2008

8631

CBR-308-HOF-43

MECHANICAL ENGINEERING - 2008

Paper I 000,56

(Conventional)

70

Time Allowed : Three Hours | *Maximum Marks : 200*

INSTRUCTIONS

Candidates should attempt FIVE questions.

The number of marks carried by each question is indicated at the end of the question.

Answers must be written in ENGLISH.

Assume suitable data, if necessary, and indicate the same clearly.

For air $R = 0{\cdot}287$ kJ/kg-K, $C_p = 1{\cdot}005$ kJ/kg-K, $\gamma = 1{\cdot}4$, $M = 28{\cdot}966$ kg/kg-mole

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1. (a) A finite thermal system having heat capacity, $C = 0{\cdot}04\ T^2$, J/K is initially at 600 K. Estimate the maximum work obtainable from the thermal system if the surroundings is at 300 K. *8*

(b) State Gouy – Stodola theorem of irreversibility. Estimate the irreversibility associated with the expansion process of air through a very small constriction in a pipe from pressure and temperature, respectively of 8 bar and 600 K to pressure of 1·2 bar. Assume air to be an ideal gas. The temperature of surroundings is 25° C. *7*

(c) A tank contains 50 kg of water initially at a temperature of 30° C. Water at the rate of 200 kg/h and temperature of 30° C enters the tank through an inlet pipe. A cooling coil immersed in the tank removes heat energy from water at the rate of 8 kW. A mechanical stirrer ensures thorough mixing of water in the tank so as to maintain a uniform temperature of water at any instant and in the process add heat energy at the rate of 0·2 kW to water.

Neglecting kinetic and potential energy changes and taking the average specific heat of water as 4·2 kJ/kg-K, derive an expression for the variation of instantaneous temperature of water in the tank with respect to time. 10

(d) Show that the properties at the critical state for a gas obeying van der Waals equation of state $p = \frac{RT}{V - b} - \frac{a}{V^2}$ are given by

$p_c = \frac{a}{27 b^2}$, $V_c = 3b$ and $T_c = \frac{a}{27 Rb}$.

Hence show that the coefficients 'a' and 'b' are expressed as

$a = \frac{27 R^2 T_c^2}{64 p_c}$ and $b = \frac{RT_c}{8 p_c}$ and the critical coefficient for the van der Waals gas is 2·66.

2. (a) What is supercharging of diesel engine power plant ? What are its objectives ? Discuss various methods of supercharging. *15*

(b) The following data are known for a four cylinder four stroke petrol engine : cylinder dimensions : 11 cm bore, 13 cm stroke; engine speed : 2250 rpm; brake power : 50 kW; friction power : 15 kW; fuel consumption rate : 10·5 kg/h; calorific value of fuel : 50,000 kJ/kg; air inhalation rate : 300 kg/h; ambient condition : 15° C, 1·03 bar. Estimate (i) brake mean effective pressure (ii) volumetric efficiency (iii) brake thermal efficiency, and (iv) mechanical efficiency. *10*

(c) Using a simple vertical sectional diagram, explain the function of principal components of the nuclear reactor of a pressurised water reactor (PWR) nuclear power plant. List the advantages and disadvantages of PWR nuclear power plant. *15*

3. (a) A copper sphere weighing 3 kg is heated in a furnace to a temperature of 300° C and is suddenly taken out and allowed to cool in ambient air at 25° C.

If it takes 60 min for the copper sphere to cool down to 35° C, what is the average surface heat transfer coefficient ? Take density of copper sphere = 8950 kg/m^3 and specific heat C_p = 0·383 kJ/kg °C.

State the assumptions made and derive the relation used. *10*

(b) From the von Karman's integral momentum equation for the laminar boundary layer under forced convective conditions, obtain the expressions for the hydrodynamic boundary layer thickness and the drag coefficient for the case of a linear velocity profile in the boundary layer. *10*

(c) The base of a rectangular enclosure (150 cm × 100 cm) and height 150 cm is maintained at 500° C. The top surface is held at 350° C. If the side walls are perfectly insulated and the surfaces are diffuse grey with an emissivity of 0·7, calculate (i) the net rate of heat supply to the base. (ii) If the skin temperature of the outside of the top wall is at 70° C and heat loss from this surface to a big factory shed at 30° C, what is the convective heat transfer coefficient at this surface ? *20*

4. (a) The discharge Q over a V-shaped notch is known to depend on the angle θ of the notch, the head H of the water surface, the velocity of approach V_o and the gravity g. Find the dimensionless form of the discharge equation. *10*

(b) If gravity, viscosity and surface tension are equally important in a model, show that for dynamic similarity, the relationship between viscosity ratio μ_r, surface tension ratio σ_r and model scale ratio L_r is given by

$$\frac{\mu_r L_r^{1/2}}{\sigma_r} = 1$$

15

(c) A thin rectangular plate 10 m long and 2 m wide is to be towed in sea water at a steady speed of 5 m/s. Both the surfaces of the plate are rough, whose roughness magnitude is assumed as 5 mm. Estimate the power required to tow the plate. Assume $\rho = 1020$ kg/m^3 and $\mu = 0{\cdot}0018$ Pa.s. *15*

5. (a) By using the energy equation

$$V\,dv + \frac{dp}{\rho} + d\,(\text{losses}) = 0,$$

the continuity equation ρAV = constant, and

$C = \sqrt{\frac{dp}{d\rho}}$, show that for subsonic flow in a pipe, the velocity must increase in the downstream direction. *10*

(b) Show that oblique and normal shock waves in a gas are analogous to open-channel waves when the open channel width is constant. *15*

(c) Helium enters a 100 mm-1D pipe from a converging-diverging nozzle at $M = 1{\cdot}30$, $P = 14$ kPa, $T = 225$ K. Estimate for an isothermal flow (i) the maximum length of pipe for no choking, (ii) the downstream conditions, and (iii) the length from the exit to the section where $M = 1{\cdot}0$, $f = 0{\cdot}016$. *15*

6. (a) A horizontal pipe of diameter D_1 has a sudden expansion to a diameter D_2. At what ratio D_1/D_2 would the differential pressure on either side of the expansion be maximum ? What is the corresponding loss of head and differential pressure head ? *10*

(b) In an isentropic flow, for flow conditions termed critical at the throat section, show that for an air flow having K = 1·4, the absolute temperature drops about 17% from reservoir to throat, the critical pressure is 52·8% of the reservoir pressure and the density is reduced by 37%. *15*

(c) The frictional torque T of a disc of diameter D rotating at a speed N in a fluid of viscosity μ and density ρ in a turbulent flow is given by

$$T = D^5 N^2 \rho \varphi \left[\frac{\mu}{D^2 N \rho}\right].$$

Prove this by the method of dimensions. *15*

7. (a) A jet of water makes an angle with the direction of motion of a series of moving blades. If the blade angle at inlet and outlet are θ and ϕ with the direction of motion, derive an expression for the work done. If there is no shock at entry, show that the maximum efficiency that can be achieved from the system is

$$\eta_{max} = \frac{\cos^2 \alpha}{2}\left[1 + \frac{K \cos \phi}{\cos \theta}\right].$$ Assume

$K = \left(\frac{V_{r_2}}{V_{r_1}}\right)$. Also state what would be the maximum efficiency for semi-circular vanes when K = 1. *15*

(b) Discuss briefly the classification of a hydroelectric plant based on

(i) availability of water head

(ii) nature of load capacity. *10*

(c) During a trial run on a pump, cavitation occurred when the sum of static pressure and velocity head at inlet was reduced to 3·2 m. The pump total head was 35 m at a discharge of 0·045 m^3/sec. The vapour pressure of water = 1·8 kPa and the barometer pressure = 750 mm of Hg. If the pump is to operate at some other location where the atmospheric pressure was reduced to 620 mm of Hg and the temperature is so reduced that the vapour pressure of water is 830 Pa, what is the value of cavitation parameter when the pump develops the same total head and discharge ? Is it necessary to reduce the height of the pump and if so, by how much ? *15*

8. (a) A two stage compression with intercooling in between stages and a single stage turbine with regeneration is employed in an open cycle gas turbine plant. Air at 1 bar and 15° C enters the compressor and the maximum pressure ratio is 5 and the maximum temperature in the cycle is 800° C. The rate of air flow through the cycle is 250 kg/sec and the calorific value of the fuel used

is 42 MJ/kg. The isentropic efficiencies of both the compressors is 0·8 and the effectiveness of the regenerator is 0·7, and the isentropic efficiency of the turbine is 0·9. The combustion efficiency is 0·95, the mechanical efficiency is 0·96 and the generator efficiency is 0·75. Take C_p of air = 1·005 kJ/kg K and γ = 1·4 and for gases C_p = 1·08 kJ/kg K and γ = 1·33.

Assuming perfect intercooling and neglecting pressure and heat losses, determine

(i) the air fuel ratio

(ii) the cycle efficiency

(iii) the power supplied by the plant

(iv) the specific fuel consumption and the fuel consumption per hour *15*

(b) What is a supercritical boiler ? What are its merits and demerits ? *8*

(c) In a reaction turbine with radial vanes at inlet, the velocity of flow at outlet is 'K' times that at inlet. Prove that

$$\eta_h = \frac{2}{2 + K^2 \tan^2 \alpha} \quad \text{and}$$

$$u_1 = \sqrt{\frac{2 g H}{2 + K^2 \tan^2 \alpha}} .$$ *10*

(d) Why are steam turbines compounded ? What are the different methods of compounding ? *7*