MECHANICAL ENGINEERING

Paper – II

*Time Allowed : **Three Hours***

*Maximum Marks : **200***

Question Paper Specific Instructions

Please read each of the following instructions carefully before attempting questions :

*There are **EIGHT** questions in all, out of which **FIVE** are to be attempted.*

*Questions no. **1** and **5** are **compulsory**. Out of the remaining **SIX** questions, **THREE** are to be attempted selecting at least **ONE** question from each of the two Sections A and B.*

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 Booklet must be clearly struck off.

All questions carry equal marks. The number of marks carried by a question/part is indicated against it.

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

Assume suitable data, if necessary and indicate the same clearly.

Neat sketch may be drawn, wherever required.

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

Newton may be converted to kgf using the equality 1 kilonewton (1 kN) ---- 100 kgf, if found necessary.

All answers should be in SI units.

Take : 1 kcal = 4·187 kJ and 1 kg/cm^2 – 0·98 bar

1 bar = 10^5 pascals

Universal gas constant = 8314·6 J/kmol-K

Psychrometric chart is enclosed.

SECTION A

Q1. (a) A fluid contained in a cylinder receives 150 kJ of mechanical energy by means of a paddle wheel, together with 50 kJ in the form of heat. At the same time, a piston in the cylinder moves in such a way that the pressure remains constant at 200 kN/m^2, during the fluid expansion from 2 m^3 to 5 m^3. What is the change in internal energy and in enthalpy ? *8*

(b) Consider a chilled-water pipe of length L, inner radius r_1, outer radius r_2 and thermal conductivity k. Water flows in the pipe at a temperature T_f and the heat transfer coefficient at the inner surface is 'h'. If the pipe is well insulated on the outer surface,

(i) express the differential equation and the boundary conditions for steady one-dimensional heat conduction through the pipe.

(ii) obtain a relation for the variation of temperature in the pipe solving the differential equation. *8*

(c) Briefly describe the following non-petroleum based liquid fuels used in IC engines : *8*

(i) Benzol

(ii) Vegetable oils

(iii) Alcohol

(iv) Acetone

(d) Explain in detail the influence of any four factors on the volumetric efficiency of an automotive IC engine. *8*

(e) A 40 cm long, 800 W electric resistance heating element with diameter 0·5 cm and surface temperature 120°C is immersed in 75 kg of water initially at 20°C. Determine how long it will take for this heater to raise the water temperature to 80°C. Also, determine the convection heat transfer coefficients at the beginning and at the end of the heating process. *8*

Q2. (a) (i) Explain the terms : Available energy, Availability and Irreversibility. *6*

(ii) Deduce an expression for the availability in a non-flow process. Also, prove that for a non-flow process between equilibrium states, when the system exchanges heat only with the environment, $I = T_o (\Delta S)_{univ}$. *9*

(b) Explain how fuel-air cycles are devised. How are they different from air standard cycles ? Also, sketch the variation of thermal efficiency with reference to compression ratio and equivalence ratio for the fuel-air cycle. Further, explain the trends observed by giving reasons. *15*

(c) What are biodiesels ? How are they produced ? Can we replace with biodiesels, the conventional fuels for CI engines ? Summarize your response by considering different properties of biodiesels vis-a-vis diesel fuel. *10*

Q3. (a) Glycerine (C_p = 2400 J/kg °C) at 20°C and 0·3 kg/s is to be heated by ethylene glycol (C_p = 2500 J/kg °C) at 60°C with the same mass flow rate in a thin-walled double-pipe parallel-flow heat exchanger. If the overall heat transfer coefficient is 380 W/m^2 °C and the heat transfer surface area is 5·3 m^2, determine

(i) the rate of heat transfer,

(ii) the outlet temperatures of the glycerine and glycol.

The specific heats of glycerine and ethylene glycol are given to be 2·4 and 2·5 kJ/kg °C, respectively. Also, the effectiveness (ε) of double-pipe parallel-flow heat exchanger is given by

$$\varepsilon = \frac{1 - \exp[-NTU(1 + C)]}{1 + C}$$

where, $C = C_{min}/C_{max} = (\dot{m}\ C_p)_{min}/(\dot{m}\ C_p)_{max}$ *15*

(b) (i) Sketch the performance graph for typical DI and IDI automotive diesel engines and discuss the variation of brake power and indicated power with speed. Give your reasoning for observed trends. *5*

(ii) In a test of a four-cylinder, four-stroke petrol engine of 75 mm bore and 100 mm stroke, following results were obtained at full throttle at a constant speed and constant fuel supply of 0·082 kg/min :

brake power with all cylinders working = 15·24 kW

brake power with cylinder no. 1 cut-off = 10·45 kW

brake power with cylinder no. 2 cut-off = 10·38 kW

brake power with cylinder no. 3 cut-off = 10·23 kW

brake power with cylinder no. 4 cut-off = 10·45 kW

Estimate the indicated power of the engine under these conditions. If the calorific value of the fuel is 44 MJ/kg, find the indicated thermal efficiency of the engine. Compare this with air standard efficiency assuming clearance volume for each cylinder being 50 cc. For air, $\gamma = 1{\cdot}4$. *10*

(c) At 273·15 K the specific volumes of water and ice are 0·001 and 0·001091 m^3/kg respectively and the latent heat of fusion of ice is 334 kJ/kg. Determine the melting point increase due to increase of pressure by 1 atm (101·325 kPa). *10*

Q4. (a) Air flows across a 20 cm square plate with a velocity of 5 m/s. Free-stream conditions are 10°C and 1 atm. A heater in the plate surface furnishes a constant heat-flux condition at the wall so that the average wall temperature is 100°C. Calculate the surface heat flux and the value of 'h' at a position of x = 10 cm. Assume Pr = 0·7, Dynamic viscosity (μ) = $1{\cdot}974 \times 10^{-5}$ kg/ms and k = 0·0284 W/mK. *15*

(b) 0·5 kg of air at 600 kPa receives an addition of heat at constant volume so that its temperature rises from 110°C to 650°C. It then expands in a cylinder polytropically to its original temperature and the index of expansion is 1·32. Finally, it is compressed isothermally to its original volume. Calculate :

(i) the change in entropy during each of the three stages,

(ii) the pressures at the end of constant volume heat addition and at the end of expansion. Sketch the processes on the P-v and T-s diagrams.

For Air, assume C_p = 1·005 kJ/kg K and R = 0·287 kJ/kg K *15*

(c) A gaseous fuel mixture with molar analysis of 72% CH_4; 9% H_2; 14% N_2; 2% O_2 and 3% CO_2 burns completely with moist air to form gaseous products of combustion at 1 atm, comprising CO_2 : H_2O and N_2 only. If the dew point temperature is 60°C [P_{sat} = 0·1992 bar], determine the amount of water vapour present in the combustion air, in kmol per kmol of fuel mixture. (1 atm = 1·01325 bar) *10*

SECTION B

Q5. (a) For steam generators, explain the concept of circulation ratio. Also, mention the range in which circulation ratio may vary. *8*

(b) What is the function of a cooling tower ? For a cooling tower, explain the following : *8*

(i) Approach

(ii) Range

(iii) Cooling efficiency

(c) An evacuated insulating material consists of outer layers of aluminium with emissivity of 0·11 and three polished aluminium shields having emissivity of 0·04. These shields are placed 2 mm apart. The total thickness neglecting the thickness of the outer layers is 8 mm. Calculate the radiation heat transfer across the assembly for temperature of 300 K and 85 K. Also calculate the effective thermal conductivity. *8*

(d) Clearly mention the principles on which turbomachines are based. *8*

(e) Explain in brief which refrigerants you would choose for each of the following applications and why : *8*

(i) A cold storage of 100 TR capacity using reciprocating compressor.

(ii) An 800 TR air-conditioning plant using centrifugal compressor.

Q6. (a) Derive the area – velocity relationship for the compressive fluid flow. Draw the conclusions when :

(i) Mach number is less than unity.

(ii) Mach number is more than unity.

(iii) Mach number is equal to unity. *15*

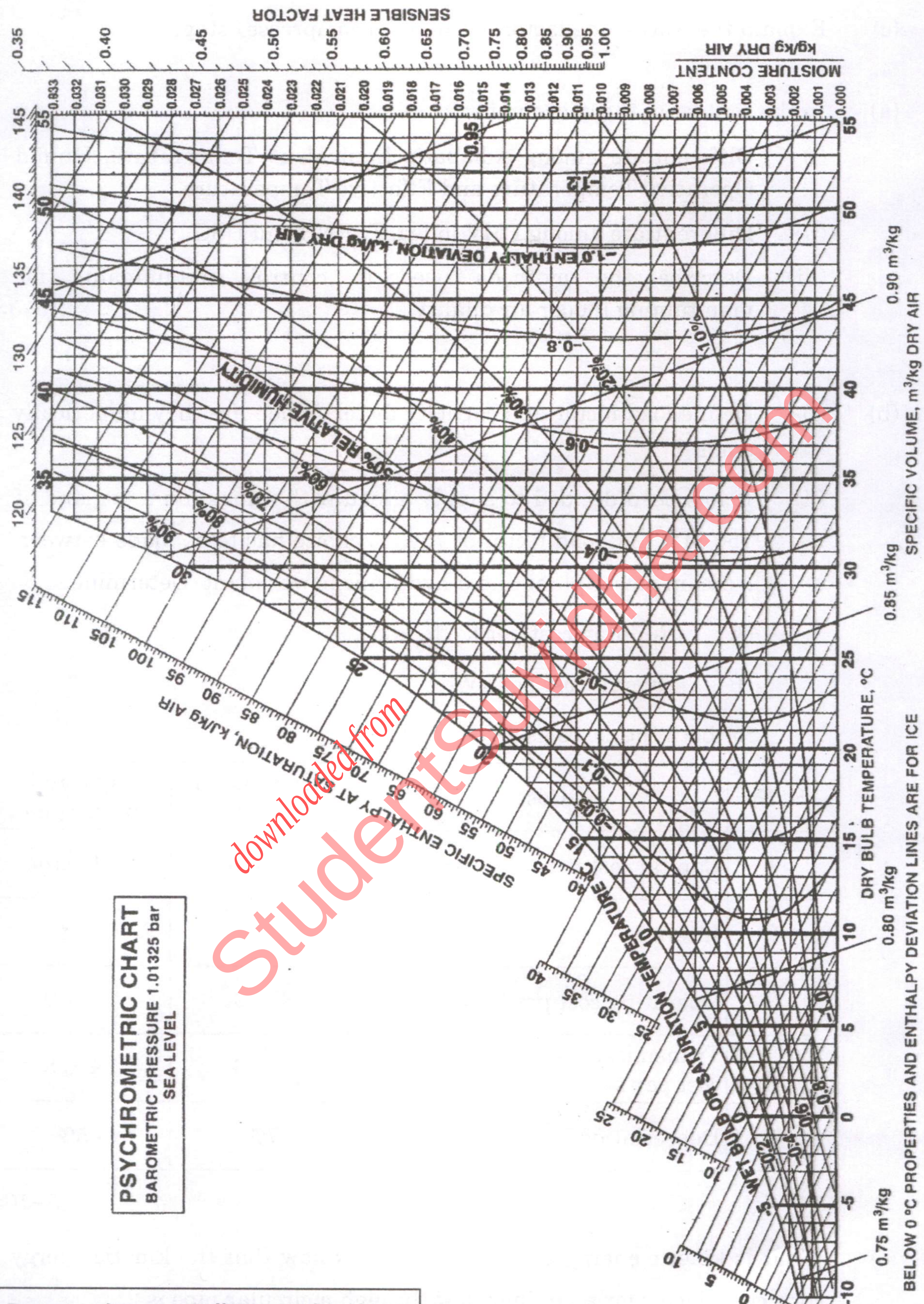
(b) An air-conditioned space is maintained at 25°C DBT and 50% RH. The outside conditions are 40°C DBT and 25°C WBT. The space has a sensible heat gain of 24·5 kW. Conditioned air is supplied to the space as saturated air at 10°C. The equipment consists of an air washer. The air washer comprises 25% outside air. Calculate the following :

(i) Volume flow rate of air supplied to space

(ii) Latent heat gain of space

(iii) Cooling load of air washer

Use Psychometric Chart to solve this problem. Use Room sensible heat factor = 0·813. *15*



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(c) Explain the work-done factor for an axial compressor stage. *10*

Q7. (a) In the context of thermal comfort :

(i) Differentiate among Adiabatic Equivalent Temperature, Humid Operative Temperature and Effective Temperature.

(ii) Differentiate among PMV index, TSENS and DSC.

(iii) Describe the methods used to control contaminants for maintaining indoor air quality. *5×3=15*

(b) (i) Define load factor and capacity factor. When are they numerically equal ?

(ii) It has been decided to supply a load with a maximum demand of 750 MW and load factor of 75%. A choice has to be made between a steam power plant and a hydraulic power plant. Determine,

(A) Running cost per kWh, and

(B) Overall cost per kWh

for both the cases as given below :

S. No.	Cost	Steam power plant	Hydraulic power plant
1	Capital cost per MW installed	₹ 30 crore	₹ 40 crore
2	Interest	8%	7%
3	Operating cost per kWh	₹ 2·0	₹ 1·0
4	Transmission and distribution cost per kWh	₹ 0·6	₹ 0·8
5	Depreciation	7%	5%

5+10=15

(c) What is kinetic energy correction factor ? Show that the kinetic energy correction factor for a laminar flow through a circular pipe is 2. *10*

Q8. (a) An air-cooled condenser for a package air-conditioning unit is to be designed to transfer 25 kW of heat from R22 condensing inside 1·35 cm OD and 1·2 cm ID tubes at 55°C. The mass flow rate of the refrigerant is 0·162 kg/s. The refrigerant-side heat transfer coefficient is given by

$$Nu = 0{\cdot}026\ (Pr)^{\frac{1}{3}}\ (Re_m)^{0{\cdot}8}$$

Air circulated is 100 CMM (cubic meters per minute) entering at 40°C. The air side heat transfer coefficient is given by

$$Nu = 0{\cdot}193\ Pr^{\frac{1}{3}}\ Re^{0{\cdot}618}$$

The face velocity of air is 5 m/s. The air side has 5 fins/cm so that finned surface to outside bare tube surface area ratio is 20. Determine the finned surface area of the condenser. Neglect the resistance of metal wall. Assume, efficiency of finned surface and refrigerant side temperature drop as η_f = 0·9 and 5°C, respectively. Prandtl number = 0·7. *15*

Use the following data :

<u>R22 (at 55°C)</u>

$k_f = 0{\cdot}08\ Wm^{-1}K^{-1}$

$\rho_f = 1072\ kg/m^3$

$\mu_f = 2{\cdot}12 \times 10^{-4}\ kg\ m^{-1}s^{-1}$

$C_p = 1{\cdot}52$ kJ/kg K

<u>Air (at 40°C)</u>

$\mu = 2 \times 10^{-5}\ kg\ m^{-1}\ s^{-1}$

$k = 0{\cdot}03\ Wm^{-1}K^{-1}$

$\rho = 1{\cdot}2\ kg/m^3$

(b) (i) Explain the significance of the specific speed of a turbine.

(ii) A hydraulic turbine develops 800 kW power under a head of 8 m at a speed of 80 rpm and gives an efficiency of 90%. If a model $\frac{1}{8}$ full size is constructed to operate under a head of 6 m, determine :

(A) its speed,

(B) power developed, and

(C) water consumption

to run under the conditions similar to the prototype. *5+10=15*

(c) A heat pump installation is proposed for a home heating unit with an output rated at 30 kW. The evaporator temperature is 10°C (h_g = 2519·7 kJ/kg) and the condenser pressure is 0·5 bar (h_f = 340·47 kJ/kg). Using an ideal vapour compression cycle, estimate the power required to drive the compressor if steam/water mixture is used as the working fluid. Assume saturated vapour at compressor inlet and saturated liquid at condenser outlet. The enthalpy of steam at the end of compression is 3320 kJ/kg. Also calculate the COP and mass flow rate of fluid. *10*