

ENGINEERING SERVICES  
EXAMINATION-2014

Sl. No. 42584

A-DMHH-N-NFA

MECHANICAL ENGINEERING

Paper I  
(Conventional)

Time Allowed : Three Hours

Maximum Marks : 200

INSTRUCTIONS

*Please read each of the following instructions carefully before attempting questions.*

*Candidates should attempt FIVE questions in all.*

*Question No. 1 is compulsory.*

*Out of the remaining SIX questions attempt any FOUR questions.*

*The number of marks carried by a part of a question are indicated against it.*

*Answers must be written in ENGLISH only.*

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

*For air  $R = 0.287$  kJ/kg-K,  $C_p = 1.005$  kJ/kg-K,  $\gamma = 1.4$ ,  
 $M = 28.97$  kg/kg-mole, Universal gas constant  
 $R = 8.314$  kJ/kg mole-K.*

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

*Neat sketches may be drawn, wherever required.*

*Attempts of questions shall be counted in chronological 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 answer book must be clearly struck off.*

*A psychrometric chart is attached to this question paper for necessary use by the candidate.*

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1. Answer *all* of the following :

(a) Give reasons why the Carnot cycle cannot be considered as the theoretical cycle for steam power plants even though its efficiency is the highest for the given heat source and sink temperatures. A Carnot cycle heat engine has an efficiency of 40%. If the high temperature is raised by 10%, what is the new efficiency keeping the same low temperature? 10

(b) What do you understand by the lumped capacity? What are the physical assumptions necessary for a lumped capacity unsteady state analysis to apply?

Determine time required in minutes for a 50 mm diameter steel sphere ( $\rho = 7800 \text{ kg/m}^3$ ,  $c = 0.46 \text{ kJ/kg-K}$ ,  $k = 35 \text{ W/m-K}$ ) to cool from  $600^\circ\text{C}$  temperature to  $100^\circ\text{C}$  temperature if exposed to a cooling air at  $30^\circ\text{C}$ . The convection heat transfer coefficient is  $10 \text{ W/m-K}$ . 10

(c) (i) From fundamental laws derive the Prandtl-Mayer relation for a normal shock in compressible fluid flow in a constant area duct for a perfect gas. 5

- (ii) Show that the maximum efficiency for a jet striking at the centre of a single symmetrically curved vane moving with a velocity  $u$  is given by  $\frac{16}{27} \cos^2 \frac{\theta}{2}$  where  $\theta$  is the curvature of the vane. 5

- (d) Define specific speed of a hydraulic turbine. Where is it used? Show that the specific speed ( $N_s$ ) can be expressed as :

$$N_s = \sqrt{\frac{N^2 P}{H^{5/2}}} = \frac{N\sqrt{P}}{H^{5/4}}$$

$N$  = Speed,  $P$  = Power developed or shaft power and  $H$  = Head under which the turbine is working.

What is the range of specific speed in r.p.m. for Pelton wheel? 10

- (e) Calculate the volume rate of flow of water through a pipe of 100 mm dia. When measured by (a) An orifice plate of orifice size 50 mm dia and (b) venturi tube of throat size 50 mm dia. The recorded D.P. 250 pa. The density of water is  $1000 \text{ kg/m}^3$ . Assume orifice  $c_d$  equal to 0.6 and venturi  $c_d$  equal to 0.9. 10

- (f) A single acting reciprocating pump has a plunger 10 cm diameter and a stroke of 200 mm. The centre of the pump is 4 m above the water level in the sump and 14 m below the level of water in a tank to which water is delivered by the pump. The diameter and length of suction pipe are 40 mm and 6 m respectively while those of delivery pipe are 30 mm and 18 m respectively. Determine the maximum speed at which the pump may be run without separation, if separation occurs at  $7.848 \text{ N/cm}^2$  below the atmospheric pressure. Take atmospheric pressure head = 10.3 m of water. 10

- (g) Use the following mathematical relation for any three properties  $x, y, z$

$$\left(\frac{\partial x}{\partial y}\right)_z \left(\frac{\partial y}{\partial z}\right)_x \left(\frac{\partial z}{\partial x}\right)_y = -1$$

to show the following relations for the Joule-Thomson coefficient

$$\mu_j = \left(\frac{\partial T}{\partial p}\right)_h = \frac{T \left(\frac{\partial v}{\partial T}\right)_p - v}{c_p} = \frac{RT^2}{pc_p} \left(\frac{\partial Z}{\partial T}\right)_p$$

$Z$  is the compressibility factor. 10

- (h) Write down the chemical formula of R-134a. What does 'a' signify in the nomenclature? Explain the effect of critical temperature and critical pressure of refrigerant on the COP of the cycle.

A straight-charged Thermostatic Expansion Valve (TEV) is designed to operate at an evaporator temperature of  $7^{\circ}\text{C}$  with a degree of superheat of  $5^{\circ}\text{C}$ . R-134a is the refrigerant used in the refrigeration system as well as the bulb.

Find :

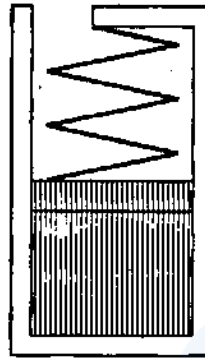
- (i) The required spring pressure at the design condition,
- (ii) Assuming the spring pressure to remain constant, find the degree of superheat, if the same TEV operates at an evaporator temperature of  $-23^{\circ}\text{C}$ .

The saturation temperature and corresponding pressure of R-134a are given in the Table below :

$T_{\text{sat}}, ^{\circ}\text{C}$	-23	-13	-12	-11	2	7	12	13
$P_{\text{sat}}, \text{kPa}$	116.39	177.92	185.24	192.8	314.62	374.63	443.01	457.76

10

2. (a)



A cylinder having a piston restrained by a linear spring (of spring constant  $15 \text{ kN/m}$ ) contains  $0.5 \text{ kg}$  of saturated vapour water at  $120^\circ\text{C}$ , as shown in the above figure. Heat is transferred to the water, causing the piston to rise. If the piston cross-sectional area is  $0.05 \text{ m}^2$ , and the pressure varies linearly with volume until a final pressure of  $500 \text{ kPa}$  is reached. Find the final temperature in the cylinder and the heat transfer for the process. The properties of water are given in the Table below :

$t, ^\circ\text{C}$	$p, \text{kPa}$	$v_g, \text{m}^3/\text{kg}$	$u_g, \text{kJ/kg}$	$h_g, \text{kJ/kg}$
120	198.50 ( $p_{\text{sat}}$ )	0.89186	2529.2	2705.9
151.83	500.00 ( $p_{\text{sat}}$ )	0.37477	2559.5	2746.6
801	500.00	0.99055	3664.2	4159.2
802	500.00	0.99147	3666.1	4161.6
803	500.00	0.99240	3668.0	4163.9
804	500.00	0.99333	3669.9	4166.3
805	500.00	0.99425	3671.8	4168.6

10

- (b) In an oil cooler the oil enters 10 mm diameter tubes at 160°C and is cooled to 40°C. The mean velocity of oil in the tubes is 1.5 m/s. Calculate the mean heat transfer coefficient. For turbulent flow of liquid being cooled take  $Nu = 0.0265 Re^{0.8} Pr^{0.3}$  and for laminar flow  $Nu = 3.65$ . Take all properties at bulk mean temperature and the properties are listed below :

t °C	P kg/m <sup>3</sup>	v centi stokes	K W/m K	c kJ/kg K
40	878	251.0	0.144	1.96
100	839	20.4	0.137	2.22
160	806	5.7	0.131	2.48

1 centi stoke =  $10^{-6}$  m<sup>2</sup>/s.

10

- (c) The cylinder bore diameter of a single acting reciprocating pump is 150 mm and stroke is 300 mm. The pump runs at 50 rpm and lifts water through a height of 25 m. The delivery pipe is 32 m long and 100 mm diameter. Find the theoretical discharge and power required to run the pump. If the actual discharge is 4.2 lit/s find the percentage slip. Also determine the acceleration head at the beginning and middle of delivery stroke.

10

3. (a) In an air standard Otto cycle the maximum and minimum temperatures are  $1400$  and  $15^\circ\text{C}$ . The heat supplied per kg of air is  $800$  kJ. Calculate the compression ratio and cycle efficiency. Also calculate the maximum to minimum pressure ratio in the cycle. 10
- (b) An R717 based vapour compression refrigerating machine works between  $38^\circ\text{C}$  and  $-20^\circ\text{C}$  temperature. The ammonia leaves the compressor dry and saturated. Liquid ammonia is undercooled to  $30^\circ\text{C}$  temperature inside the condenser, before throttling. Find the theoretical COP of the machine. The  $c_p$  of saturated ammonia liquid is  $4.91$  kJ/kg-K. If net refrigeration required is  $25.0$  TR, find the mass flow rate of ammonia in kg/h, assuming relative COP  $0.75$ . The saturation properties of R717 are given in the following Table :

t, $^\circ\text{C}$	Liquid		Vapour
	h, kJ/kg	s, kJ/kg-K	h, kJ/kg
38	380.78	1.6134	1489.36
-20	108.55	0.6538	1437.68

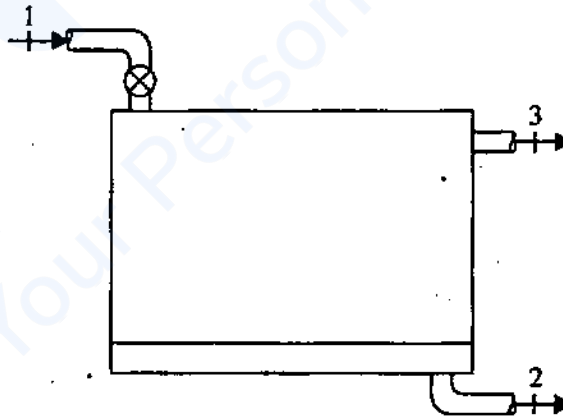
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- (c) A smaller power plant produces steam at 3 MPa, 600°C in the boiler. It keeps the condenser at 45°C by transfer of 10 MW out as heat transfer. The first turbine section expands to 500 kPa and then flow is reheated followed by the expansion in the low pressure turbine. Find the reheat temperature so the turbine output is saturated vapour. For this reheat find the total turbine power output and the boiler heat transfer. Properties of water are given in the Table below :

$t, ^\circ\text{C}$	$p, \text{kPa}$	$v_f, \text{kg/m}^3$	$v_g, \text{m}^3/\text{kg}$	$h_f, \text{kJ/kg}$	$h_g, \text{kJ/kg}$	$s_f, \text{kJ/kg-K}$	$s_g, \text{kJ/kg-K}$
45	9.59 ( $p_{\text{sat}}$ )	0.00101	15.252	188.42	2583.19	0.63861	8.1647
233.85	3000 ( $p_{\text{sat}}$ )	0.0012167	0.066664	1008.29	2803.99	2.6455	6.1870
600	3000	-	0.13245	-	3682.34	-	7.5084

10

4. (a)



A geothermal supply of hot water at 500 kPa, 150°C is fed to an insulated flash evaporator at the rate of 1.5 kg/s. A stream of saturated

liquid at 200 kPa is drained from the bottom of the chamber and a stream of saturated vapour at 200 kPa is drawn from the top and fed to a turbine. Find the rate of entropy generation in the flash evaporator. Properties of water are given in the Table below :

p, kPa	t, °C	$h_f$ , kJ/kg	$h_g$ , kJ/kg	$s_f$ , kJ/kg-K	$s_g$ , kJ/kg-K
200	120.20 ( $t_{sat}$ )	504.68	2706.63	1.5300	7.1271
500	151.83 ( $t_{sat}$ )	640.08	2746.60	1.8603	6.8202
500	150.00	632.18	-	1.8417	-

10

- (b) In a chemical plant a solution of density  $1100 \text{ kg/m}^3$  and specific heat capacity  $4.6 \text{ kJ/kg-K}$  is to be heated from  $65$  to  $100^\circ\text{C}$ . The required flow rate of the solution is  $11.8 \text{ kg/s}$ . A tubular heat exchanger is used for this with the solution flowing at about  $1.2 \text{ m/s}$  in  $25 \text{ mm}$  bore iron tubes and being heated by wet steam at  $115^\circ\text{C}$ . The length of the tubes is not to exceed  $3.5 \text{ m}$ . Taking inside and outside heat transfer coefficient as  $5$  and  $10 \text{ kW/m}^2 \text{ K}$  and neglecting the thermal resistance of the tube wall estimate the number of tubes and the number of tube passes required. 10

- (c) A water storage tank  $10\text{ m} \times 10\text{ m} \times 10\text{ m}$  has a drainage opening on one of the vertical sides at the bottom which is trapezoidal in shape with a width  $2\text{ m}$  at the bottom  $4\text{ m}$  at the top and  $1\text{ m}$  height. A gate of same dimension hinged along the top edge is used to close it. What is the minimum horizontal force required to be applied at the bottom to keep the gate closed if the tank has full of water in it? Will there be any change in the force required if the tank is only half full? If yes how much?
- 10

5. (a) A four cylinder 4 stroke diesel engine has a bore of  $212\text{ mm}$  and stroke  $292\text{ mm}$ . At full load at  $720\text{ rpm}$  the break mean effective pressure is  $5.93\text{ bar}$  and specific fuel consumption is  $0.226\text{ kg/kWH}$ . The air fuel ratio as determined by exhaust gas analysis is  $25 : 1$ . Calculate the break thermal efficiency and volumetric efficiency of the engine. Atmospheric conditions are  $1.01\text{ bar}$  and  $15^\circ\text{C}$ . The calorific value of fuel may be taken as  $44200\text{ kJ/kg}$ .
- 10

- (b) One kg of air at 35°C DBT and 60% RH is mixed with 2 kg of air at 20°C DBT and 13°C dew point temperature. Calculate the specific humidity, temperature and enthalpy of the mixture. Assume specific heat of steam as 1.88 kJ/kg K and the following properties may be used :

Temperature °C	Saturation pressure $p_s$ bar	Enthalpy of saturated steam $h_g$ kJ/kg
13	0.0150	2525.4
20	0.0234	2538.2
26	0.0336	2549.1
27	0.0356	2550.9
35	0.0563	2565.4

10

- (c) Air at 27°C temperature and 100 kPa pressure flows over a flat plate at a speed of 2.5 m/s. Calculate the boundary layer thickness at distance of 25 and 50 cm from the leading edge of the plate. Calculate the mass flow that enters the boundary layer between  $x = 25$  cm and  $x = 50$  cm from leading edge. The viscosity of air at 27°C is  $30.8 \mu\text{Pa}\cdot\text{m}$ . Assume unit depth in  $z$ -direction.

10

6. (a) A 100 cc petrol Engine with a compression ratio of 6 compresses the air fuel mixture to 900 kPa and 375°C. At the end of compression the ignition is started and the pressure rises along a straight line and attains the highest value of 3.0 MPa after the piston has travelled 4% of the working stroke. The air fuel ratio is 15:1. Take  $R$  for mixture as 0.275 kJ/kg-K, calorific value of fuel = 44 MJ/kg and  $c_v = 0.965$  kJ/kg-K. Find the heat loss per kg of charge during explosion. Flue gases and air has same gas constant. 10

- (b) The following data relates to an air-conditioned space :

Outdoor condition	38°C DBT/50% RH
Room condition	24°C DBT/50% RH
Sensible heat load	24 kW
Latent heat load	6 kW
Bypass factor of the cooling coil	0.16

If the ventilation requirement is such that on mass flow rate basis 20% fresh air is introduced and 80% supply air is recirculated, determine

- (i) Supply air flow rate
  - (ii) Outside air sensible heat
  - (iii) Outside air latent heat
  - (iv) Grand total heat
  - (v) Effective room sensible heat factor. 10
- (c) (i)  $1 \text{ m}^3$  of air is heated at constant pressure from  $15^\circ\text{C}$  to  $300^\circ\text{C}$  and then cooled at constant volume back to its initial temperature. If the initial pressure is 1.03 bar calculate the net heat flow and overall change in entropy. Show the process on a T S diagram. 5
- (ii) With simple schematic diagram explain the differences between fire tube and water tube boilers. Mention the merits and demerits of both. 5

7. (a) A sample bituminous coal gave the following ultimate analysis by mass :

Carbon 81.9%,

Hydrogen 4.9%,

Oxygen 6%,

Nitrogen 2.3% and

Ash 4.9%.

Calculate

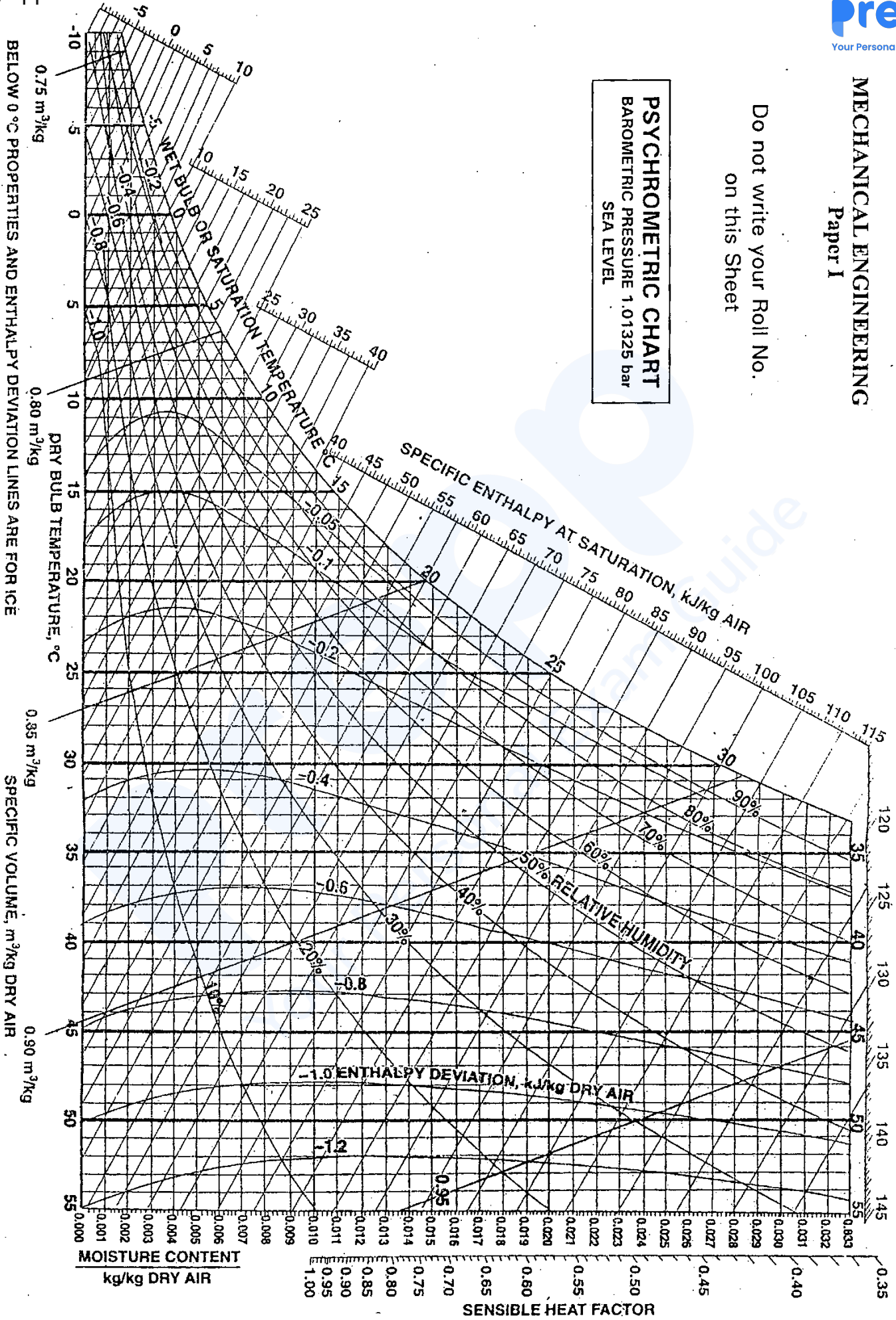
- (i) the stocheometric air fuel ratio for complete combustion and
- (ii) the volumetric analysis of wet and dry products of combustion when the air supplied is 25% in excess of that required for complete combustion. 10
- (b) Three thin-walled, long, circular cylinders 1, 2 and 3 of diameters 150 mm, 250 mm and 350 mm respectively are arranged concentrically. Temperature of cylinder 1 is 80 K and that of cylinder 3 is 300 K. Emissivity of cylinder 1, 2 and 3 is 0.05, 0.1 and 0.2 respectively. Assuming that there is vacuum inside the annular spaces, determine the steady state temperature attained by cylinder 2. 10

- (c) Find an expression for the drag force on smooth sphere of diameter  $D$ , moving with a uniform velocity  $V$  in a fluid of density  $\rho$  and dynamic viscosity  $\mu$ . 10

MECHANICAL ENGINEERING  
Paper I

Do not write your Roll No.  
on this Sheet

PSYCHROMETRIC CHART  
BAROMETRIC PRESSURE 1.01325 bar  
SEA LEVEL



BELOW 0°C PROPERTIES AND ENTHALPY DEVIATION LINES ARE FOR ICE

Ref. Point for S.H.F. is 25°C, 50% R.H.