

# MECHANICAL ENGINEERING

## Paper – I

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.*

*Questions No. **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.*

*Diagrams / Figures, wherever required, shall be drawn in the space provided for answering the question itself.*

*Unless otherwise mentioned, symbols and notations have their usual standard meanings.*

*Attempts of questions shall be counted in sequential 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 Question-cum-Answer (QCA) Booklet must be clearly struck off.*

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



## SECTION A

- Q1.** (a) (i) Explain with examples the concept of Rheology of fluids. 8
- (ii) Clearly mention the basic difference between the Euler's equations of motion and the Navier-Stokes equations. 4
- (b) Explain the concept of mixing length introduced by Prandtl and state the relationship that exists between the turbulent shearing stress and the mixing length. 12
- (c) A stationary mass of gas is compressed without friction from an initial state of  $0.45 \text{ m}^3$  and  $0.12 \text{ MPa}$  to a final state of  $0.15 \text{ m}^3$  and  $0.12 \text{ MPa}$ , the pressure remaining constant during the process. There is a transfer of  $57.6 \text{ kJ}$  of heat from the gas during the process. How much does the internal energy of the gas change ? 12
- (d) What is condensation ? Explain the terms filmwise condensation and dropwise condensation. Which one is more preferred ? Justify. 12
- (e) Explain the working of roots blower supercharger with diagram and mention its advantages. 12

- Q2.** (a) (i) The velocity distribution in the boundary layer over a high spillway face was found to have the following form :

$$\frac{u}{U_{\infty}} = \eta^{0.22}, \text{ where } \eta = y / \delta$$

The free stream velocity  $U_{\infty}$  at a certain section was observed to be  $20 \text{ m/s}$  and boundary layer thickness of  $5 \text{ cm}$  was estimated from the velocity distribution measured at the section. The discharge passing over the spillway was  $5 \text{ m}^3/\text{s}$  per metre length of spillway.

Determine,

- (I) Displacement thickness,
- (II) Momentum thickness,
- (III) Energy thickness, and
- (IV) Loss of energy up to the section under consideration.

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- (ii) A plate 4 m long and 20 cm wide is immersed in a fluid of density  $1.2 \text{ kg/m}^3$  and kinematic viscosity  $10^{-4} \text{ m}^2/\text{s}$ . The fluid is moving with a velocity of 5 m/s. Calculate,

(I) Boundary layer thickness, and

(II) Drag force on both sides of the plate.

Assume Blasius's solution.

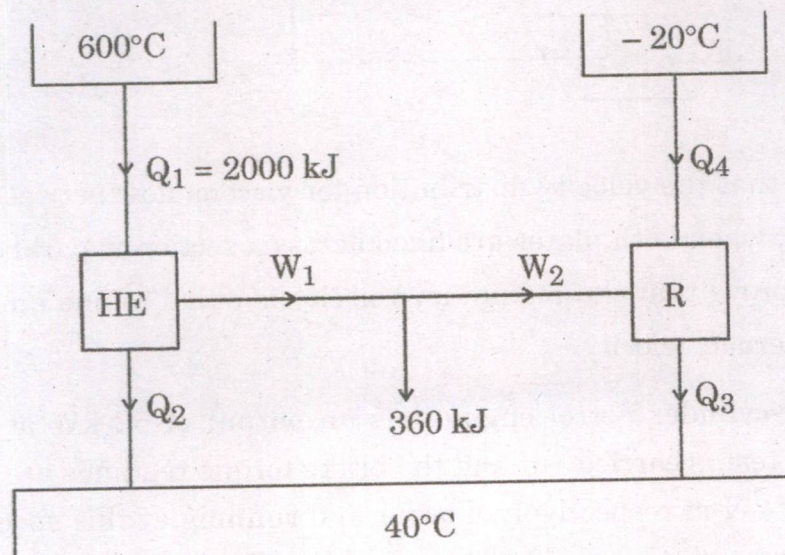
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- (b) A reversible heat engine operates between two reservoirs at temperatures of  $600^\circ\text{C}$  and  $40^\circ\text{C}$ . The engine drives a reversible refrigerator which operates between reservoirs at temperatures of  $40^\circ\text{C}$  and  $-20^\circ\text{C}$ . The heat transfer to the heat engine is 2000 kJ and net work output of the combined engine refrigerator plant is 360 kJ.

- (i) Evaluate the heat transfer to the refrigerant and the net heat transfer to the reservoir at  $40^\circ\text{C}$ .

- (ii) Evaluate heat transfer to the refrigerant and the net heat transfer to the reservoir when the efficiency of the heat engine and COP of the refrigerator are each 40% of their maximum possible values.

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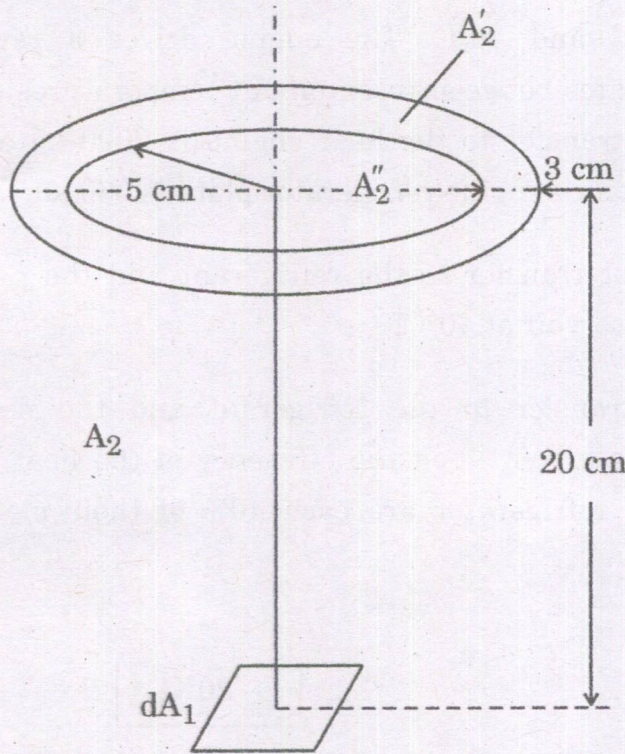




- (c) Write down the properties of a black body. How do we define spectral emissivity of a real surface ? Consider a small plane surface area  $dA_1$  placed parallel to a circular ring  $A'_2$  of inner radius 5 cm and width 3 cm as shown in the figure.

Calculate the fraction of the radiation emitted by the surface  $dA_1$  that is intercepted by the ring ( $A'_2$ ) and also the fraction that passes through the hole (area =  $A''_2$ ) in the ring if the surfaces are placed 20 cm apart. Assume  $dA_1$  is a very small (differential) surface element.

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- Q3.** (a) Prove that the velocity distribution for viscous flow between two parallel plates, when both plates are fixed across a section is parabolic in nature. Also, prove that the maximum velocity is equal to one and a half times the average velocity.

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- (b) A four-cylinder petrol engine has an output of 52 kW at 2000 rpm. A Morse test is carried out and the brake torque readings are 177, 170, 168 and 174 N-m respectively. For normal running at this speed the specific fuel consumption is 0.364 kg/kW hr. The calorific value of fuel is 44,200 kJ/kg. Calculate the mechanical and brake thermal efficiency of the engine.

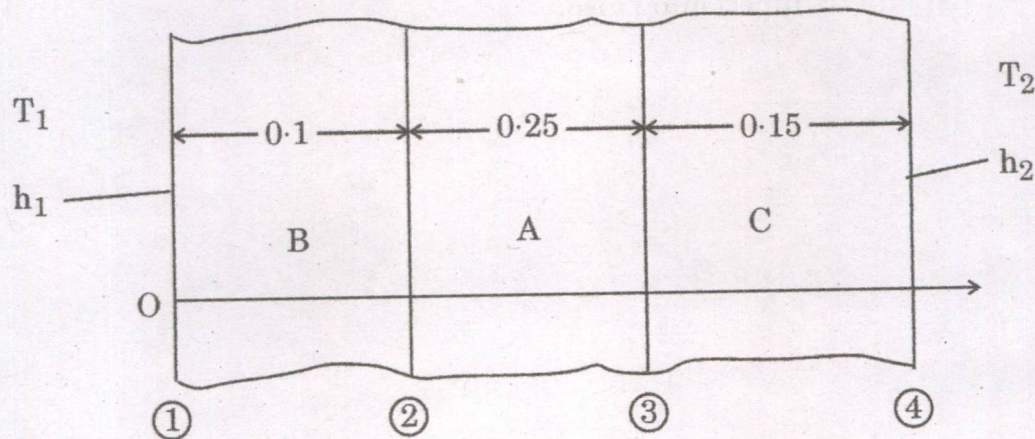
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- (c) A heat generating slab A (thickness = 0.25 m, thermal conductivity  $K_A = 15 \text{ W/m } ^\circ\text{C}$ ) is sandwiched between two other slabs B (thickness = 0.1 m,  $K_B = 10 \text{ W/m } ^\circ\text{C}$ ) and C (thickness = 0.15 m,  $K_C = 30 \text{ W/m } ^\circ\text{C}$ ) as shown in the figure. There is no heat generation in slab B or C. The temperature distribution in slab A is known to be  $T_A = 90 + 4500x - 11000x^2$ , where  $T$  is in  $^\circ\text{C}$  and  $x$  is the distance in metres from left surface of B. The wall B is in contact with a fluid at temperature  $T_1 = 40^\circ\text{C}$ , the wall heat transfer coefficient being  $h_1$ . Similarly, the free surface of C loses heat to a medium at temperature  $35^\circ\text{C}$ , and the surface heat transfer coefficient is  $h_2$ . Assume steady state condition.

- (i) Calculate the temperature at the surfaces of slab A. What is the maximum temperature in A and where does it occur?
- (ii) Determine the temperature gradient at both the surfaces of each of the slabs A, B and C.
- (iii) Find the temperature profiles in slabs B and C. Also, calculate the values of the heat transfer coefficients  $h_1$  and  $h_2$ .

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**Q4.** (a) (i) Show that the streamlines and equipotential lines form a net of mutually perpendicular lines. 10

(ii) Why do we use fins in heat exchanging devices ? How do we define fin efficiency ?

Give a few examples of different finned surfaces with sketches. 10

(b) What is a polytropic process ?

Give an expression between temperature and volume between two states of a polytropic process.

Find out entropy change between the two states of an ideal gas.

A mass of 0.25 kg of an ideal gas has a pressure of 300 kPa, a temperature of 90°C and a volume of 0.07 m<sup>3</sup>. The gas undergoes an irreversible adiabatic process to a final pressure of 300 kPa and final volume of 0.10 m<sup>3</sup>, during which the work done on the gas is 25 kJ. Evaluate  $C_p$  and  $C_v$  of the gas and the increase in entropy of the gas. 20

(c) What is catalytic converter package ? Show the arrangement of catalytic converter package with the help of a diagram for HC, CO and NO<sub>x</sub>. Explain its functioning also. 20



## SECTION B

- Q5.** (a) (i) What is the significance of specific speed of a centrifugal pump ?
- (ii) A centrifugal pump operates at its optimal efficiency and delivers 3 cubic metre per second over a height of 22 m. The pump has a 36 cm diameter impeller and rotates at 3250 rpm. Compute the specific speed of the pump
- (1) in terms of discharge, and
- (2) in terms of power if maximum efficiency of the pump is 80%. 12
- (b) A shell and coil type of evaporator is to be designed for a refrigerator. Coil is bare tube of copper. Refrigerant flows inside the tube and shell side water in stagnant condition. Coil is maintained at  $-5^{\circ}\text{C}$ . Heat transfer coefficient on water side is  $4100 \text{ W/m}^2\text{K}$ . The load on the evaporator is 2.8 kW. The LMTD is  $18^{\circ}\text{C}$ . The tube side heat transfer coefficient is given by

$$h_i = 0.555 \left[ \frac{9.81(\rho_f - \rho_g) k_f^3 \cdot h_{fg}}{\mu_f \cdot \text{evaporator temp} \times D_i} \right]$$

The properties of refrigerant are as given below at  $-5^{\circ}\text{C}$ .

Dynamic viscosity =  $0.000191 \text{ kg/ms}$

Density of liquid =  $1136 \text{ kg/m}^3$

Density of vapour =  $14.43 \text{ kg/m}^3$

Tube inner diameter  $D_i = 0.005715 \text{ m}$  and thickness of tube is  $0.001905 \text{ m}$ .

Thermal conductivity of refrigerant =  $0.0857 \text{ W/mK}$ .

Thermal conductivity of tube is  $400 \text{ W/mK}$ .

Thermal conductivity of ice is  $2.25 \text{ W/mK}$ .

Latent heat of vapourization is  $173.1 \text{ kJ/kg}$ .

Find the tube length required.

12



- (c) Air at DBT  $35^{\circ}\text{C}$  and WBT  $23^{\circ}\text{C}$  is passed over a coil and air comes out of the coil at DBT  $25^{\circ}\text{C}$  and WBT  $20^{\circ}\text{C}$ . Show the procedure on skeletal psychrometric chart.
- Mention the name of the process taking place.
  - Find the coil surface temperature.
  - Find the bypass factor of the coil. 12
- (d) (i) What are the performance parameters of cooling towers ? Define them. 6
- What are the main advantages and disadvantages of mechanical draught cooling towers ? 6
- (e) With the help of sketches, define Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Compare HAWT and VAWT in respect of
- Efficiency
  - Space requirement
  - Cost
  - Design and installation
  - Noise
  - Self-starting 12

- Q6.** (a) (i) Explain the working of counterflow Ranque-Hilsch tube refrigeration system with the help of a sketch.
- Also define the following terms :
- Cold mass flow ratio
  - Normalised temperature drop
  - Cold orifice diameter ratio
  - Isentropic efficiency 15
- (ii) Explain how the critical temperature of a refrigerant affects the performance of a refrigeration system represented on T-s diagram. 5



- (b) In an air conditioning system two streams are mixed adiabatically. One stream is at DBT  $15^{\circ}\text{C}$  and WBT  $12^{\circ}\text{C}$  and the flow rate is  $20 \text{ m}^3/\text{min}$ . The second stream volume flow rate is  $30 \text{ m}^3/\text{min}$ . After mixing the two streams the condition of air is found to be  $30^{\circ}\text{C}$  DBT and  $23^{\circ}\text{C}$  WBT. Find the 2<sup>nd</sup> stream condition before mixing. Also, find the DBT, WBT, enthalpy, mass flow rate, volume flow rate, specific humidity, and relative humidity of the 2<sup>nd</sup> stream before mixing. On the skeletal chart, show the procedure to get the 2<sup>nd</sup> stream condition. 20

- (c) In a direct contact counterflow splash-type filled cooling tower of a thermal power station, air enters at the bottom and leaves at the top of the cooling tower. Water is sprayed from the top of the cooling tower. The water enters at  $35^{\circ}\text{C}$  and leaves at  $28^{\circ}\text{C}$ . The ambient conditions are  $25^{\circ}\text{C}$  DBT and 55% RH. Water and air specific heats are  $4.1867$  and  $1 \text{ kJ kg K}$  and mass flow rates are  $18.5$  and  $15.5 \text{ kg/s}$  respectively. Density of water is  $1000 \text{ kg/m}^3$ . Find the following :

- (i) Range
- (ii) Approach
- (iii) Cooling capacity of tower
- (iv) Evaporation loss

Evaporation loss ( $\text{m}^3/\text{hr}$ ) is given by

$$\text{Evaporation loss} = 0.00085 \times 1.8 \times \text{circulation rate } (\text{m}^3/\text{hr}) \times \delta T$$

$\delta T$  = difference in water entry and exit temperature. 20

- Q7. (a) (i) A jet of velocity of  $20 \text{ m/s}$  strikes a flat plate inclined at  $30^{\circ}$  with the axis of the jet. If the cross-sectional area of the jet is  $20 \text{ cm}^2$ , find the force exerted by the jet on the plane. Also calculate the components of the force in the direction normal to the jet. Find also the ratio in which the discharge gets divided after striking the plate. Take density of water as  $1000 \text{ kg/m}^3$ . 10



- (ii) What is tidal range ?

A simple single-basin type tidal power plant has a basin area of  $20 \text{ km}^2$ . The tide has a range of 8 m. The turbine stops operation when the head on it falls below 2 m. Determine the average power generated during one filling/emptying process in MW if the turbine – generator efficiency is 70%. Assume specific gravity of sea water as 1.025.

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- (b) The draft tube of a Kaplan turbine has inlet diameter 2.5 m and inlet is set at 2.8 m above the tail race. When the turbine develops 2200 metric horsepower under a net head of 6.2 m, it is found that the vacuum gauge fitted at the inlet to the draft tube indicates a negative head of 4 m. If the turbine efficiency is 88%, calculate the draft tube efficiency. Further, if the turbine output is reduced to 50% with the same head, speed and draft tube efficiency, calculate the reading of the vacuum gauge. Assume, atmospheric pressure is 10.3 m of water and specific weight of water is  $1000 \text{ kg/m}^3$ .

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- (c) (i) Explain with the aid of illustrative sketch the working of a Ramjet engine. What are its applications ?
- (ii) Mention the various industrial wastes and by-products used as boiler fuels. Briefly explain them.

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- Q8.** (a) A flat plate collector is of size 2 m length and 1 m width with one glass cover and  $0^\circ$  slope with horizontal. The gap between absorber plate and glass cover is 0.05 m and absorber plate to back plate is 0.015 m. Ambient air is passed between absorber plate and back plate at the rate of  $m = 0.1 \text{ kg/s}$ . The solar radiation is  $I = 800 \text{ W/m}^2$ , Transmittance-Absorptance Product is  $T_A = 0.8$ , Overall loss coefficient  $U_L = 9.65 \text{ W/m}^2 \text{ K}$ , Ambient temperature  $T_a = 300 \text{ K}$ , Specific heat of air  $C_p = 1006.4 \text{ J/kg K}$ , natural convection heat transfer coefficient is  $12.08 \text{ W/m}^2 \text{ K}$ .

Find the plate temperature  $T_p$  and heat removal factor  $F_R$ . Use the correlations given below :



- (i) Plate temperature

$$T_p = T_a + \left[ \frac{I \times T_A}{U_L} \right] \left( 1 - G \xi \frac{C_p}{U_L} \right)$$

where

$$\xi = 1 - \exp \left[ \left( \frac{-U_L}{G C_p} \right) \left( 1 + \frac{U_L}{h} \right)^{-1} \right]$$

Heat removal factor is given by

$$F_R = \left( G \frac{C_p}{U_L} \right) \left[ 1 - \exp \left( \frac{-F' U_L}{G C_p} \right) \right]$$

$$\text{where } F' = \left( 1 + \frac{U_L}{h} \right)^{-1}$$

where  $G$  is the mass flow rate per unit area of absorber plate area ( $\text{kg/s/m}^2$ ). 10

- (ii) A company wanted 2 hours of buffer storage for a 1.5 MW solar thermal power plant that operates between  $230^\circ\text{C}$  and  $380^\circ\text{C}$ . Estimate the amount of material that is needed if Lithium Nitrate is used. Lithium Nitrate has the properties at melting point  $252^\circ\text{C}$ , latent heat  $530 \text{ kJ/kg}$ , specific heat of solid  $2.02$  and liquid  $2.041 \text{ kJ/kg K}$  respectively. Density of solid  $2310 \text{ kg/m}^3$  and liquid  $1776 \text{ kg/m}^3$ , energy density  $261 \text{ kWh/m}^3 \text{ K}$  and thermal conductivity  $1.35 \text{ W/mK}$ . 10

- (b) The percentage composition of a solid fuel used in a boiler of a power station is as follows :

Carbon 90%, Hydrogen 3.5%, Oxygen 3%, Nitrogen 1%, Sulphur 1% and the remaining being ash.

Determine the excess air supplied for the combustion of coal if the volumetric analysis of dry flue gases shows the following composition :

$\text{CO}_2$  : 10%,  $\text{CO}$  : 1%,  $\text{N}_2$  : 82%,  $\text{O}_2$  : 7%

Take oxygen as 23% in the air by mass. 20



(c) A single stage, single acting air compressor 30 cm bore and 40 cm stroke runs at 200 rpm. The suction pressure is 1 bar at 15°C and delivery pressure is 5 bar. Determine the indicated mean effective pressure and the ideal power required to run it, when

- (i) Compression is isothermal,
- (ii) Compression follows the law  $PV^{1.25} = \text{Constant}$ ,
- (iii) Compression is reversible adiabatic ( $\gamma = 1.4$ ), and
- (iv) Compression is irreversible adiabatic ( $n = 1.5$ ).

Neglect clearance.

Determine the isothermal efficiency for (ii), (iii) and (iv). Assume isentropic or reversible adiabatic index,  $\gamma = 1.4$  and  $R = 0.287 \text{ kJ/kg K}$ . 20



## SI METRIC

of 101.325 kPa  
AT SEA LEVEL





