

MECHANICAL ENGINEERING

(Paper II)

Time Allowed : Three Hours	Maximum Marks : 300
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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.

SECTION 'A'

1. Answer any three of the following (Answers to each of the parts (a), (b) and (c) should be in about 200 words only): **20×3=60**

- (a) The equation of state of a certain gas is $v = RT/P + K/RT$ (where K is a constant). Show that the change in temperature during throttling (enthalpy before and after remaining the same) of such a gas from an initial pressure P_1 to a final pressure P_2 is given by

$$\frac{T_2^2 - T_1^2}{4K} = \frac{P_1 - P_2}{C_p R}$$

where C_p is assumed constant during the process 1-2.

- (b) Consider a large plane wall of thickness $L = 0.3$ m, thermal conductivity $k = 2.5$ w/m-K, and surface area $A = 12$ m². The left side of the wall at $x = 0$ is subjected to a net heat flux of $q = 700$ w/m², while the temperature at that surface is maintained at $T_1 = 80$ °C. Assuming constant thermal conductivity and no heat generation in the wall: (i) express the differential equation and boundary conditions for steady, one-dimensional heat conduction through the wall (ii) Obtain a relation for the variation of temperature in the wall by solving the differential equation. (iii) Evaluate the temperature of the right surface of the wall.
- (c) With the help of diagrams, explain the following: (i) Normal shock, (ii) Oblique shock, (iii) Attached shock and (iv) Detached shock. Explain why shock-waves cannot develop in a subsonic flow.
- (d) Explain the effect of the following factors on the performance of an SI engine: (i) spark timing (ii) engine speed (iii) mass of induced charge (iv) heat losses.

2. (a) Reflectivity measurements are often used to obtain surface radiation properties. Diffuse spectral reflectivity of a fire brick wall maintained at 500 K is shown below: **40**

[Figure: Graph of spectral reflectivity ρ_λ (vertical axis, marks 0.2, 0.5, 0.9, 1.0) against wavelength λ (μm) (horizontal axis, marks 0, 2.4, 12, $\rightarrow \infty$). Step function: $\rho_\lambda = 0.9$ for $0 < \lambda < 2.4$ μm; $\rho_\lambda = 0.5$ for $2.4 < \lambda < 12$ μm; $\rho_\lambda = 0.2$ for $\lambda > 12$ μm (continuing to ∞).]

The wall is exposed to a bed of coal at 2500 K. Determine the total hemispherical emissivity and emissive power of the fire brick wall. What is the total absorptivity of the wall to the irradiation resulting from emission by coal? Use the following Planck's radiation functions:

λT (μmK)	$F(0-\lambda)$
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1200,	0.0025
6,000	0.7393
30,000	0.9912

Assume that the brick wall is opaque and the spectral distribution of irradiation at the brick wall approximates that due to emission from a black body at 2500 K.

- (b) A 30 cm × 30 cm horizontal duct made of sheet metal carries warm air. The duct is maintained at 65°C and is 10 m long. Heat loss from duct to the ambient air takes place due to free convection only. If the ambient air is at 25°C, calculate the heat loss from the duct. Use the following free convection correlations. Heat transfer from the upper surface of a horizontal plate: $Nu = 0.54 (Ra_L)^{1/4}$; Heat transfer from the lower surface of a horizontal plate: $Nu = 0.27 (Ra_L)^{1/4}$; Heat transfer from vertical plate: $Nu = 0.59 (Ra_L)^{1/4}$. The properties of air at 45° are: $Pr = 0.695$, $\nu = 1.85 \times 10^{-5} m^2/sec$, $k = 0.028$ w/mK. **20**
3. (a) Derive an equation for a Fanno flow. Give two examples of Fanno flow in thermal system. Show that the upper and lower branches of a Fanno curve represent subsonic and supersonic flows respectively. **25**
- (b) Air at 1 MPa and 600°C enters a converging nozzle with a velocity of 150 m/s. Determine the mass flow rate through the nozzle for a nozzle throat area of $50 cm^2$ when the back pressure is (i) 0.7 MPa and (ii) 0.4 MPa. Given: $C_p = 1.005 kJ/kg \cdot K$; $K = 1.4$; $R = 0.287 kJ/kg \cdot K$. For, $P_t/P_0 = 0.670$, $Ma_t = 0.778$ and $T_t/T_0 = 0.892$ where, subscript t represents the properties at the throat. **25**
- (c) For compressible flows, explain with the help of diagrams, the shapes of nozzles and diffusers in subsonic and supersonic regimes. **10**
4. (a) The following set of observations refer to a trial on a Single-cylinder, Four-stroke, Solid injection diesel engine of 200 mm-bore and 400 mm stroke: Gross mean effective pressure = 6.2 bar; Pumping mean effective pressure = 0.44 bar; Speed of the engine = 262 rpm; Brake torque = 668 N-m; Fuel supply rate = 4.5 kg/hr; Calorific value of the fuel = 52,000 kJ/kg; Cooling water flow rate = 6 kg/min; Cooling water temperature gain = 47°C. Calculate the Indicated Power, Brake Power and Mechanical efficiency of the engine. Draw up a heat balance sheet for the trial expressing various quantities in kJ/min, if the fuel contains 13.5% H_2 (by mass) and air supply to the engine is 2.71 kg/min at 17°C. The exhaust gases leave the engine at 400°C. The following data may be used: Mean specific heat of exhaust gases = 1 kJ/kgK; Specific heat of steam = 2.1 kJ/kgK; Latent heat of steam = 2250 kJ/kg. Estimate the heat carried away by steam in exhaust gases. **50**
- (b) List the advantages and disadvantages of hydrogen as an alternative IC engine fuel. Explain two methods by which hydrogen can be used in CI engine. **10**

SECTION 'B'

5. Answer any THREE of the following:–
- (a) How do you classify draught? What are the advantages of the forced draught over the induced draught? What are the limitations of chimney draught? What are the different losses taken into consideration in designing the draught system? **20**
- (b) Explain with a neat diagram the working of a supercharged boiler. What are its advantages over conventional boilers? Why economizers are essentially used irrespective of the fuel used in boiler furnace? **20**
- (c) The input-output curve of a 60 MW power station is given by $I = 5 \times 10^6 [8 + 8L + 0.4L^2]$ kJ/hr. where, I = Input in kJ/hr; L = Load in MW. Determine: (i) The heat input per day to the power

station if it works for 20 hours at full load and remaining period at no load. (ii) Saving per kWh of energy produced if the plant works at full load for all 24 hours generating the same amount of energy. **20**

- (d) A customer complained of poor cooling for an air-conditioning system of 100 TR capacity. The supplier carried out test on condenser which is water cooled and noted power input to the motor. The observations made are as under: Cooling water flow rate: 10 liter/sec; Inlet water temperature: 30°C; Outlet water temperature: 41.12°C; Power input to motor: 120 kW (94.92 % efficiency). Determine the actual refrigerating capacity and state whether the cooling capacity is lower, higher or as per specifications. **20**

6. (a) Explain with the help of diagrams the difference of working between an open cycle gas turbine and a closed cycle gas turbine. What advantages are derived by using regeneration for open cycle constant pressure gas turbine? Explain properly with the help of diagram. **30**

- (b) Deduce expressions for optimum pressure ratio for (i) maximum specific output work and (ii) max. cycle efficiency for a Brayton cycle in terms of highest and lowest temperatures in the cycle and considering isentropic efficiencies of turbo-compressor and turbo-expander. **30**

7. (a) Develop an expression for enthalpy of moist air per unit mass of dry air as under: $h = 1.005t + w(2500 + 1.88t)$ kJ/kg where t is DBT and w is humidity ratio. **15**

- (b) Discuss the importance of liquid-vapour heat exchanger (LVHE) in the vapour compression refrigeration system. Clearly mention advantages and disadvantages of using such heat exchangers. Represent the cycle on T-s and P-h diagrams and illustrate the influence of LVHE. **15**

- (c) Moist air enters a chamber at 5°C DBT and 2.5°C WBT at a rate of $90 \text{ m}^3/\text{min}$. The barometric pressure is 1.01325 bar. While passing through the chamber, the air absorbs sensible heat at the rate of 40.7 kW and picks up 40 kg/hr of saturated steam at 110°C. Determine the dry and wet bulb temperatures of leaving air. Properties of steam are given below: Enthalpy of saturated steam at 110°C is 2691.3 kJ/kg. **30**

8. (a) For a Rankine cycle, using usual notations, show that the thermal efficiency can be expressed as:

$$\eta_{th} = 1 - \frac{h_2 - h_3}{h_1 - h_4}$$

and the second law efficiency can be expressed as:

$$\psi = \eta_{th} \left(\frac{T_H}{T_H - T_0} \right)$$

where T_H is the highest temperature in the entire system and T_0 is the condensation temperature. **15**

- (b) “The boiler efficiency is very high as against the thermal efficiency of Rankine cycle.” Comment on this statement with the help of laws of thermodynamics and schematic diagrams. **10**

- (c) A reaction turbine having identical blading delivers dry saturated steam at 3 bar. The velocity of steam is 100 m/sec. The mean blade height is 40 mm and the exit angle of the moving blade is 20°. At the mean radius, the axial flow velocity equals 3/4th of blade speed. For a steam flow rate of 10,000 kg/hr, determine: (a) the rotor speed in rev/min, (b) the power output of stage, (c) the diagram efficiency, (d) the percentage increase in relative velocity in the moving blade due to expansion in these blades and (e) The enthalpy drop of steam in the stage. Specific volume of dry saturated steam at 3 bar is $0.6055 \text{ m}^3/\text{kg}$. **35**
