MECHANICAL ENGINEERING PAPER-I

Time Allowed: **Three Hours** Maximum Marks: **300**

Question Paper Specific Instructions

Please reach each of the following instruction 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 rotations carry their usual standard meanings.

Psychometric Chart is given in Page No.8.

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 QCA Booklet must be clearly struck off.

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

SECTION-A

1. **(a)** **(i)** Explain with examples theconcept of Rheology of fluids.

(ii) ClearlymentionthebasicdifferencebetweentheEuler's equations of motion and the Navier-Stokes equations.

[8 + 4 Marks]

(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 Marks]

(c) A stationary massof gasis compressed without friction from aninitial state of 0.45 m^3 and 0.12 MPa to a final state of 0.15 m^3 and0.12MPa, the pressure remaining constant during the process.There isa transferof 57.6 kJ of heat from thegasduring theprocess. Howmuch doestheinternal energy of thegaschange?

[12 Marks]

(d) Whatiscondensation? Explain the terms film wise condensation and drop wise condensation. Whichone is more preferred? Justify.

[12 Marks]

(e) Explain the working ofrootsblowersupercharger with diagram and mention its advantages.

[12 Marks]

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2. **(a)** **(i)** Thevelocitydistributionintheboundarylayeroverahigh spillway facewas found to havethe following form:

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

The free stream velocity U_∞ at a certain section was observed to be 20m/sand boundary layer thickness of 5 cm was estimated from the velocity distribution measured at the section. The discharge passing over the spillway was 5 m^3/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.

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

(I)Boundary layer thickness, and

(II) Drag forceon both sidesof the plate. .

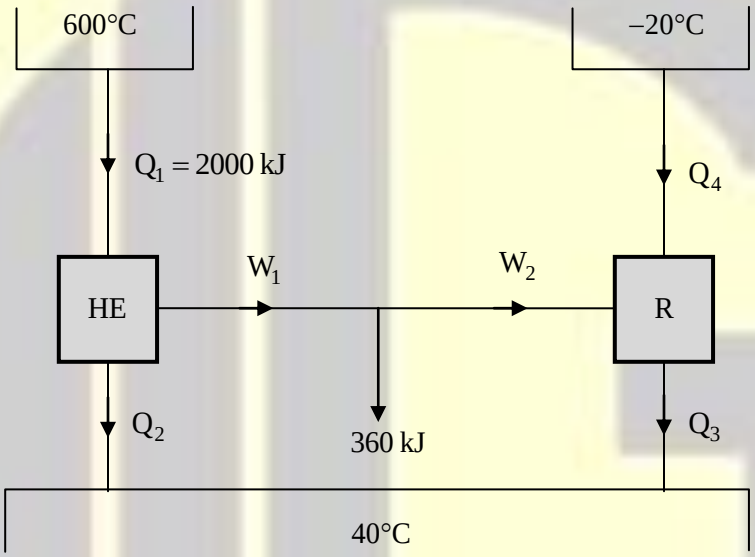
Assume Blasius's solution.

[14 + 6 Marks]

(b) A reversible heat engine operates between two reservoirs at temperatures of 600°C and 40°C. The engine drives a reversible refrigerator which operates between reservoirs attemperatures of 40°C and –20°C. The heat transfer to the heat engine is2000kJ and network output of the combined engine refrigerator plant is 360 kJ.

(i) Evaluate the heat transfer tothe refrigerant andthe netheat transfer to the reservoir at 40°C.

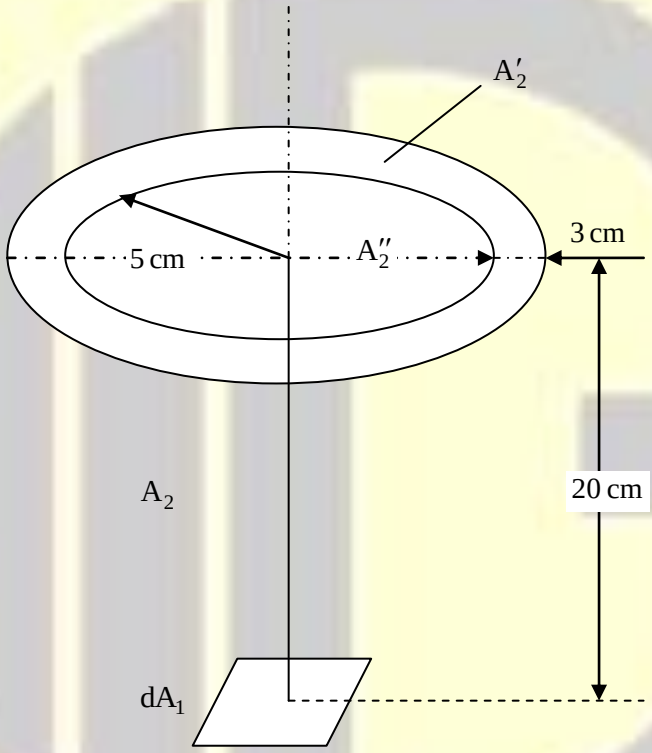
(ii) Evaluate heattransfertotherefrigerantandthenetheattransfer tothe reservoir when the efficiency of the heat engineand COPoftherefrigerator areeach 40%oftheir maximumpossiblevalues.



[6 + 20 Marks]

(c) Write down the properties of a blackbody. Howdo we definespectral emissivity of a realsurface? Consider a small plane surface area dA_1 placed parallel to a circular ring A_2' of innerradius5 cm and width 3 cm as shown in the figure.

Calculate the fractionof 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 $(\text{area} = A_2'')$ in the ring if the surfaces are placed 20 cm apart. Assume dA_1 is a very small (differential) surface element.



[20 Marks]

3. **(a)** Prove that the velocitydistribution for 'viscous flow between two parallel plates, when both plates are fixed across a section is parabolic in nature.

Also, prove thatthe maximum velocityis equal to one and a half times the average velocity.

[20 Marks]

(b) A four-cylinder petrol engine hasanoutputof 52 kWat 2000 rpm.AMorse test is carriedout and the brake torque readings are 177, 170, 168 and 174 N-m respectively.For normalrunningat thisspeed the specific fuelconsumptionis0.364kg/kW hr.Thecalorificvalueoffuelis44,200 kJ/kg. Calculate the mechanical and brake thermal efficiency of the engine.

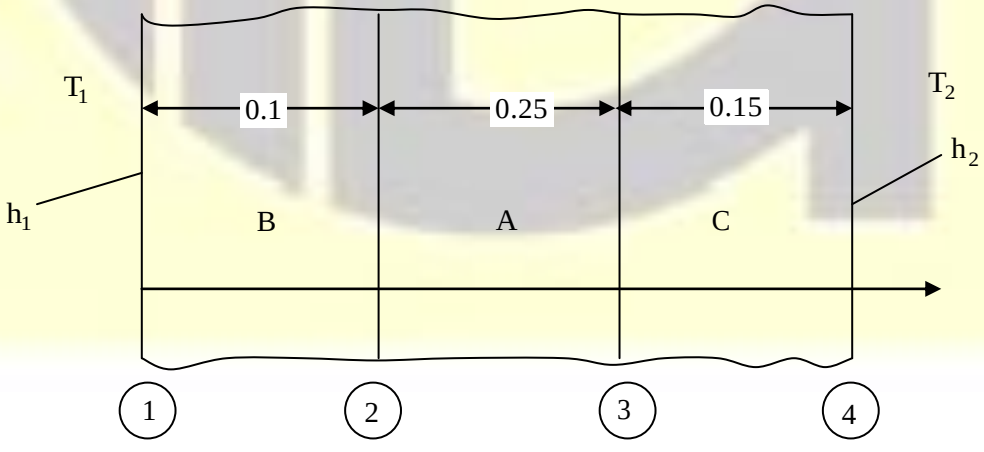
[20 Marks]

(c) A heat generating slab A (thickness = 0.25 m, thermal conductivity $K_A = 15\ W/m\,°C$) is sandwiched between two other slabs B (thickness = 0.1 m, $K_B = 10\ W/m\,°C$) and C (thickness = 0.15 m, $K_C = 30\ W/m\,°C$) 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 $T_A = 90 + 4500x - 11000\,x^2$, where T is in °C and x is the distance in metres from left surface of B. The wall B is in contact with a fluid at temperature $T_1 = 40°C$, the wall heat transfer coefficient being h_1. Similarly, the free surface of C loses heat to a medium at temperature 35°C, and the surface heat transfer coefficient is h_2. Assume steady state condition.

(i) Calculate the temperature at the surfaces of slabA.What isthemaximum temperature in A andwhere does it occur?

(ii) Determine the temperature gradient at both the surfaces of eachof the slabsA, B and C.

(iii) Find the temperature profiles inslabsB andC. Also, calculate the values of the heat transfer coefficients h_1 and h_2.



[20 Marks]

4. **(a)** **(i)** Showthat thestreamlines andequipotential linesform anet of mutually perpendicular lines.

(ii) Whydoweusefinsinheatexchanging devices?Howdowedefine fin efficiency?

Givea fewexamples of differentfinned surfaces with sketches.

[10 + 10 Marks]

(b) What is a polytropic process?

Givean expression between temperatureandvolume between two states of a polytropic process.

Find out entropy change between thetwo states of an ideal gas. A mass of 0.25kg of an ideal gas has a pressure of 300 kPa, a temperature of 90°C and a volume of 0.07 m^3. The gas undergoes an irreversible adiabatic process to a final pressure of 300 kPa and final volume of $0.10\,m^3$, during which the work done on the gas is 25kJ.

Evaluate C_p and C_v of the gas and the increase in entropy of the gas.

[20 Marks]

(c) What is catalytic converter package? Show the arrangement of catalytic converter package with the help of a diagram for HC, CO and NO_x. Explain it's functioning also.

[12 Marks]

SECTIONB

5. **(a)** **(i)** What is thesignificance of specific speedof a centrifugal pump?

(ii) A centrifugal pump operates at its optimal efficiency anddelivers3 cubic metre persecondovera height of 22 m. Thepump hasa36 cmdiameter impeller androtates at 3250 rpm.Compute the specific speedof thepump

(1)in terms of discharge, and

(2)in terms of powerif maximum efficiency of the pump is 80%.

[12 Marks]

(b) A shell andcoiltypeof evaporator isto bedesigned for a refrigerator.Coilis bare tube of copper.Refrigerant flows inside thetube and shell sidewater instagnantcondition. Coilismaintained at -5°C. Heat transfer coefficient on water side is $4100\ W/m^2K$. The load on the evaporator is 2.8 kW.TheLMTDis 18°C. Thetube sideheat transfercoefficient is givenby

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

The properties of refrigerant areas givenbelow at –5°C.

Dynamic viscosity = 0.000191 kg/ms

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

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

Tube inner diameter Di = 0.005715 m and thickness of tube is 0.001905 m.

Thermal conductivity of refrigerant= 0.0857 W/mK Thermal conductivity of tube is 400 W/mK

Thermal conductivity of ice is 2.25 W/mK

Latent heat of vapourization is 173.1 kJ/kg

Find the tube length required.

[12 Marks]

(c) Air at DBT 35°C andWBT 23°C is passed overa coil andaircomesout of thecoil at DBT 25°C andWBT 20°C. Showthe procedure on skeletal psychrometric chart.

(i) Mention thename of theprocesstaking place.

(ii) Findthecoil surface temperature.

(iii) Findthe bypassfactor of the coil.

[12 Marks]

(d) **(i)** What aretheperformance parameters of coolingtowers ? Define them.

(ii) What are themainadvantages anddisadvantages of mechanical draught cooling towers?

[6 + 6 Marks]

(e) With thehelpof sketches, defineHorizontal Axis WindTurbine (HAWT) andVertical Axis WindTurbine (VAWT). Compare HAWT and VAWT in respect of

(i) Efficiency

(ii) Spacerequirement

(iii) Cost

(iv) Designandinstallation

(v) Noise

(vi) Self-starting

[12 Marks]

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6. **(a)** **(i)** Explain the working of counter flow Ranque-Hilsch tube refrigeration system with thehelpof a sketch.

Also definethefollowing terms:

(I) Cold mass flow ratio

(II) Normalized temperature drop

(III) Cold orifice diameter ratio

(IV) Isentropic efficiency

(ii) Explain how the critical temperature of a refrigerant affects the performance of are frigeration system represented on T-s diagram.

[15 + 5 Marks]

(b) In an air conditioning system two streams are mixed adiabatically. One stream is at DBT15°C and WBT12°C and the flow rate is $20\,m^3/min$. The second stream volume flow rate is $30\,m^3/min$. After mixing the two streams the condition of air is found to be 30° CDBT and 23°C WBT. Find the 2nd stream condition before mixing. Also, find the DBT, WBT, enthalpy, mass flow rate, volume flow rate, specific humidity, and relative humidity of the 2nd stream before mixing. On the skeletal chart, show the procedure to get the 2nd stream condition.

[20 Marks]

(c) In adirectcontactcounterflowsplash-typefilledcoolingtowerofa thermal powerstation,air enters at the bottom andleaves at thetop of thecoolingtower.Water issprayed fromthe topof thecooling tower. Thewater enters at 35°C and leaves at 28°C. The ambient conditions are25°C DBTand55% RH.Waterandairspecificheats are4. 1867and1kJ kg Kandmass flowratesare18.5 and15.5 kg/srespectively.

Density of water is 1000 kg/m3.Find the following:

(i) Range

(ii) Approach

(iii) Coolingcapacity of tower

(iv) Evaporation loss

Evaporation loss (m^3/hr) is given by

Evaporation loss= 0.00085 ×1.8 x circulation rate $(m^3/hr) \times \delta T$

δT = difference in water entry and exit temperature.

[20 Marks]

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7. **(a)** **(i)** A jetof velocityof 20 m/s strikes a flat plate inclined at30° with the axis of the jet. If the cross-sectional area of the jet is $20\ cm^2$, find the force exerted by the jeton the plane.Also calculate the components of the forceinthe direction normal tothejet.Findalsothe ratioinwhichthedischarge getsdivided after strikingtheplate. Take density of water as $1000\ kg/m^3$.

(ii) What is tidal range?

A simple single-basin typetidal powerplant has a basin area of $20\ km^2$. The tide has a range of 8m. Theturbine stopsoperationwhen thehead on it fallsbelow2 m. Determine the average power generated during one filling/emptying process in MW if the turbine – generator efficiency is70%. Assume specificgravityofsea water as 1.025.

[10 Marks]

(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 metrichorsepower 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. Ifthe turbine efficiency is 88%, calculate the draft tube efficiency. Further, if the turbine output is reduced to 50% with the same head, speed anddraft tube efficiency, calculate the reading of the vacuum gauge. Assume, atmospheric pressure is 10.3 m of water and specific weight of water is $1000\ kg/m^3$.

[20 Marks]

(c) **(i)** Explain with theaidof illustrative sketch theworking of a Ramjet engine. What are its applications?

(ii) Mention the various industrial wastes and by-products used as boiler fuels. Briefly explain them.

[10 + 10 Marks]

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8. **(a)** A flatplate collectoris of size2 m length and1 m width with oneglasscoverand0° slopewith horizontal. Thegapbetween absorber plate andglasscoveris0.05 mandabsorber platetobackplateis0.015 m.

Ambient air is passed between absorber plate and backplate at the rate of m = 0.1 kg/s. The solar radiation is $I = 800\ W/m^2$,

Transmittance-Absorptance Product is $T_A = 0.8$, Overall loss coefficient $U_L = 9.65\ W/m^2K$, Ambient temperature $T_a = 300\ K$, Specific heat of air $C_p = 1006.4\ J/kgK$, natural convection heat transfer coefficientis12.08 W/m^2K.

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

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

Heat removal factor is given by

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

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

where G is themassflow rate perunit area of absorber plate area $\left(kg/s/m^2\right)$.

(ii) A company wanted 2 hours of buffer storage fora1.5MWsolar thermal powerplant thatoperates between 230°Cand380°C. Estimatetheamount ofmaterial thatisneededifLithium Nitrate isused.Lithium Nitrate hastheproperties at melting point 252°C, latent heat 530 kJ/kg, specificheat of solid2.02 andliquid 2.041 kJ/kg K respectively. Density of solid $2310\ kg/m^3$ and liquid $1776\ kg/m^3$, energy density $261\ kWh/m^2K$ and thermal conductivity 1.35 W/mK

[10 + 10 Marks]

(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: CO_2 : 10%, CO : 1%, N_2 : 82%, O_2 : 7%

Take oxygen as 23% in the air by mass.

[20 Marks]

(c) A single stage, single acting aircompressor 30 cm boreand 40 cm stroke runs at 200rpm.Thesuction pressureis1 barat 15°C anddeliverypressure is 5 bar.Determine theindicated mean effective pressure andthe idealpower required to run it, when

(i) Compression is isothermal,

(ii) Compression follows the law $PV^{1.25} = \text{Constant}$

(iii) Compression is reversible adiabatic (y = 1.4), and

(iv) Compression is irreversible adiabatic (n = 1.5). Neglect clearance.

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

[20 Marks]