

MECHANICAL ENGINEERING
Paper—II

Time Allowed : Three Hours

Maximum Marks : 200

QUESTION PAPER SPECIFIC INSTRUCTIONS

Please read each of the following instructions carefully before attempting questions.

There are **EIGHT** questions in all, out of which **FIVE** are to be attempted.

Question no. **1** and **5** are compulsory. Out of the remaining **SIX** questions, **THREE** are to be attempted selecting at least **ONE** question from each of the two Sections A and B.

Attempts of questions shall be counted in chronological 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 answer book must be clearly struck off.

All questions carry equal marks. The number of marks carried by a question / part is indicated against it.

Answers must be written in **ENGLISH** only.

Unless other-wise mentioned, symbols and notations have their usual standard meanings.

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

Neat sketches may be drawn, wherever required.

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/cm² = 0.98 bar

1 bar = 10⁵ pascals.

Universal gas constant = 8314.6 J/kmol-K.

SECTION—A

- Q. 1(a) Write the two statements of the Second Law of Thermodynamics and prove their equivalence. 10
- Q. 1(b) When a Brayton cycle is reversed and operated as refrigerator, show that the ideal COP of such a cycle is given by
- $$\text{COP} = \left[\left(\frac{\rho_2}{\rho_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]^{-1}$$
- where ρ_2 and ρ_1 are higher and lower pressure respectively.
Explain the physics of air refrigeration. 10
- Q. 1(c) What is meant by abnormal combustion ? Explain with appropriate diagrams the phenomenon of knock in S.I. Engines. 10
- Q. 1(d) What are different types of combustion chambers in C.I. engines ? Explain with a neat sketch, an open type indicating its merits and demerits. 10

Q. 2(a) Derive an expression for air standard efficiency of dual combustion cycle in terms of compression ratio, cut-off ratio, and ratio of specific heats. 10

Q. 2(b) (i) State the Zeroth Law of Thermodynamics and highlight its significance. 5

Q. 2(b) (ii) For an isothermal process, show that :

$$\int_1^2 p dv = - \int_1^2 v dp. \quad 5$$

Q. 2(c) (i) Write a brief note on alternate fuels for I.C. Engines. 5

Q. 2(c) (ii) Explain octane and cetane ratings of fuels. 5

Q. 2(d) (i) In a system executing a non flow process the work and heat per degree change of

temperature are given by $\frac{dW}{dT} = 200 \text{ W} \cdot \text{s}/^\circ\text{C}$ and $\frac{dQ}{dT} = 160 \text{ J}/^\circ\text{C}$. What will be the change in internal energy of the system when its temperature changes from $T_1 = 55^\circ\text{C}$ to $T_2 = 95^\circ\text{C}$? 5

Q. 2(d) (ii) The compression ratio of an air standard Otto cycle is 8. At the beginning of compression process the pressure is 1 bar and temperature 300 K. The heat transfer to the air per cycle is 1900 kJ/kg of air. Calculate thermal efficiency and mean effective pressure. 5

Q. 3(a) The following data is given for a 4 stroke, 4 cylinder diesel engine :

Diameter of cylinder = 35 cm, Piston stroke = 40 cm, Speed = 315 rpm, $I_{mep} = 7$ bar, BP = 260 kW, TFC = 80 kg/hr, CV of fuel used = 43000 kJ/kg, Hydrogen content of fuel = 13% and remaining is carbon. Air consumption 30 kg/min, cooling water circulated 90 kg/min, Rise in temperature of cooling water 38°C , piston cooling oil used 45 kg/min. Rise in temperature of cooling oil 23°C , for cooling oil $C_p = 2.3 \text{ kJ/kgK}$, exhaust gas temperature 322°C and C_p for exhaust gas 1.1 kJ/kgK , Ambient temperature 22°C , C_p for superheated steam 2 kJ/kgK and latent heat of steam 2520 kJ/kg . Find : (i) Mechanical and indicated thermal efficiency, and (ii) Draw up the heat balance sheet on minute basis.

15

Q. 3(b) Show that 2 reversible engines working between same temperature limits have the same efficiency. 10

Q. 3(c) With neat sketches explain the cooling systems used in I.C. engines. Why cooling is required in I.C. engines ? 8

Q. 3(d) What are the objects of supercharging in I.C. engines ? Explain thermodynamic cycle of supercharged I.C. engine. 7

- Q. 4(a) How are the concept of entropy and unavailable energy related to each other ? 7
- Q. 4(b) (i) The analysis by weight of a perfect gas mixture at 20°C and 1.3 bar is 10% O₂, 70% N₂, 15% CO₂ and 5% CO. For a reference state of 0°C, 1 bar determine (i) Partial pressure of the constituents, (ii) Gas constant of the mixture. 8
- Q. 4(b) (ii) Explain mechanical efficiency, thermal efficiency, volumetric efficiency of IC engines. 6
- Q. 4(b) (iii) Will an increase in volumetric efficiency increase the output of the engine ? How ? 4
- Q. 4(c) (i) How does a perpetual motion machine of second kind violate second law of thermodynamics ? 5
- Q. 4(c) (ii) Two carnot engines A and B are connected in series between 2 thermal reservoirs maintained at 1000 K and 100 K respectively. Engine A receives 500 kJ of heat from the high temperature reservoir and rejects heat to engine B. Engine B takes this heat and rejects heat to the low temperature reservoir. If A and B have equal thermal efficiencies determine :
- (a) Heat rejected by engine B.
- (b) Temp. at which heat is rejected by A.
- (c) Work done by engine A and B. 10

SECTION—B

- Q. 5(a) (i) Discuss the working of “Air washer” with the help of a schematic diagram and psychrometric chart. 5
- Q. 5(a) (ii) What method would you recommend for the design of heat exchangers, if exit temperatures of heat exchanger are not known ? Discuss the method. Identify the parameter, which is a measure of the size of the heat exchanger. 5
- Q. 5(b) What is the pressure coefficient of a centrifugal compressor ? Derive :
- $$\psi_p = 1 - \phi_2 \cos \beta_2$$
- where ϕ_2 = flow coefficient. 10
- Q. 5(c) Prove that in a multistage turbine :
- $$\eta_t = \eta_s \times \text{RF}$$
- where η_t = overall turbine efficiency
- $$\eta_s = \text{small-scale efficiency}$$
- and RF = reheat factor. 10
- Q. 5(d) A 12 cm wide and 18 cm high vertical hot surface is to be cooled by a heat sink with equally spaced fins of rectangular profile. The fins are 0.1 cm thick, 18 cm long in the vertical direction, and have a height of 2.4 cm from the base. Determine the optimum fin spacing, and the rate of heat transfer by natural convection from the heat sink if the base temperature is 80°C. Properties of air at 325.5 K are :
- $$K = 0.0279 \text{ W/m-K}, \nu = 1.82 \times 10^{-5} \text{ m}^2/\text{s}, P_r = 0.709. \quad 10$$

- Q. 6(a) Describe the working of a modern natural circulation boiler.
 Why are downcomers fewer in number and bigger in diameter, while risers are more in number and smaller in diameter ?
 Write down the functions of preheater, reheater, economiser and superheaters and their locations. 15
- Q. 6(b) (i) Compare gas turbines with steam turbines. List the applications of gas turbines and write about gas turbine fuels. 5
- Q. 6(b) (ii) A simple gas turbine takes air at 1.01 bar and 15.5°C and compresses it through a pressure ratio 5 : 1, the adiabatic efficiency of compression being 85%. The gases enter the turbine at 540°C and expand to 1.01 bar, the turbine efficiency being 80%. Estimate the flow of gases in kg per second, for a net power of 1500 kW, making the following assumptions :
 Fall of pressure through the combustion system is 0.07 bar, C_p for both air and combustion gases = 1.047 kJ/kgK, index of compression/expansion is 1.4. Neglect additional mass flow due to fuel. 10
- Q. 6(c) Write a brief note on cooling towers based on the following points :
 (i) applications
 (ii) types
 (iii) comparison with cooling ponds. 10
- Q. 7(a) The velocity of steam leaving the nozzles of an impulse turbine is 900 m/s and the nozzle angle is 20°. The blade velocity is 300 m/s and the blade velocity coefficient is 0.7. Calculate for a mass flow of 1 kg/s and for symmetrical blading :
 (i) the blade inlet angle,
 (ii) driving force on the wheel,
 (iii) the axial thrust,
 (iv) the diagram efficiency, and
 (v) power developed. 15
- Q. 7(b) Explain the meaning of (i) Draft and describe briefly different draft systems, (ii) Base load and peak load. 5
- Q. 7(c) A plant using R22 has an evaporator saturation temperature of -1°C and a condenser saturation temperature of 45°C. The vapour is dry saturated at entry to the compressor and is at a temperature of 75°C after compression to the condenser pressure. The compressor is a two stage centrifugal compressor, each stage having the same pressure ratio and enthalpy rise. Assuming no undercooling in the condenser, a slip factor of unity, axial flow of refrigerant into the compressor, radial flow of refrigerant at the impeller exit and using the properties of R22 given in Table 1 and 2, calculate :
 (i) the coefficient of performance.

- (ii) the power input required for a refrigeration capacity of 2 MW.
 (iii) the diameter of the impeller in each stage when the rotational speed is 300 rev/min.

Table 1

Saturated Values :

Temp. (0°C)	Press. (bar)	Specific enthalpy		Specific entropy		Specific volume
		h_f	h_g	s_f	s_g	v_g
		(kJ/kg)		(kJ/kg K)		m ³ /kg
-1	4.816	198.83	404.99	0.996	1.753	0.0487
45	17.290	256.40	417.31	1.187	1.693	0.0133

Table 2

Saturated Values at 17.290 bar :

Temperature 0°C	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg K)
65	436.27	1.751
70	440.77	1.764
75	445.21	1.777

20

- Q. 8(a) The configuration of a furnace can be approximated as an equilateral triangular duct which is sufficiently long that the end effects are negligible. The hot wall is maintained at $T_1 = 1000$ K and has an emissivity $\epsilon_1 = 0.8$. The cold wall is at $T_2 = 500$ K and has an emissivity $\epsilon_2 = 0.8$. The third wall is reradiating zone for which $Q_3 = 0$. Calculate the net radiation flux leaving the hot wall. 10
- Q. 8(b) What is shape factor or configuration factor ? Write down the reciprocity relation and prove it. 5
- Q. 8(c) What are the desirable properties of a good refrigerant ? List giving proper reasoning. Name few commonly used refrigerants. 10
- Q. 8(d) At a particular hydro-electric power plant site, the discharge of water is 400 m³/sec and the head is 25 m. The turbine efficiency is 88%. The generator is directly coupled to the turbine having frequency of generation of 50 cycles per second and number of poles as 24. Calculate the least numbers of turbines required if (a) a Francis turbine is used with a specific speed of 300 and (b) a Kaplan turbine is used with a specific speed of 750. 15