

**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<sup>2</sup> = 0.98 bar

1 bar = 10<sup>5</sup> pascals

Universal gas constant = 8314.6 J/kmol-K

Psychrometric chart is enclosed.

## SECTION A

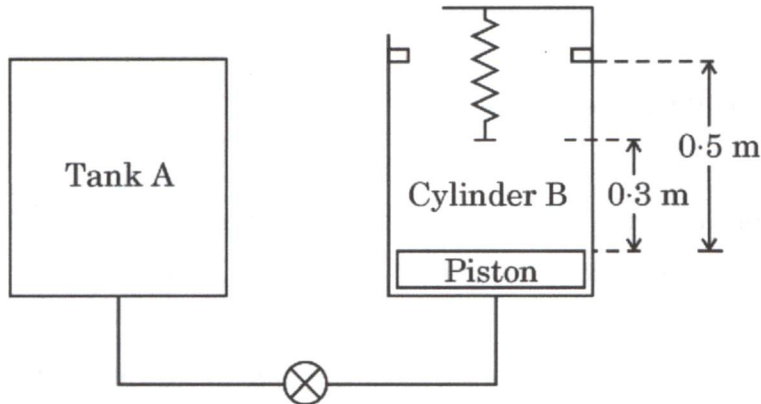
- Q1.** (a) A  $4\text{ m} \times 5\text{ m} \times 7\text{ m}$  room is heated by the radiator of steam heating system. The steam radiator transfers heat at a rate of  $10,000\text{ kJ/h}$  and a  $100\text{ W}$  fan is used to distribute the warm air in the room. The heat losses from the room are estimated to be at the rate of  $5,000\text{ kJ/h}$ . If the initial temperature of the room air is  $10^\circ\text{C}$ , determine how long it will take for the air temperature to rise to  $20^\circ\text{C}$ . Assuming constant specific heat of air [ $c_p = 1.007\text{ kJ/kg K}$ ] and take the value of  $R = 0.287\text{ kPa m}^3/\text{kg K}$  for air.  
Further assume room pressure =  $100\text{ kPa}$ . 8
- (b) Using pressure vs crank angle diagrams compare the detonation observed in SI engines with knock of CI engines. Also show that factors which favour knock in SI engines are desirable in CI engines. 8
- (c) Define the following non-dimensionless numbers and explain their physical significance : 8
- (i) Nusselt number
  - (ii) Grashof number
  - (iii) Stanton number
  - (iv) Prandtl number
- (d) On a cold winter night, with an outside ambient temperature of  $5^\circ\text{C}$ , a wall of the house loses  $30\text{ kJ}$  per minute steadily. If the inner and outer surface temperatures of the wall are maintained at  $25^\circ\text{C}$  and  $9^\circ\text{C}$  respectively, what would be the energy destruction rate (in Watts) within the wall ? 8
- (e) A furnace is shaped like a long equilateral triangular duct where the width of each side is  $2\text{ m}$ . Heat is supplied from the base surface, whose emissivity is  $\epsilon_1 = 0.8$ , at a rate of  $800\text{ W/m}^2$ , while the side surfaces, whose emissivities are  $0.5$ , are maintained at  $500\text{ K}$ . Neglecting the end effects, determine the temperature of the base surface. Can you treat this geometry as a two surface enclosure ? Take  $\sigma = 5.67 \times 10^{-8}\text{ W/m}^2\text{ K}^4$  and area of base surface =  $1\text{ m}^2$  and total area of other side surfaces =  $2\text{ m}^2$ . 8

- Q2.** (a) Tank A of volume 500 L contains air at room temperature and 700 kPa pressure. Cylinder B, initially empty, has a piston of mass 100 kg and cross-sectional area  $0.5 \text{ m}^2$ , and linear spring with spring constant 150 kN/m as shown in the figure. Now the valve is opened and air flows slowly and steadily into cylinder B. The entire system eventually reaches room temperature. Assume air as an ideal gas and atmospheric pressure as 101 kPa. Draw the entire process on P-v diagram for air in cylinder B.

Determine :

- (i) Pressure when piston just touches the spring.
- (ii) Whether the piston will be at stops in the final state.
- (iii) Final pressure of air.
- (iv) Work done by air during each process.

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- (b) Consider a water-to-water counter-flow heat exchanger with these specifications. Hot water enters at  $95^\circ\text{C}$  while cold water enters at  $20^\circ\text{C}$ . The exit temperature of hot water is  $15^\circ\text{C}$  greater than that of cold water outlet and mass flow rate of hot water is 50 percent greater than that of cold water. The product of heat transfer surface area and overall heat transfer coefficient is  $1400 \text{ W/m}^2 \text{ }^\circ\text{C}$ . Taking the specific heat of both cold and hot water to be  $c_p = 4.18 \text{ kJ/kg }^\circ\text{C}$ , determine :

- (i) outlet temperature of the cold water,
- (ii) effectiveness of the heat exchanger,
- (iii) mass flow rate of the cold water, and
- (iv) the heat transfer rate.

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- (c) Explain the thermal NO formation in SI engines during combustion. List the factors which favour NO formation in-cylinder. Also describe the in-cylinder NO suppression techniques and exhaust treatment techniques followed in modern SI engines.

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- Q3.** (a) Consider a large plane wall of thickness  $L = 0.4$  m, thermal conductivity  $k = 2.3$  W/m °C and surface area  $A = 20$  m<sup>2</sup>. The left side of the wall is maintained at a constant temperature of 80°C while the right side loses heat by convection to the surrounding air at  $T_{\infty} = 15^{\circ}\text{C}$  with a heat transfer coefficient of  $h = 24$  W/m<sup>2</sup> °C. Assuming constant thermal conductivity and no heat generation in the wall,

- (i) express the differential equation and the boundary conditions for steady one-dimensional heat conduction through the wall,
- (ii) obtain a relation for the variation of temperature in the wall by solving the differential equation, and
- (iii) calculate the rate of heat transfer through the wall.

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- (b) Air enters the compressor at the ambient condition of 100 kPa and 25°C (state 1). At the compressor exit (state 2), the pressure is 10 times of inlet pressure. The compression process is polytropic with  $n = 1.40645$ . Constant pressure heat addition takes place in a heat exchanger, where the air enters after compression. The temperature at the exit of the heat exchanger is 726.85°C (state 3). The air then enters the turbine at state 3 and leaves the turbine at 110 kPa (state 4). The expansion process in turbine is polytropic with  $n = 1.38727$ . Assume air as an ideal gas with mass flow rate of 15 kg/s through all components.

Determine :

- (i) the amount of power required for the compression process.
- (ii) heat supplied in the heat exchanger (kW).
- (iii) power generated by the turbine.
- (iv) net power output.

Solve using Air table given.

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*Ideal Gas Properties of Air, Standard Entropy at 0.1-Mpa (1-Bar) Pressure*

T (K)	u (kJ/kg)	h (kJ/kg)	$S_T^0$ (kJ/kg-K)	T(K)	u (kJ/kg)	h (kJ/kg)	$S_T^0$ (kJ/kg-K)
200	142.77	200.17	6.46260	1100	845.45	1161.18	8.24449
220	157.07	220.22	6.55812	1150	889.21	1219.30	8.29616
240	171.38	240.27	6.64535	1200	933.37	1277.81	8.34596
260	185.70	260.32	6.72562	1250	977.89	1336.68	8.39402
280	200.02	280.39	6.79998	1300	1022.75	1395.89	8.44046
290	207.19	290.43	6.83521	1350	1067.94	1455.43	8.48539
298.15	213.04	298.62	6.86305	1400	1113.43	1515.27	8.52891
300	214.36	300.47	6.86926	1450	1159.20	1575.40	8.57111
320	228.73	320.58	6.93413	1500	1205.25	1635.80	8.61208
340	243.11	340.70	6.99515	1550	1251.55	1696.45	8.65185
360	257.53	360.86	7.05276	1600	1298.08	1757.33	8.69051
380	271.99	381.06	7.10735	1650	1344.83	1818.44	8.72811
400	286.49	401.30	7.15926	1700	1391.80	1879.76	8.76472
420	301.04	421.59	7.20875	1750	1438.97	1941.28	8.80039
440	315.64	441.93	7.25607	1800	1486.33	2002.99	8.83516
460	330.31	462.34	7.30142	1850	1533.87	2064.88	8.86908
480	345.04	482.81	7.34499	1900	1581.59	2126.95	8.90219
500	359.84	503.36	7.38692	1950	1629.47	2189.19	8.93452
520	374.73	523.98	7.42736	2000	1677.52	2251.58	8.96611
540	389.69	544.69	7.46642	2050	1725.71	2314.13	8.99699
560	404.74	565.47	7.50422	2100	1774.06	2376.82	9.02721
580	419.87	586.35	7.54084	2150	1822.54	2439.66	9.05678
600	435.10	607.32	7.57638	2200	1871.16	2502.63	9.08573
620	450.42	628.38	7.61090	2250	1919.91	2565.73	9.11409
640	465.83	649.53	7.64448	2300	1968.79	2628.96	9.14189
660	481.34	670.78	7.67717	2350	2017.79	2692.31	9.16913
680	496.94	692.12	7.70903	2400	2066.91	2755.78	9.19586
700	512.64	713.56	7.74010	2450	2116.14	2819.37	9.22208
720	528.44	735.10	7.77044	2500	2165.48	2883.06	9.24781
740	544.33	756.73	7.80008	2550	2214.93	2946.86	9.27308
760	560.32	778.46	7.82905	2600	2264.48	3010.76	9.29790
780	576.40	800.28	7.85740	2650	2314.13	3074.77	9.32228
800	592.58	822.20	7.88514	2700	2363.88	3138.87	9.34625
850	633.42	877.40	7.95207	2750	2413.73	3203.06	9.36980
900	674.82	933.15	8.01581	2800	2463.66	3267.35	9.39297
950	716.76	989.44	8.07667	2850	2513.69	3331.73	9.41576
1000	759.19	1046.22	8.13493	2900	2563.80	3396.19	9.43818
1050	802.10	1103.48	8.19081	2950	2613.99	3460.73	9.46025
1100	845.45	1161.18	8.24449	3000	2664.27	3525.36	9.48198

- (c) Explain the MPFI (Multipoint Port Fuel Injection) system layout which employs mass flow sensor used in multi-cylinder SI engines. Clearly indicate the components present in the layout and their sensing/operational functions. 10

**Q4.** (a) A frictionless constant-pressure piston cylinder device, initially contains  $0.01 \text{ m}^3$  of Argon gas at 400 K and 350 kPa. Heat is now transferred to Argon from a furnace at 1200 K, and Argon expands isothermally until its volume is doubled. No heat transfer takes place between the Argon and surrounding atmospheric air, which is at  $T_0 = 300 \text{ K}$  and  $P_0 = 100 \text{ kPa}$ .

Determine :

- (i) the useful work output,
- (ii) the energy destroyed,
- (iii) the reversible work, and
- (iv) the maximum available work for this process. 15

For Argon, take  $R = 0.2081 \text{ kJ/kg K}$ .

(b) A four-cylinder, four-stroke diesel engine develops 85 kW at 2000 rpm with a specific fuel consumption of  $0.235 \text{ kg/kWh}$ , and the air/fuel ratio is 25 : 1. The analysis of the fuel shows 87% carbon and 13% hydrogen by mass. The calorific value of fuel used is  $4,25,200 \text{ kJ/kg}$ . The jacket cooling water flows at  $0.25 \text{ kg/s}$  and its temperature rise is 48 K. The exhaust gas temperature is  $320^\circ\text{C}$ . Draw up a Heat Balance Chart showing dry exhaust heat and steam heat separately. Take  $c_p = 1.85 \text{ kJ/kg K}$  for dry exhaust gas and  $c_p = 1.9 \text{ kJ/kg K}$  for superheated steam. The ambient temperature is  $20^\circ\text{C}$  and the exhaust gas pressure is  $1.013 \text{ bar}$ . 15

(c) Explain the construction and working of a three-way catalytic converter for SI engines. Give details of substrate and wash coat applied for catalysis. Also, describe the working of Lambda sensor ( $\text{O}_2$ -sensor) and explain how it helps in the control of pollutants leaving the tailpipe. 10

## SECTION B

- Q5.** (a) Explain with a neat sketch, vapour absorption refrigeration system using water and ammonia, with all modifications. 8
- (b) How can you explain using a Fanno line that a subsonic flow can never become supersonic? 8
- (c) Compare velocity compounded impulse turbines with pressure compounded impulse turbines based on the following : 8
- (i) Number of stages
  - (ii) Position in the steam turbine layout
  - (iii) Efficiency per stage
  - (iv) Type of construction of nozzle blade and cost
  - (v) Possibility of partial admission
  - (vi) Type of sealing needed for nozzle blades
  - (vii) Pressure drop per stage
  - (viii) Total cost of all stages for a given pressure drop
- (d) Explain the selection criteria of refrigerant based on : 8
- (i) Thermodynamic and thermo-physical properties
  - (ii) Environmental and safety properties
- (e) Discuss briefly the factors that should be considered while selecting the site for a nuclear power plant. 8
- Q6.** (a) A freezer of 20 TR capacity has evaporator and condenser temperature of  $-30^{\circ}\text{C}$  and  $25^{\circ}\text{C}$  respectively. The refrigerant R-12 is subcooled by  $4^{\circ}\text{C}$  before it enters the expansion valve and is superheated by  $5^{\circ}\text{C}$  before leaving the evaporator. The compression is isentropic and the valve throttling and clearance are to be neglected. If a six-cylinder, single-acting compressor with stroke equal to bore running at 1000 rpm is used, determine :

- (i) COP of the refrigeration system,
- (ii) Mass of refrigerant to be circulated per min, and
- (iii) Work input to the compressor in kW. 15

The specific heat of liquid R-12 is 1.235 kJ/kg K and of vapour R-12 is 0.733 kJ/kg K. The properties of R-12 are given below :

Saturation Temp	Pressure (bar)	Enthalpy, kJ/kg		Entropy, kJ/kg K		Specific volume, m <sup>3</sup> /kg	
		Liquid	Vapour	Liquid	Vapour	Liquid	Vapour
-30°C	1.0044	8.86	174.2	0.0371	0.7171	0.000673	0.1596
25°C	6.5184	59.7	197.73	0.2239	0.6868	0.00764	0.0269

- (b) A Parsons steam turbine with a rotor diameter of 1250 mm rotates at 2500 rpm. If the speed ratio is 0.7 and the blade angle at outlet is 20°, determine the blade angle at inlet and the diagram efficiency. Draw velocity triangles. 15
- (c) What is a Deaerator ? Explain its role in a steam power plant. Also draw a sketch to explain its construction and operation. 10

**Q7.** (a) A compressor cascade has the following data :

Velocity of air at entry = 75 m/s

Air angle at entry = 48°

Air angle at exit = 25°

Pitch – Chord ratio = 1.1

Stagnation pressure loss = 11 m of air column

Density of air = 1.25 kg/m<sup>3</sup>

Determine the actual pressure recovery coefficient and the maximum diffuser efficiency. 15

- (b) Steam at exit of a boiler is at 60 bar and 500°C. It flows with a velocity of 10 m/s and mass flow rate of 80 kg/s. Determine the number and length of superheater coils of 50 mm internal diameter and 5 mm thickness to be provided. Assume the heat flux in the superheater coils is to be limited to 140 kW/m<sup>2</sup> due to materials restriction. 15

Use the attached table :



p(bar) = 60.00

SAT t(°C)											
275.55											
SAT.LIQ	1213.7	3.0273	.0013187								
SAT.VAP	2785.0	5.8908	.03244								
t	h	s	v	t	h	s	v	t	h	s	v
°C	kJ/kg	kJ/kg K	m <sup>3</sup> /kg	°C	kJ/kg	kJ/kg K	m <sup>3</sup> /kg	°C	kJ/kg	kJ/kg K	m <sup>2</sup> /kg
0	6.1	.0003	.0009972								
10	47.8	.1505	.0009974	310	2920.7	6.1310	.037481	610	3679.6	7.1931	.066024
20	89.5	.2950	.0009990	320	2954.2	6.1880	.038744	620	3703.1	7.2195	.066862
30	131.1	.4347	.0010016	330	2986.1	6.2412	.039949	630	3726.5	7.2456	.067697
40	172.7	.5698	.0010052	340	3016.5	6.2913	.041105	640	3750.0	7.2715	.068529
50	214.4	.7007	.0010094	350	3045.8	6.3386	.042222	650	3773.5	7.2971	.069359
60	256.1	.8278	.0010144	360	3074.0	6.3836	.043304	660	3797.1	7.3225	.070187
70	297.8	.9512	.0010201	370	3101.5	6.4267	.044357	670	3820.7	7.3476	.071013
80	339.6	1.0713	.0010263	380	3128.3	6.4680	.045385	680	3844.3	7.3725	.071837
90	381.5	1.1883	.0010332	390	3154.4	6.5077	.046391	690	3868.0	7.3972	.072658
100	423.5	1.3023	.0010406	400	3180.1	6.5462	.047379	700	3891.7	7.4217	.073478
110	465.6	1.4136	.0010487	410	3205.4	6.5834	.048350	710	3915.4	7.4459	.074296
120	507.8	1.5224	.0010573	420	3230.3	6.6196	.049306	720	3939.1	7.4700	.075112
130	550.2	1.6288	.0010665	430	3254.9	6.6549	.050249	730	3962.9	7.4938	.075927
140	592.8	1.7332	.0010764	440	3279.3	6.6893	.051181	740	3986.8	7.5175	.076740
150	635.6	1.8355	.0010870	450	3303.5	6.7230	.052109	750	4010.7	7.5409	.077551
160	678.6	1.9361	.0010983	460	3327.4	6.7559	.053016	760	4034.6	7.5642	.078361
170	722.0	2.0351	.0011103	470	3351.3	6.7882	.053920	770	4058.6	7.5873	.079170
180	765.7	2.1325	.0011232	480	3375.0	6.8199	.054817	780	4082.6	7.6102	.079977
190	809.7	2.2287	.0011371	490	3398.6	6.8511	.055707	790	4106.6	7.6329	.080782
200	854.2	2.3237	.0011519	500	3422.2	6.8818	.056592	800	4130.7	7.6554	.081587
210	899.2	2.4178	.0011680	510	3445.7	6.9119	.057470				
220	944.7	2.5110	.0011853	520	3469.1	6.9417	.058344				
230	990.9	2.6038	.0012042	530	3492.5	6.9710	.059212				
240	1037.9	2.6962	.0012249	540	3515.9	7.0000	.060076				
250	1085.8	2.7886	.0012476	550	3539.3	7.0285	.060937				
260	1134.7	2.8813	.0012729	560	3562.7	7.0568	.061793				
270	1185.1	2.9749	.0013013	570	3586.0	7.0846	.062646				
280	2804.9	5.9270	.033173	580	3609.4	7.1122	.063495				
290	2846.7	6.0017	.034718	590	3632.8	7.1395	.064341				
300	2885.0	6.0692	.036145	600	3656.2	7.1664	.065184				

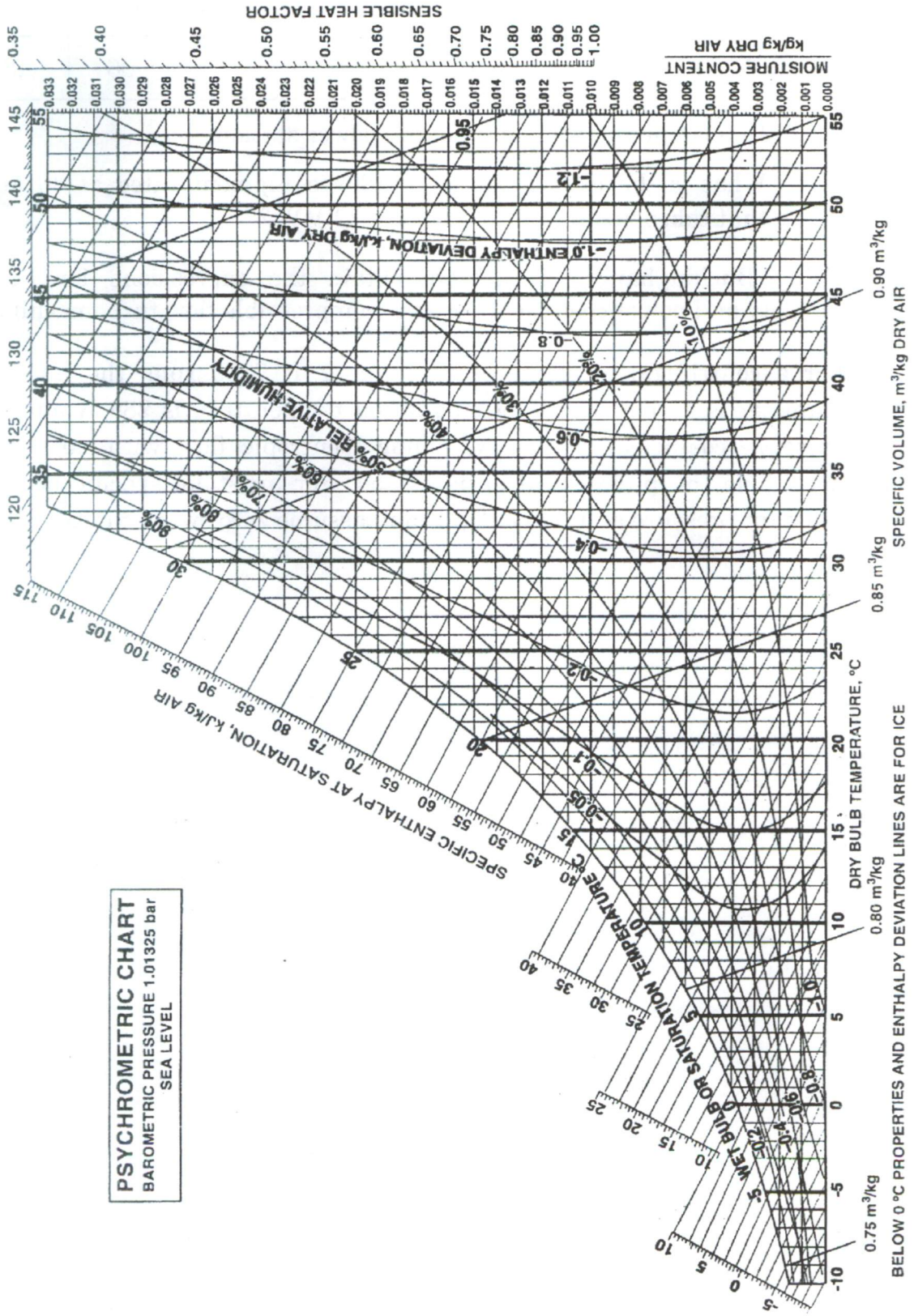
(c) Air at 30°C dry bulb temperature and 60% relative humidity is passed through a cooling coil at the rate of 250 m<sup>3</sup>/min. The air leaves the coil at 14°C dry bulb temperature. If the bypass factor of the cooling coil is 0.1, find :

- (i) Surface temperature of the cooling coil,
- (ii) Relative humidity of the air leaving the cooling coil,
- (iii) Capacity of the cooling coil in kW, and
- (iv) Sensible heat factor.

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Assume barometric pressure = 1.01325 bar

Solve the problem by using Psychrometric chart.



**PSYCHROMETRIC CHART**  
 BAROMETRIC PRESSURE 1.01325 bar  
 SEA LEVEL

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

- Q8.** (a) The maximum demand of a power station is 96 MW and the daily load curve is described below :

Time (hours)	0 – 6	6 – 8	8 – 12	12 – 14	14 – 18	18 – 22	22 – 24
Load (MW)	48	60	72	60	84	96	48

- (i) Determine the load factor of the power station.
- (ii) What is the load factor of standby equipment rated at 30 MW that takes up all load in excess of 72 MW ? 15
- (b) Using Buckingham's Pi theorem obtain the expressions for head, capacity and power coefficients of an incompressible flow turbomachine. 15
- (c) For a centrifugal air compressor running at 7200 rpm, the impeller diameter is 45 cm. The inlet stagnation temperature is 288 K and the pressure coefficient is 0.8. Assuming isentropic flow with no shock, determine the pressure ratio developed. For air, take specific heat at constant pressure as 1.005 kJ/kg K and assume zero swirl at entry. 10