

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 parts (answer to each part should not exceed 200 words): **20×3=60**
- (a) Consider a Carnot cycle heat engine operating in the outer space. Heat can be rejected from this engine only by thermal radiation, which is proportional to the radiator area and the fourth power of the absolute temperature of the radiator (T_1). Show that for a given engine work output and given temperature of the higher temperature reservoir (T_H), the radiator area will be a minimum when the ratio $T_1/T_H = 3/4$.
 - (b) A fluid, contained in a horizontal cylinder fitted with a frictionless leak-proof piston, is continuously agitated by means of stirrer passing through the cylinder cover. The cylinder diameter is 0.40 m. During the stirring process lasting 10 minutes, the piston slowly moves out a distance of 0.485 m against the atmosphere. The net work done by the fluid during the process is 2 kJ. The speed of the electric motor driving the stirrer is 840 rpm. Determine the torque in the shaft and the power output of the motor.
 - (c) A simple carburetor has a venturi throat diameter of 20 mm and the coefficient of flow is 0.8. The diameter of the fuel orifice is 1.14 mm and the coefficient of fuel is 0.65. The gasoline surface is 5 mm below the throat. Calculate– (i) The air-fuel ratio for a pressure drop of 0.08 bar when the nozzle tip is neglected; (ii) The air-fuel ratio when the nozzle tip is taken into account; (iii) The minimum velocity of air or critical air velocity required to start the fuel flow when the nozzle tip is provided. Assume the density of air and fuel to be 1.20 kg/m^3 and 750 kg/m^3 respectively.
 - (d) Consider a diffuse circular disc of diameter D and area A_j and a plane diffuse surface of area $A_i \ll A_j$. The surface are parallel and A_i is located at a distance L from the centre of A_j . Obtain an expression for view factor.
2. (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 $T_1 = 900 \text{ K}$ and has an emissivity $\varepsilon_1 = 0.8$. The cold wall is at $T_2 = 400 \text{ K}$ and has an emissivity $\varepsilon_2 = 0.8$. The third wall is reradiating zone for which $Q_3 = 0$. The accompanying sketch illustrates the configuration. Calculate the net radiation heat flux leaving the hot wall. **20**
- [Figure: Cross-section of the duct: an equilateral triangle with both base angles marked 60° . Left inclined wall labelled ① with $T_1 = 900 \text{ K}$, $\varepsilon_1 = 0.8$; right inclined wall labelled ② with $T_2 = 400 \text{ K}$, $\varepsilon_2 = 0.8$; base wall labelled ③ (reradiating, $Q_3 = 0$).]

- (b) The diagram shows a truncated conical section fabricated from a material of thermal conductivity K . The circular cross-section of the conical section has the diameter $D = ax$, where a is a constant and x is the axial distance of the section from the apex of the cone. The temperatures at the two end faces of the conical section (at distances x_1 and x_2 from the apex) are respectively T_1 and T_2 while the lateral surface of the truncated cone is thermally insulated. (i) Derive an expression for the temperature distribution $T(x)$ in symbolic form assuming one-dimensional steady-state conditions. Sketch the temperature distribution. (ii) Calculate the heat rate q_x through the cone in x -direction. **40**

[Figure: Truncated cone lying along a horizontal axis, apex (vertex) on the right, x measured from the apex towards the left (arrow labelled x pointing left). The small end face (right) is at distance x_1 from the apex and is at temperature T_1 ; the large end face (left) is at distance x_2 from the apex and is at temperature T_2 . The inclined lateral surface is hatched and labelled "Thermal Insulation"; dimension lines show x_1 and x_2 measured from the apex.]

3. (a) A refrigeration system operates using simple saturated cycle with a certain refrigerant. The condensing and evaporating temperatures for the refrigerant are 35°C and -15°C respectively. Determine the COP of the system. If a liquid vapour heat exchanger is installed in the system, with the temperature of the vapour leaving the heat exchanger at 15°C , what will be the change in the COP? Use the following data for the refrigerant used: **30**

t ($^\circ\text{C}$)	h_f (kJ/kg)	h_g (kJ/kg)	s_g (kJ/kg-K)	Superheated 20 K: h (kJ/kg)	Superheated 20 K: s (kJ/kg-K)	Superheated 40 K: h (kJ/kg)	Superheated 40 K: s (kJ/kg-K)
35	69.5	201.5	0.6839	216.4	0.731	231.0	0.7741
-15	–	181.0	0.7052	193.2	0.751	205.7	0.7942

- (b) 10 cu m of atmospheric air at 25°C DBT and 12°C WBT is flowing per minute through a duct. Dry saturated steam at 100°C is injected through the duct. Dry saturated steam at 100°C is injected into the air stream with a rate of 1.2 kg/min. (i) What is the temperature of air after mixing the steam? (ii) What is the relative humidity of air after mixing the steam? **30**

4. (a) Sketch the axial-flow turbine cascade. Show the velocity with its components at entry exit indicating the forces exerted by the flow on blades. State the expression of ideal lift in terms of flow angles and show that it is equal to $\rho C_m \Gamma$, where C_m is the mean velocity and Γ is the circulation. **10**

- (b) The first axial-flow air compressor stage without inlet guide vanes is operating at a speed of 15000 r.p.m. in the atmospheric conditions of $T_0 = 288\text{ K}$, $P_0 = 1.01\text{ bar}$. The rotor mean blade ring diameter is 0.34 m and hub to tip ratio is 0.5. Atmospheric air enters the stage with a velocity of 150 m/s. Consider constant axial velocity through the stage and take stage efficiency as 0.86, mechanical efficiency as 0.97, work done factor as 0.97, $C_p = 1.005\text{ kJ/kg-K}$ and $R = 0.287\text{ kJ/kg-K}$. Sketching the axial compressor stage with velocity diagrams and labelling with most general notations used in practice, determine the following for attaining relative velocity ratio across rotor (de Haller number) of 0.73: (i) Mass flow rate in kg/s (ii) Maximum Mach number at rotor blade at entry (iii) Angles made by relative and absolute velocity at rotor entry and exit with axial direction (iv) Power required to drive the compressor (v) Stage pressure ratio **50**

SECTION 'B'

5. Answer any three questions **20×3=60**

- (a) Sketching 'load curve' and 'load duration curve' explain their purposes. Define also 'demand factor' and 'plant-use factor'. The loads for certain industries are tabulated below for 24 hours.

During load duration and load curve, find power required for 40% of the time of the day. If the capacity of the power plant is 35 MW, find the capacity factor of the power plant:

Time	6 AM to 8 AM	8 AM to 9 AM	9 AM to 11 AM	11 AM to 2 AM	2 AM to 5 AM
Load (in MW)	18	26	30	22	24
Time	5 PM to 8 PM	8 PM to 12 PM	12 PM to 5 PM	5 PM to 6 PM	
Load (in MW)	30	20	15	16	

If the load is supplied by two power plants, one is acting as a base load plant having capacity of 25 MW and other as peak load plant having capacity of 10 MW, find load factor, capacity factor and use factor for both power plants.

- (b) The stator blades of a gas turbine are supplied with gas whose stagnation enthalpy h_0 and stagnation temperature T_0 vary with radius r . There is cylindrical flow through the stator blades is reversible and adiabatic. Show that, in the cross-sectional plane at exit from the stator blades

$$dh_0 - T ds = C^2 \sin^2 \alpha \frac{dr}{r} + C dC$$

Hence, when the gas can be assumed to be a perfect gas and the stagnation pressure P_0 is constant over the annulus, show that

$$\frac{dT_0}{T_0} = 2 \left(\sin^2 \alpha \frac{dr}{r} + \frac{dC}{C} \right)$$

- (c) A quarter-scale turbine model is tested under a head of 10.8 m. The full-scale turbine is required to work under a head of 30 m and to run at 7.14 rev/s. At what speed the model must run? If it (model) develops 100 kW and uses 1.085 m^3 of water per second at this speed, what power will be obtained from the full-scale turbine, its efficiency being 3% better than that of model? What is the dimensionless specific speed of full-scale turbine?
- (d) Steel ball bearings ($K = 50 \text{ W/m}^2 \cdot \text{K}$, $\alpha = 1.3 \times 10^{-5} \text{ m}^2/\text{s}$) having a diameter of 40 mm are heated to a temperature of 650 °C and then quenched in a tank of oil at 55 °C. If the heat transfer coefficient between the ball bearings and the oil is $300 \text{ W/m}^2 \cdot \text{K}$, determine: (i) the duration of time the bearings must remain in oil to reach a temperature of 200 °C; (ii) the total amount of heat removed from each bearing during this time; (iii) the instantaneous heat transfer rate from the bearings when they are first immersed in oil and when they reach 200 °C.

6. (a) Define Rayleigh flow and mention its governing relations. Using them, establish the expression for the flow in the form $p + G^2 v = \text{Const.}$, where G is the mass flow rate per unit area. Show the plot of this equation on h - s and p - v planes. Show also that at maximum enthalpy state $M = \frac{1}{\sqrt{\gamma}}$.

- (b) For the Rayleigh flow, establish the expression for T/T^* terms of Mach number, M .
- (c) Air enters a 5 cm diameter frictionless duct with a Mach number 2. Its static temperature is 250 °C and stagnation pressure 6 bar. For increasing Mach number to 3, find the amount of heat to be transferred and change in static temperature. You may use the following table for air having $\gamma = 1.4$:

M	T/T^*	P/P^*	P_0/P_0^*	T_0/T_0^*
2	0.5289	0.3636	1.503	0.7934
3	0.2803	0.1765	3.424	0.6534

7. (a) Why is the use of dust collector necessary in case of thermal power plant? Discuss the location of electrostatic precipitator with reference to sulphur content of coal and flue gas temperature. **20**

- (b) From the following data for the underfeed stoker boiler, find draft required in mm of water column and power required to drive the fan: **40**

Mean temperatures of flue gases passing through duct	227 °C
Plenum pressure	15 cm of water
Atmospheric pressure	75 cm of Hg
Mean velocity of flue gases in duct	900 m/min
Length of the duct	150 m
Mean size of the non-circular duct	75 cm^2
Number of 90° bends	4
Number of 45° bends	4
Loss of draft in every 90° bend	0.1 cm of water
Draft available from chimney	1.5 cm of water
Fuel bed resistance for underfeed stoker	10 cm of water
Fan efficiency	60%
Motor efficiency	92.5%

Assuming that 45° bend is equivalent to one-half of 90° bend, resistance offered by non-circular duct is 20% higher than a similar circular duct, friction factor for circular duct is 0.006, find draft required to be produced by fan and the fan power for flue gases. Take $R = 294.35 \text{ J/kg-K}$.

8. To avoid having additional inlet and outlet pipes through the wall of the pressure vessel of pressurised water nuclear reactors, it is usual to employ a steam - heated reheat cycle. Steam is bled from the boiler delivery main to reheat the steam leaving the high-pressure turbine before it enters the low-pressure turbine. The data for the cycle are as follows: **60**

Boiler outlet condition	Saturated steam at 60 bar
LP turbine inlet pressure	5 bar
Condenser pressure	0.05 bar
HP turbine isentropic efficiency	0.80 bar
LP turbine isentropic efficiency	0.87 bar
Reheat temperature	270 °C

The feed pump terms can be neglected, and it may be assumed that the bled steam leaves the reheater at a temperature equal to that at the high-pressure turbine exit. Determine the dryness fractions at the high- and low-pressure turbine exit and the cycle efficiency. Also determine these quantities if no reheating were used. Comment briefly on the result.
