

MECHANICAL ENGINEERING (Paper II)

Time Allowed : Three Hours	Maximum Marks : 250
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QUESTION PAPER SPECIFIC INSTRUCTIONS

(Please read each of the following instructions carefully before attempting questions)

There are EIGHT questions divided in two Sections.

Candidate has to attempt FIVE questions in all.

Question Nos. 1 and 5 are compulsory and out of the remaining, any THREE are to be attempted choosing at least ONE question from each Section.

The number of marks carried by a question/part is indicated against it.

Wherever any assumptions are made for answering a question, they must be clearly indicated.

Word limit in questions, wherever specified, should be adhered to.

Attempts of questions shall be counted in sequential order. Unless struck off, attempt of a question shall be counted even if attempted partly. Any page or portion of the page left blank in the Question-cum-Answer Booklet must be clearly struck off.

SECTION 'A'

1. (a) Derive the optimum pressure ratio of an ideal gas turbine plant for maximum network. Also, show with the help of T-s diagram that, an optimum pressure ratio exists. **10**
- (b) Consider one-dimensional isentropic flow of a perfect gas. Derive an appropriate expression to show that the shape of the nozzle for supersonic flow is divergent in cross-section. **10**
- (c) A small sphere (of outside diameter = 60 mm) with a surface temperature of 300°C is located at the geometric centre of a large sphere (of inside diameter = 360 mm) with an inner surface temperature of 15°C. Calculate how much of emission from the inner surface of the large sphere is incident upon the outer surface of the small sphere. Assume that both bodies approach black body behaviour. What is the net interchange of heat between the two spheres? **10**
- (d) Steam at atmospheric pressure enters the shell of a surface condenser, in which the water flows through a tube bundle, at the rate of 0.05 kg/s. The inner diameter of the tube is 25 mm. The overall heat transfer coefficient, (U_i) based on the inner diameter is $230 \text{ W/m}^2 \text{ } ^\circ\text{C}$. The inlet and outlet temperatures of water are 15°C and 70°C, respectively. The condensation of steam takes place on the outside surface of the tubes. Calculate the following: (i) The effectiveness of the heat exchanger and NTU. (ii) Length of each tube. (iii) The rate of steam condensation. Assume C_p of water $4.18 \frac{\text{kJ}}{\text{kg } ^\circ\text{C}}$; $h_{fg} = 2257 \frac{\text{kJ}}{\text{kg}}$ (latent heat of condensation). **10**
- (e) Propane (C_3H_8) is burned with 100% excess air in an adiabatic burner. Both the fuel and air enter the burner at 25°C and 1 bar. Estimate the maximum temperature that can be attained in the flame. The molar heat capacities of the product gases are as follows:

$$C_p^\circ(\text{CO}_2) = 19.8 + 7.344 \times 10^{-2} T$$

$$C_p^\circ(\text{H}_2\text{O}) = 32.24 + 1.924 \times 10^{-3} T$$

$$C_p^\circ(\text{O}_2) = 28.11 - 3.68 \times 10^{-6} T$$

$$C_p(N_2) = 31.15 - 1.357 \times 10^{-2} T$$

Here C_p° is in J/mol. K and T is in K. Assume standard heat of this reaction as $\Delta H_{298}^\circ = -2045.5 \text{ kJ}$. **10**

2. (a) Explain what do you mean by kinetic energy correction factor. Show that the kinetic energy correction factor for laminar flow through a circular pipe is 2. Further, explain what will happen to the kinetic energy correction factor when the flow is considered to be turbulent. **20**
- (b) A plane wall 90 mm thick ($k = 0.18 \text{ W/m}^\circ\text{C}$) is insulated on one side while the other side is exposed to environment at 80°C . The rate of heat generation within the wall is $1.3 \times 10^5 \text{ W/m}^3$. If the convective heat transfer coefficient between the wall and the environment, (h) is $520 \text{ W/m}^2^\circ\text{C}$, determine the maximum temperature in the wall. Derive the expression used, starting from the steady state one-dimensional heat conduction with heat generation equation. **20**
- (c) Show that the slope of a reversible adiabatic process on a temperature versus pressure diagram, when multiplied by C_p is given by $T \nu \beta$. **10**
3. (a) A centrifugal compressor running at 16,000 rpm takes in air at 17°C and compresses it through a pressure ratio of 4 : 1 with an isentropic efficiency of 82%. The blades are radially inclined and the slip factor is 0.85. Guide vanes at inlet give the air an angle of pre-whirl of 20° to the axial direction. The mean diameter of the impeller eye is 200 mm and the absolute air velocity at inlet is 120 m/s. Calculate the impeller tip diameter. Take $C_p = 1.005 \frac{\text{kJ}}{\text{kg K}}$; $\gamma = 1.4$. Also draw the velocity triangles at inlet and impeller exit. **20**
- (b) A nine (9)-cylinder, 4-stroke petrol engine of bore 14.5 cm and stroke 18 cm, has a compression ratio of 7 : 1 and develops 350 kW at 2000 rpm when running on a mixture of 15% weak. The fuel used has a heating value of 47 MJ/kg and contains 85.2% C and 14.8 H_2 . Assuming a volumetric efficiency of 76% at 15°C and 1 bar and mechanical efficiency of 90%, calculate the indicated thermal efficiency of the engine. Given, $R = 287 \text{ J/kg-K}$. **20**
- (c) A boiler furnace of 3 m height is made in the shape of a frustum of a cone with the bottom diameter 5 m (d_1) and top diameter 6 m (d_2). The emissivity of both the surfaces is 0.9. The bottom surface is at 1000°C and the top surface is at 500°C . Considering the inclined surface is refractory surface, find (i) the radiation heat transfer from the bottom to top surface and (ii) the inclined surface temperature. Radiation Shape Factor $F_{1-2} = 0.4$. **10**
4. (a) A 2-stroke motor cycle petrol engine cylinder consists of 15 fins on its outer surface. If the outside and inside diameters of each fin are 200 mm and 100 mm respectively, the average fin surface temperature is 475°C and the atmospheric air temperature is 25°C , calculate the heat transfer rate from the fins for the following cases: (i) when the motor cycle is stationary; (ii) when the motor cycle is running at a speed of 60 kmph. The fin may be idealized as a single horizontal plate of the same area, and the significant length may be taken as $L = 0.9 d_o$, where d_o is the outer diameter of the fin. Assume d_o as 200 mm. The properties of air may be taken as follows: $k = 4.266 \times 10^{-2} \text{ W/m}^\circ\text{C}$; $\nu = 40.61 \times 10^{-6} \text{ m}^2/\text{s}$; $Pr = 0.677$ For turbulent flow (forced convection): $Nu = 0.036 (Re)^{0.8} (Pr)^{0.33}$ For natural convection: $Nu = 0.54 (Gr \cdot Pr)^{1/4}$ if $(Gr \cdot Pr) < 10^9$ $Nu = 0.10 (Gr \cdot Pr)^{0.33}$ if $(Gr \cdot Pr) > 10^9$. **20**
- (b) A gas turbine operating on actual simple Brayton cycle is to be designed for maximum output. If the maximum and minimum temperatures of the cycle, the efficiencies of compressor and turbine are fixed, derive the expression for optimum actual pressure ratio. What will be the value of optimum

pressure ratio for turbine, if the ratio of maximum and minimum temperature is 3 and $\gamma = 2$? Take efficiencies of turbine and compressor as 0.9 and 0.8 respectively. **20**

- (c) Explain what do you mean by Highest Useful Compression Ratio (HUCR) for S.I. engines and also state its importance. **10**

SECTION 'B'

5. (a) Justify the suitability of thermostatic expansion valve in comparison to automatic expansion valve. **10**
- (b) Explain with a neat sketch, how air charge, air consumption, torque and mechanical efficiency vary with the range of speed in I.C. engines. **10**
- (c)(i) A steam power plant, working on Rankine cycle has constant steam temperature. The condenser pressures are 25, 50 and 75 mm of Hg and inlet steam pressure varies from 20 to 160 bar. Explain with the help of performance curve and reason how the thermal efficiency will vary. **6**
- (c)(ii) Which are the factors effecting Nozzle efficiency? **4**
- (d) Air flows in a circular duct which suddenly contracts in the cross sectional area. Draw the flow sketch and locate the points on the sketch where turbulent flow will occur and calculate the dynamic loss co-efficient. Take the co-efficient of contraction as 0.62. **10**
- (e) What is an Orsat apparatus? Draw a neat diagram of Orsat apparatus and explain its functioning. **10**
6. (a) In a drier operating at steady state atmospheric air at 30°C and 101.325 kPa with a relative humidity of 40% is first heated to 110°C at constant pressure. The heated air is then allowed to pass over the material to be dried and the air leaves the drier at 70°C with a relative humidity of 0.5. If it is required to remove 60 kg/min of moisture from the material, determine the mass flow rate of dry air required in kg/min and the rate of heat transfer to the air as it passes through the heating unit. Use $h_{g110^\circ\text{C}}^{1\text{bar}} = 2696.12 \text{ kJ/kg}$. **20**

[Figure: Psychrometric chart (barometric pressure 1.01325 bar, sea level) printed below the question on the same page; marked "Do not write your Roll No. on this Sheet"]

- (b) The angles at inlet and discharge of the blading of a 50% reaction steam turbine are 35° and 20° respectively. The speed of rotation is 1500 rpm and at a particular stage, the mean ring diameter is 0.67 m, and the steam condition is 1.5 bar, 0.96 dry. Estimate (i) the required height of blading to pass 3.6 kg/s of steam, and (ii) the power developed by the ring. Assume, at 1.5 bar pressure, $v_f = 0.001052 \frac{\text{m}^3}{\text{kg}}$ and $v_{fg} = 1.15937 \frac{\text{m}^3}{\text{kg}}$. **20**
- (c) What are the functions of condenser in a refrigerating machine? Name different types of condensers. Describe with neat sketch the evaporative condenser. **10**
7. (a) A refrigerating machine, rated to produce 40 tons of refrigeration, is used for air conditioning between the operative temperatures of 42°C and 6°C of condenser and evaporator respectively. The refrigerant is dry saturated at the end of compressor. Find the capacity of the plant, power and capacities of compressor and condenser. Properties of refrigerant **20**

Temp. ($^\circ\text{C}$)	Pressure bar	Enthalpy (kJ/kg) h_f	Enthalpy (kJ/kg) h_g	Entropy (kJ/kg-K) S_f	Entropy (kJ/kg-K) S_g	Volume (m^3/kg)
42	1.957	249.7	410.7	1.125	1.6712	0.6975
6	0.5160	–	407.15	1.018	1.687	0.04035
–32	0.0875	–	390.85	0.9178	1.715	0.1665

If the evaporator's temperature is reduced to -32°C , what will be effect on capacity of plant, power and capacities of compressor and condenser?

- (b) Differentiate between normal and abnormal combustion in SI engines. List out the three major knock limited parameters and explain its use in the engine design. **10**
- (c) Dry saturated steam at 5 bar enters a convergent-divergent nozzle at a velocity of 100 m/s. The exit pressure is 1.5 bar. The throat and exit areas are 1280 mm^2 and 1600 mm^2 respectively. Assuming isentropic flow upto the throat and taking the critical pressure ratio as 0.58, estimate the mass flow rate. If the nozzle efficiency is 0.973, determine the exit condition of steam dryness fraction. Show the process on T-s and h-s diagrams. Properties of Steam **20**

P (bar)	Enthalpy (kJ/kg) h_f	Enthalpy (kJ/kg) h_{fg}	Entropy (kJ/kg K) s_f	Entropy (kJ/kg K) s_{fg}	Volume (m^3/kg) v_f	Volume (m^3/kg) v_{fg}
5.0	640.23	2108.5	1.8607	4.9606	0.00109	0.3708
2.9	556	2168	1.660	5.344	0.00107	0.6253
1.5	467.11	2226.5	1.4336	5.7897	0.00105	1.158

8. (a) In a cogeneration plant, the power load is 5.6 MW and the heating load is 1.163 MW. Steam is generated at 40 bar and 500°C and is expanded isentropically through a turbine to a condenser at 0.06 bar. The heating load is supplied by extracting steam from the turbine at 2.0 bar, which is condensed in the processor device to saturated liquid at 2.0 bar and then pumped back to the boiler. Compute, (i) the steam generation capacity of the boiler in kg/hr, (ii) the heat input to the boiler in kW, (iii) the fuel burning rate of the boiler in t/h, if a coal of calorific value 25 MJ/kg is burned and the boiler efficiency is 88, (iv) the heat rejected to the condenser (v) the rate of flow of cooling water in the condenser if the temperature rise of water is 6°C . Neglect pump works. Draw the T-s diagram. Properties of steam: At 40 bar 500°C . $v=0.08643 \text{ m}^3/\text{kg}$, $h=3445.3 \text{ kJ/kg}$, $s=7.0901 \text{ kJ/kg K}$. **20**

P_{sat} (bar)	Volume (m^3/kg) v_f	Volume (m^3/kg) v_g	Enthalpy (kJ/kg) h_f	Enthalpy (kJ/kg) h_g	Entropy (kJ/kg K) s_f	Entropy (kJ/kg K) s_g
2.0	0.00106	0.8857	520.72	2712.1	1.5706	7.0878
0.06	0.00101	25.22	149.79	2565.79	0.520	8.335

- (b) Discuss the lubrication of the following engine parts with the help of neat sketches: (i) Main bearings (ii) Cylinder and small end bearing of connecting rod (iii) Crank and Gudgeon pin. **15**
- (c) Explain with a sketch how heat is absorbed at various stages from feed water to steam generation in water tube boilers. **15**
