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 sketches 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) $1{\cdot}0\ m^3$ of air is heated reversibly at a constant pressure from 25°C to 500°C, and is then cooled reversibly at constant volume back to initial temperature. If the initial pressure is 1 bar, find the (i) net heat flow, and (ii) overall change in entropy. Represent the process on T-s plot. Take $C_p = 1{\cdot}005$ kJ/kg K and $R = 0{\cdot}287$ kJ/kg K for air. *8*

(b) An air compressor takes in air at 1 atm and 25°C. The compressed air is discharged through a pipeline having an internal diameter of 2 cm. The average velocity of the discharged air is 10 m/s and the discharge pressure is 5 bar. Assuming that the compression occurs quasistatically and adiabatically, calculate the work input to the compressor. Consider the inlet velocity to the compressor is negligible.

Take $C_p = 1{\cdot}005$ kJ/kg K and $\gamma = 1{\cdot}4$ for air. *8*

(c) A four-cylinder, four-stroke SI engine is operating at a speed of 4000 rpm. Determine :

(i) How many times the spark will trigger in one minute per cylinder.

(ii) Number of thermodynamic cycles per cylinder per second.

(iii) If the combustion phenomenon takes place over 72° of crank rotation, find out duration of combustion in seconds. *8*

(d) The following particulars refer to a furnace wall :

Hot gas temperature = 2000°C

Room air temperature = 45°C

Heat flow by radiation from gases to inside surface of the wall = $23{\cdot}26\ kW/m^2$

Convective heat transfer coefficient at the interior surface = $11{\cdot}63\ W/m^2\ K$

Thermal conductance of the wall = $58\ W/m^2\ K$

Heat flow by radiation from external surface to surroundings = $9{\cdot}3\ kW/m^2$

Interior wall surface temperature = 1000°C

Determine for the external surface of the wall (i) surface temperature, and (ii) convective heat transfer coefficient. *8*

(e) Define Grashof number and give its formula. Specify the necessary condition for the following cases in terms of Reynolds number and Grashof number : *8*

(i) When combined effects of free and forced convection must be considered.

(ii) When forced convection effects are to be neglected.

(iii) When free convection effects are to be neglected.

Q2. (a) A steady flow compressor is used to compress air from 1 atm, 30°C to 10 atm in an adiabatic process. If the first law efficiency of the process is 80%, calculate the irreversibility and the second law efficiency of the process. Consider the lowest available temperature is 25°C.

Take $C_p = 1{\cdot}005$ kJ/kg K and $\gamma = 1{\cdot}4$ for air. *15*

(b) A silent Diesel Genset of 500 kW capacity is to be installed in a Forest Division having a diesel engine with compression ratio of 18 : 1 and expansion ratio of 14 : 1. Calculate the air standard cycle efficiency. Assume ratio of specific heats $\gamma = 1{\cdot}4$. If the relative efficiency of this engine is 50% and calorific value of diesel fuel is 44000 kJ/kg, find out specific fuel consumption of this engine in kg/kWh. If this engine is to be operated at full load condition for 2 hours a day, find out the diesel fuel inventory to be ordered for a period of next 15 days. Also, work out number of diesel drums to be ordered and payable amount to the supplier of fuel. Consider drum capacity as 200 litres per drum and cost of diesel fuel per litre as ₹ 87. Consider diesel density as 0·85 kg/litre. *15*

(c) A $0{\cdot}6\ m \times 0{\cdot}6\ m$ thin square plate in a room at 30°C is placed horizontally with hot side up while the other side is insulated. Determine the rate of heat transfer from the plate by natural convection if the temperature of hot surface is 90°C. Use correlation $Nu_L = 0{\cdot}54\ Ra_L^{1/4}$. The properties of air at film temperature of 60°C are $k = 0{\cdot}02808$ W/mK, $Pr = 0{\cdot}7202$, $\nu = 1{\cdot}896 \times 10^{-5}\ m^2/s$. What will be the heat loss due to radiation ? Assume $\sigma = 5{\cdot}67 \times 10^{-8}\ W/m^2K^4$ and emissivity of plate surface as 1. *10*

Q3. (a) Answer the following in the context of combustion in I.C. Engine : *15*

(i) Discuss how ignition lag and ignition delay are different in combustion phenomenon.

(ii) Explain how engine speed and turbulence affect the first two stages of combustion in SI engine.

(iii) In case of SI engine, for a given speed of 1500 rpm, the ignition lag and propagation of flame front in degree of crank rotation are 8° and 12° respectively. If the engine speed doubles to 3000 rpm, find out the value of ignition lag and propagation of flame front in degrees of crank rotation.

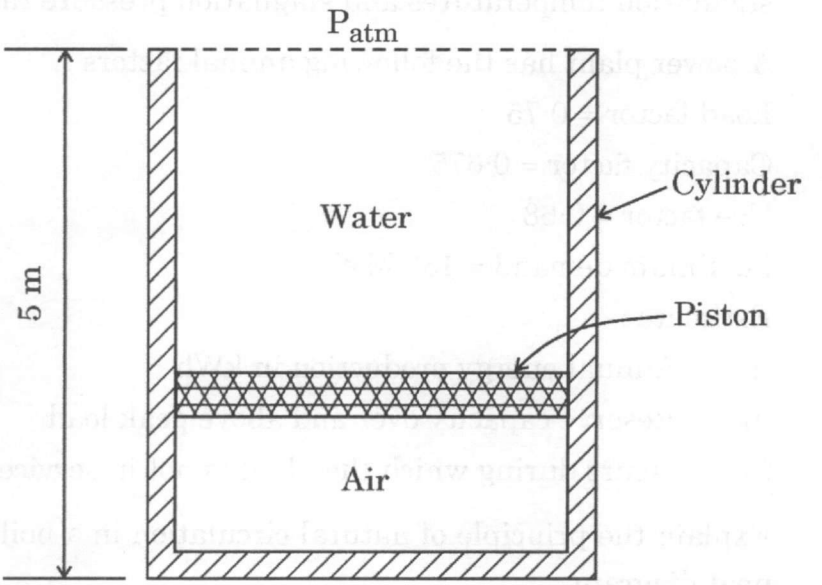
(b) Nowadays all heavy duty diesel fuelled trucks and buses are equipped with Diesel Exhaust Fluid (DEF) tank and Selective Catalytic Reduction (SCR) system. State its purpose and explain its working stating chemical reactions taking place. *15*

(c) A reversible heat engine in a satellite operates between a hot reservoir (T_1) and a radiating panel at T_2. Radiation from the panel is given as $Q_2 = KAT_2^4$. For a given work output and T_1, estimate the temperature ratio $\left(\frac{T_2}{T_1}\right)$ if the area of the radiating panel has to be minimum. Determine the minimum area of the panel for a work output of 0·5 kW and $T_1 = 900$ K. Consider $K = 5{\cdot}67 \times 10^{-8}$ W/m^{2}K^4. *10*

Q4. (a) Metal plates ($k = 180$ W/mK, $\rho = 2800$ kg/m^3 and $C_p = 880$ J/kg K) with a thickness of 2 cm exiting an oven are conveyed through a 10 m long cooling chamber at a speed of 4 cm/s. The plates enter the cooling chamber at an initial temperature of 700°C. The temperature of air in the cooling chamber is 15°C, and the plates are cooled with blowing air and the convection heat transfer coefficient is given as a function of the air velocity, $h = 33\ V^{0{\cdot}8}$, where h is in W/m^{2}K and V is in m/s. To prevent any incident of thermal burn, it is necessary to design the cooling process such that the plates exit the cooling chamber at a relatively safe temperature of 50°C or less. Determine the air velocity and heat transfer coefficient such that the temperature of the plates exiting the cooling chamber is 50°C. Assume heat transfer by radiation is negligible. *15*

(b) (i) Consider a spherical balloon is filled from a bottle of helium gas, which is at pressure 'P_H'. If the surface tension of the balloon material is 'S' and the atmospheric pressure is 'P_0', establish a relation between P_H, S and P_0 as the function of balloon's diameter 'D' at any given instant of time. *5*

(ii) A 5 m high cylinder with cross-sectional area of 0·25 m^2 has a massless piston at the bottom with water on top of it, as shown in the figure. Air at 25°C and volume of 0·5 m^3, under the piston is heated so that the piston moves up, spilling the water out over the side. Find the total heat transfer to the air to push all the water out. Consider the water temperature as 20°C and atmospheric pressure is 1 atm. The density of water can be taken as 998 kg/m^3. *10*



Consider C_v = 0·718 kJ/kg K and R = 0·287 kJ/kg K for air.

(c) In a car manufacturing company, Propane is used as fuel in heaters for preheating of paints. Calculate the Air-to-Fuel ratio for complete combustion of C_3H_8 (Propane), if 15% excess air is supplied to the heater. *10*

SECTION B

Q5. (a) A 4 litre vessel is filled with carbon dioxide gas at 25°C and 5 atm. A 20 mm diameter circular rubber plug with a thickness of 10 mm is used to contain the gas inside the vessel. Determine the rate of mass loss of carbon dioxide from the vessel through the rubber plug. Take binary diffusion coefficient for CO_2 in rubber (D_{AB}) = $1{\cdot}1 \times 10^{-10}$ m^2/s, molar mass of CO_2 = 44·01 kg/kmol and solubility of CO_2 in rubber at 25°C = 0·04015 kmol/m^3 bar. Assume atmospheric pressure as 1·01325 bar. *8*

(b) Why is a throttling device used in place of an expander in a vapour compression refrigeration cycle ? *8*

(c) Derive an expression for Total-to-Total efficiency of a turbine in terms of stagnation temperatures and stagnation pressure ratio. *8*

(d) A power plant has the following annual factors :

Load factor = 0·75

Capacity factor = 0·675

Use factor = 0·68

Maximum demand = 180 MW

Estimate :

(i) Annual energy production in kWh

(ii) Reserve capacity over and above peak load

(iii) Hours during which the plant is not in service per year *8*

(e) Explain the principle of natural circulation in a boiler with the help of a neat diagram. *8*

Q6. (a) An air heater consists of a semicircular tube for which the plane surface is maintained at 1000 K and the other surface is well insulated. The tube radius is 20 mm and both surfaces have an emissivity of 0·8. If atmospheric air flows through the tube at 0·01 kg/s and its mean temperature, T_m = 400 K, what is the rate at which heat must be supplied per unit length to maintain the plane surface at 1000 K ? What is the temperature of the insulated surface ? For air at 400 K and 1 atm, take k = 0·0338 W/m K, $\mu = 230 \times 10^{-7}$ kg/s m, C_p = 1014 J/kg K, Pr = 0·69. Use correlation $Nu_D = 0{\cdot}023\ Re_D^{0{\cdot}8}\ Pr^{0{\cdot}4}$.

Assume fully developed flow.

Take Stefan-Boltzmann's constant, $\sigma = 5{\cdot}67 \times 10^{-8}$ W/m^2K^4. *15*

(b) Dry saturated ammonia is compressed in a reciprocating compressor from saturation pressure at –10°C to saturation pressure at 40°C. The compressor has four cylinders, each with a bore of 10 cm and a stroke of 8 cm, clearance volume ratio is 0·04 and it runs at 750 rpm. Find : *15*

(i) Volumetric efficiency assuming isentropic compression,

(ii) The swept volume flow rate,

(iii) The mass flow rate, and

(iv) Refrigeration capacity.

Use saturation and superheat tables for NH_3 given below :

Saturation Table :

T (°C)	P (bar)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	S_g (kJ/kg K)
– 10	2·908	0·418	134·95	1431·409	5·4712
40	15·55	0·0832	371·47	1472·02	4·8728

Superheat table at 15·55 bar :

Degree of Superheat	60°C	80°C
v (m^3/kg)	0·108	0·116
h (kJ/kg)	1647·9	1700·3
S (kJ/kg K)	5·3883	5·5253

(c) Discuss the influence of ratio of blade speed to steam speed on blade efficiency in a single stage impulse turbine. *10*

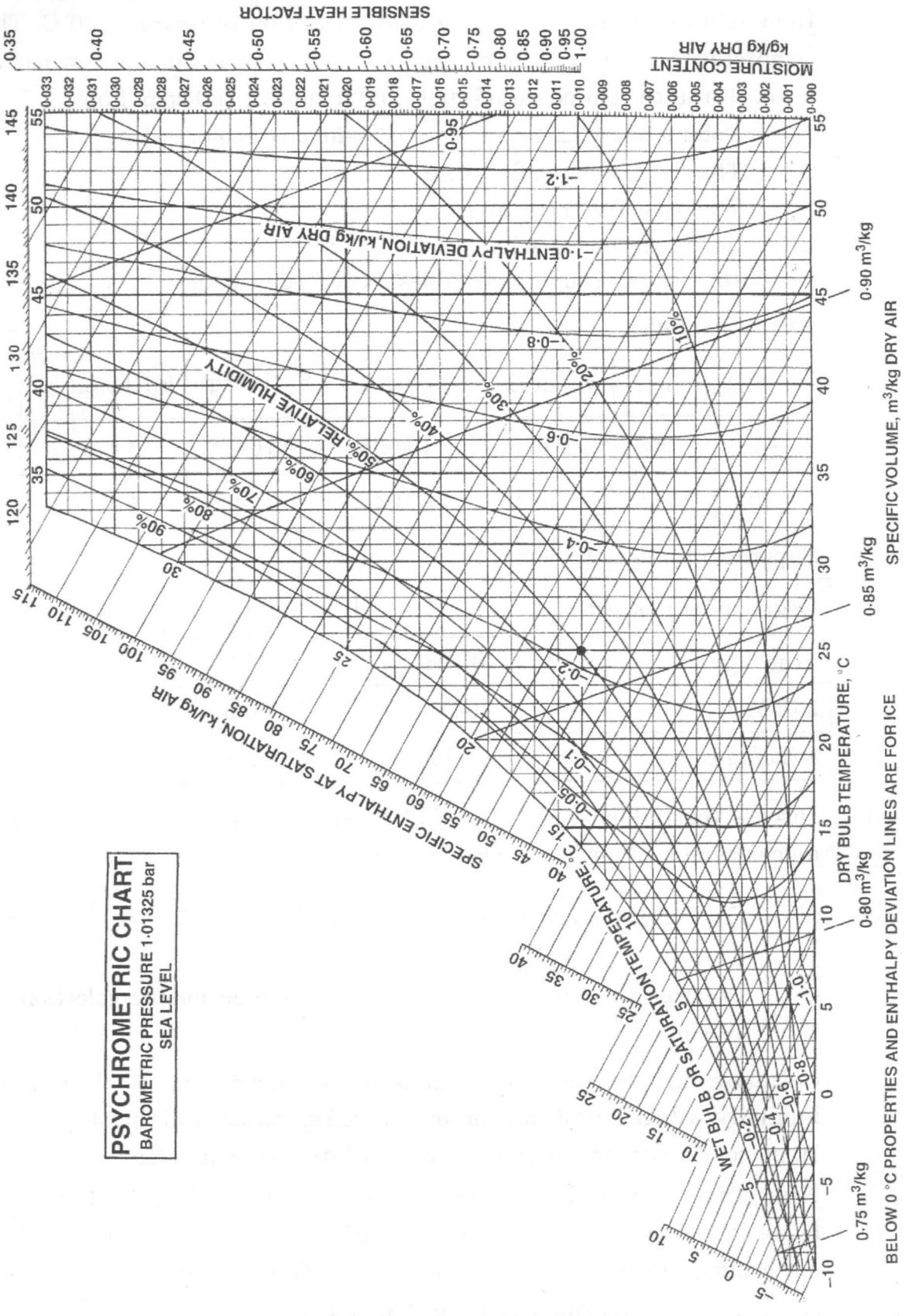
Q7. (a) (i) Explain the working of a Loeffler boiler with the help of a neat diagram. *10*

(ii) Describe the various factors to be considered for the selection of site for a steam power plant. *5*

(b) Calculate the tonnes of refrigeration required and final relative humidity when moist air enters a refrigeration coil at 40°C and 50 percent relative humidity at a rate of 120 m^3/min and leaves at 30°C.

Now, if the surface temperature of coil is set to 13°C and coil contact factor is 0·90, work out the tonnes of refrigeration required and also find out condensate flow rate. Assume barometric pressure as 1·01325 bar. Solve the problem using Psychrometric chart. *15*

Question 7(b)


PSYCHROMETRIC CHART
BAROMETRIC PRESSURE 1·01325 bar
SEA LEVEL
SENSIBLE HEAT FACTOR
MOISTURE CONTENT
kg/kg DRY AIR
ENTHALPY DEVIATION, kJ/kg DRY AIR
RELATIVE HUMIDITY
SPECIFIC ENTHALPY AT SATURATION, kJ/kg AIR
WET BULB OR SATURATION TEMPERATURE, °C
DRY BULB TEMPERATURE, °C
SPECIFIC VOLUME, m³/kg DRY AIR
BELOW 0 °C PROPERTIES AND ENTHALPY DEVIATION LINES ARE FOR ICE

(c) The following data pertain to a centrifugal compressor :

Ambient temperature = 20°C

N = 14000 rpm

G = 22 kg/sec

Pressure ratio = 4

Atmospheric pressure = 1 bar

$V_{f_1} = V_{f_3}$ = 130 m/sec (inlet velocity of flow = Exit velocity of flow from diffuser)

Double sided impeller slip factor = 0·8

Adiabatic efficiency = 0·76

Work input factor = 1·02

Assume C_p as 1·005 kJ/kg K

$\gamma = 1{\cdot}4$

Determine the impeller tip diameter. *10*

Q8. (a) Derive the expressions for force on the blades, work done, blade efficiency and axial thrust for steam impulse turbine. *15*

(b) In an auditorium which is to be maintained at a temperature not exceeding 24°C and a relative humidity not exceeding 50%, a sensible heat load of 132 kW and 84 kg/h of moisture has to be removed. Air is supplied to the auditorium at 15°C.

Calculate :

(i) How many kg of air per hour must be supplied ?

(ii) What is the dew point temperature of supply air and what is its relative humidity ?

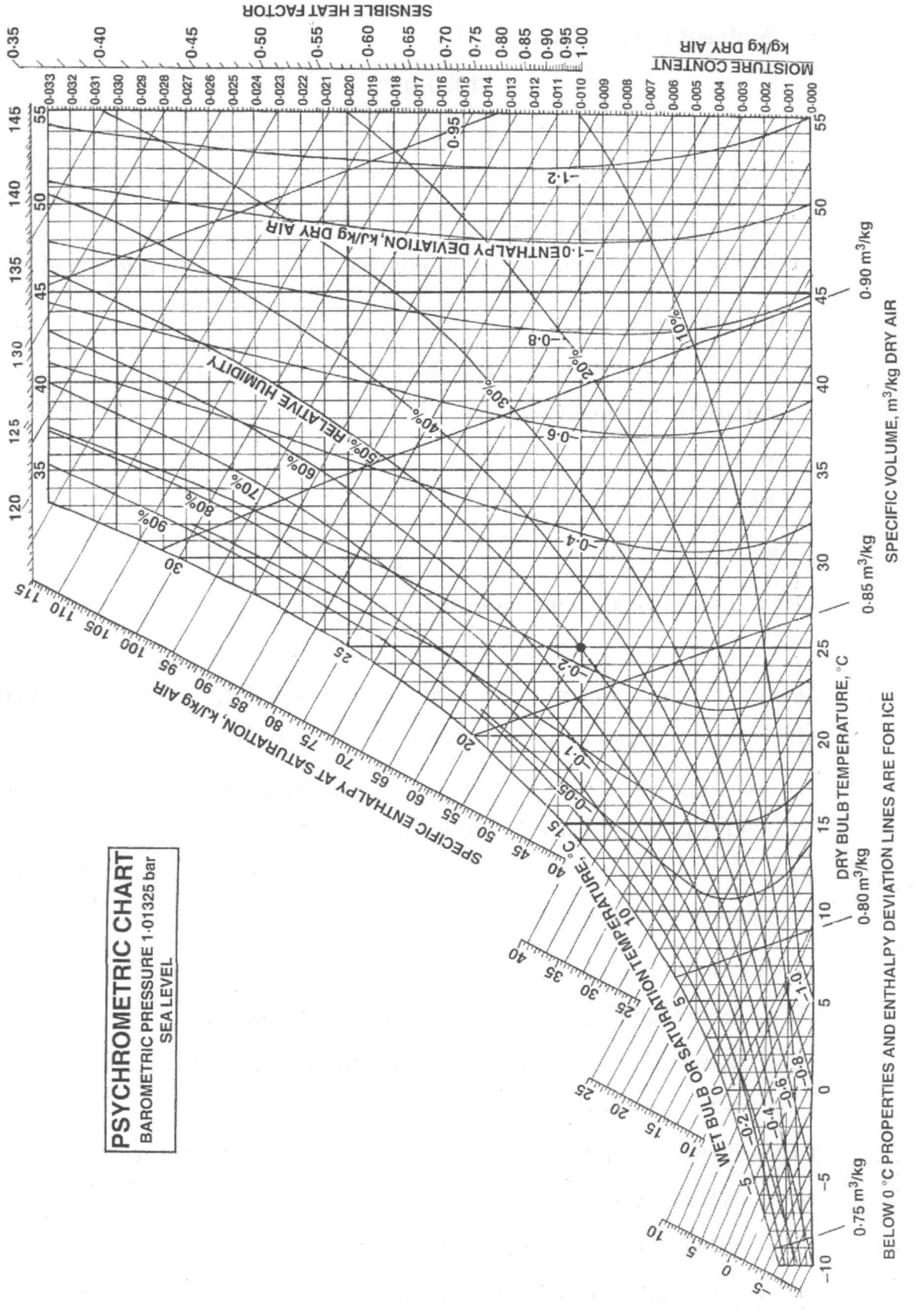
(iii) How much latent heat is picked up in the auditorium ?

(iv) What is the sensible heat factor ?

(v) What is the ADP of coil and its BPF ?

The psychrometric chart is attached. *15*

Question 8(b)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SPECIFIC VOLUME, m³/kg DRY AIR
BELOW 0 °C PROPERTIES AND ENTHALPY DEVIATION LINES ARE FOR ICE

(c) A small air compressor has the following data :

Air flow rate : 2 kg/s

Pressure ratio : 2·5

Rotational speed : 45000 rpm

Efficiency : 89%

The conditions of air at the inlet of the compressor are 1 bar and 30°C.

(i) Calculate the power required to drive this compressor.

(ii) A geometrically similar compressor of five times of this size is to be constructed. Determine the corresponding (I) speed, (II) mass flow rate, (III) pressure ratio, and (IV) power required.

Assume the entry conditions and efficiency of both the compressors to be the same.

Consider C_p = 1·005 kJ/kg K and γ = 1·4 for air. *10*