CSM—49/24
PART—II/PAPER—VII
MECHANICAL ENGINEERING
PAPER—II

Candidate must not write on this margin.

Time : 3 Hours

Full Marks : 250

The question paper contains **18 (Eighteen)** *questions in* **GROUP—A, (12)** *and* **GROUP—B, (06)** *together.*

GROUP—A

Candidates to attempt **10 *(ten)*** *questions within word limit of* **250**.

Each question carries **15** *marks.*

1. A gas in a piston-cylinder assembly undergoes an expansion process for which the relationship between pressure and volume is given by PV^n = constant. The initial pressure is 3 bar, the initial volume is $0{\cdot}1\ m^3$ and the final volume is $0{\cdot}2\ m^3$. Determine the work for the process, in kJ, if *(a)* $n = 1{\cdot}5$, *(b)* $n = 1{\cdot}0$ and *(c)* $n = 0$.

2. Air is contained in a vertical piston-cylinder assembly fitted with an electrical resistor. The atmosphere exerts a pressure of 1 bar on the top of the piston, which has a mass of 45 kg and a face area of $\cdot09\ m^2$. Electric current passes through the resistor and the volume of the air slowly increases by $\cdot045\ m^3$ while its pressure remains constant. The mass of the air is ·27 kg and its specific internal energy increases by 42 kJ/kg. The air and piston are at rest initially and finally. The piston-cylinder material is a ceramic composite and thus a good insulator. Friction between the piston and cylinder wall can be ignored and the local acceleration of gravity is $g = 9{\cdot}81\ m/s^2$. Determine the heat transfer from the resistor to the air, in kJ, for a system consisting of *(a)* the air alone and *(b)* the air and the piston.

3. Water, initially a saturated liquid at 100 °C, is contained in a piston-cylinder assembly. The water undergoes a process to the corresponding saturated vapour state, during which the piston moves freely in the cylinder. If the change of state is brought about by heating the water as it undergoes an internally reversible process at constant pressure and temperature, determine the work and heat transfer per unit of mass, each in kJ/kg. Also draw $p \sim v$ diagram and $T \sim S$ diagram to show work done and heat transfer respectively. The different values of water at 100 °C are given as : specific volume and entropy at saturated liquid state are $1{\cdot}0435\ m^3/kg$ and 1·3069 kJ/kg.K; specific volume and entropy at saturated vapour state are $1{\cdot}673\ m^3/kg$ and 7·3549 kJ/kg.K; pressure is 1·014 bar.

Candidate must not write on this margin.

4. A petrol engine is supplied with fuel having a formula C_7H_{16}. *(a)* Calculate the weight of air per kilogram of fuel which would just suffice for theoretically complete combustion. *(b)* In an actual experiment, an analysis of exhaust gases showed equal volumes of unused oxygen and carbon dioxide. There is no carbon monoxide. Find the ratio of fuel to air as actually supplied.

5. A single-cylinder four-stroke diesel engine develops a power of 30 kW at 300 r.p.m. The specific fuel consumption is 0·28 kg/kWh fuel of 35° API. The fuel is injected at an average pressure of 160 bar. The duration of injection is 28° of crank travel. The pressure in the combustion chamber is 35 bar. The coefficient of velocity is 0·92. Determine the velocity of injection of the fuel and diameter of the fuel orifice.

6. Referring to the $p \sim v$ diagram, show that the compression ratio for the maximum work of an Otto cycle is given by

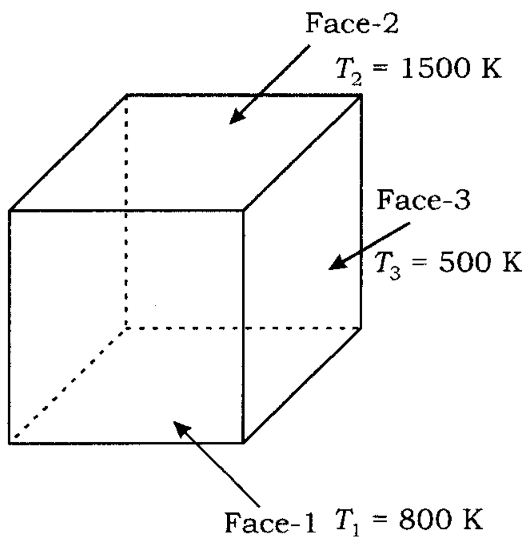
$$r = \left(\frac{T_3}{T_1}\right)^{1/2(\gamma-1)}$$

where T_1 and T_3 are the lower and upper limits of absolute temperatures respectively. Also, prove that the intermediate temperatures for this condition are $T_2 = T_4 = \sqrt{T_1 T_3}$.

7. Water at the rate of 68 kg/min is heated from 35 °C to 75 °C by an oil having specific heat of 1·9 kJ/kg·°C. The fluids are used in a counter-flow double-pipe heat exchanger and the oil enters the exchanger at 110 °C and leaves at 75 °C. The overall heat-transfer coefficient is 320 W/m^2·°C. Draw the temperature scheme of heat exchanger and calculate the heat exchanger area.

Candidate must not write on this margin.

8. Consider the 5 m × 5 m × 5 m cubical furnace shown in the figure below, whose surfaces closely approximate black surfaces. The base, top and side surfaces of the furnace are maintained at uniform temperatures of 800 K, 1500 K and 500 K, respectively. The view factor from surface 1 to 2 is 0·2. Determine *(a)* the net rate of radiation heat transfer between the base and the side surfaces, *(b)* the net rate of radiation heat transfer between the base and the top surface, and *(c)* the net radiation heat transfer from the base surface.



9. A compressor draws air from atmosphere at 1 bar and 290 K at a velocity of 70 m/s. The isentropic efficiency of the compressor is 72%. The stagnation pressure ratio is 3. Find the stagnation pressure at the exit and the power of the driving motor, if the mechanical efficiency is 95% for a flow rate of 30 kg/min.

10. An axial flow air compressor has a pressure ratio of 1 : 6. The compressor draws air from atmosphere at a temperature of 300 K. The inlet velocity may be considered negligible. The isentropic compression efficiency of the compressor is 0·88. The velocity of air at the outlet is 40 m/s. The specific heat of air over the working range is 1·004 kJ/kg, γ = 1·4. Find the power required to drive the compressor to compress air at a nominal rate of 1 kg/s.

Candidate must not write on this margin.

11. A small turbine runs at 600 r.p.m. using water at 0·05 m^3/s at a head of 12 m with an overall efficiency of 0·87. This turbine is accepted as a model for developing a prototype turbine to be used in a powerhouse with an available head of 60 m and a flow rate of 6·6 m^3/s. The speed selected for the prototype is 300 r.p.m. Find the scale-up factor and the number of turbines required for the powerhouse. Assume the same efficiency for the prototype.

12. A power station supplies the following loads to the consumers :

Time in hours	0 − 6	6 − 10	10 − 12	12 − 16	16 − 20	20 − 22	22 − 24
Load in MW	30	70	90	60	100	80	60

(a) Draw the load curve and estimate the load factor of the plant.

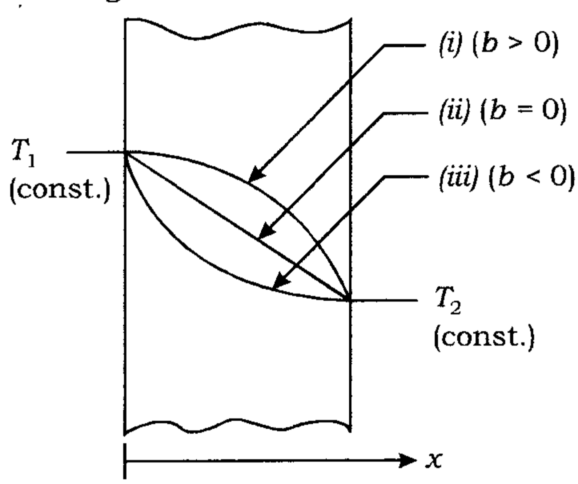
(b) What is the load factor of a standby equipment of 30 MW capacity, if it takes up all loads above 70 MW? What is its use factor?

GROUP—B

Candidates to attempt **05** ***(five)*** *questions within word limit of* **300**.
Each question carries **20** *marks.*

13. What is the principal role of Clapeyron equation during phase change? Derive Clapeyron equation.

14. Obtain an analytical expression for the temperature distribution $T(x)$ in the plane wall of given figure having uniform surface temperatures T_1 and T_2 at x_1 and x_2, respectively, and a thermal conductivity which varies linearly with temperature : $k = k_0(1 + bT)$. Verify that for $b > 0$, the temperature profile is concave downward as shown in the figure below.



15. Moist air enters a duct at 10 °C, 80% relative humidity, and a volumetric flow rate of 150 m^3/min. The mixture is heated as it flows through the duct and exits at 30 °C. No moisture is added or removed, and the mixture pressure remains approximately constant at 1 bar. For steady-state operation, determine *(a)* the rate of heat transfer, in kJ/min, and *(b)* the relative humidity at the exit without using Psychrometric chart. Changes in kinetic and potential energy can be ignored.

Use the following data : specific enthalpy of dry air at inlet = 283·1 kJ/kg; specific enthalpy of dry air at outlet = 303·2 kJ/kg; specific enthalpy of water vapour at inlet = 2519·8 kJ/kg; specific enthalpy of water vapour at outlet = 2556·3 kJ/kg; relative humidity at inlet = 0·8; saturation pressure of water vapour at 10 °C = 0·01228 bar, saturation pressure of water vapour at 30 °C = 0·04246 bar.

Candidate must not write on this margin.

16. A refrigeration compressor has two single-acting cylinders of 7·5 cm bore and 7·5 cm stroke and works as a single-stage compressor. The clearance is 4% of piston displacement. Ammonia vapour at – 10 °C with a degree of superheat of 5 °C, is compressed to a pressure having saturation temperature of 30 °C and to a temperature of 105 °C. Assuming heat transferred from the compressor to be 25 kJ/kg and the actual volumetric efficiency equal to 85% of the volumetric efficiency based on the idealized indicator diagram, calculate the following :

(a) the compressor adiabatic efficiency;

(b) the flow capacity of the compressor, if the compressor runs at 960 rev/min.

Properties of Ammonia $p(N/m^2)$	$t(°C)$	$V_g(m^3/kg)$	$h_g(kJ/kg)$
$2 \cdot 28 \times 10^5$	−15	0·5	1442·8
$11 \cdot 3 \times 10^5$	30	0·11	1465·1

Assume the average value of c_p of superheated ammonia vapour to be 2·675 kJ/kg.deg and n = 1·3.

17. In an axial flow turbine, the blade velocity is 60 m/s. The fluid enters at 30° to the plane of the wheel at a velocity of 80 m/s. Calculate the blade inlet angle. If the blades are to be designed for *(a)* R = 0·25 and *(b)* R = 0·5, then calculate the blade outlet angle and specific work in each case.

18. Steam enters a turbine steadily at 3 MPa and 450 °C at a rate of 8 kg/s and exits at 0·2 MPa and 150 °C. The steam is losing heat to the surrounding air at 100 kPa and 25 °C at a rate of 300 kW, and the kinetic and potential energy changes are negligible. The value of enthalpy and entropy at dead state P_0 = 100 kPa, T_0 = 25 °C are h_0 = 104·83 kJ/kg and s_0 = 0·3672 kJ/kg K. Determine *(a)* the actual power output, *(b)* the maximum possible power output, *(c)* the second-law efficiency, *(d)* the exergy destroyed and *(e)* the exergy of the steam at the inlet conditions.

$P(T_{sat})$ = 3 MPa (233·90 °C), T_{sat} is the saturation temperature.

T[°C]	v[m^3/kg]	u[kJ/kg]	h[kJ/kg]	s[kJ/kg K]
Sat. Liquid	0·00122	1004·78	1008·42	2·6457
Sat. Vapour	0·06668	2604·1	2804·2	6·1869
450 °C	0·10787	3020·4	3344·9	7·0856

$P(T_{sat})$ = 0·2 MPa (120·23 °C)

T[°C]	v[m^3/kg]	u[kJ/kg]	h[kJ/kg]	s[kJ/kg K]
Sat. Liquid	0·00106	504·49	504·70	2·6457
Sat. Vapour	0·06668	2604·1	2804·2	6·1869
150 °C	0·9596	2576·9	2769·1	7·2810

★★★

Candidate must not write on this margin.

SPACE FOR ROUGH WORK

Candidate must not write on this margin.

SEAL

SPACE FOR ROUGH WORK

Candidate must not write on this margin.

SEAL

CONFIDENTIAL