

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. (a) Air enters a steady flow adiabatic turbine at 1600 K and exhausts to atmosphere at 1000 K, $P_{atm} = 1 \text{ bar}$. If the second law efficiency is 85%, what is the turbine inlet pressure? What is irreversibility during expansion process? Given, surrounding temperature is 25°C. Properties of air

T, [K]	h, [kJ/kg]	s, [kJ/kg-K]
1000	1046	8.6905
1600	1757	8.1349

- (b) A very long AISI 316 stainless steel ($K = 14 \text{ W/m-K}$) rod 5 mm in diameter has one end maintained at 100°C. The surface of the rod is exposed to ambient air at 30°C with average convective heat transfer coefficient of $50 \text{ W/m}^2 \cdot \text{K}$. Neglecting radiation heat transfer, estimate how long the rod must be to treat it as “infinitely long” to yield a reasonable accurate estimation of heat loss. If the rod is made of copper ($K = 350 \text{ W/m-K}$), will the length be different? How much will it be and why? Compare the heat transfer rates for both the rods. The analysis may be based on fin tip heat loss alone. 12
- (c)(i) What is meant by firing order in internal combustion engines? 2
- (c)(ii) What are the firing orders used in 4 and 6 cylinder inline engines? 4
- (c)(iii) What are the three purposes of firing order in ‘V’ engines? 6
- (d) A boiler receives a flow of 5000 kg/hr liquid water at 5 MPa, 20°C and it adds energy to the flow to exit state of 450°C, 4.5 MPa. Determine the necessary minimum pipe flow area for inlet and outlet pipes. The velocity of water is maintained under 20 m/s. If this boiler is to operate on Moon, discuss two major design changes in this type of boiler. Given properties of water: $v_{inlet} = 0.001 \text{ m}^3/\text{kg}$, $v_{exit} = 0.0716 \text{ m}^3/\text{kg}$ 12
- (e) Nitrogen flows in a pipe with velocity 300 m/s at 500 kPa, 300°C. What is availability with respect to an ambient at 100 kPa and 20°C? 12
2. (a)(i) Explain briefly the design and off-design characteristics of an axial flow compressor. 10
- (a)(ii) Explain the phenomena of surge and choking in centrifugal compressors. 10
- (b) The volumetric heat generation rate in a cylindrical nuclear reactor fuel rod of 5 cm diameter is $5 \times 10^7 \text{ W/m}^3$. Under steady state operating condition, the temperature distribution in the rod is $t = 800 - 4.167 \times 10^5 r^2$. Density, specific heat and thermal conductivity of rod material are 1100

kg/m^3 , $800 J/kg\cdot K$ and $30 W/m\cdot K$ respectively. (i) What are the rates of heat transfer per unit length of the rod at the centre line (axis) and at the rod surface? (ii) If the reactor power level is suddenly increased to $10^8 W/m^3$, what are the initial time rate of change of temperature at the centre line and at the surface? **20**

- (c) A stream of air flows in an insulated tube of constant cross-sectional area of $0.9 m^2$. At a section 1, the pressure is 0.6 bar, temperature is $22^\circ C$ and mass velocity is $150 kg/s\cdot m^2$. The pressure in space in which tube exhausts is so low that choking condition prevails. Determine, (i) Mach no. at section 1. (ii) Mach no., temperature and pressure at the exit of tube. (iii) Total force exerted in axial direction which must be exerted to hold the tube stationary. Given, $R = 287 J/kg\cdot K$ $\gamma = 1.4$ Fanno line (Adiabatic constant area flow with friction) table $\gamma = 1.4$ **20**

M	$\frac{T}{T^*}$	$\frac{e}{e^*}$	$\frac{p}{p^*}$	$\frac{p_0}{p_0^*}$	$\frac{I}{I^*}$	$\frac{4fL_{max}}{D}$
0.58	1.124	0.615	1.828	1.213	1.121	0.576
0.60	1.119	0.635	1.763	1.188	1.105	0.491
0.62	1.114	0.654	1.703	1.166	1.091	0.417
0.64	1.109	0.674	1.646	1.145	1.079	0.353

3. (a) A small power plant produces 25 kg/s steam at 3 MPa, $600^\circ C$ in the boiler. It cools the condenser with ocean water coming in at $12^\circ C$ and returned at $15^\circ C$. Condenser exit is $45^\circ C$. Find (i) net power output. (ii) required mass of ocean flow water. Given: $h_{x=0}^{45^\circ C} = 188.4$ $V_1 = 0.001 m^3/kg$ $p_{sat}^{45^\circ C} = 9.59 kPa$ $h_{3MPa}^{600^\circ C} = 3682$ $S_{3MPa}^{600^\circ C} = 7.50 kJ/kg\cdot K$ **20**
- (b)(i) A closed cylindrical vessel 0.2 m in diameter and 1.2 m long is filled with water upto a height of 0.8 m from the bottom. Find the speed of the vessel about its vertical axis, when the axial depth of water is zero. **10**
- (b)(ii) How would you define the strength of shock wave? What do you mean by weak shock? Also find the expression for the strength of shock in terms of density ratio. **10**
- (c) An air-conditioning system (see figure) operates at a total pressure of 1 atm. It consists of a heating section and a humidifier that supplies wet steam (saturated) at $100^\circ C$. Air enters the heating section at $10^\circ C$ and 70 percent relative humidity at the rate of $35 m^3/min$. It leaves at $20^\circ C$ and 60% relative humidity. Determine (i) temperature and relative humidity of air when it leaves the heating section, (ii) the rate of heat transfer to the heating section, and (iii) the rate at which water is added to the air in the humidifying section. **20**

[Figure: Duct with air at 1 atm flowing left to right; state ① at inlet: $10^\circ C$, 70%, $35 m^3/min$; a heater (heating coil) in the duct, followed by state ②; then a humidifier – a vertical pipe supplying “Sat. steam $100^\circ C$, $h = 2675 kJ/kg$ ” and spraying it into the air (three arrows) – followed by state ③ at exit: $20^\circ C$, 60%]

Also draw skeleton Psychrometric chart representation showing the process.

4. (a) A steel strip emerges from hot roll section of a steel mill at a constant speed of 0.1 m/s and a temperature of $500^\circ C$. The length, width and thickness of the steel strip are 10 m, 1 m and 0.003 m respectively. Air at a mean velocity and free stream temperature of 20 m/s and $20^\circ C$ respectively flows transversely over the strip. Density, specific heat and emissivity of steel strip, respectively, are $7850 kg/m^3$, $620 J/kg\cdot K$ and 0.7. The thermal conductivity, kinematic viscosity and Prandtl number for air at $20^\circ C$ are respectively $0.044 W/m\cdot K$, $4.5 \times 10^{-5} m^2/s$ and 0.68. Neglect the variation in strip temperature across its width and thickness. (i) Write the governing equation for the temperature distribution along the length of the strip. (ii) Neglecting radiation from the steel strip, derive an expression for the temperature of steel strip. (iii) Neglecting radiation from the steel strip,

calculate the steel strip temperature at the trailing edge. The following correlation for convection heat transfer may be used:

$$\overline{Nu} = 0.037 Re_{x-l}^{0.8} Pr^{1/3}$$

Symbols have the usual meaning.

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- (b) A designer is given the job of designing a steam based power plant to compete with a nuclear power plant. Sketch five cycles (all versions of Rankine cycle) that may qualify for such a job. Justify your answer with the notion that nuclear power is cheaper under the given steam-water conditions. **20**
- (c)(i) What are the effects of the following additives that are added to petrol to improve its combustion and other characteristics? 1. Antioxidant 2. Corrosion inhibitor 3. Anti icing agent 4. Antiknock agent 5. Metal deactivator **10**
- (c)(ii) What are the measures required for the reduction of the following emissions from diesel engine? 1. Particulate Emission 2. Smoke Emission 3. NO_x Emissions 4. HC Emissions 5. SO_x Emissions **10**

SECTION 'B'

5. (a) With the help of a neat sketch explain the concept of a flow net. Clearly mention the various assumptions made. Also explain the uses of flow net. **12**
- (b) The average friction coefficient, when an incompressible fluid flows over a stationary flat surface with free stream velocity of 10 m/s, is 0.008. The average temperature of the plate and free stream fluid temperature are respectively at 120°C and 20°C respectively. Fluid properties known: density = 0.88 kg/m^3 and specific heat = 1001 J/kg-K, Pr = 0.65. Estimate the average rate of heat transfer per unit area of the plate. Flow over the plate is laminar. **12**
- (c)(i) Draw the actual p – v diagram of a four stroke Otto cycle engine and indicate the pumping loss by hatching. **4**
- (c)(ii) Explain four deviations of the actual p – v diagram from the hypothetical p – v diagram of four stroke Otto cycle engine. **8**
- (d) In the event of failure of heaters in a spacecraft, heat is lost by radiation at the rate of 100 kJ/hr while electronic instruments generate 75 kJ/hr inside the spacecraft. Initially the air inside the spacecraft is at 1 bar, 25°C with a volume of 10 m^3 . How long it will take to reach air temperature of 0°C? **12**
- (e) A small expander (turbine with heat transfer) has 0.05 kg/s helium entering at 1000 kPa, 300 K. The power output on shaft is measured at 55 kW. Find the rate of heat transfer neglecting kinetic energy. $C_{p,He} = 5.193 \text{ kJ/kg-K}$ **12**
6. (a) Derive

$$\left(\frac{\partial T}{\partial P} \right)_S = \left(\frac{\partial v}{\partial S} \right)_P$$

$$\left(\frac{\partial P}{\partial T} \right)_v = \left(\frac{\partial S}{\partial v} \right)_T$$

$$\left(\frac{\partial v}{\partial T} \right)_P = - \left(\frac{\partial S}{\partial P} \right)_T$$

from the first principles. Explain any assumptions needed here.

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- (b) A tubular gas heater heats air flowing at the rate of 5.5 kg/s from 20°C to 75°C using saturated steam condensing at 1.3 bar (saturation temperature, $t_{sat} = 107^\circ\text{C}$). It is proposed to double the flow rate of

air to heat the same for the same rise in temperature in the same gas heater. One way of doing this is to increase the condensing pressure of saturated steam. What should be the pressure needed if the overall heat transfer coefficient remains the same for both the operating conditions? Specific heat of air = 1.005 kJ/kg-K. For steam, the following pressure and the corresponding saturation temperature are known:

p (bar)	2	3	4	5	6	7	8	9
$t_{sat}(^{\circ}\text{C})$	120.2	133.5	143.6	151.8	158.8	165.0	170.4	175.4

- (c)(i) What is the purpose of shrouding the inlet valve in compression ignition engines? **4**
- (c)(ii) With the help of cross-section figures and schematics show the shrouded inlet valve and masked cylinder head for producing net in-cylinder angular momentum viz., swirl in compression ignition engine. **12**
- (c)(iii) Give two disadvantages and their effects of open combustion chambers. **4**
7. (a) Draw the schematic arrangement of a simple cycle with intercooled and heat exchanger and explain briefly the working principle. Also draw the P – V and T – S diagrams of the cycle. Further, derive expressions for specific work output and the efficiency of a simple cycle with intercooled and heat exchanger. Draw their trends as a function of pressure ratio. **20**
- (b)(i) Explain how the Diesel Fuel is rated by the following with their salient features: Critical Compression Ratio Method – CCR **8**
- (b)(ii) Calculated Cetane Index – CCI **4**
- (b)(iii) Diesel Index **8**
- (c) A commercial refrigerator with refrigerant 134a as the working fluid keeps a space cooled at – 30°C. It rejects heat to cooling water that enters the condenser at 18°C and at the rate of 0.25 kg/s and it leaves at 26°C. The refrigerant enters the condenser at 1.2 MPa and 65°C and it leaves at 42°C. The inlet state of compressor is 60 kPa and – 34°C. It gains a net heat of 450 W from the surroundings. Sketch T – S diagram and determine, (i) refrigeration load (ii) COP (iii) theoretical maximum refrigerant load for the same power input to the compressor. Given properties: $h_{-34^{\circ}\text{C}}^{60\text{ kPa}} = 230.03\text{ kJ/kg}$, $h_{65^{\circ}\text{C}}^{1200\text{ kPa}} = 295.16\text{ kJ/kg}$, $h_{42^{\circ}\text{C}}^{1200\text{ kPa}} = 111.23\text{ kJ/kg}$, $x_{111.23\text{ kJ/kg}}^{60\text{ kPa}} = 0.47$, $h_{\text{water}, 18^{\circ}\text{C}} = 75.4\text{ kJ/kg}$, $h_{\text{water}, 26^{\circ}\text{C}} = 108.9\text{ kJ/kg}$ **20**
8. (a) An electric furnace consisting of two flat surface heaters, top and bottom, is used to heat treat a coating that is applied to both surfaces of a thin metal plate inserted midway between the heaters. The heaters and the plate are 2 m × 2 m on a side, and each heater is separated from the plate by a distance of 0.5 m. Each heater is well insulated on its back side and has an emissivity of 0.9 at its exposed surface. The plate and side walls have emissivities of 0.6 and 0.3 respectively. Under steady operating conditions, both heaters are at 800 K while the side walls are at 400 K. View factor between the heaters and the plate is 0.62. (i) Sketch the system and its equivalent thermal network and label all pertinent resistances and potentials. (ii) Calculate the associated resistances and driving potentials. (iii) Calculate the required electrical power. **20**
- (b) A low temperature power plant operates with a refrigerant maintaining – 20°C in the condenser, a pressure of 3 MPa and superheat of 80°C. There is one open feedwater heater operating at 800 kPa with an exit as saturated liquid at 0°C. (i) Sketch the schematic of this plant. (ii) Sketch the corresponding T – S diagram. (iii) Set up equations only to compute extraction fraction of the flow out of turbine and the turbine work per unit mass flowing through boiler. (iv) Indicate in your answer which refrigerant properties are needed. **20**
- (c) Discuss briefly how the following alternate fuels considered for Compression Ignition Engines i.e., Diesel Engines compare with respect to introduction into the engine, calorific value, part load and full load operation and safety aspect: (i) Biogas produced from cow dung, water hyacinth, algae and

municipal wastes (ii) Hydrogen Gas (iii) Ethyl Alcohol (iv) Cashewnut Shell Liquid (CNSL)
4×5=20

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