

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)

(a)(i) State Clausius inequality theorem and explain its significance. An inventor has claimed that he has developed an engine which receives 1000 kJ of heat at a temperature of 1000 K and rejects 200 kJ of heat at a temperature of 600 K, delivering the remaining input as work. Check whether the claim is possible using the above theorem. In case this engine has to be reversible, determine the amount of heat to be rejected. **10**

(a)(ii) Determine the pressure of saturated steam at 40 °C if the saturation pressure at 35 °C is 5.628 kPa. The enthalpy of evaporation and the specific volume at 35 °C are 2418.6 kJ/kg and $25.22 \text{ m}^3/\text{kg}$ respectively. Assume that enthalpy of evaporation is essentially constant in this range and $R = P v_g / T$. **10**

(b) Show using Maxwell's relations:

$$C_p - C_v - T \left(\frac{\delta V}{\delta T} \right)_p^2 \left(\frac{\delta P}{\delta V} \right)_T$$

20

(c) Explain what do you understand by 'Octane number' of a fuel. Describe how it determined experimentally is. **20**

(d) Explain the reasons for using supercharging in industrial diesel engines. What are the possible limitations in the application of supercharging in diesel engines? **20**

2. (a)(i) Distinguish between available energy and availability. **5**

(a)(ii) Oil at 167 °C is cooled to 47 °C at the rate of 1600 kg/hr in a heat exchanger. Water at 17 °C is used at the rate of 6400 kg/hr for the cooling. The specific heat of the oil is 2.1 kJ/kg K. Assuming dead state as 17 °C, determine the loss in available energy. **15**

(b) In the winter season while outside is at 5 °C, a heat pump is used to maintain the living space at 20 °C. The heat gain into the space is 1.1 kJ/s per degree difference in temperature between inside and outside. Determine the power required to drive the heat pump. If during summer the same motor power is used to maintain the space at 20 °C, determine the maximum outside temperature upto which this will be possible. Heat loss rate can be assumed as in the winter season. **20**

(c) The efficiency of a reversible engine can be increased in two ways (i) increasing the source temperature maintaining the sink temperature constant, and (ii) reducing the sink temperature

maintaining the source temperature constant. Show analytically that the second method will lead to larger improvement in efficiency for the same incremental change in temperature. **20**

3. (a) Describe the laboratory method of determination of volumetric efficiency of I.C. engines giving the details of calculation. **20**

- (b) A four cylinder two stroke cycle diesel engine running at 3000 rpm has a bore of 120 mm and stroke of 125 mm. The brake torque was measured as 420 Nm. The volumetric efficiency of the engine is 0.62. The air fuel ratio is 21 : 1. Calorific value of the fuel is 45000 kJ/kg. The density of air at suction was 1.1 kg/m^3 . Determine the brake thermal efficiency and brake mean effective pressure. If an orifice tank with orifice diameter of 90 mm was used, determine the water head across the orifice. Take coefficient of discharge for orifice (C_d) = 0.61 **40**

4. (a) Show that the mass of air, m_a , supplied for the combustion of 1 kg of fuel of known carbon content, C%, can be determined from the volumetric analysis of dry products of combustion using

$$m_a = \frac{1}{33} \frac{N_2 C}{C O_2 + C O}$$

where N_2 , $C O_2$ and $C O$ are the percentages by volume of gases nitrogen, carbon dioxide and carbon monoxide respectively **30**

- (b) Coal having the following composition is burnt in a furnace: Carbon 86.1%, Hydrogen 3.9%, Oxygen 14% rest ash. The volumetric analysis of dry products was: $C O_2 = 12.7\%$, $C O = 1.4\%$, $O_2 = 4.1\%$, $N_2 = 81.8\%$. Determine the percentage of excess air. Also determine the loss due to incomplete combustion, if $C O$ burning to $C O_2$ will release 24000 kJ/kg of carbon in $C O$. **30**

SECTION 'B'

5. Answer any three of the following parts (answer to each part should not exceed 200 words)

- (a) Derive the integral momentum equation for the boundary layer over a flat plate and determine the boundary layer thickness, δ , at a distance x from the leading edge assuming linear velocity profile $(u/u_\infty) y/\delta$ where u is the velocity at the location at a distance y from the plate, and u_∞ is the free stream velocity. **20**
- (b) Describe giving the layout, a refrigeration system that can use solar heat as the input. **20**
- (c) Derive the following relation using the method of dimensional analysis:

$$\frac{P}{\rho N^3 D^5} = f \left[\frac{Q}{N D^3}, \frac{\rho N D^2}{\mu} \right]$$

where P is the power, N is the rpm, D is the rotor diameter, Q is the volume flow rate and ρ and μ are density and viscosity respectively of the fluid handled. **20**

- (d)(i) Explain what is meant by stagnation properties of a flowing gas. **5**
- (d)(ii) Show that stagnation pressure remains constant for reversible adiabatic flow. **5**
- (d)(iii) Show that for the flow of a gas through a varying cross-section

$$\frac{dA}{A} = - \frac{du}{u} (1 - M^2)$$

What conclusions can be drawn from the above for area variation for subsonic, sonic and supersonic flows? The symbols have usual meaning. **10**

6. (a) Show that the shape factor F_{1R2} for two parallel black surfaces of equal area connected by re-radiating walls at constant temperature is given by

$$F_{1R2} = (1 + F_{1-2})/2$$

where F_{1R2} is the shape factor of surface 1 with respect to surface 2, when connected by re-radiating surface R **20**

- (b) A furnace is in the shape of a cylinder of 2 m diameter and 2 m height. The top is at 1000 K while the base is at 700 K. The emissivity of the surface is 0.6. The enclosing curved surface acts as non-absorbing re-radiating surface. Determine the radiation exchange between the top and bottom surfaces. The shape factor between the top and bottom surfaces when sides are open is 0.5. **40**

7. (a) Compare vapour compression and vapour absorption systems for the following applications (i) Household use (ii) Ice plant (iii) Central air-conditioning (iv) Process cooling, and (v) Process air-conditioning **20**

- (b) A refrigerator with evaporator and condenser temperatures of -10°C and 32°C uses R11. The vapour is superheated by 8°C at entry to the compressor and the superheating is obtained by undercooling the liquid before entry to evaporator. Assuming isentropic compression, determine the power required for a cooling load of 350 kJ/s, the overall efficiency for power use being 75%. Discuss about the choice of the type of compressor for this plant. Properties values are tabulated below. **40**

Temp. $^\circ\text{C}$	Specific Volume of vapour m^3/kg	Enthalpy kJ/kg: liquid	Enthalpy kJ/kg: vapour	Entropy of vapour kJ/kg K	Specific heat of kJ/kg K
-10	0.61141	191.44	384.64	1.7023	0.562
32	0.13104	227.96	406.23	1.6807	0.620

8. (a) A double sided centrifugal compressor has eye root and tip diameters of 18 cm and 30 cm and is to deliver 16 kg of air per second at 16000 rpm. The design ambient conditions are 15°C and 1 bar and the compressor has to be a part of a stationary power plant. Determine (i) suitable values for impeller vane angles at the root and tip of the eye if the air is given 20° of pre-whirl at all radii. The axial component of the velocity is constant throughout the impeller and is 150 m/s. (ii) the power required if the power input factor is 1.05 and mechanical efficiency is 95%, and (iii) the maximum Mach number at the eye. Take for air $C_p = 1.005 \text{ kJ/kg K}$ and $C_p/C_v = 1.4$. **30**

- (b) During a boiler trial, steam was produced at a pressure of 20 bar and superheat temperature of 360°C using feed water at 30°C at the rate of 90,000 kg/hr. Coal with 3% moisture having calorific value of 34,000 kJ/kg of dry coal was burnt at the rate of 1000 kg/hr. The temperature of flue gases at the exit was 200°C while inlet air was at 30°C . Coal contains 80% carbon, 6% hydrogen and rest ash. Volumetric analysis of dry flue gases is: $\text{CO}_2 = 12\%$, $\text{O}_2 = 10\%$ and $\text{N}_2 = 78\%$. Enthalpy of steam at 20 bar, $360^\circ\text{C} = 3159.3 \text{ kJ/kg}$, enthalpy of water at $30^\circ\text{C} = 126 \text{ kJ/kg}$. In the flue gas, the enthalpy of steam at exit condition is 2879.7 kJ/kg. Specific heat of gas = 1.01 kJ/kg. Draw the heat balance sheet. **30**
