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CSM—49/22

MECHANICAL ENGINEERING

PAPER—II

Time : 3 Hours

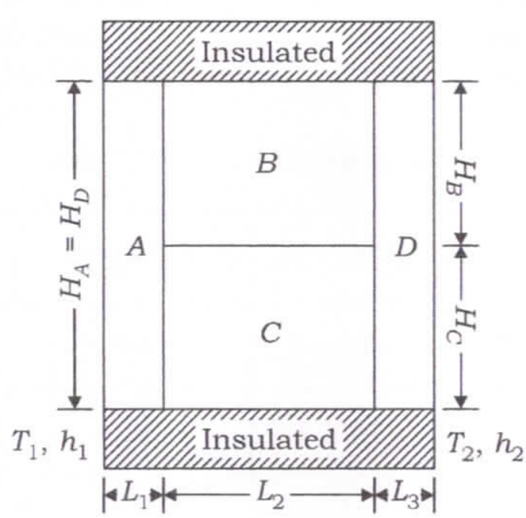
Full Marks : 250

The figures in the right-hand margin indicate marks.

*Candidates should attempt **any 10 (ten)** questions of **GROUP—A** with word limit of 250 words and should attempt **any 5 (five)** questions from **GROUP—B** with word limit of 300 words.*

GROUP—A

1. A composite wall, having unit length normal to the plane of the paper, is insulated at the top and bottom, as shown in the figure. It is comprised of four different materials *A*, *B*, *C* and *D*. Dimensions are $H_A = H_D = 3$ cm, $H_B = H_C = 1 \cdot 5$ cm ; $L_1 = L_3 = 0 \cdot 05$ m, $L_2 = 0 \cdot 1$ m. The thermal conductivities of the materials are $K_A = K_D = 50$ W/mK, $K_B = 10$ W/mK, $K_C = 1$ W/mK. The temperature of the fluid in contact with *A* and the corresponding heat transfer coefficient are $T_1 = 200$ °C, $h_1 = 50$ W/m^{2}K. The temperature of the fluid in contact with *D* and the corresponding heat transfer coefficient are $T_2 = 25$ °C, $h_2 = 10$ W/m^{2}K. Assuming one-dimensional heat transfer condition, determine *(a)* the total thermal resistance of the wall and *(b)* the rate of heat transfer through the wall. 12+3=15



2. An iron rod ($K = 41{\cdot}5$ W/mK) of 15 mm diameter and 160 mm long extends out of a hot surface of temperature 150 °C into the environment at 36 °C. The free end of the rod is insulated. If the film heat transfer coefficient is 25 W/m^2K, calculate *(a)* the rate of heat flowing out of the hot surface through the rod, *(b)* the temperature at the insulated end of the rod, *(c)* the fin effectiveness and *(d)* the fin efficiency. 8+3+2+2=15

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3. In an air conditioning system, air is to be cooled and dehumidified by means of a cooling coil. The data are as follows :

Initial condition of the air at the inlet to the cooling :

Dry bulb temperature = 25 °C, Partial pressure of water vapour = 0·019 bar, Absolute total pressure = 1·02 bar (102 kPa).

Final condition of the air at the exit of the cooling coil :

Dry bulb temperature = 15 °C, Relative humidity = 90%.

Other data :

Saturation pressure for water at 15 °C = 0·017 bar (1·7 kPa), enthalpy of saturated water at 15 °C = 62·98 kJ/kg.

Determine *(a)* moisture removed from air per kg of dry air and *(b)* heat removed by the cooling coil per kg of dry air. 10+5=15

4. A 50-TR ammonia refrigeration cycle operates between a condenser pressure of 20 bar and an evaporator pressure of 5 bar. The compression process is isentropic and there is no sub-cooling at the exit of the condenser. The temperature after isentropic compression is 75 °C. Determine *(a)* the state of the refrigerant at the exit of the evaporator, *(b)* the mass flow rate of the refrigerant, *(c)* the rate of heat rejection (in kW) in the condenser and *(d)* the COP of the cycle. Ammonia vapour may be considered as an ideal gas with c_p (specific heat at constant pressure) = 2·56 kJ/kg-K. 6+3+3+3=15

Table for properties of Ammonia

Pressure (bar)	Saturation Temp. (°C)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg-K)	s_g (kJ/kg-K)
5	−15	223·2	1466·8	0·432	5·5545
20	35	440·5	1491·8	1·192	5·0514

5. Heat is supplied to a reversible engine from two constant temperature sources at 800 K and 400 K. The engine rejects heat to a constant temperature sink at 200 K. The engine executes a number of cycles while developing a power of 100 kW and rejecting 3500 kJ of heat per minute. Determine *(a)* the rate of heat supplied by the source at 800 K, *(b)* the rate of heat supplied by the source at 400 K and *(c)* the efficiency of the engine. 5+5+5=15

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6. Air at 101·325 kPa, 20 °C is taken into a gas turbine power plant at a velocity of 140 m/s through an opening of 0·15 m^2 cross-sectional area. The air is compressed, heated and expanded through a turbine and exhausted at 0·18 MPa, 150 °C through an opening of 0·10 m^2 cross-sectional area. The net power output from the plant is 375 kW. Calculate *(a)* the mass flow rate of air, *(b)* the exit velocity of air, *(c)* the rate of heat input, *(d)* the efficiency of the plant and *(e)* the change in entropy per kg of air. Assume air as an ideal gas with $R = 0{\cdot}287$ kJ/kg and $c_p = 1{\cdot}005$ kJ/kg-K. 3+2+5+3+2=15

7. A two-stage single-acting reciprocating air compressor takes in air at 1 bar and 300 K. Air is discharged at 10 bar. The intermediate pressure is ideal for minimum work and perfect intercooling. The law of compression is $pv^{1{\cdot}3}$ = constant. The rate of discharge is 0·1 kg/s. Calculate *(a)* the power required to drive the compressor, *(b)* saving in work in comparison to single-stage compression, *(c)* isothermal efficiency and *(d)* heat transferred in the intercooler. Take, for air, $R = 0{\cdot}287$ kJ/kg and $c_p = 1{\cdot}005$ kJ/kg-K. 5+4+3+3=15

8. A single-cylinder four-stroke diesel engine having a bore of 18 cm and stroke of 32 cm develops a torque of 390 Nm and Indicated Mean Effective Pressure (IMEP) of 700 kPa at 280 r.p.m. The following observations were made during the experiment :

Fuel consumption = 3 kg/hr, air fuel ratio = 22, room temperature = 20 °C and barometric pressure = 1 bar.

If the calorific value of the fuel is 42 MJ/kg, determine *(a)* the indicated power, *(b)* the indicated thermal efficiency, *(c)* the mechanical efficiency and *(d)* the volumetric efficiency.

4+3+3+5=15

9. An engine fuel has a composition of 86% carbon and 14% hydrogen by mass. The engine is supplied with this fuel and air from the atmosphere. The equivalence ratio of the air-fuel mixture is 1·25. Assuming that all the hydrogen in fuel is burnt and the carbon is burnt to CO and CO_2, so that no free carbon is left. Calculate the percentage analysis of dry exhaust gases by volume. 15

10. (a) How is a pollutant defined?

(b) What are the main pollutants from automobiles?

(c) What are the major causes for the formation of pollutants in an internal combustion engine?

(d) What is a three-way catalytic converter?

(e) How does it function? 2+2+6+2+3=15

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11. The following data pertains to a power plant :

Installed capacity = 200 MW; Capital cost = ₹20,000 per kW; Annual cost of fuel, taxes and salaries = ₹600 × 10^6; Rate of interest = 5% of the capital; Rate of depreciation = 5% of the capital; Annual load factor = 65%; Capacity factor = 55%; Energy used in running plant auxiliaries = 4% of the total unit generated.

Determine *(a)* the reserve capacity, *(b)* the reserve factor and *(c)* the cost of energy per kWh. 6+2+7=15

12. Describe various factors for selecting sites for hydroelectric power plants. 15

GROUP—B

13. Consider steady one-dimensional heat flow in a plate of 20 mm thickness with a uniform heat generation of 80 MW/m^3. The left and right faces are kept at constant temperatures of 160 °C and 120 °C, respectively. The plate has a constant thermal conductivity of 200 W/mK. Determine *(a)* the temperature distribution across the thickness of the plate, *(b)* the location of the maximum temperature from the left face and *(c)* the maximum temperature within the plate. 12+5+3=20

14. A one-shell-pass, one-tube-pass heat exchanger has a counterflow configuration between the shell and tube side fluids. The total number of tubes within the heat exchanger is 10 and the tube dimensions are ID = 10 mm, OD = 12 mm. Saturated dry stream enters the shell side at a flow rate of 2 kg/s and a temperature of 100 °C and leaves the exchanger as a condensed liquid at the same temperature. On the tube side, cold water enters at a flow rate of 100 kg/s with an inlet temperature of 25 °C. The convective heat transfer coefficients inside and outside the tube are 400 W/m^{2}K and 60 W/m^{2}K respectively. The tube wall resistance may be neglected. The specific heat of water is 4·18 kJ/kg-K and the latent heat of steam is 2500 kJ/kg. Determine *(a)* the exit temperature of the water, *(b)* the overall heat transfer coefficient on the basis of the outside tube area and *(c)* the length of the tubes of the exchanger. 4+8+8=20

15. Air enters a compressor in a steady flow manner at 140 kPa, 17 °C and at a velocity of 70 m/s. Air leaves the compressor at 350 kPa and 110 m/s velocity. The isentropic efficiency of compression is 83%. Assume adiabatic compression. The environment is a 100 kPa and 7 °C. If the air flow rate is 5 kg/s, determine *(a)* the actual amount of power required, *(b)* the change in availability, *(c)* the minimum amount of power required, *(d)* the irreversibility of the process and *(e)* the net rate of change of entropy of the universe. Take air as an ideal gas with $R = 0{\cdot}287$ kJ/kg and $c_p = 1{\cdot}005$ kJ/kg-K. 8+6+2+2+2=20

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16. A gas occupies $0{\cdot}024\ m^3$ at 700 kPa and 95 °C. It is expanded in the non-flow process according to the law $pv^{1{\cdot}2}$ = constant to a pressure of 70 kPa after which it is heated at constant pressure back to its original temperature. The cycle is completed by an isothermal process by which the system comes back to its initial state. *(a)* Sketch the cycle on the *p-v* and *T-s* diagrams *(b)* calculate the work done for each process, *(c)* calculate the heat transferred in each process, *(d)* calculate the change of entropy during each process and *(e)* calculate the efficiency of the cycle. Assume the gas to be ideal and take $c_p = 1{\cdot}047$ kJ/kg-K and $c_v = 0{\cdot}775$ kJ/kg-K for the gas. 3+5+5+5+2=20

17. A centrifugal compressor running at 12000 r.p.m. delivers 600 m^3/min of free air. The air is compressed from 1 bar and 27 °C to a pressure ratio of 4 with an isentropic efficiency of 85%. The blades are radial at the impeller outlet and the flow velocity of 60 m/s may be assumed constant throughout. The outer radius of the impeller is twice the inner radius and the slip factor is 0·9. Calculate *(a)* the final temperature of the air, *(b)* the power input to the compressor, *(c)* the impeller diameter at the inlet and outlet and *(d)* the width of the impeller at the inlet. Assume the gas to be ideal and take $c_p = 1{\cdot}005$ kJ/kg-K and $R = 0{\cdot}287$ kJ/kg-K for the gas. 5+3+6+3+3=20

18. An axial flow compressor having 10 stages works with 50% degree of reaction. It compresses air with a pressure ratio of 5. The inlet conditions of air are 27 °C and 100 kPa. The air enters the compressor with a velocity of 110 m/s. The mean speed of the rotor blade is 220 m/s. The blades are symmetrical. The isentropic efficiency of the compressor is 85%. Calculate *(a)* the work input per kg of air and *(b)* the blade angles. Assume the gas to be ideal and take $c_p = 1{\cdot}005$ kJ/kg-K and $R = 0{\cdot}287$ kJ/kg-K for the gas. 6+14=20

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