Candidate must not write on this margin.

CSM—49/23

PART—II/PAPER—VII

MECHANICAL ENGINEERING

PAPER—II

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. Argon gas enters an adiabatic turbine steadily at 900 kPa and 450 °C with a velocity of 80 m/s and leaves at 150 kPa with a velocity of 150 m/s. The inlet area of the turbine is 60 cm^2. If the power output of the turbine is 250 kW, determine *(i)* the mass flow rate of argon, *(ii)* the exit temperature of the argon and *(iii)* the exit diameter of the turbine. Argon may be considered as an ideal gas with gas constant, $R = 0{\cdot}2081$ kJ/kg.K and constant pressure-specific heat $C_p = 0{\cdot}5203$ kJ/kg.k.

2. A heat engine receives waste energy at 70 °C and rejects heat to the surroundings, which is at a temperature of 30 °C. The power developed by the engine is used to run a heat pump, which also absorbs waste energy at 70 °C and delivers the heat to a reservoir at 200 °C. The sum of the waste energy received by the heat engine and the heat pump is 10 MW. If the efficiency of the heat engine is 75% of its maximum efficiency and the COP of the heat pump is 75% of its maximum COP, determine : *(i)* the rate of heat delivered by the heat pump to the reservoir at 200 °C, *(ii)* the rate of exergy lost during the whole process and *(iii)* the rate of entropy generation of the universe during the whole process.

3. The wall of a refrigerator is constructed of fiberglass insulation ($k = 0{\cdot}035$ W/m °C) sandwiched between two layers of 1 mm thick sheet metal ($k = 15{\cdot}1$ W/m °C). The refrigerated space is maintained at 3 °C and the average heat transfer coefficients at the inner and outer surface of the wall are 4 W/m^2 °C and 9 W/m^2 °C, respectively. The average kitchen temperature is 25 °C. If the temperature of the outer surface of the refrigerator (open to the kitchen) is 20 °C, determine *(i)* the thickness of fiberglass insulation and *(ii)* the temperature of the inner surfaces of the refrigerator (facing the refrigerated space).

Candidate must not write on this margin.

4. The components of an electronic system dissipating 90 W are located in a 1 m long circular horizontal duet of 15 cm diameter. The components in the duct are cooled by forced air, which enters at 32 °C at a rate of 0·65 m^3/min. Assuming 85 percent of the heat generated inside is transferred to air flowing through the duct and the remaining 15 percent is lost through the outer surfaces of the duct, determine *(i)* the exit temperature of air and *(ii)* the highest component surface temperature in the duct. Assume uniform heat flux. Empirical correlations for the average Nusselt number is given by :

$$Nu_D = \frac{h_i D}{k} = 0{\cdot}023\,\mathrm{Re}_D^{0{\cdot}8}\,\mathrm{Pr}^{0{\cdot}4}$$

Air properties are : Density $(\rho) = 1{\cdot}143\ \mathrm{kg/m^3}$, kinematic viscosity $(\nu) = 1{\cdot}67 \times 10^{-5}\ \mathrm{m^2/s}$, thermal conductivity $(k) = 0{\cdot}0268$ W/m-K, specific heat at constant pressure $(C_p) = 1{\cdot}006$ kJ/kg.K.

5. Two thin radiation shields with emissivities of $\varepsilon_3 = 0{\cdot}10$ and $\varepsilon_4 = 0{\cdot}15$ on both sides are placed between two very large parallel plates, which are maintained at uniform temperatures $T_1 = 600$ K and $T_2 = 300$ K and have emissivities $\varepsilon_1 = 0{\cdot}6$ and $\varepsilon_2 = 0{\cdot}7$, respectively. Determine *(i)* the net rates of radiation heat transfer between the two plates with and without the shields per unit surface area of the plates and *(ii)* the temperatures of the radiation shields in steady operation. Stefan Boltzman constant, $\sigma = 5{\cdot}67 \times 10^{-8}\ \mathrm{W/m^2.K^4}$.

6. Humid air at a rate of 0·1 kg/s enters a heating and humidifying unit at 5 °C, 50% RH. The absolute total pressure of air is 1·02 bar. The air is heated in the heating section. In the humidifying section, liquid water at 10 °C and a rate of 0·002 kg/s is sprayed into the flowing air. The air leaves the unit at 30 °C, 1·02 bar. By using the property relations, calculate *(i)* the relative humidity at the outlet and *(ii)* the rate of heat transfer to the unit. The saturation pressure of water at 5 °C is 0·0873 kPa and at 30 °C, it is 4·2467 kPa. The enthalpy of liquid water at 10 °C is 42·02 kJ/kg.

7. A factory has an estimated maximum power demand of 700 kW and a load factor of 25%. Offers by two power supply agencies are as follows. Supply agency 1 : The tariff is ₹ 40 per kW of maximum demand plus 2 paise per kWh energy consumption, Capital cost = ₹ 70,000, Interest and depreciation = 10%. Supply agency 2 : Capital Cost = ₹ 2,50,000, Fuel consumption = ₹ 0·3 kg per kWh, Cost of fuel = ₹ 70 per tonne of fuel, Wages = 0·4 paise per kWh, Maintenance cost = 0·3 paise per kWh, Interest and depreciation = 15%. Determine the cost of energy per kWh for *(i)* supply agency 1 and *(ii)* supply agency 2.

Candidate must not write on this margin.

8. The following data apply to a double-sided centrifugal compressor : Impeller eye tip diameter = 0·28 m, Impeller eye root diameter = 0·14 m, Impeller tip diameter = 0·48 m, Mass flow of air = 10 kg/s, Inlet stagnation temperature = 290 K, Inlet stagnation pressure = 1 bar, air enters axially with velocity = 145 m/s, Slip factor = 0·89, Power input factor = 1·03, Rotational speed = 15000 r.p.m. Calculate *(i)* the impeller vane angles at the eye tip and eye root, *(ii)* the power input and *(iii)* the maximum Mach number at the eye.

9. A six-cylinder, four-stroke CI engine develops 130 kW of power output at 1800 r.p.m. The calorific value of the fuel is 42000 kJ/kg and its percentage composition by mass is 86% carbon, 13% hydrogen and 1% non-combustibles. The absolute volumetric efficiency is 85%, the indicated thermal efficiency is 38% and the mechanical efficiency is 80%. The air consumption is 110% in excess of that required for stoichiometric combustion. Estimate *(i)* the mass of oxygen in the exhaust gas per kg of fuel consumed, *(ii)* the mass flow rate of air to the engine and *(iii)* the bore and stroke of the engine, taking a stroke/bore ratio as 1·2. Assume the density of air at the given conditions as 1·3 kg/m^3.

10. A single-acting reciprocating air compressor has a cylinder bore of 15 cm and a stroke length of 25 cm. The crank speed is 600 r.p.m. Air is taken from the atmosphere (1 atm, 27 °C) and is delivered at 11 bar. Assuming the index for polytropic compression $n = 1{\cdot}25$. The compressor has a clearance volume, which is 1/20th of the stroke volume and its mechanical efficiency is 80%. Considering air as an ideal gas, determine *(i)* the volumetric efficiency of the compressor, *(ii)* the time required to deliver 1 m^3 of air at the compressor outlet conditions and *(iii)* the power required to drive the compressor.

11. Compare the advantages and disadvantages of steam power and hydroelectric power plants.

Candidate must not write on this margin.

12. Discuss the effects of detonation or knocking in Spark-Ignition Engines.

GROUP—B

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

13. Discuss various methods for controlling emissions of polluting gases from spark ignition engines.

14. Steam in a heating system flows through tubes whose outer diameter is 5 cm and whose walls are maintained at a temperature of 180 °C. Circular aluminium alloy 2024-T6 fins ($k = 186$ W/m °C) of outer diameter 6 cm and constant thickness 1 mm are attached to the tube. The spacing between the fins is 3 mm, and thus there are 250 fins per meter length of the tube. Heat is transferred to the surrounding air at $T_\infty = 25\,°\mathrm{C}$, with a heat transfer coefficient of 40 $\mathrm{W/m^2\,°C}$. The heat transfer efficiency of each fin is given as 97%. Determine the increase in heat transfer from the tube per meter of its length as a result of adding fins.

15. A shell-and-tube heat exchanger with 1-shell pass and 8-tube passes is used to heat ethyl alcohol ($C_p = 2670\,\mathrm{J/kg°C}$) in the tubes from 25 °C to 70 °C at a rate of 2·1 kg/s. The heating is to be done by water ($C_p = 4190\,\mathrm{J/kg°C}$) that enters the shell at 95 °C and leaves at 60 °C. The outer diameter of the tubes is 28 mm. If the overall heat transfer coefficient based on outer diameter of the tubes is 800 $\mathrm{W/m^2\,°C}$ and the length of the pipe in each pass is 1 m, determine *(i)* the mass flow rate of water, *(ii)* the number of tubes required and *(iii)* the effectiveness of the heat exchanger. Take LMTD correction factor as 0·93.

16. In an air refrigeration 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 is then expanded in a turbine to 0·1 MPa with an isentropic efficiency of 78%. The power developed by the turbine is fed to the compressor. The low-temperature air absorbs a cooling load of 3 tonnes of refrigeration at constant pressure before re-entering the compressor. Assuming air to be an ideal gas, determine *(i)* the air mass flow rate, *(ii)* the net power required to run the system, *(iii)* the COP of the refrigerator and *(iv)* the rate of heat rejection in the heat exchanger. Take, for air, the specific heat at constant pressure $C_p = 1{\cdot}005\,\text{kJ/kg-K}$.

17. An axial flow compressor has the following data : Blade velocity at mean radius = 185 m/s, Blade velocity at tip = 240 m/s, Stagnation temperature rise in this stage = 15 K, Axial velocity (constant from root to tip) = 140 m/s, work done factor = 0·85, Degree of reaction at mean radius = 50%. Calculate, for a free vortex design, the stage air angles *(i)* at the mean radius and *(ii)* at the tip.

18. A simple jet carburettor is required to supply 5 kg of air per minute and 0·4 kg per minute of fuel of density 780 kg/m^3. The air is initially at 1·013 bar and 27 °C. The airflow velocity at the throat is 90 m/s and the velocity coefficient for the venturi is 0·80. Assume isentropic flow of air and the flow to be compressible. Determine *(i)* the diameter of the throat. If the pressure drop across the fuel metering orifice is 0·75 of that at the throat and the coefficient of discharge of the fuel is 0·6, calculate *(ii)* the orifice diameter.

★★★

Candidate must not write on this margin.

SPACE FOR ROUGH WORK

Candidate must not write on this margin.

SPACE FOR ROUGH WORK

Candidate must not write on this margin.

SPACE FOR ROUGH WORK

Candidate must not write on this margin.