1·F·S–2009

Sl. No. 541

B–JGT–J–NFB

MECHANICAL ENGINEERING

Paper—II

Time Allowed : Three Hours	Maximum Marks : 200

INSTRUCTIONS

Candidates should attempt Question Nos. 1 and 5 which are compulsory, and THREE of the remaining questions, selecting at least ONE question from each Section.

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

Answers must be written in ENGLISH only.

If any data is considered insufficient, assume suitable value and indicate the same clearly.

Newton may be converted to kgf using the equality 1 kilonewton (1 kN) = 100 kgf, if found necessary.

All answers should be in SI units.

Take : 1 kcal = 4·187 kJ and 1 kg/cm^2 = 0·98 bar
1 bar = 10^5 pascals

Universal gas constant = 8314·6 J/kmol-K

Section—A

1. Answer any *four* parts :

(a) With the help of Maxwell's relations, prove that Joule-Thomson coefficient (μ_j) of a gas is given by

$$\mu_j = \left(\frac{\partial T}{\partial p}\right)_h = \frac{T^2}{C_p}\left[\frac{\partial}{\partial T}\left(\frac{v}{T}\right)\right]_p$$

What does this equation signify? 10

(b) Discuss the functions of intake and exhaust systems of an SI engine with their design objectives and sketches. 10

(c) Discuss the parameters affecting engine heat transfer. 10

(d) *(i)* Define thermal boundary layer and show its distribution over a flat plate. 5

(ii) Prove Reynolds' analogy with reference to turbulent flow as given below : 5

$$St_x = \frac{C_{fx}}{2}$$

(e) Bring out the various psychrometric processes that are shown on a psychrometric chart and give a simple sketch of each system to achieve it. 10

2. *(a)* 100 kg/s of steam enters a steam turbine at an enthalpy of 3250 kJ/kg and a velocity of 160 m/s. The steam comes out at an enthalpy of 2640 kJ/kg with a velocity of 100 m/s. At steady-state condition, the turbine develops work equal to 55 MW. Heat transfer between the turbine and surroundings occurs at an average outer temperature of 350 K. The entropy of steam at inlet and exit of the turbine are 6·93 kJ/kg-K and 7·35 kJ/kg-K respectively. Neglect the changes in potential and kinetic energy between inlet and outlet. Work out the following :

(i) Draw the system with control volume and show the processes on p-v and T-s diagrams

(ii) The rate at which entropy is produced within the turbine per kg of steam flowing

(iii) Suggest methods to improve the performance of the steam turbine 20

(b) A satellite incorporates a reversible heat engine which operates between a hot reservoir at T_1 and a radiating panel at T_2. The radiation from the panel is given by $Q_2 = kAT_2^4$, where k is Stefan-Boltzmann constant and A is the area of the panel. Work out the following :

(i) Draw the system under given conditions

(ii) Prove that the area of the panel for a given work output and a value of T_1 will be minimum when $T_2 / T_1 = 3/4$

(iii) Further, prove that the minimum area of the panel will be given by

$$A_{\min} = \frac{256W}{27kT_1^4}$$

where W is the output of the engine 20

3. *(a)* In a simple carburettor, the petrol in the float chamber stands 6 mm below the jet opening. The engine consumes 6·4 kg fuel/h. The fuel jet diameter is 1·25 mm and the discharge coefficient of the fuel orifice is 0·64. If the air-fuel ratio is 16 : 1, estimate—

(i) the air velocity at the throat;

(ii) the throat diameter;

(iii) the pressure drop in cm of water.

The coefficient of discharge for air is 0·85 and the ambient conditions are pressure = 1 bar and temperature = 288 K. Take the density of fuel and air as 770 kg/m^3 and 1·1122 kg/m^3 respectively. Neglect compressibility effect. 20

(b) A four-cylinder petrol-fueled car is to be converted to run on *(i)* CNG and *(ii)* hydrogen. Draw schematic diagrams indicating the changes required for conversion in each case. Justify your answer on the basis of the properties of the fuels. 20

4. *(a)* For some high degree of research work in the field of medicine, liquid nitrogen is stored in a spherical thin-walled metallic container at 100 K. The container has a diameter of 0·8 m and is covered with an evacuated reflective insulation composed of silica powder ($K = 0{\cdot}0017$ W/m-K). The insulation is 35 mm thick and the outer surface is exposed to ambient air at 30 °C. The convective heat transfer coefficient between ambient air and insulation is 20 W/m^2-K. The latent heat of vaporization and the density of liquid nitrogen are 200 kJ/kg and 805 kg/m^3 respectively. Work out the following :

(i) Sketch the system and thermal circuit, and write the assumptions made

(ii) The rate of heat transfer to the liquid nitrogen

(iii) The rate of liquid boil-off and the loss per day 20

(b) With the help of a suitable diagram, explain the purpose of cascading vapour compression refrigeration systems.

In an ammonia vapour refrigeration plant, the pressure range is from 3·15 bar in the evaporator to 10·5 bar in the condenser, the compression is isentropic and before entering the throttle valve the refrigerant ammonia is subcooled. The temperatures of the refrigerant at entry and exit from the condenser are 50 °C and 20 °C respectively, and the water being circulated in the condenser at the rate of 10·5 kg/min has a temperature rise of 10 °C. The compressor unit is single-cylinder, single-acting with bore 10 cm, stroke 15 cm while running at 200 rev/min having an indicated mean effective pressure equal to 3·5 bar.

If the plant produces 50 kg/h of ice at 0 °C from water at 15 °C, determine *(i)* COP, *(ii)* flow rate of refrigerant and *(iii)* condition of vapour at entry to the compressor. Take latent heat of ice as 335 kJ/kg. The relevant properties of ammonia are as follows :

Pressure (bar)	*Saturation temperature* (K)	*Enthalpy* (kJ/kg)		*Specific heat* (kJ/kg-K)	
		Liquid	*Vapour*	*Liquid*	*Vapour*
3·15	264	−35·6	1264	—	—
10·5	304	134	1294	4·6	2·8

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Section—B

5. Answer any *four* parts :

(a) Discuss the stalling phenomena in an axial flow compressor and write its effects on the performance. 10

(b) Define Fanno and Rayleigh lines with reference to normal shock wave. Show these lines on *h*-*s* diagram for subsonic, sonic and supersonic conditions. Give the physical meaning of these lines. 10

(c) With the help of a sketch, discuss the working principle of a pulverized coal direct-firing system of a steam power plant. 10

(d) With the help of a sketch, discuss the working principle of bubbling fluidized-bed boiler. 10

(e) Discuss the need of governing of steam turbines. With the help of a sketch, discuss the working principle of a hydromechanical speed-governing loop. 10

6. (a) In a solar water-heating system, a flat-plate solar collector with no cover plate is used to collect the solar radiation to heat water. The surface emissivity of the absorber is 0·15 while the solar absorptivity is 0·96. At a given time of the day, the absorber temperature is 120 °C when the solar irradiation is $800\ W/m^2$, the effective sky temperature is −6 °C. The ambient temperature is 27 °C. Assume that the heat transfer convection coefficient for the calm dry condition is given by

$$h = 0 \cdot 23(T_s - T_\infty)^{1/3}\ W/m^2\text{-K}$$

Assume steady-state condition, bottom surface is well-insulated and the absorber surface is diffused. Work out the following :

(i) Sketch the system and its control volume

(ii) The useful heat removal rate in W/m^2 from the collector

(iii) The efficiency of the collector

(iv) State effect on collector efficiency with reasoning, if the cover plate is installed 20

(b) (i) For an office of $6 \text{ m} \times 3 \text{ m} \times 4 \text{ m}$ size, the inside and outside conditions are dbt = 22 °C, $\phi = 55\%$ ($h = 45$ kJ/kg) and dbt = 40 °C, wbt = 26 °C ($h = 80 \cdot 5$ kJ/kg and $\nu = 0 \cdot 94 \text{ m}^3/\text{kg}$ of dry air) respectively. Further, it may be presumed that the office has structural load of 6000 kJ/h, 5 tube lights each of 40 W ratings, 13·5 air changes per 24 hour for the infiltration load, $7 \cdot 1 \times 10^{-3} \text{ m}^3/\text{s}$ per person of ventilation, 10 persons' occupancy and each occupant releases 500 kJ/h.

Work out the capacity of a window air-conditioner that will suffice to achieve the desired objective. 10

(ii) A steam power plant employs a wet-type cooling tower which receives warm water at 30 °C at the rate of 1·2 kg per kg of air. Air enters the tower at the dbt of 20 °C and relative humidity of 60% and leaves it at a dbt of 28 °C and 90% relative humidity. Make-up water is added at 20 °C. Calculate—

(A) the temperature of water leaving the tower;

(B) the approach and range of the cooling tower;

(C) the fraction of water evaporated.

For inlet (1) and outlet (2) air

$t_{wb_1} = 15 \cdot 2$ °C

$t_{wb_2} = 26 \cdot 7$ °C

$h_1 = 43$ kJ/kg dry air

$h_2 = 83 \cdot 5$ kJ/kg dry air

$\omega_1 = 0 \cdot 00881$ kg water vapour/kg dry air

$\omega_2 = 0 \cdot 02132$ kg water vapour/kg dry air

$h_v = 84$ kJ/kg 10

7. *(a)* An industrial centrifugal compressor running at 9000 r.p.m. delivers 650 m^3/min of free air. The air is compressed from 1 bar and 30 °C to a pressure ratio of 4·5 with an isentropic efficiency of 0·86. Blades are radial at outlet and the flow velocity of 70 m/s may be assumed throughout constant. The outer radius of impeller is twice the inner and the slip factor may be assumed as 0·92. At inlet, the blade area coefficient may be taken as 0·95. Work out the following :

(i) Draw the system and show the compression process on *h-s* diagram. Also, draw velocity diagrams

(ii) The final temperature of air

(iii) The power input to compressor, if mechanical efficiency is 0·95

(iv) The impeller diameter at inlet and outlet

(v) The breadth of impeller at inlet

(vi) The impeller blade angle at inlet 20

(b) A 15-stage 50% reaction turbine develops a diagram power of 10 MW. The inlet condition of steam is at 15 bar, 350 °C, while the condenser pressure is 0·14 bar. The stage efficiency is 75% for each stage and the reheat factor is 1·04. At a certain stage, the steam is at 1 bar, dry saturated. The exit angle of the blades is 20° and the blade velocity ratio is 0·7. The blade height may be taken as 1/12 of the mean blade diameter. Work out the following :

(i) The flow rate of steam required, assuming that all the stages develop equal work

(ii) The mean blade diameter

(iii) The speed of the rotor

(iv) Sketch the system and velocity diagrams, and show the process on *h*-*s* diagram

Given that enthalpy drop (from Mollier chart) = 855 kJ/kg. At 1 bar, $v_g = 1 \cdot 694\ m^3/kg$. 20

8. *(a)* Draw a labelled schematic diagram of a modern radiant power boiler with natural circulation. Clearly show *(i)* boiler drum, *(ii)* various accessories, *(iii)* primary air and secondary air supply systems, and *(iv)* feedwater system. How is the balance draft created? Explain. 20

(b) Differentiate between a base load and a peak load power plant. Explain with suitable examples.

A power plant caters to a peak load of 160 MW. It has an annual load factor of 0·85, capacity factor of 0·8 and use factor of 0·82. Calculate—

(i) the annual energy produced;

(ii) reserve capacity over and above the peak load;

(iii) hours during which the plant is not in service per year;

(iv) annual revenue earned, if the energy is sold at Rs 3 per kW. 20

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