CSM – 55/18

Mechanical Engineering

Paper – II

Time : 3 hours

Full Marks : 300

The figures in the right-hand margin indicate marks.

Candidates should attempt Q. No. 1 from Section – A and Q. No. 5 from Section – B which are compulsory and ***three*** *of the remaining questions, selecting at least* ***one*** *from each Section.*

SECTION – A

1. Answer any **three** of the following :

   (a) A reversible engine works between three thermal reservoirs **P**, **Q** and **R**. The engine absorbs an equal amount of heat from the thermal reservoirs **P** and Q kept at temperatures T_P and T_Q respectively, and

rejects heat to the thermal reservoir R kept at temperature T_R. The efficiency of the engine is β times the efficiency of the reversible engine, which works between the two reservoir P and R. Prove that : 20

$$\frac{T_P}{T_Q} = (2\beta - 1) + 2(1 - \beta)\frac{T_P}{T_R}$$

(b) A reciprocating air compressor takes in $2m^3$/min at 0.11 MPa, 20° C of air which it delivers at 1.5 MPa, 111° C to an after cooler where the air is cooled at constant pressure to 25° C. The power absorbed by the compressor is 4.15 kW. Determine the heat transfer in (i) the compressor, and (ii) the cooler, state your assumptions. 20

(c) A refrigerator is designed to cool 280 kg/hr of hot liquid of specific heat 3350 J/kg at 120°C using a parallel flow arrangement heat exchanger. 1200 kg/hr of cooling water is available for cooling purpose at a

temperature of 15°C. If the overall heat transfer coefficient is 1190 W/m^{2}K and the surface area of the heat exchanger is 0.35m^2, calculate the outlet temperature of the cooled liquid, water and also the effectiveness of the heat exchanger. 20

(d) A turbine blade 6 cm long and having a cross sectional area 5 cm^2 and perimeter 14 cm, is made of stainless steel (K = 23.3 W/mK). The temperature at the root is 550° C. The blade is exposed to a hot gas at 890° C. The heat transfer coefficient between blade surface and gas is 442 W/m^{2}K. Determine the temperature distribution and rate of heat flow at the root of the blade. Assume the tip of the blade to be insulated. 20

2. (a) Two vessels, A and B, each of volume 3m^3 may be connected by a tube of negligible volume. Vessel A contains air at 0.7 MPa, 95°C, while vessel B contains air at 0.35Mpa, 205°C. Find the change of entropy

when A is connected to B by working from the first principles and assuming the mixing to be complete and adiabatic. For air use the following relations :

Specific heat of air is 1.005 kJ/kg, $h = C_p T$, and $\frac{v}{T} = \frac{0.287}{p}$, where p, v and T are pressure in (kPa), volume (in m^3) and temperature (in K) respectively. 30

(b) A single acting air compressor has a cylinder of bore diameter 15cm and the piston stroke is 25 cm. The crank speed is 600 rpm. Air is taken from atmosphere (1 atm, 27°C) is delivered at 11 bar. Assuming polytropic compression $pv^{1.25}$ = constant , find the power required to drive the compressor, when its mechanical efficiency is 80%. The compressor has clearance volume which is $1/20^{th}$ of the stroke volume. How long will it take to deliver $1m^3$ of air at compressor outlet conditions? Find the volumetric efficiency of the compressor. 30

3. (a) A full load test on a two-stroke engine yielded the given results : speed 450 rpm, brake load 55kg, indicated mean effective pressure = 3bar, fuel consumption 5.4 kg/hr, rise in jacket water temperature 36° C, jacket water flow rate 440 kg/hr, air fuel ratio by mass = 30, temperature of exhaust gas 350° C, temperature of test room 17° C, barometric pressure 73cm of Hg, cylinder diameter 22 cm, stroke length 25 cm, brake diameter 1.2 m, calorific value of fuel is 43 MJ/kg, proportion of hydrogen by mass in the fuel 15%, R = 0.287 kJ/kgK, mean specific heat of dry exhaust gases =1 kJ/kg K, specific heat of dry steam 2 kJ/kg K.

Assume enthalpy of super-heated steam to be 3180 kJ/kg. Determine :

(i) The indicated thermal efficiency.

(ii) The specific fuel consumption in g/kW h.

(iii) Volumetric efficiency based on atmospheric conditions.

Draw up a heat balance for the test on percentage basis indicating the contribution of each item in balance. 30

(b) Air at $27^{\circ}C$ and 1 atm flows over a plate at a speed of 2m/s. The plate is heated over its entire length to a temperature of $60^{\circ}C$. Calculate the heat transfer in (i) the first 20cm of the plate and (ii) the first 40cm of the plate.

The following data are to be used Air kinematic viscosity = 17.36×10^{-6} m^2/s, thermal conductivity (air) = 0.02749 W/mk, Prandtl No = 0.7 C_p (air) = 1.006 kJ/kg K.

30

4. (a) An ammonia ice plant operates between condenser temperature of $35^{\circ}C$ and an evaporator temperature of $-15^{\circ}C$. It produces 10 tons of ice per day from water at $30^{\circ}C$ to ice at $-5^{\circ}C$. Assuming simple saturation cycle, using only tables of properties for ammonia determine : (i) capacity of the refrigeration plant, (ii) the mass flow rate of refrigerant, (iii) the

discharge temperature and (iv) the compressor cylinder diameter and stroke if its volumetric efficiency is 0.65, rpm N = 1200 and stroke/bore ratio L/D = 1.2 (V) the horse power of the compressor motor if the adiabatic efficiency of the compressor is 0.85 and mechanical efficiency is 0.95. Also, determine the theoretical and actual COP.

Data given :

Enthalpies and entropy for ammonia

$h_{g(-15^oC)}$ = 1443.9 kJ/kg $S_{g(-15^oC)}$ = 5.8223 kJ/kgK $h_{f(35^oC)}$ = 366.1 kJ/kg

Entropies and enthalpy of vapour saturated at 35°C and super-heated by 50K and 100K are as follows :

$S_{g(35^oC)}$ = 5.206 kJ/kgK $S_{(50K)}$ = 5.6466 kJ/kgK $S_{(100K)}$ = 5.9806 kJ/kgK $h_{g(35^oC)}$ = 1488.6 kJ/kg $h_{(50K)}$ = 1633.6 kJ/kg $h_{(100K)}$ = 1761.6 kJ/kg

Specific volume of vapour (at –15°C) = 0.509 m^3/kg. 30

(b) A centrifugal compressor has a pressure ratio of 4/1 with an isentropic efficiency of 82% when running at 16,000 rpm. It takes in air at 17°C. Guide vanes at inlet give the air a prewheel of 20° to the axial direction at all radii and the mean diameter of the eye is 200mm, the absolute air velocity at inlet is 120m/s. At exit the blades are radially inclined and the impeller tip diameter is 550mm. Calculate the slip factor of the compressor. 30

SECTION – B

5. Answer any **three** of the following :

(a) Mention the various important characteristics of a good ignition system ? Explain the details of firing order. 20

(b) What is effective temperature ? State the factors that control the effective temperature. Also, explain the term cooling load. 20

(c) What do you mean by Base load, intermediate load, and peak load of a power plant ? Why base load plants loaded heavily ? What do you mean by load duration curve ? 20

(d) What is surging in axial flow compressor ? What are its effects ? Also, explain stalling in an axial compressor stage. How is it developed ? 20

6. (a) A gas turbine power plant has an output of 100MW at the generator terminals : Its data is given below : 30

Air compressor inlet pressure and temperature $P_1 = 1.013$ bar and $T_1 = 310K$

Compressor pressure ratio = 8.0 and Efficiency = 0.85

Turbine inlet temperature = 1350K and Efficiency = 0.9

Turbine inlet pressure = 0.98 × compressor exit pressure

Turbine exit pressure = 1.02 bar

Calorific value of fuel Q_f = 40 MJ/kg

Combustion efficiency = 0.98

Mechanical efficiency = 0.97

Generator efficiency = 0.98

Take γ = 1.33 R = 0.287 kJ/kgK for the gas

C_{pg} specific heat of gas 1.157 KJ/kgK

Determine :

(i) Gas flow rate

(ii) Fuel-air ratio

(iii) Air flow rate

(iv) Thermal efficiency of the power plant

(v) Overall efficiency

(vi) Ideal joule cycle efficiency

(b) The filament of a 75 W light bulb may be considered as a black body radiating into a black enclosure at 70°C. The filament diameter is 0.1 mm and the length is 5cm. Considering only radiation, determine the filament temperature. Use Stefan constant = 5.672×10^{-8}. 30

7. (a) What are the considerations to be made while selecting site for hydroelectric, thermal and nuclear power plant ? 30

(b) What do you mean by natural and mechanical draught ? How a natural draught is caused ? What are the functions of Forced Draft (FD) and Induced Draft (ID) fan ? Where these fans are located ? 30

8. (a) Draw an illustrative diagram of a centrifugal compressor stage indicating the names of its principal parts. Also, state the functions of different parts. 30

(b) Explain the effect of following factors on the performance of an engine : 30

(i) Compression ratio

(ii) Air-fuel ratio

(iii) Spark timing

(iv) Engine speed

(v) Mass of inducted charge

(vi) Heat losses