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 provide for answering the question itself.

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

Psychrometric Chart is given on Page No. 46.

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.

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

SECTION A

Q1. (a) The velocity components in a two-dimensional incompressible flow are :

$u = 8x^2y - \frac{8}{3}y^3$ and $v = -8xy^2 + \frac{8}{3}x^3$.

Show that these velocity components represent a possible case of an irrotational flow. *12*

(b) (i) Carnot efficiency and 2^{nd} law efficiency of a heat engine are 70% and 90% respectively. Determine the first law efficiency. *4*

(ii) A heat engine operates between two reservoirs at 800°C and 20°C. One-half of the work output of the engine is used to drive a Carnot heat pump that removes heat from the cold surroundings at 2°C and transfers it to a house maintained at 22°C. If the house is losing heat at a rate of 62,000 kJ/h, determine the minimum rate of heat supply to the heat engine required to keep the house at 22°C. *8*

(c) A hollow sphere of inside radius 3 cm and outside radius 5 cm is electrically heated at inner surface at a constant rate of heat flux of 10^5 W/m^2. The outer surface of the sphere dissipates heat to the surrounding air at 40°C. Assuming k = 15 W/mK for the sphere material and h = 400 W/m^2 K, calculate the inner and outer surface temperatures of the sphere. *12*

(d) A V-8 engine with 7·5 cm bores is redesigned from two valves per cylinder to four valves per cylinder. The old design had one inlet valve of 34 mm diameter and one exhaust valve of 29 mm diameter per cylinder. These are replaced with two inlet valves of 27 mm diameter and two exhaust valves of 2 mm diameter. If the maximum valve lift equals 22% of the valve diameter for all valves, calculate the increase of inlet flow area per cylinder. Also discuss the advantages and disadvantages of the new system. *6+6*

(e) Describe briefly the working principle of a vortex tube refrigeration system mentioning its advantages and disadvantages. *12*

Q2. (a) (i) Prove that equipotential lines and constant function streamlines are orthogonal to each other. *4*

How do you distinguish between developing flow and fully developed flow ? *2*

(ii) A spherical balloon having 3 m diameter weighs 130 N and contains helium having density of 0·22 kg/m^3, whereas the surrounding air has a density of 1·225 kg/m^3. The balloon is tied with the cable which is inclined to the ground. Determine the inclination of the cable to the ground when a wind of 5 m/s blows past the balloon. Take $C_D = 0{\cdot}2$. *14*

(b) A frictionless piston-cylinder device initially contains 0·01 m^3 of argon gas at 400 K and 350 kPa. Heat is now transferred to argon from a furnace at 1200 K, and the argon expands isothermally until its volume is doubled. The heat transfer takes place in such a way that there is no heat loss from argon to the atmosphere. The atmosphere is at 300 K. Determine (i) the work done by argon, (ii) the heat transferred to argon, and (iii) entropy generation and irreversibility during the process. *20*

Take R = 0·2081 kJ/kg-K for argon.

(c) Show that for fully developed laminar flow in a tube with a parabolic velocity profile $u = 2\,u_m \left[1 - \left(\frac{r}{R}\right)^2\right]$, the Nusselt number is $\frac{48}{11}$ if the wall temperature increases linearly with x. Symbols have their usual meanings. *20*

Q3. (a) (i) Prove that the total pressure which is the summation of static and dynamic pressure, also known as stagnation pressure, decreases in an irreversible adiabatic process when a gas is flowing in a steady flow device of constant cross-section without any work transfer. *6*

(ii) A heat engine operates between the maximum and minimum temperatures of 671°C and 60°C respectively, with an efficiency of 50% of its Carnot efficiency. It drives a heat pump which uses river water at 4·4°C to heat a block of flats in which the temperature is to be maintained at 21·1°C. Assume that a temperature difference of 11·1°C exists between the working fluid and the river water, on the one hand, and the required room temperature on the other. Also assume that the heat pump would be operated with a COP of 50% of the ideal COP. Find the heat input to the engine per unit heat output from the heat pump. *14*

(b) (i) A cubical oven has inner sides equal to 0·4 m. One of the faces of the oven forms the door. If the five other inside faces are black and maintained at 600°C, find the rate of heat loss if the oven door is kept open. *10*

Take Stefan constant $\sigma = 5 \cdot 67 \times 10^{-8}$ W/m^2 K^4.

(ii) Explain briefly why dropwise condensation is preferred to filmwise condensation. *10*

(c) In an air-conditioning system, the inside conditions are dry bulb temperature 25°C and relative humidity 50%. The outside conditions are dry bulb temperature 40°C and wet bulb temperature 27°C. The room sensible heat factor is 0·8. 50% of room air is rejected to atmosphere and an equal quantity of fresh air is added before air enters the air-conditioning apparatus.

Assuming fresh air is added at a rate of 100 m^3/minute, draw the process diagram and determine the following :

(i) Room sensible and latent heat load

(ii) Sensible and latent heat load due to fresh air

(iii) Apparatus dew point

(iv) Humidity ratio

Take density of air = 1·2 kg/m^3 at a pressure of 1·01325 bar and humid specific heat = 1·022 kJ/kg K. Bypass factor is zero. *20*

Q4. (a) (i) For the same compression ratio and heat rejection, show that the efficiency of Otto cycle is greater than Diesel cycle using T-s plot. *4*

(ii) An ideal gas is compressed reversibly and adiabatically from state a to state b. It is then heated reversibly at constant volume to state c. After expanding reversibly and adiabatically to state d such that $T_b = T_d$, the gas is again reversibly heated at constant pressure to state e such that $T_e = T_c$. Heat is then rejected reversibly from the gas at constant volume till it returns to state a. Show that $T_a = \frac{T_b^{\gamma+1}}{T_c^{\gamma}}$; where $\gamma = \frac{C_p}{C_v}$. *16*

(b) The following data refers to a single-stage vapour compression system :

Refrigerant used : R-134a

Condensing temperature = 35°C

Evaporator temperature = – 10°C

Compressor : rpm = 2800

Efficiency = 0·8

Clearance volume/Swept volume = 0·03

Swept volume = 269·4 cm^3

Expansion index = 1·12

Condensate subcooling = 5°C

Determine : (i) tonnage, (ii) power, (iii) COP of refrigeration and (iv) heat rejection to condenser. *20*

Properties of R – 134 a :

t, °C	P, bar	V_g, m^3/kg	h_f, kJ/kg	h_g, kJ/kg	s_f, kJ/kg K	s_g, kJ/kg K
– 10	2·014	0·0994	186·7	392·4	0·9512	1·733
35	8·870	–	249·1	417·6	1·1680	1·715

Assume : Specific heat of vapour at 8·87 bar is 1·1 kJ/kg K and that of liquid is 1·458 kJ/kg K. Suction vapour is dry saturated and compression process is isentropic. Compressor is single acting.

(c) A two-stroke single cylinder SI engine of 10 cm bore having compression ratio 8·5, consumes 15·75 kg/hr of fuel when running at 3500 rpm. The piston speed is 14 m/s and the indicated mean effective pressure is 5 bar. The A/F ratio is 15 : 1, the calorific value of the fuel is 44 MJ/kg. Assume 'R' for the mixture as 290 J/(kg K), the pressure and temperature of the mixture as 1·05 bar and 27°C respectively, η_{mech} = 85%.

Calculate : *20*

(i) The scavenging ratio

(ii) The scavenging efficiency

(iii) The trapping efficiency

(iv) The ip

(v) The bp

(vi) The brake thermal efficiency

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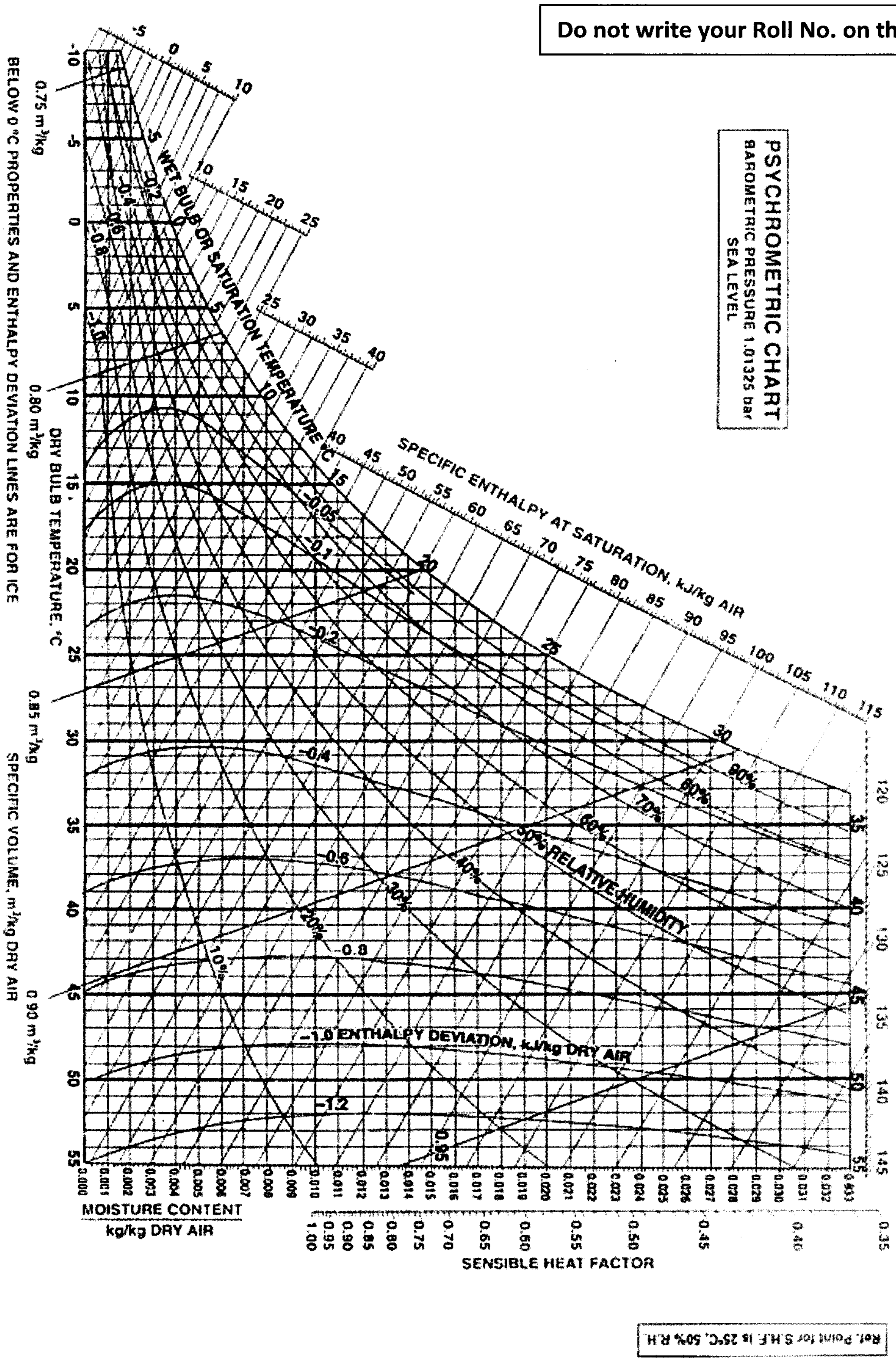

SECTION B

Q5. (a) Reciprocating pump gives fluctuating output and you want uniform or near uniform output from it. Suggest possible solutions or modifications with justifications and illustrations. *12*

(b) Draw an equivalent thermal-circuit diagram of a liquid flat plate collector with two glass covers considering the thermal resistance of glass covers. Neglect thermal resistance from sides. *12*

(c) What are the different types of stresses induced in steam turbine blades ? How are these computed and designed to safely bear them ? *12*

(d) What are regenerative fuel cells ? Briefly describe its working with a properly labelled diagram. *4+8*

(e) A gas turbine power plant operating on an ideal Brayton cycle takes in air at the initial conditions of 5°C and 1·03 bar. The pressure ratio is 7 and the maximum temperature is 816°C. Determine the work ratio and the mass flow rate of air for a net output of 3750 kW. *12*

For air C_p = 1·005 kJ/kg K and γ = 1·4.

Q6. (a) An axial compressor stage has the following data :

Temperature and pressure at entry = 300 K, 1·0 bar

Degree of reaction = 50%

Mean blade ring diameter = 36 cm

Rotational speed = 18000 rpm

Blade height at entry = 6 cm

Air angles at rotor and stator exit = 25°

Axial velocity = 180 m/s

Work done factor = 0·88

Stage efficiency = 85%

Mechanical efficiency = 96·7%

Determine : *20*

(i) Air angles at rotor and stator entry
(ii) Mass flow rate of air
(iii) Power required to drive the compressor
(iv) Loading coefficient
(v) Pressure ratio developed by the stage

(b) A centrifugal pump with backward curved vanes is running at 1200 rpm against a head of 35 m. The discharge through the pump is 0·28 m^3/s. If the blade angle at outlet is 30°, flow velocity at outlet is 4 m/s and hydraulic or manometric efficiency is 0·85, determine diameter and width of impeller at outlet. Draw velocity triangles. *20*

(c) (i) How is biogas production related to sustainable waste management ?

(ii) What is meant by biogas enrichment ?

(iii) Explain the working of a power generation set-up using municipal organic waste. *4+6+10*

Q7. (a) Parabolic trough collector based solar thermal power plants with thermal storage are becoming popular as they can generate power even during off-sunshine hours. Explain the working of such a plant with neat sketch. Also explain the basic thermodynamic cycle, on which such plants operate, using T-s plot. *20*

(b) A Kaplan turbine generates 12 MW of shaft power under 20 m head. If inlet guide vane angle is 30° and diameters of runner and hub are taken to be 6 m and 4 m respectively, determine (a) runner vane angles (inlet and outlet), (b) guide vane angle at outlet, and (c) speed of runner. The absolute velocity at the outlet should be kept minimum. Assume hydraulic efficiency as 80% and overall efficiency as 75%. Draw velocity triangles. *20*

(c) (i) If the circulation ratio is 12·5, find the dryness fraction at the top of a riser tube of a boiler. *3*

(ii) Feedwater enters the economizer at 170°C and leaves at 336·75°C whereas flue gas enters the economizer at 815°C and leaves at 450°C. If overall heat transfer coefficient is 70 W/m^2 K and heat transfer through economizer is 511134 kW, determine the outside surface area. *7*

(iii) A surface condenser receives 250 t/h of steam at 40°C with 12% moisture. The cooling water enters at 32°C and leaves at 38°C. The pressure inside the condenser is found to be 0·078 bar. The velocity of circulating water is 1·8 m/s. The condenser tubes are of 25·4 mm outer diameter and 1·25 mm thickness. Taking overall heat transfer coefficient as 2600 W/m^2 K, determine the rate of flow of cooling water, the rate of air leakage into the condenser shell, the length of tubes and number of tubes. At 40°C, h_{fg} = 2407 kJ/kg, p_{sat} = 0·07375 bar, v_f = 0·001008 m^3/kg and v_{fg} = 19·544 m^3/kg. *10*

Q8. (a) Wind is blowing at a speed of 12 m/s. It enters a turbine wheel at standard atmospheric pressure and 15°C. The turbine wheel has a cross-sectional area of 90 m^2. Determine the power of the incoming wind, theoretical maximum possible power available according to Betz criterion and a reasonably attainable turbine power in kW assuming 40% efficiency of the turbine. Find out the torque if the turbine wheel rotates at 30 RPM. Also determine the axial thrust if the turbine were operating at maximum efficiency. *20*

(b) The following data refers to a two-row velocity compounded impulse wheel which forms the first stage of a combination turbine :

Steam velocity at nozzle outlet	: 630 m/s
Mean blade velocity	: 125 m/s
Nozzle angle	: 16°
Outlet angle, first row of moving blades	: 18°
Outlet angle, fixed guide blades	: 22°
Outlet angle, second row of moving blades	: 36°
Steam flow rate	: 2·6 kg/s

The ratio of the relative velocity at outlet to that at inlet is 0·84 for all the blades. Calculate :

(i) The velocity of whirl

(ii) The tangential thrust on the blades

(iii) The axial thrust on the blades

(iv) The power developed

(v) The blade efficiency *20*

(c) A Francis turbine is running at 500 rpm under a head of 190 m. The blade angle at inlet is 50° and guide vane angle at inlet is 20°. If the peripheral speed of runner at inlet is 35 m/s and discharge is 9 m^3/s, determine (i) power developed by the runner, (ii) diameter and width of the runner at inlet, and (iii) hydraulic efficiency of the turbine.
Draw velocity triangle at inlet. *20*