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 first law of thermodynamics for a change of state and prove that energy is a property. 6

(*b*) The pressure volume relation for a non-flow reversible process is $P = (8 - 4\ V)$ bar, where V is in m^3. If 130 kJ of work is supplied to the system, calculate the final pressure and volume of the system. Take the initial volume as $0.5\ m^3$. 4

(*c*) In a nozzle, the ideal gas expands from a pressure of 20 bar to 3 bar and the process is reversible adiabatic. The inlet conditions are 500 °C and 35 m/s. Determine the area and velocity at the outlet section of the nozzle, if the flow rate is 5 kg/s. Take R = 190 kJ/kgK and r = 1.35. 6

(*d*) State the statements of second law of thermodynamics as pertaining to a heat engine and a refrigerator. 4

2. (*a*) List out the limitations of first law of thermodynamics. 4

(*b*) A combination of three Carnot engines, *A*, *B* and *C*, working in a series, operate between temperatures 1000 K and 300 K. Calculate the intermediate temperature, if the amount of work produced by the engines is in the proportion of 5 : 4 : 3. 8

(*c*) Prove that the efficiency of Carnot engine is higher compared to that of an irreversible heat engine, both working between same temperature limits. 6

(*d*) Distinguish between thermodynamic work and heat transfer. 2

3. (*a*) Derive Clapeyron equation. 6

(*b*) Sketch and explain the essential components of a Rankine vapour power cycle. 4

(*c*) Obtain an expression for thermal efficiency of an air standard Otto cycle. 6

(*d*) For a non-flow polytropic process, prove that the heat transfer, $Q = \left(\frac{n - r}{n - 1}\right) C_v (T_2 - T_1)$, where n = polytropic index, r = ratio of specific heats. 4

4. (*a*) Explain the working of an actual gas turbine with P-V and T-s diagrams. 4

(*b*) Derive Maxwell's relations. 4

(*c*) A four-cylinder engine has the following data : Bore = 15 cm, stroke = 15 cm, piston speed = 510 m/min. brake power = 60 kW, mechanical efficiency = 80%, mean effective pressure = 5 bar. Determine whether this is a two-stroke engine or four-stroke engine. 4

(*d*) Define the following terms : 8 × 1

(*i*) Dew point temperature

(*ii*) Energy

(*iii*) Property of the system

(*iv*) Air-fuel ratio

(*v*) Steady flow

(*vi*) Saturation ratio

(*vii*) Specific humidity

(*viii*) Mean effective pressure.

Group B

5. (*a*) Explain the modes of heat transfer. 3

(*b*) Obtain the general heat conduction equation in cartesian co-ordinates. 8

(*c*) Discuss the effects of various parameters on thermal conductivity. 4

(*d*) A thermal wall, 320 mm thick, is made up of an inner layer of firebrick (k = 0.84 W/m°C) covered with a layer of insulation (k = 0.16 W/m°C). The reactor operates at a temperature of 1325 °C and the ambient temperature is 25 °C. Determine the thickness of firebrick and insulation which gives minimum heat loss. Take maximum temperature of insulation as 1200 °C. 5

(*a*) Obtain the momentum equation for a hydrodynamic boundary layer over a flat plate. 8

(*b*) Explain the phenomenon of film condensation. 4

(*c*) A steel pipe ($k = 72$ W/m°C) of outer diameter 34 mm and 2 mm radial thickness carries dry saturated steam at 120°C. The pipe has been provided with asbestos insulation ($k = 0.3$ W/m°C) to check and minimize the rate of steam condensation. The pipe is located in surroundings at 25°C. Taking unit length of pipe, calculate (*i*) thickness of asbestos insulation for which the rate of steam condensation is same as that when the pipe is uninsulated, and (*ii*) mass flow rate of condensation when the above insulation is provided. Take surface conductances on air side and steam side as 13 W/m^2°C and 500 W/m^2°C, respectively. h_{fg} at 120°C = 2300 kJ/kg. 8

(*a*) Find out the amount of heat transferred through an iron fin of length 50 mm, width 100 mm and thickness 5 mm. Assume k = 210 kJ/mh°C and h = 42 kJ/m^{2}h°C for the material of the fin and the temperature at the base of the fin as 80°C. Also, determine the temperature at the tip of the fin, if the atmosphere temperature is 20°C. 6

(*b*) Define (*i*) efficiency of fin, and (*ii*) effectiveness of fin. 1+1

(*c*) Explain the design considerations for a fin. 4

(*d*) A horizontal tubular single shell, single pass condenser is used to condense saturated steam at 80°C. The condenser is a shell and tubes are of brass (k = 110 W/m°C) of 15.9 mm outer diameter, 13.4 mm inner diameter. Steam is outside the tubes and cooling water enters the tubes at 20°C with a velocity of 1.4 m/s and leaves at 40°C. If the rate of cooling water supply is 55000 kg/hr and the latent heat of condensation of steam at 80°C is 2304 kJ/kg, calculate (*i*) number of tubes, and (*ii*) length of each tube. For calculating the tube side heat transfer coefficient, use Dittus-Boetter equation and for the shell side heat transfer coefficient, the average value may be taken as 10760 W/m^{2}K. Data: Properties of water at 30°C are:

k = 0.659 W/mK, C_p = 4.180 kJ/kg-K

ρ = 979.8 kg/m^3, $\mu = 0.4044 \times 10^{-3}$ Pa.s 8

8. (*a*) Obtain an expression for LMTD for a parallel flow heat exchanger. 6

(*b*) A counterflow heat exchanger is used to cool 2000 kg/hr of oil (C_p = 2.5 kJ/kgK) from 105°C to 30°C by the use of water entering at 15°C. If the overall heat transfer coefficient is expected to be 1.5 W/m^{2}K, make calculations for the water flow rate, the surface area required, and the effectiveness of heat exchanger. Presume that the exit temperature of the water is not to exceed 80°C. Use NTU effectiveness approach. 6

(*c*) State Stephen-Boltzmann law and Kirchhoff law for radiation heat transfer with proper units of measurements. 3

(*d*) Determine the rate of heat loss by radiation from a steel tube of outside diameter 70 mm and 3 m long at a temperature of 227°C, if the tube is located within a square brick conduit of 0.3 m side and 27°C. Take $\varepsilon_{steel} = 0.79$, $\varepsilon_{brick} = 0.93$. 5

Group C

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

(*i*) For a given set of operating pressure limits of Rankine cycle, the highest efficiency occurs for

(*a*) saturated cycle.

(*b*) superheated cycle.

(*c*) reheat cycle.

(*d*) regenerative cycle.

(*ii*) For spheres, the critical thickness of insulation is given by

(*a*) $h/2k$

(*b*) $2k/h$

(*c*) k/h

(*d*) $k/2\pi h$

where k = thermal conductivity, and h = convective heat transfer coefficient.

(*iii*) A cycle, consisting of two reversible adiabatics and two isochoric processes, is known as

(*a*) Brayton cycle.

(*b*) Otto cycle.

(*c*) Dual cycle.

(*d*) Sterling cycle.

(*iv*) The most widely used heat insulating material for pipeline carrying steam is

(*a*) saw dust.

(*b*) cotton.

(*c*) 85% magnesia content and glass wool.

(*d*) asbestos.

(*v*) With increase in the temperature of intake air, IC engine efficiency

(*a*) decreases.

(*b*) increases.

(*c*) remains same.

(*d*) depends on other factors.

(*vi*) The total emissivity power is defined as the total amount of radiation emitted by a black body

(*a*) per unit time.

(*b*) per unit temperature.

(*c*) per unit thickness.

(*d*) per unit area.

(*vii*) A steel ball of mass 1 kg and specific heat 0.4 kJ/kg K is at a temperature of 60°C. It is dropped into 1 kg of water at 20°C. The final steady state temperature of water is

(*a*) 23·5°C

(*b*) 30°C

(*c*) 35°C

(*d*) 40°C

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

THERMAL SCIENCE AND ENGINEERING

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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 300K 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

(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: $\rho = 1.1374$ 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*) $x v_f$

(*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.

(*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.

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

(*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.

W'10:6AN:MC 405 (1498) (11) AG—1,9(

S'11 : 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*) (*i*) What does the state postulate say and what is the necessity of this postulate? 2

(*ii*) State the zeroth law of thermodynamics and prove that this law is the basis for all temperature measurements. 2

(*b*) It is proposed to compress air (ideal gas) reversibly from an initial state of 100 kPa and 27 °C to a final state of 500 kPa and 27 °C. Compare the work required for the following processes: (*i*) Heating at constant volume followed by cooling at constant pressure, (*ii*) isothermal compression, (*iii*) adiabatic compression followed by cooling at constant volume. For air, C_v = 20.93 J/mol K and C_p = 29.302 J/mol K. 8

(*c*) A pressure vessel is connected to a gas maintained at 1.4 MPa and 85°C through a valve. The valve is opened and 2.7 kg of gas is allowed into the vessel which was at vacuum initially. When the valve is closed, the gas in the vessel stabilizes at 700 kPa and 60°C. Determine the heat transfer associated with the filling process. Also, determine the volume of the pressure vessel and the initial volume of the gas allowed into the vessel. Assume C_p = 0.88 kJ/(kg-K), C_v = 0.67 kJ/(kg-K) and neglect the velocity of gas in the main. 8

2. (*a*) (*i*) Show that the transfer of heat through a finite temperature difference is irreversible.

(*ii*) A room is maintained at 27°C while the surroundings are at 2°C. The temperature of inner and outer surfaces of the wall (k = 0.71 W/mK) are measured to be 21°C and 6°C, respectively. Heat flows steadily through the wall 5 m × 7 m in cross-section and 0.32 m in thickness. Determine the (*i*) rate of heat transfer through the wall, (*ii*) rate of entropy generation in the wall, and (*iii*) rate of total entropy generation with this heat transfer process. 8

(*b*) Establish the equivalence of Kelvin-Planck and Clausius statements of the second law of thermodynamics. 6

(*c*) The lowest temperature which has been achieved till date is 0.0014 K. Suppose a sample is to be maintained at that temperature. The energy losses

as heat from the sample are estimated at 50 J/s and the ambient temperature is 35°C. Suppose a reversible heat engine which uses a source at 400°C and the ambient atmosphere as the sink to drive a reversible heat pump in order to maintain the sample at the required temperature. Determine the power required to operate the heat pump and the ratio of energy absorbed by the heat engine from the source to the energy absorbed by the heat pump from the sample. 6

3. (*a*) What are the availability functions for a closed system and for a steady flow system ? 2 kg of air at 500 kPa, 80°C expands adiabatically in a closed system until its volume is doubled and its temperature becomes equal to that of the surroundings which is at 100 kPa, 5°C. For this process, determine the (*i*) maximum work, (*ii*) change in availability, and (*iii*) irreversibility. For air, take, C_v = 0.718 kJ/kgK, $u = C_vT$, where C_v is constant, and $pV = mRT$, where p is pressure (in kPa) ; V = volume (in m^3) ; m = mass (in kg) ; R = a constant equal to 0.287 kJ/kg-K and T = temperature (in K). 8

(*b*) Explain the working of an actual gas turbine with the help of p–V and T–s diagrams. 4

(*c*) Explain Joule-Thomson coefficient. What is inversion temperature ? 4

(*d*) Explain the vapour compression cycle of refrigeration with the help of T–s and p–h diagrams. 4

4. (*a*) A rigid and insulated tank of volume $10 m^3$ is divided into two equal compartments by a partition. One compartment is filled with nitrogen at 10 bar and 500K while the other compartment is filled with helium at 2 bar and 300K. The partition is removed and the gases are allowed to mix. Calculate the (*i*) final temperature and pressure of the mixture; (*ii*) molar composition of the mixture; and (*iii*) entropy change associated with the mixing process. Molar heat capacities of gases are:

C_v (for N_2) = 20.8641 kJ/molK

C_v (for He) = 12.4717 kJ/molK

$C_{p_{N_2}}$ = 29.1783 kJ/molK

$C_{p_{He}}$ = 20.7860 kJ/molK 8

(*b*) The efficiency of a Carnot engine can be increased either by decreasing the sink temperature while keeping the source temperature constant or by increasing the source temperature while keeping the sink temperature constant. Which one of the above two possibilities is more effective? 6

(*c*) Why is Carnot cycle not practicable for a steam power plant? Name the real being adopted. Draw the schematic diagram, p–V and T–s diagrams of this cycle. 4

(*d*) What is adiabatic saturation? 2

Group B

5. (*a*) Show that the temperature variation for heat conduction through a cylindrical wall having uniform *K* is logarithmic.

A hollow cylinder, with inner radius 30mm and outer radius 50mm, is heated at the inner surface at the rate of $10^5 W/m^2$ and dissipates heat by convection from the outer surface into a fluid at temperature 100°C with a heat transfer coefficient of 400 W/m^2K. There is no energy generation and the thermal conductivity of the solid is assumed to be constant at 15 W/mK. Calculate the temperatures of inside and outside surfaces of the cylinder. 8

(*b*) What is meant by transient heat conduction? What is lumped capacity? An aluminium sphere, weighing 5.5 kg and initially at a temperature of 290°C, is suddenly immersed in a fluid at 15°C. The convective heat transfer coefficient is 58 W/m^2K. Estimate the time required to cool the aluminium sphere to 95°C, using the lumped capacity method of analysis. Take the properties of aluminium as follows: 8

ϱ (density) = 2700 kg/m^3
C (specific heat) = 900 J/kgK
K (conductivity) = 205 W/mk.

(*c*) What do you mean by critical radius of insulation? Show that it is given by k_i/h_a, where k_i is the thermal conductivity of insulation and h_a, the heat transfer coefficient. 4

6. (*a*) Atmospheric air at $T_\infty = 275$ K and a free stream velocity $u_\infty = 20$ m/s flows over a flat plate $L = 1.5$ m long and is maintained at a uniform temperature $T_w = 325$ K.

(*i*) Calculate the average heat transfer coefficient, h_m, over the region, where the boundary layer is laminar. 4

(*ii*) Find the average heat transfer coefficient over the entier length $L = 1.5$ m of the plate. 4

(*iii*) Calculate the total heat transfer rate Q from the plate to the air over the length $L = 1.5$ m and width $w = 1$ m. Assume transition occurs at $Re_X = 2 \times 10^5$. 4

The physical properties of atmospheric air are taken as follows at $(T_w + T_\infty)/2 = 300\ K$

$K = 0.026$ W/mK

Pr = 0.708

$\nu = 16.8 \times 10^{-6}$ m^2/s

$\mu_\infty = 1.98 \times 10^{-5}$ kg/(m-s).

Also, take the average heat transfer coefficient for the laminar layer (neglecting the viscosity correction) from the relation

$$h_m = 0.664\,(k/x_e)\,Pr^{1/3}\,Re_X^{1/2}$$

The average heat transfer coefficient (neglecting viscosity correction) over $L = 1.5$ m is to be taken from the relation

$$h_m = 0.036\,(k/L)\,Pr^{0.43}\,[(Re_L)^{0.8} - 9200].$$

(*b*) Explain the Colburn analogy in detail. 4

(*c*) Sketch temperature and velocity profiles in free-convection on a vertical wall. Why an analytical solution of a free convection heat transfer problem more difficult than that of a forced convection problem ? 4

7. (*a*) Consider a cross-flow heat exchanger with hot and cold fluids entering at uniform temperature. Illustrate, with sketches, the exit temperature distribution for the following cases : 4

(*i*) Both fluids are unmixed

(*ii*) Cold fluid is unmixed and hot fluid is mixed.

(*b*) A heat exchanger is to be designed to cool $m_h = 8.7$ kg/s in an ethyl alcohol solution [$C_{ph} = 3840$ J/kg-K] from $T_1 = 75$°C to $T_2 = 45$°C with cooling water [$C_{p_c} = 4180$ J/kg-K] entering the tube side at $t_1 = 10$°C at a rate of $m_c = 9.6$ kg/s. The overall heat transfer coefficient based on the outer tube surface is $U_0 = 500$ W/m^{2}K. Calculate the heat transfer area for (*i*) parallel flow, shell and tube, and (*ii*) counter flow, shell and tube. 6

(*c*) If the local heat transfer coefficient for the thermal boundary layer over a flat plate has a power-law dependent on $x\,b_x = Cx^n$, where C is a constant, then show that the quantity averaged from $x = 0$ to x (in this case $h_{x,ave}$) is simply $h_{x_{ave}} = h_x/(1+n)$. Apply this to show that, for the laminar thermal boundary layer over a flat plate, the average heat transfer coefficient over a distance x is twice its local value. 5

(*d*) Discuss various regimes in boiling heat transfer. 5

8. (*a*) What is shape factor ? Show that 6

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

(*b*) Explain the electrical analogy for radiative heat transfer in a black enclosure. Draw the equivalent electrical network for radiative flux between four walls of a black enclosure. 6

(*c*) Define/explain *any four* of the following: 4×2

(*i*) Gray body

(*ii*) Kirchhoff's law

(*iii*) Monocromatic emissive power of a body.

(*iv*) Transmissivity of a surface

(*v*) Wien's displacement law

(*vi*) Solid angle.

Group C

9. Explain/answer the following in brief: 10×2

(*i*) How can a heat pump upgrade low grade waste heat ?

(*ii*) All spontaneous processes are irreversible. Explain.

(*iii*) What is the absolute thermodynamic temperature scale ? Why is it called absolute ?

(*iv*) What is the difference between heat and internal energy ?

(*v*) The amount of entropy generation quantifies the intrinsic irreversibility of a process. Explain.

(*vi*) In a gas-to-liquid heat exchanger, why are fins provided on the gas side ?

(*vii*) Explain why the condenser tubes are usually horizontal.

(*viii*) What is a black body and opaque body ?

(*ix*) What is the range of wavelength for visible radiation, i.e., light ?

(*x*) What do you mean by a non-conducting and re-radiating wall ?

W'11:6 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*) Define the thermodynamic system. Differentiate between open system, closed system and isolated system. 8

(*b*) 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. 3 × 4

2. (*a*) Derive an expression for the efficiency of a reversible heat engine. 8

(*b*) The law of the expansion curve of a gas engine indicator is found to be $pv^{1.3}$ = constant and the ratio of specific heat of the mixture is 1.40. If the expansion ratio is 5.2 and the pressure and temperature before expansion are 8.5 bar, 330 °C, respectively and pressure after expansion is 1 bar, what is the rate of heat transfer per kg of gas ? 12

3. (*a*) Derive the general energy equation for steady flow system and simplify it for the compressor. 10

(*b*) In an air compressor, air flows steadily at the rate of 15 kg/min. The air enters the compressor at 5 m/s with a pressure of 1 bar and a specific volume of 0.5 m^3/kg. It leaves the compressor at 7.5 m/s with a pressure of 7 bar and a specific volume of 0.15 m^3/kg. The internal energy of the air leaving the compressor is 165 kJ/kg greater than that of the air entering. The cooling water in the compressor jackets absorbs heat from the air at the rate of 500 kJ/s. Find (*i*) power required to drive the compressor ; and (*ii*) ratio of the inlet pipe diameter to outlet pipe diameter. 10

4. (*a*) Derive an expression for the efficiency of diesel cycle. 10

(*b*) Two engines are to operate on Otto and diesel cycles with the following data : Maximum temperature = 1500 K ; exhaust temperature = 700 K ; ambient conditions = 1 bar and 300 K. Compare the compression ratios, maximum pressures, and efficiencies of two engines. 10

Group B

5. (*a*) Prove that, for a cyclindrical body as shown in Fig. 1, the heat transfer by conduction is given by 10

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

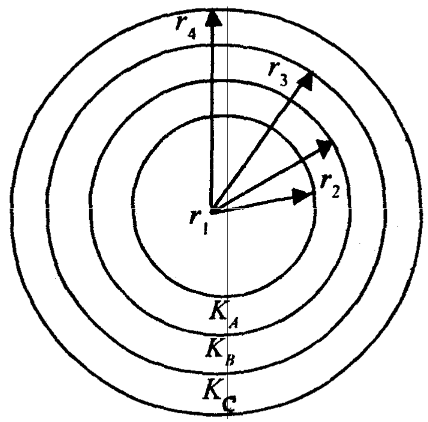

Fig. 1

(*b*) 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. The thermal conductivity of one material is 5 times that of the other. Assuming that the inner and outer surface temperature of insulation is fixed, how much will heat transfer be increased when better insulation material is next to the pipe that it is outer layer ? 10

6. (*a*) Derive the momentum equation for laminar boundary layer over a flate plate. What are the assumptions involved in the derivation of this equation ? 10

(*b*) A plate of length 750 mm and width 250 mm has been placed longitudinally in a stream of crude oil which flows with a velocity of 5 m/s. If the oil has a specific gravity of 0.8 and kinematic viscosity of 1 stoke, calculate the following : 3 + 3 + 4

(*i*) Boundary layer thickness at the middle of plate.

(*ii*) Shear stress at the middle of plate.

(*iii*) Friction drag on one side of the plate.

7. (*a*) Derive an expression for the effectiveness of a parallel flow heat exchanger in terms of NTU. 8

(*b*) Oil (C_p = 3.6 kJ/kg °C) at 100 °C flows at the rate of 30,000 kg/h 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/h. The heat transfer area is 10 m^2 and U = 1000 W/m^2 °C). Calculate the following: 6 + 6

(*i*) Outlet temperature of oil and water.

(*ii*) Maximum possible outlet temperature of water.

8. (*a*) Define the flowing terms : 3 + 3 + 4

(*i*) Total intensity of radiation

(*ii*) Shape factor

(*iii*) Stefan-Boltzmann law

(*b*) Calculate the following for an industrial furnace in the form of a black body and emitting radiation at 2500 °C. 5 × 2

(*i*) Monochromatic emissive power at 1.2 μm length.

(*ii*) Wavelength at which the emission is maximum.

(*iii*) Maximum emissive power.

(*iv*) Total emissive power.

(*v*) Total emissive power of the furnace, if it is assumed as a real surface with emissivity equal to 9.0.

Group C

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

(*i*) The value of one bar (in SI unit) is equal to

(*a*) 1 × 10^2 N/m^2
(*b*) 1 × 10^3 N/m^2
(*c*) 1 × 10^4 N/m^2
(*d*) 1 × 10^5 N/m^2

(*ii*) Which one of the following statemet is *correct* ?

(*a*) The heat and work are boundary phenomena.
(*b*) The heat and work represent the energy crossing the boundary of the system.
(*c*) The heat and work are path functions.
(*d*) All of the above.

(*iii*) Kelvin-Planck's statement deals with

(*a*) conservation of work.

(*b*) conservation of heat.

(*c*) conversion of heat into work.

(*d*) conversion of work into heat.

(*iv*) When the gas is heated at constant volume, the heat supplied

(*a*) increases the internal energy of the gas.

(*b*) increases the temperature of the gas.

(*c*) does some external work during expansion.

(*d*) Both (*a*) and (*b*) above.

(*v*) The heat absorbed/rejected by the working substance is given by

(*a*) $\delta Q = T.ds$

(*b*) $\delta Q = T/ds$

(*c*) $\delta Q = ds/T$

(*d*) None of the above.

where ds = increase/decrease of entropy ; T = absolute temperature ; and δQ = heat absorbed/rejected.

(*vi*) For the same maximum pressure and temperature,

(*a*) Otto cycle is more efficient than diesel cycle.

(*b*) diesel cycle is more efficient than Otto cycle.

(*c*) dual cycle is more efficient than Otto and diesel cycles.

(*d*) dual cycle is less efficient than Otto and diesel cycles.

(*vii*) Which one of the following is the *correct* statement ?

(*a*) For a given compression ratio, both Otto and diesel cycles have the same efficiency.

(*b*) For a given compression ratio, Otto cycle is more efficient than diesel cycle.

(*c*) For a given compression ratio, diesel cycle is more efficient than Otto cycle.

(*d*) The efficiency of Otto or diesel cycle has nothing to do with compression ratio.

(*viii*) Which one of the following is the *correct* statement ?

(*a*) All the reversible engines have the same efficiency.

(*b*) All the reversible and irreversible engines have the same efficiency.

(*c*) Irreversible engines have maximum efficiency.

(*d*) None of the above.

(*ix*) The thermal efficiency of an ideal gas turbine plant is given by

(*a*) r^{y-1}

(*b*) $1 - r^{y-1}$

(*c*) $1 - (1/r)^{y/y-1}$

(*d*) $1 - (1/r)^{(y-1)/y}$

where r = pressure ratio.

(*x*) The condition for an irreversible cyclic process is

(*a*) $\oint \frac{\delta Q}{T} = 0$

(*b*) $\oint \frac{\delta Q}{T} < 0$

(*c*) $\oint \frac{\delta Q}{T} > 0$

(*d*) None of the above.

(*xi*) The average value of thermal conductivity for water at 20 °C saturate is about 0.51.

(*a*) True

(*b*) False

(*xii*) A composite slab has two layers of different materials with thermal conductivities k_1 and k_2. If each layer has the same thickness, then the equivalent thermal conductivity of the slab will be

(*a*) $k_1\ k_2$

(*b*) $k_1 + k_2$

(*c*) $k_1 + k_2 / k_1\ k_2$

(*d*) $2\ k_1\ k_2 / k_1 + k_2$

(*xiii*) The logarithmic mean temperature difference (t_m) is given by

(*a*) $t_m = \Delta t_1 - \Delta t_2 / \ln\ (\Delta t_1 / \Delta t_2)$

(*b*) $t_m = \ln\ (\Delta t_1 / \Delta t_2) = (\Delta t_1 - \Delta t_2)$

(*c*) $t_m = (\Delta t_1 - \Delta t_2) / \ln\ (\Delta t_1 / \Delta t_2)$

(*d*) $t_m = \ln\ (\Delta t_1 / \Delta t_2) / (\Delta t_1 / \Delta t_2)$

(*xiv*) In counter-current flow heat exchangers,

(*a*) both the fluids at inlet are in their hottest state.

(*b*) both the fluids at inlet are in their coldest state.

(*c*) both the fluids at exit are in their hottest rate.

(*d*) one fluid is coldest and the other is hottest at inlet.

(*xv*) When t_{C_1} and t_{C_2} are the temperatures of cold fluid at entry and exit, respectively and t_{h_1} and t_{h_2} are the temperatures of hot fluid at entry and exit point, and cold fluid has lower heat capacity rate as compared to hot fluid, then effectiveness of the heat exchanger is given by

(*a*) $(t_{C_1} - t_{C_2}) / (t_{h_1} - t_{C_1})$

(*b*) $(t_{h_2} - t_{h_1}) / (t_{C_2} - t_{h_1})$

(*c*) $(t_{h_1} - t_{h_2}) / (t_{h_1} - t_{C_1})$

(*d*) $(t_{C_2} - t_{C_1}) / (t_{h_1} - t_{C_1})$

(*xvi*) In free convection heat transfer, transition from laminar to turbulent flow is governed by the critical value of the

(*a*) Reynold's number.

(*b*) Grashoff's number.

(*c*) Reynold's number, Grashoff's number.

(*d*) Prandtl number, Grashoff's number, (*xvii*) A heat exchanger, with heat transfer surface area A and overall heat transfer coefficient U, handles two fluids of heat capacities C_{max} and C_{min}. The number of transfer units (NTU) used in the analysis of heat exchanger is specified as

(*a*) $A \times C_{min} / U$
(*b*) $U / A \times C_{min}$
(*c*) $A \times UC_{min}$
(*d*) $A \times U/C_{min}$

(*xviii*) The emissivity for a black body is

(*a*) 0
(*b*) 0.5
(*c*) 0.75
(*d*) 1

(*xix*) Which one of the following statement is *correct*?

(*a*) A grey body is one which absorbs all radiations incident on it.
(*b*) At thermal equilibrium, the emissivity and absorptivity are same.
(*c*) The energy absorbed by a body to the total energy falling on it is called emissivity.
(*d*) A perfect body is one which is black in colour.

(*xx*) When α is absorptivity ; ρ, the reflectivity ; and τ, the transmittivity, then for a diathermanous body,

(*a*) $\alpha = 1$, $\rho = 0$ and $\tau = 0$.
(*b*) $\alpha = 0$, $\rho = 1$ and $\tau = 0$.
(*c*) $\alpha = 0$, $\rho = 0$ and $\tau = 1$.
(*d*) $\alpha + \rho = 1$ and $\tau = 0$.

S'12:6 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.

Use of steam tables and Mollier chart are permissible.

Group A

1. (*a*) Under what conditions is the work done equal to $\int pdv$? 3

(*b*) Show that energy is a property of a system. What are the modes in which energy is stored in a system ? 7

(*c*) In a gas turbine, the gas enters at the rate of 5 kg/s with a velocity of 50 m/s and enthalpy of 900 kJ/kg and leaves the turbine with a velocity of 150 m/s and enthalpy of 400 kJ/kg. The loss of heat from the gases to the surroundings is 25 kJ/kg. Assume for gas, $R = 0.285$ kJ/kgK and $C_p = 1.004$ kJ/kg-K,

(*Turn Over*)

and the inlet conditions to be at 100 kPa and 27 °C. Determine the power output of the turbine and the diameter of the inlet pipe. 10

2. (*a*) To produce network in a thermodynamic cycle, a heat engine has to exchange heat with two thermal reservoirs. Explain. 3

(*b*) How is a reversible process only a limiting process, never to be attained in practice ? What do you understand by internal and external irreversibilities ? 5

(*c*) A heat pump is to be used to heat a house in winter and then reversed to cool the house in summer. The interior temperature is to be maintained at 20 °C. Heat transfer through the walls and roof is estimated to be 0.525 kW per degree temperature difference between the inside and outside. (*i*) If the outside temperature in winter is 5 °C, what is the minimum power required to drive the heat pump ? (*ii*) If the power output is the same as in part (*i*), what is the maximum outer temperature for which the inside can be maintained at 20 °C ? 12

3. (*a*) Determine the maximum work obtainable by using one finite body at temperature T and a thermal energy reservoir at temperature T_0, $T > T_0$. 5

(*b*) Explain how an electrical calorimeter is used to determine the quality of wet steam. 5

(*c*) Steam expands isentropically in a nozzle from 1 MPa, 250 °C to 10 kPa. The steam flow rate is 1 kg/s. Find the velocity of steam at the exit from the nozzle. Neglect the inlet velocity of steam.

The exhaust steam from the nozzle flows into a condenser and flows out as saturated water. The cooling water enters the condenser at 25 °C and leaves at 35 °C. Determine the mass flow rate of cooling water. 10

4. (*a*) Give the basic components of a steam power plant. Why is Carnot cycle not suitable for such a plant ? 4

(*b*) A cyclic steam power plant is to be designed for a steam temperature of 400 °C at turbine inlet and the exhaust pressure of 0.1 bar. After isentropic expansion of steam in the turbine, the moisture content at the turbine exhaust is not to exceed 15%. Determine the greatest allowable steam pressure at the turbine inlet, and calculate the Rankine cycle efficiency for these steam conditions. 10

(*c*) What is an air standard cycle ? Why are such cycles conceived ? Show that the efficiency of the Otto cycle depends only on the compression ratio. 6

Group B

5. (*a*) Show that the temperature profile for heat conduction through a wall of constant thermal conductivity is a straight line and in the presence of a heat source it becomes parabolic. 5

(*b*) To measure the thermal conductivity of an opaque material, a spherical shell of inner radius of 26 cm and outer radius of 34 cm was constructed, and a 100 W electric light bulb placed in the centre. At steady state, temperatures of inner and outer surfaces were measured to be 339 K and 311K, respectively. What is the thermal conductivity of the material ? 7

(*c*) Calculate the junction temperature of a copper thermocouple, initially at 25 °C, which when placed in a gas steam of 200 °C measures a temperature of 198 °C in 5 sec. For copper, take $\rho = 8940$ kg/m^3,

$C = 384$ J/kg-K, $K = 390$ W/mK and the convective heat transfer coefficient = 400 W/m^{2}K. Derive the equation required to solve the problem. 8

6. (*a*) Define local and mean heat transfer coefficients. On what factors does the value of *h* depend in forced convection ? Show that the Reynold's number for flow in a circular tube of diameter, *D*, can be expressed as $Re = 4\ \dot{m}/\pi D\mu$. 6

(*b*) State the scope and application of dimensional analysis in heat transfer processes. What are the two methods of determining dimensionless groups to correlate experimental data ? 6

(*c*) It was found during a test in which water flowed with a velocity of 2.44 m/s through a tube (2.54 cm i.d. and 6.08 m long), that the head lost due to friction was 1.72 m of water. Estimate the surface heat transfer coefficient based on Reynold's analogy. Take $\rho = 998$ kg/m^3 and $C_p = 4.18$ kJ/kgK. 8

7. (*a*) What is nucleate boiling ? Why do bubbles form on on the heating surface ? 6

(*b*) A chemical ($C_p = 3.3$ kJ/kgK) flowing at the rate of 20,000 kg/hr enters a parallel flow heat exchanger at 120 °C. The flow rate of cooling water ($C_p = 4.186$ kJ/kgK) is 50,000 kg/h with an inlet temperature of 20 °C. The heat transfer surface area is 10 m^2 and the overall heat transfer coefficient is 1050 W/m^{2}K. Calculate the (*i*) effectiveness of the heat exchanger, and (*ii*) outlet temperatures of water and chemical. 5 + 5

(*c*) Why are heat transfer coefficients for natural convection much less than those in forced convection ? 4

8. (*a*) Why is Planck's law the basic law of thermal radiation ? Explain graphically how $E_{b\lambda}$ and T are related ? 5

(*b*) On what factors does the radiant heat exchange between two bodies depend ? Show that the emissive power of a black body is π-times the intensity of emitted radiation. 7

(*c*) Determine the rate of heat loss by radiation from a steel tube of outside diameter 0.07 m and 3 m long at a temperature of 227 °C if the tube is placed within a square brick conduit 0.3 m side and at 27 °C. Take ε (steel) = 0.79 and ε (brick) = 0.93. 8

Group C

9. Answer the following in brief : 10 × 2

(*i*) What is a quasi-static process ? What is its characteristic feature ?

(*ii*) What is the standard fixed point in thermometry ? Define it.

(*iii*) Which property of a system increases when heat is transferred at (*a*) constant volume, and (*b*) constant pressure ?

(*iv*) What do you mean by steady state and steady flow ?

(*v*) What are the causes of irreversibility of a process ?

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

(*vii*) Why is an isentropic process not necessarily an adiabatic process ?

(*viii*) Why is second law called a directional law of nature ?

(*ix*) Why has an insulated small diameter wire a higher current carrying capacity than an uninsulated one ?

(*x*) How does transient heat conduction differ from steady conduction ?

W'12: 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.

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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 first law of thermodynamics for a change of state and prove that energy is a property. 6

(*b*) Nitrogen gas at 300 K, 101 kPa and 0·1 m^3 is compressed slowly in an isothermal process to 500 kPa. Calculate the work done during the process. 4

(*c*) (*i*) Explain system approach and control volume approach in the analysis of a flow process. 2

(*ii*) A high velocity water jet nozzle has 0·02 m and 0·0001 m as its inlet and outlet diameters, respectively. Water discharges from the nozzle at a rate of 0·0060 kg/s. If the outlet pressure is 0·2 MPa, determine the pressure at the inlet assuming the flow to be isothermal. 8

2. (*a*) Prove that the efficiency of Carnot engine is higher compared to that of an irreversible heat engine, both working between same temperature limits. 6

(*b*) A body at temperature T_1 and of constant heat capacity C_p is put in contact with a thermal reservoir at temperature T_f, which is higher than T_1. The pressure ratio remains constant while the body comes to equilibrium with the reservoir. Show that the change in entropy of the universe is equal to

$$C_p\left[x - \ln(1+x)\right], \text{ where } x = -(T_f - T_1)/T_f. \quad 4$$

(*c*) (*i*) Does heat transfer inevitable cause of a temperature rise ? 2

(*ii*) A reversible heat engine, operating between thermal reservoirs at 300 °C and 30 °C drives a reversible refrigerator which refrigerates a space at -15 °C and delivers heat to a thermal reservoir at 30 °C. The heat input to the heat engine is 1900 kJ and there is a net work output from the combined plant (heat engine and refrigerator) of 290 kJ. Determine the heat transfer to the refrigerant and the total heat transfer to the 30 °C thermal reservoir. 8

3. (*a*) Derive the Clapeyron equation. 6

(*b*) In a steam boiler, hot gases from a fire transfer heat to water vaporize at constant temperature. In a certain case, the gases are cooled from 1100 °C to 550 °C while the water evaporates at 220 °C. The specific heat of gases is 1.005 kJ/kg-K and the latent heat of the water at 220 °C is 1858 kJ/kg. All the heat is transferred from the gases to the water. How much does the total entropy of the combined system of gas and water increase as a result of the irreversible heat transfer ? Obtain the result on the basis of 1 kg of water evaporated. If the temperature of the surroundings is 30 °C, find the increase in unavailable energy due to irreversible heat transfer. 8

(*c*) (*i*) Differentiate between heat and internal energy. 2

(*ii*) Derive Maxwell's relations. 4

4. (*a*) Sketch and explain the essential components of a Rankine vapour power cycle. 4

(*b*) Explain the working of an actual gas turbine with p-v and T-s disgrams. 4

(*c*) An ideal diesel cycle, using air as the working fluid, has a compression ratio of 16 and a cut-off ratio of 2. The intake conditions are 100 kPa and 20 °C and 2000 cm^3. Using the cold-air-standard assumptions, determine the (*i*) T and P at the end of each process, (*ii*) net work output, (*iii*) thermal efficiency, and (*iv*) mean effective pressure. Take for air, R = 0·287 kJ/kg-K, C_p = 1·0045 kJ/kg-K and C_v = 0·7175 kJ/kg-K. 8

(*d*) Define the following: 4 × 1

(*i*) Saturation ratio

(*ii*) Specific humidity

(*iii*) Dew-point temperature

(*iv*) Psychrometry

Group B

5. (*a*) Derive the general heat conduction equation in cartesian co-ordinates. 8

(*b*) A thin-walled copper tube of outside metal radius $r = 0{\cdot}01$ m carries steam at 400 K. It is inside a room where the surroundings temperature is 300 K. The tube is insulated with magnesia insulation of an approximate thermal conductivity of 0·07 W/(m-K). (*i*) What is the critical thickness of insulation for an external convective heat transfer coefficient $h = 4{\cdot}0$ W/m²-K ? (Assume negligible conduction resistance due to the wall of the copper tube) ; (*ii*) Under these conditions, determine the rate of heat transfer per m of tube length for (*I*) a 0·002 m thick layer of insulation, (*II*) critical thickness of insulation, and (*III*) 0·05 m thick layer of insulation. 6

(*c*) (*i*) What are the influences of fin length and fin thickness on the efficiency? 2

(*ii*) Consider two very long slender rods of the same diameter but of different materials. One end of the each rod is attached to a base surface maintained at 100 °C, while the surfaces of rods are exposed to ambient air at 20 °C. By traversing the length of each rod with a thermocouple, it was observed that the temperatures of the rods were equal to the positions $X_A = 0{\cdot}15$ m and $X_B = 0{\cdot}075$ m, where X is measured from the base surface. If the thermal conductivity of rod A is known to be $K_A = 72$ W/m-K, determine the value of K_B for the rod B. 4

6. (*a*) Obtain the momentum equation for a hydrodynamic boundary layer over a flat plate. 8

(*b*) Air at a pressure of 101 kPa and 20 °C flows with

a velocity of 5 m/s over a 1 m × 5 m flat plate whose temperature is kept constant at 140 °C. Determine the rate of heat transfer from the plate, if the air flows parallel to the (*i*) 5 m long side; and (*ii*) 1 m side. The properties of air at 80 °C are : $k = 0{\cdot}03$ W/mK, Pr = 0·706, $\upsilon = 2\times10^{-5}\,\text{m}^2/\text{s}$. If $\text{Re}_L > 5\times10^5$, then use $\text{Nu}_L = 0.037\{(\text{Re}_L^{4/5} - 871)\}\,\text{Pr}^{1/3}$. Use $\text{Nu}_L = 0{\cdot}664\,\text{Re}_L^{1/2}\text{Pr}^{1/3}$, if $\text{Re}_L < 5\times10^5$. 6

(*c*) (*i*) Define Grashof number. What is its physical significance? 2

(*ii*) What is the difference between evaporation and boiling? 2

(*iii*) What is the difference between nucleate and film boiling? 2

7. (*a*) Derive an expression for the effectiveness of a parallel flow heat exchanger in terms of NTU. 8

(*b*) Explain the phenomenon of film condensation. 4

(*c*) What is a radiation shield? 2

(*d*) Engine oil is to be cooled from 80 °C to 50 °C by using a heat exchanger of counter-flow and concentric tube-type, with cooling water available at 20 °C. Water flows inside tube with ID of $D_i = 2{\cdot}5$ cm at a rate of $m_w = 0{\cdot}08$ kg/s and oil flows through the annulus at a rate of $m_{oil} = 0{\cdot}16$ kg/s. The heat transfer coefficient for the water side and oil side are respectively $h_w = 1000$ W/m²-K and $h_{oil} = 80$ W/-m²K, the fouling factors are $F_w = 0{\cdot}00018$ m² K/W and $F_{oil} = 0{\cdot}00018$ m²K/W and and the tube wall resis-tance is negligible. Calculate the tube length required. Take $C_{pw} = 4180$ J/kg-K and $C_{p/oil} = 2090$ J/kg-K. 6

8. (*a*) State and prove the Kirchhof's law of radiation heat transfer. 6

(*b*) Determine six view factors from the base of a cube to each of its five surfaces, i.e, $F_{11} + F_{12} + \cdots + F_{16}$. 4

(*c*) Define the following : 4 × 1

(*i*) Emissivity

(*ii*) Absorptivity

(*iii*) Reflectivity

(*iv*) Transmissivity

(*d*) Define radiation intensity. Prove that the intensity of radiation is given by $I_b = E_b/\pi$. 6

Group C

9. Answer the following in brief : 10 × 2

(*i*) Give the Clausius statement of the second law of thermodynamics.

(*ii*) Show that the work is a path function and not a property.

(*iii*) Which property distinguishes thermodynamics from other sciences ?

(*iv*) How does the energy value provide a useful measure of the quality of energy ?

(*v*) What is a heat pump ? How does it differ from a refrigerator ?

(*vi*) Explain the concept of thermal resistance. What are its applications ?

(*vii*) Explain 'fouling factor' and 'effectiveness' as applied to heat exchangers.

(*viii*) Define a black body and a gray body.

(*ix*) State Planck's law of monochromatic radiation. What is its significance ?

(*x*) For the thickness of hydrodynamic boundary layer and thermal boundary layer to be the same, what is the value of Prandtl number ?

S'13 : 6 AN : MC 405 (1498)

THERMAL SCIENCE AND ENGINEERING

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

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Group A

1. (*a*) Explain the difference between energy in transit and energy in storage. What is the energy per unit mass for a (*i*) non-flow system, and (*ii*) flow system? 6

(*b*) A mass of 8 kg expands within a flexible container so that the p-v relationship is of the form $pv^{1.2}$ = constant. The initial pressure is 1000 kPa and the initial volume is $1 m^3$. The final pressure is 5 kPa. If the specific internal energy of the gas decreases by 40 kJ/ kg, find the heat transfer in magnitude and direction. 6

(c) At the inlet to a pipeline, the condition of steam is p = 4MPa, t = 400 °C, h = 3213.6 kJ/kg and v = 0.073 m³/kg. At the discharge end, the conditions are found to be p = 3.5 MPa, t = 390 °C, h = 3202.6 kJ/kg, and v = 0.084 m³/kg. If there is a heat loss of 8.5 kJ/ kg from the pipeline, calculate the steam flow rate. 8

2. (a) What is a reversible process ? How is a reversible process only a limiting process, never to be attained in practice ? 5

(b) Establish the equivalence of Kelvin-Planck and Clausius statements. 5

(c) A heat pump provides 3×10^4 kJ/h to maintain a dwelling at 23 °C on a day when the outside temperature is 0 °C. The power input to the heat pump is 4 kW. Determine the COP of the heat pump and compare it with the COP of a reversible heat pump operating between the reservoirs at the same two temperatures. 6

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

3. (a) Why is an isentropic process not necessarily an adiabatic process ? 2

(b) Show that the maximum work obtainable from a finite body at temperature T and a TER at T_0 is given by

$$W(max) = C_p\left[(T - T_0) - T_0 \ln(T/T_0)\right]$$

where C_p is the heat capacity of the body. 4

(c) Show that isothermal dissipation of work is irreversible. 4

(d) A gas is flowing through a pipe at the rate of 2 kg/s. Because of inadequate insulation, the gas temperature decreases from 800 °C to 790 °C between two sections in the pipe. Neglecting pressure losses, calculate the rate of energy degradation due to this heat loss. Take T_0 = 300 K and C_p = 1.1 kJ/kgK. For the same temperature drop of 10 °C, when the gas cools from 80 °C to 70 °C due to heat loss, what is the rate of energy degradation ? Take the same values of T_0 and C_p. What is the inference you can draw from this example ? 10

4. (a) What is the reversible cycle that represents the steam power plant ? Draw and explain the cycle with the help of flow and T- s diagrams. 4

(b) What is an air stand cycle ? Why are such cycles conceived ? 2

(c) Show that the efficiency of the Otto cycle depends only on the compression ratio. 4

(d) In a gas turbine plant working on the Brayton cycle, the air at the inlet is at 27 °C, 0.1 MPa. The pressure ratio is 6.25 and the maximum temperature is 800 °C. The turbine and compressor efficiencies are each 80 %. Find the

(i) compressor work per kg air;

(ii) turbine work per kg air ;

(iii) heat supplied per kg air ;

(iv) cycle efficiency ; and

(v) turbine exhaust gas temperature. 5 × 2

Group B

5. (*a*) Show that the temperature profile for heat conduction through a wall of constant thermal conductivity is a straight line and in the presence of a heat source, it becomes parabolic. 3

(*b*) A pipe is insulated to reduce the heat loss from it. However, measurements indicate that the rate of heat loss has increased instead of decreasing. Can the measurements be right ? 3

(*c*) Discuss the criteria of selection of fins. What is the difference between the fin effectiveness and fin efficiency ? 4

(*d*) The cooling system of an electronic package has to dissipate 0.153 kW from the surface of an aluminium plate 100 mm × 150 mm. It is proposed to use eight fins, each 150 mm long and 1 mm thick. The temperature difference between the plate and the surroundings is 50 K, the thermal conductivity of plate and fins is 0.15 W/ mK and the heat transfer coefficient is 0.04 kW/m^{2}K. Calculate the heights of the fins required. 10

6. (*a*) What is the lumped system analysis for transient heat conduction ? When is it applicable ? 3

(*b*) A solid copper ball of 100 mm diameter and ρ = 8954 kg/m^3, C_p = 383 J/kgK, k = 386 W/mK is at a uniform temperature of 250 °C. It is suddenly immersed in a well-stirred fluid which is maintained at a uniform temperature of 50 °C, the heat transfer coefficient between the ball and the fluid is h = 200 W/m^{2}K. Estimate temperature of the copper ball after a lapse of 5 min of immersion. 6

(*c*) How is the friction factor for flow in a tube related to the pressure drop ? How is the pressure drop related to the pumping power for a given mass flow rate ? 4

(*d*) It was found during a test in which water flowed with a velocity of 2.44 m/s through a tube (2.54 cm inner diameter and 6.09 m long) that the head loss due to friction was 1.27 m of water. Estimate the surface heat transfer coefficient based on Reynolds analogy. Take ρ = 998 kg/m^3 and C_p = 4.187 kJ/kgK. 7

7. (*a*) Lubricating oil (ρ = 865 kg/m^3, k = 0.14 W/mK, C_p = 1.79 kJ/kgK and $\upsilon = 9 \times 10^{-6}$ m^2/s) at 60 °C enters a 1 cm diameter tube with a velocity of 3.5 m/s while the tube wall is maintained constant at 30 °C. Calculate the tube length required to cool the oil to 45 °C. Use Dittus-Boelter equation to find *h*. 10

(*b*) With the help of Buckingham π-theorem, show that for natural convection heat transfer

$$Nu \doteq B.Gr^a\, Pr^b$$

where B, a and b are constants. 5

(*c*) Why is the bulk temperature of condensate always sub-cooled ? 2

(*d*) What is nucleate boiling ? Why is it important ? 3

8. (*a*) Show that the emissive power of a black body is π times the intensity of radiation. 5

(*b*) On what factors does the radiant heat exchange between two bodies depend ? 2

(*c*) State and explain the reciprocity theorem in thermal radiation. 3

(*d*) Two fluids A and B exchange heat in a counter flow heat exchanger. Fluid A enters at 420 °C and has a mass flow rate of 1 kg/s. Fluid B enters at 20 °C and has a mass flow rate of 1 kg/s. The effectiveness of heat exchanger is 75%. Determine the (*i*) heat transfer rate and (*ii*) exit temperature of fluid B. Specific heat of fluid A = 1 kJ/ kgK and that of fluid B = 4.1 kJ/kgK. 8

(*e*) What do you mean by fouling factor ? 2

Group C

9. (A) Choose the *correct* answer for the following : 10 × 1

(*i*) In which the following processes for an ideal gas, the heat transfer is completely converted to work :

(*a*) Reversible adiabatic process

(*b*) Reversible isobaric process

(*c*) Reversible isothermal process

(*d*) Reversible isochoric process

(*ii*) At absolute zero temperature, the isotherm coincides with an

(*a*) isobar.

(*b*) adiabatic.

(*c*) isochore.

(*d*) isenthalpe.

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

(*a*) $\int_1^2 pdv$

(*b*) $-\int_1^2 vdp$

(*c*) $u_1 - u_2$

(*d*) $p_1v_1 - p_2v_2$.

(*iv*) When a system is in equilibrium, any conceival change in entropy would be

(*a*) maximum.

(*b*) positive.

(*c*) negative.

(*d*) zero.

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

(*a*) dew point temperature.

(*b*) wet bulb temperature.

(*c*) dry bulb temperature.

(*d*) effective temperature.

(*vi*) The Reynolds number of a fluid flowing through a pipe depends on

(*a*) the velocity of fluid.

(*b*) the diameter of the pipe.

(*c*) the kinematic viscosity of the fluid.

(*d*) All of the three above.

(*vii*) For buoyancy induced flow and heat transfer, the relevant dimensionless number is

(*a*) Reynolds number.

(*b*) Prandtl number.

(*c*) Grashof number.

(*d*) Nusselt number.

(*viii*) which one of the following has the least value of thermal conductivity?

(*a*) Water

(*b*) Air

(*c*) Rubber

(*d*) Plastic

(*ix*) For a balanced counter flow heat exchanger, the effectiveness is given by

(*a*) $\varepsilon = \frac{1-\exp(-\text{NTU})}{2}$

(*b*) $\varepsilon = \frac{1+\exp(-\text{NTU})}{2}$

(*c*) $\varepsilon = \frac{\text{NTU}}{\text{NTU}+1}$

(*d*) $\varepsilon = \frac{\text{NTU}+1}{\text{NTU}}$

(*x*) Most solids are

(*a*) highly absorptive.

(*b*) highly transmittive.

(*c*) highly reflective.

(*d*) opaque.

(B) Write in brief on *any five* of the following : 5 × 2

(*i*) Inequality of Clausius

(*ii*) Vapour compression refrigeration cycle

(*iii*) Diesel cycle

(*iv*) Quality of energy

(*v*) Kirchhoff's law of radiation

(*vi*) Critical radius of insulation

(*vii*) Film condensation

(*viii*) Hydrodynamically fully developed flow in a pipe.

W'13 : 6 AN : MC 405 (1498)

THERMAL SCIENCE AND ENGINEERING

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Group A

1. (*a*) State the zeroth law of thermodynamics and prove that it is the basis of temperature measurement. 4

(*b*) What do you understand by path function and point function ? What are exact and inexact differential ? 4

(*c*) How does steady flow energy equation related to Euler's equation and Bernoulli's equation ? 4

(*d*) State the first law of thermodynamics. In a gas turbine, the gas enters at the rate of 5 kg/s with a velocity of 50 m/s and enthalpy of 900 kJ/kg and leaves the turbine with a velocity of 150 m/s and enthalpy of 400 kJ/kg. The loss of heat from the gases to the surroundings is 25 kJ/kg. Assume for gas R = 0.285 kJ/kg-K and C_p = 1.004 kJ/kg-K and the inlet conditions to be at 100 kPa and 27 °C. Determine the power output of the turbine and the diameter of the inlet pipe. 8

2. (*a*) Write the Kelvin-Planck and Clausius statements of the second law of thermodynamics. Prove that they mean the same. 6

(*b*) What is the qualitative difference between heat and work ? Define thermal efficiency of a heat engine cycle. Can this be 100%. 4

(*c*) A heat engine operates between a source of 600 °C and a sink of 20 °C. Determine the least rate of heat rejection per kW net output of the engine. 4

(*d*) A fluid undergoes a reversible adiabatic compression from 0.5 MPa, 0.2 m^3 to 0.05 m^3 according to the law $pv^{1.3}$ = constant. Determine the change in enthalpy, internal energy and entropy and the heat transfer and work transfer during the process. 6

3. (*a*) Define the second law efficiency. How is it different from the first law efficiency in case of a simple power plant ? 4

(*b*) Calculate the decrease in available energy when 25 kg of water at 95 °C is mixed with 35 kg of water at 35 °C, the pressure being taken as constant and the temperature of the surroundings being 15 °C. (C_p of water = 4.2 kJ/kg-K). 6

(*c*) Write the Maxwell's equations and first and second T-ds equations. 4

(*d*) Explain 'Absolute Thermodynamic Temperature Scale'. 6

4. (*a*) Why is Carnot cycle not practicable for a steam power plant ? Name the real cycle adopted and draw it on p-v, T-s and h-s diagrams. 4

(*b*) What is an air-standard cycle ? Why are these conceived ? What is compression ignition engine ? Why is the compression ratio here is more than that of an SI engine ? State four processes of diesel cycle. 6

(*c*) With the help of a schematic diagram, explain the working of a typical gas turbine and draw the Brayton cycle on p-v diagram. Derive the expression for efficiency in terms of four temperatures. 6

(*d*) What is psychrometrics ? What is an adiabatic saturation process ? 4

Group B

5. (*a*) In a cylindrical fuel rod of a nuclear reactor, the internal heat generation is given by

$$\dot{q} = \dot{q}_0\left[1-\left(\frac{r}{r_0}\right)^2\right]$$

where $\dot{q}_o$ is a constant and r_0 = outer radius. Calculate the temperature drop from the centre line to the surface of a 2.5 cm outer diameter rod having a thermal conductivity of 20 W/mK, if the rate of heat removal is 2.5 MW/m^2. 8

(*b*) What is critical thickness of insulation on a small diameter wire or pipe ? Explain physical significance and derive the expression. 6

(*c*) The temperature of the air stream in a tube is measured with the help of a thermometer placed in a protective well filled with oil. The thermometer well is made of a steel tube (k = 55.8 W/mK), 120 mm long and 1.5 mm thick. The surface heat transfer coefficient from the air to the protective well is 23.3 W/m² K and the temperature recorded by the thermometer is 84 °C. Estimate the measurement error, if the temperature at the base of the well is 40 °C. Explain the theory behind the solution. 6

6. (*a*) Derive the following equation for a small metal casting being quenched in a bath after removing it from a hot surface.

$$T = (T_0 - T_\infty)\ \exp\left\{-\frac{hAt}{\rho CV}\right\} + T_\infty$$

where T_0 = initial temperature ; T_∞ = environmental temperature ; t = time ; h = convective heat transfer coefficient ; A = surface area ; ρ = density of solid (casting) ; C = specific heat of solid (casting) ; and V = volume. State the important assumption/condition for derivation. 6

(*b*) What is (*i*) Sieder and Tate, and (*ii*) Dittus-Boelter equations ? Where and when are these applied ? 4

(*c*) Atmospheric air at T_∞ = 275 K and a free-stream velocity u_∞ = 20 m/s flows over a flat plate L = 1.5 m long that is maintained at a uniform temperature of T_W = 325 K.

(*i*) Calculate the average heat transfer coefficient, h_m, over the region where the boundary layer is laminar.

(*ii*) Find the average heat transfer coefficient over the entire length L = 1.5 m of the plate.

(iii) Calculate the total heat transfer rate, Q, from the plate to the air over the length L = 1.5 and width w = 1 m.

Assume : Transition occurs at $Re_C = 2 \times 10^5$.

Physical properties of air at 300 K = $(T_W + T_\infty)/2$ are : k = 0.026 W/mK ; ρ_r = 0.708 ; $\upsilon = 16.8 \times 10^{-6}$ m²/s.

The relations for portion (*i*) and (*ii*) of question are as follows :

$$h_m = 0.664\left(\frac{k}{x_c}\right) P_r^{1/3}\ Re_x^{1/2}$$

(region where boundary is laminar).

and $$h_m = 0.036\left(\frac{k}{L}\right) P_r^{0.43}\ \left[Re_L^{0.6} - 9200\right]$$

(over the entire length). 4

(*d*) Write a note on 'thermally and hydrodynamically fully developed flow through a pipe. Define Prandtl number and explain its significance. 3 + 3

7. (*a*) Define radiation intensity. Prove that the intensity of radiation is given by $I_b = E_b / \pi$. 6

(*b*) State and explain Kirchhoff's law. What are the conditions under which it is applicable ? 4

(*c*) A surface with A = 2 cm² emits radiation as a black body at T = 1000 K.

(*i*) Calculate the radiation emitted into a solid angle subtended by $0 \le \phi \le 2\pi$ and $0 \le \theta \le \pi/6$.

(*ii*) What is the fraction of energy emitted into the above solid angle of that emitted into the entire hemispherical space ? 6

(*d*) Explain the meaning of the term 'view factor'. State and explain the reciprocity relation. 4

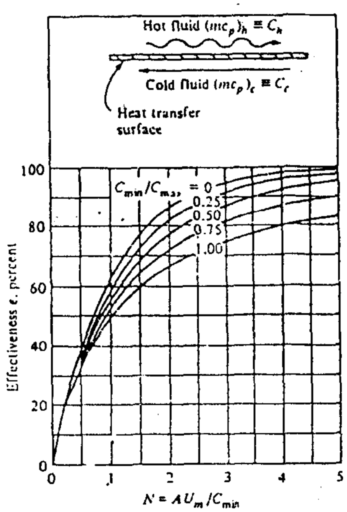
8. (*a*) Engine oil is to be cooled from 60 °C to 45 °C using seawater at inlet temperature of 20 °C with a temperature rise of 15 °C. The design heat load is

Q = 140 kW and the mean overall heat transfer coefficient based on the outer surface area of the tubes is 70 W/m²K. Calculate the heat transfer area for single-pass (*i*) counterflow, and (*ii*) parallel flow arrangements. 6

(*b*) Distinguish between filmwise and dropwise condensation. Which of the two gives a higher heat transfer coefficient ? Why ? 2

(*c*) Discuss the various regimes in boiling heat transfer. Why is the heat transfer coefficient in nucleate boiling 10-20 times greater than in film boiling. 6

(*d*) A counterflow heat exchanger of area $A = 12.5\ m^2$ is to cool [C_{ph} = 2000 J/kgs] oil with water [C_{pc} = 4170 J/kg–s]. The oil enters at $T_{h_{in}}$ = 100 °C and m_h = 2 kg/s, while the water enters at $T_{c_{in}}$ = 20 °C and m_c = 0.48 kg/s. The overall heat transfer coefficient is U_m = 400 W/m²-K. Calculate the exit temperature of water, $T_{c_{out}}$, and the total heat transfer rate Q. Use the following graph for solution. 6



Effectiveness for a counterflow heat exchanger.

Group C

9. Answer the following in brief: 10 × 2

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

(*ii*) What is the higher and lower grade energy ?

(*iii*) What is the property introduced by the first law of thermodynamics ? Why should specific heat not be defined in terms of heat transfer ?

(*iv*) Explain Clausius inequality.

(*v*) How does the subject of thermodynamics differ from the concept of heat transfer ? Define thermodynamic property.

(*vi*) What is thermal diffusivity ? Explain its importance in heat conduction problems.

(*vii*) What is meant by 'thermal resistance' ? Explain the electrical analogy for solving heat transfer problems.

(*viii*) Explain the meaning of Reynolds analogy. Describe the relation between fluid friction and heat transfer.

(*ix*) Define the term 'shape factor' related to the graphical analysis of two-dimensional heat conduction problems.

(*x*) Define Grashof number and explain its significance in free convection heat transfer.