

MECHANICAL ENGINEERING (Paper II)

Time Allowed : Three Hours

Maximum Marks : 300

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:

- (a) (i) 0.5 m^3 of gas at 10 kPa and 130°C expands adiabatically to 1 kPa. It is then isothermally compressed to its original volume. $C_p = 1.005 \text{ k J/k g - K}$ and $C_v = 0.718 \text{ k J/k g - K}$. Represent these processes on P-V diagram. Find final temperature and pressure of gas. (ii) For compression work to be minimum, what should be process of compression? Is it used in practice? **20**

- (b) (i) For normal shock wave derive the following expression:

$$\frac{p_{ay}}{p_x} = \left[1 + \frac{\gamma - 1}{2} M_x^2 \right]^{\gamma/(\gamma - 1)} \cdot \left[\frac{2\gamma}{\gamma + 1} M_x^2 - \frac{\gamma - 1}{\gamma + 1} \right]$$

where x and y are the conditions before and after the shock wave. (ii) Show Fanno line in adiabatic flow with friction on h-s diagram and explain the physical significance. **20**

- (c) A decorative plastic film on a copper sphere having 10 mm diameter is cured in an oven at 75°C . Upon removal from the oven, the copper sphere is subjected to an air stream at a pressure, temperature and velocity of 1 bar, 23°C and 10 m/s respectively. How long it will take for the sphere to cool down to 35°C ? State the assumptions made and justify the method of analysis used. For copper, the density, specific heat and thermal conductivity are, respectively, 8933 kg/m^3 , 388 J/kg-K and 350 W/m-K . The following correlation for forced convection may be used:

$$Nu_d = 2 + \left[0.4 Re_d^{1/2} + 0.06 Re_d^{2/3} \right] Pr^{0.4}$$

For air, kinematic viscosity, thermal conductivity and Prandtl number at the mean film temperature under consideration are $15.53 \times 10^{-6} \text{ m}^2/\text{s}$, 0.025 W/m-K and 0.708 respectively. **20**

- (d) (i) Derive the following expressions for lift (C_L) and drag (C_D) coefficients for flow with friction through a compressor (axial flow type) cascades:

$$C_L = 2 \frac{S}{C} (\tan \alpha_1 - \tan \alpha_2) \cos \alpha_m - C_D \tan \alpha_m$$

$$C_D = \xi \frac{S}{C} \cdot \frac{\cos^3 \alpha_m}{\cos^2 \alpha_1}$$

where S , C , α_1 , α_2 , α_m and ξ denote pitch, chord, inlet flow angle, outlet flow angle, average flow angle and total pressure loss coefficient. (ii) Show the variation of C_L and C_D with incidence and discuss physical significance. **20**

2. (a) A Carnot engine operates between source temperature of 500 K and sink temperature of 300 K. It produces work utilising the heat of 10 kJ from the source at 500 K. The work produced by this engine is utilised by a Carnot refrigerator operating between refrigerator temperature of 200 K and sink temperature of 300 K. Represent schematically these engine and refrigerator operations. Find out: (i) Work produced by the Carnot engine. (ii) Refrigerating effect produced at 200 K by the Carnot refrigerator. (iii) Total heat rejected to the sink at 300 K. (iv) By how much the refrigerator temperature be increased to get double the refrigerating effect as per (ii) above? (v) Total heat rejected to the sink at 300 K when the refrigerator operates as per the temperature for (iv) above. **20**
- (b) The velocity distribution in the fully developed flow region of steady incompressible laminar flow of a fluid in a horizontal pipe is given by $\frac{u}{u_m} = 1 - \left(\frac{r}{R}\right)^2$, where u and u_m are respectively the velocities of any radial distance, r , from the axis and at the axis of the pipe and R is the radius. Show that the kinetic energy correction factor, α and momentum correction factor, β are respectively equal to 2 and 1.33. **20**
- (c) Air at the rate of 35 kg/s flows through a nozzle in which a normal shock occurs in the diverging section down-stream of the throat. The nozzle has an area of cross section equal to 40 cm^2 at the section of shock. The pressure and velocity of fluid just before the shock are 2.5 bar and 480 m/s respectively. Find the Mach number, pressure and temperature after the shock. Comment on the results. Normal shock table: **20**

M_1	M_2	p_2/p_1	T_2/T_1	ρ_2/ρ_1	P_{02}/P_{01}
1.42	0.7314	2.1858	1.2676	1.7243	0.9531
1.43	0.7274	2.2190	1.2742	1.7416	0.9503

3. (a) The temperature of product of combustion in a boiler decreases from 1100 °C to 550 °C while the pressure remains constant at 0.1 MPa. Water at 0.8 MPa, 150 °C is converted into steam at 0.8 MPa, 250 °C with the surroundings is at 100 kPa and 25 °C. Sketch the control volume depicting the terminal and process conditions and show on a T-s diagram the processes. Calculate the following: (i) change in availability of water on unit mass of water basis, (ii) change in availability of product of combustion per kg of water, (iii) process irreversibility per unit mass of water, (iv) second law efficiency, and (v) entropy generated per kg of water. Take average specific heat of product of combustion as 1.09 kJ/kg-K. Specific enthalpy and specific entropy of water at 0.8 MPa, 150 °C are, respectively, at 632.2 kJ/kg and 1.8418 kJ/kg-K and that of steam at 0.8 MPa, 250 °C are respectively at 2950 kJ/kg and 7.0389 kJ/kg-K. **20**
- (b) A heat transfer equipment utilises 5 mm diameter, 10 cm long smooth circular cross-sectioned conduits drilled horizontally in a plate longitudinally on which a constant heat flux is imposed uniformly. Air enters each conduit at 27 °C with a mean velocity of 3.0 m/s and leaves at 77 °C. If 20 conduits are arranged in the plate, calculate the following: (i) total rate of heat removed from the plate, (ii) exit conduit wall temperature, and (iii) local heat transfer coefficient at the exit of each conduit. Sketch the variation in local heat transfer coefficient along the length of conduit. The following correlations are known for convection heat transfer: (1) $Nu_d = 4.364$, for fully developed laminar flow, (2) $Nu_d = 0.023 Re_d^{0.8} Pr^{0.4}$, for turbulent flow, (3)

$Nu_z = 1.3 \left[\frac{Re_d Pr}{(z/d)} \right]^{1/3}$, developing flow with $\left[\frac{Re_d Pr}{(z/d)} \right] > 10$ 'z' is the axial location from the inlet along the length of conduit. Properties of air at 52 °C: $C = 1006 \text{ J/kg-K}$, $\rho = 1.1774 \text{ kg/m}^3$, $\nu = 18.22 \times 10^{-6} \text{ m}^2/\text{s}$, $K = 0.028 \text{ W/m-K}$, $Pr = 0.703$. **20**

- (c) A 0.5 m diameter disc heater is horizontally placed and enclosed concentrically in a hemispherical shaped surface. The surface of the enclosure having an emissivity of 0.7 is maintained at 500 K. The disc heater, having emissivity of 0.8 is maintained at 1200 K. The diameter of the hemisphere is 2 m and the remaining base area enclosed is open to surroundings at 300 K and may be considered as black with reference to radiation exchange. Sketch the schematic and thermal radiation network. Using thermal network method, calculate the heat exchange between heater and hemispherical enclosure and that between heater and surroundings. Neglect convection heat transfer. Assume heater and hemispherical surface are opaque, diffuse and gray. **20**

4. (a) An open cycle gas turbine takes in air at 300 K and 1 bar and develops a pressure ratio of 20. The turbine inlet temperature is 1650 K. The polytropic efficiency of compressor and turbine each is 90%. The pressure loss in the combustor is 3% and the alternator efficiency is 97%. Take $c_{p_a} = 1.005 \text{ kJ/kg-K}$ and $c_{p_g} = 1.128 \text{ kJ/kg-K}$ for air and gas respectively. The calorific value of fuel is 42 MJ/kg. Work out the following: (i) Sketch the system and show the process on T-s diagram. (ii) The overall efficiency. (iii) The specific power output. (iv) The fuel to air ratio. (v) The specific fuel consumption. (vi) Show in general the variation of gas turbine thermal efficiency with compressor ratio for various turbine inlet temperatures. (vii) What is the reason that thermal efficiency of gas turbine plant increases with decrease in compressor inlet temperature? **20**

- (b) During a test on a two stroke engine on full load, the following observations were recorded: Speed = 350 rpm; Net brake load = 590 N; Mean effective pressure = 2.8 bar; Fuel oil consumption = 4.3 kg/h; Cooling water required = 500 kg/h; Rise in cooling water temperature = 25 °C; Air used per kg of fuel = 33 kg; Room temperature = 25 °C; Exhaust gas temperature = 400 °C; Cylinder diameter = 220 mm; Stroke length = 280 mm; Effective brake diameter = 1 m; C.V. of fuel oil = 43900 kJ/kg; Proportion of hydrogen in fuel = 15%; Mean specific heat of exhaust gases = 1.0 kJ/kg-K; Specific heat of steam = 2.09 kJ/kg-K. Calculate the following: (i) Indicated power (ii) Brake power (iii) Draw heat balance sheet on the basis of kJ/min. **20**

- (c) A cross flow heat exchanger consists of a bundle of 32 straight 0.6 m long tubes in a rectangular duct of cross sectional area of 0.6 m^2 . Hot water at 150 °C and a mean velocity of 0.5 m/s enters each tube having inner and outer diameters of 10.2 mm and 12.5 mm respectively. Atmospheric air at 10 °C enters the heat exchanger with a volumetric flow rate of $1 \text{ m}^3/\text{s}$. The mean convective heat transfer coefficient on the outside air flow is $400 \text{ W/m}^2\text{-K}$. Assume tube side flow is fully developed and negligible thermal resistance due to tube wall. Heat transfer is only between air and water. Calculate exit temperatures of water and air and the total heat transfer rate. The following properties are known: For air: at 10 °C, $\rho = 1.2407 \text{ kg/m}^3$, at 40 °C, $\rho = 1.1181 \text{ kg/m}^3$, $C_p = 1007 \text{ J/kg-K}$. For water: $\rho = 922 \text{ kg/m}^3$, $C_p = 4297 \text{ J/kg-K}$, $K = 0.688 \text{ W/m-K}$, $\mu = 188 \times 10^{-6} \text{ N-s/m}^2$, $Pr = 1.18$. Take cross flow correction factor as 0.8. Heat transfer correlations: (1) $Nu_d = 4.364$, for fully developed laminar tube flow. (2) $Nu_d = 0.023 Re_d^{0.8} Pr^{0.3}$, for turbulent flow in tube. (3)

$$\varepsilon = \frac{1 - e^{-C_R(1 - e^{-N})}}{C_R}, \text{ minimum fluid mixed and the other unmixed in cross flow exchanger}$$

$$\varepsilon = 1 - e^{-\left(\left[1 - e^{-C_R N} \right] \cdot \frac{1}{C_R} \right)}, \text{ minimum fluid unmixed and the other mixed in cross flow exchanger, where}$$

ϵ : effectiveness, C_R : capacity ratio, N: Number of Transfer Units. Symbols have the usual meaning.

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SECTION 'B'

5. Answer any THREE of the following:

(a) Two identical petrol engines having the following specifications are used in vehicles: Engine 1: Swept volume = 3300 cc, Normally aspirated, bmep = 9.3 bar, rpm = 4500, Compression ratio = 8.2, Efficiency ratio = 0.5, Mechanical efficiency = 0.9, Mass of the engine = 200 kg. Engine 2: Super charged, Swept volume = 3300 cc, bmep = 12.0 bar, rpm = 4500, Compression ratio = 5.5, Efficiency ratio = 0.5, Mechanical efficiency = 0.92, Engine mass = 220 kg. If both the engines are supplied with just adequate quantity of petrol for the test run, determine the duration of test run so that the specific mass per kW of brake power is same for both the engines. Calorific value of petrol = 44000 kJ/kg. Assume both the engines operate on four stroke cycle. Also compare two engines and suggest their applications with reasoning. **20**

(b) (i) With the help of a sketch discuss the working principle of a high pressure Benson boiler with advantages. (ii) Discuss the purpose of drum used in boiler and show internal details for mechanism of separation of moisture in drum. **20**

(c) (i) Derive the expression for optimum ratio for blade velocity to steam velocity in the case of Parson's reaction steam turbine with the sketch of blade shape of a stage and velocity triangles. (ii) Give a cylinder layout of a 500 MW steam turbine and explain the reasons of double flow cylinders used. **20**

(d) Comment on the following (Be brief) with the help of schematic diagram, if required (i) In the reciprocating compressors used in vapour compression system, the mass of refrigerant discharged by the compressor reduces as the pressure ratio is increased. (ii) Thermostatic expansion valve is preferred over automatic expansion valve as throttling device. (iii) COP of refrigeration system increases when water cooled condenser is used in place of air cooled condenser. (iv) Vapour at suction to the hermetically sealed compressor is always superheated vapour. (v) For low sensible heat factor applications, re-heat is necessary. **20**

6. (a) (i) Discuss the requirements of an injection system of a diesel engine. (ii) With the help of a sketch discuss the working of common rail injection system. (iii) Show the performance curves of a S.I. engine on constant speed and constant load tests. **20**

(b) A saturated vapour compression refrigeration system is extracting heat from a thermal reservoir at -10°C and rejecting heat to another thermal reservoir at 36°C . The saturation temperature of evaporator is -20°C and that of condenser is 46°C . The mass flow rate of refrigerant (R-134 a) is 0.1 kg/s. Assume environment temperature equal to 36°C . Find: (i) Refrigerating capacity in Tons (ii) Power input in kW (iii) COP (iv) COP of Carnot refrigeration cycle (v) Second law efficiency of the cycle. Compare with the help of T-s diagram, the vapour compression cycle and Carnot refrigeration cycle and show the deviation between the two cycles by shaded areas. Properties of refrigerant (Saturated) **20**

Temp ($^\circ\text{C}$)	Saturation Pressure (MPa)	Enthalpy (kJ/kg) Sat liquid h_f	Enthalpy (kJ/kg) Sat vapour h_g	Entropy (kJ/kg-K) Sat liquid S_f	Entropy (kJ/kg-K) Sat vapour S_g
-20	0.13273	173.64	386.55	0.9002	1.7413
-10	0.20060	186.70	392.66	0.9506	1.7334
36	0.91185	250.48	417.65	1.1717	1.7124
46	1.1903	265.47	421.92	1.2186	1.7089

Super heated

Pressure (MPa)	h_g (kJ/kg)	S_g (kJ/kg-K)
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1	428.91	1.7413
1.2	436.12	1.7413

- (c) (i) Derive the following expression for the critical pressure ratio (r_c) in a steam nozzle where steam enters with initial velocity and the flow is accompanied with friction:

$$r_c = \left[\frac{z}{n' + 1} \right]^{n'/(n' - 1)} \left[1 + \frac{C_1^2}{2\eta n' p_1 v_1} \right]$$

where: C_1 = initial steam velocity, p_1 = initial steam pressure, η = small stage expansion efficiency $\approx \eta_n$, n' = actual exponent of expansion, v_1 = initial steam specific volume. (ii) Show the effect of variation of back pressure on distribution of pressure and velocity all along in a convergent-divergent nozzle. **20**

7. (a) In a steam power plant, the steam generator generates steam at the rate of 120 t/h at a pressure of 100 bar and temperature of 500 °C. The calorific value of fuel used by steam generator is 41 MJ/kg with an overall efficiency of 85%. In order to have efficient combustion, 17 kg of air per kg of fuel is used for which a draught of 25 mm of water gauge is required at the base of stack. The flue gases leave the steam generator at 240 °C. The average temperature of gases in the stack may be taken as 200 °C and the atmospheric temperature is 30 °C. Work out the following: (i) The height of stack required. (ii) The diameter of stack at its base. (iii) Draw the draught distribution considering balanced draught system in a steam generator and mention the advantages of balanced draught. Take the following steam properties for solution: $h = 3375 \text{ k J/k g}$, $h_f = 632.2 \text{ k J/k g}$. **20**
- (b) Draw a neat sketch of aqua-ammonia vapour absorption system. On this sketch: (i) Indicate thermodynamic state points with (1) at the inlet of pump. (ii) Show the direction of the following energy transfers to various components: e_A – energy transfer to absorber; e_p – energy transfer to pump; e_g – energy transfer to generator; e_D – energy transfer to dephlegmator; e_c – energy transfer to condenser; e_e – energy transfer to evaporator. (iii) Mention for each of the energy transfers in (ii) above whether it is in the form of work or heat. (iv) With heat sink temperature of 27 °C, heat source temperature of 127 °C and refrigeration temperature of –13 °C, find max COP of the vapour absorption system and mention the assumptions made. **20**
- (c) (i) With the help of a neat sketch show a steam/gas combined cycle with two pressures heat recovery steam generator (HRSG). (ii) Show the processes of topping and bottoming cycle on one T-s diagram and also show T-Q diagram for process in HRSG. (iii) Discuss the advantages of combined cycles. **20**
8. (a) (i) Discuss the objectives of supercharging and show the process on p-v diagram. (ii) Give sketches of two common type of supercharging and turbocharging configurations. (iii) Discuss parameters affecting engine heat transfer. **20**
- (b) (i) Give a practical feed heating arrangement of a 660 MW steam power plant by showing steam and feed flow paths. Mention its special features. (ii) In low pressure steam turbine, steam is wet. With the help of velocity diagrams show the direction of flow of steam and water particles on moving blades and guide vanes so that the causes of erosion of blades get established. **20**
- (c) Illustrate the following processes on psychrometric chart with initial state of moist air as dry bulb temperature equal to 20 °C and relative humidity of 50%: (i) Cooling and humidification (ii) Heating and humidification (iii) Humidification at constant dry bulb temperature. Mention one application each for above humidification processes. If the moist air leaves the system for the case (iii) above, at 90% relative humidity, determine per unit mass of dry air: (i) increase in humidity ratio, ΔW (ii) increase in enthalpy, Δh (iii) increase in dry bulb temperature, Δt (iv) Determine Sensible Heat Factor (SHF) for this process. **20**

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