Engineering Services (Main)
Examination - 2025

NESP–O–MCHN

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.

Question Nos. **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 provided for answering the question itself.

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

Psychrometric Chart is given in Page No. 11.

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

1. *(a)* Prove that in case of forced vortex, the rise of liquid level at the ends is equal to the fall of liquid level at the axis of rotation. 12

(b) Explain, with the aid of neat sketch, the working principle of a Pitot static tube. Further, explain how the Pitot static tube differs from the Pitot tube. 12

(c) Using an ideal gas as working fluid, show that the thermal efficiency of an Ericsson cycle is identical to the efficiency of a Carnot cycle operating between the same temperature limits. 12

(d) Distinguish between the following :

(i) Thermodynamics and Heat transfer

(ii) Free convection and Forced convection

(iii) Black body and Gray body 12

(e) Explain the effects of the following variables on the volumetric efficiency of an IC engine :

(i) Types of fuel

(ii) Valve overlap

(iii) Inlet valve timing

(iv) Exhaust residual

(v) Exhaust gas recirculation

(vi) Engine speed 12

2. *(a)* *(i)* Enumerate, with the aid of illustrative sketches, the condition of equilibrium of a submerged body. 8

(ii) A solid cone of relative density 0·70 floats in water. What should be its minimum apex angle so that it may float its apex downwards in stable equilibrium? 12

(b) Ethylene glycol (1800 kg/hr) is cooled from 100 °C to 60 °C by cooling water that enters the annular space of a single-pass counterflow heat exchanger at 15 °C and has a mass flow rate of 1200 kg/hr. Calculate—

(i) the overall heat transfer coefficient if convective heat transfer coefficient of water-side is 8·72 kW/m^2-deg;

(ii) the necessary length of copper tubing if it has an internal diameter of 1·25 m;

(iii) also the length of the tube required if water flows in the same direction as ethylene glycol.

For turbulent flow of fluid inside the tube, the Dittus-Boelter relationship $Nu = 0 \cdot 023\ (Re)^{0 \cdot 8} (Pr)^{0 \cdot 4}$ is to be used.

The relevant physical properties of ethylene glycol at its bulk temperature of 80 °C are $C_p = 2 \cdot 64$ kJ/kg-K; $\mu = 11 \cdot 72$ kg/hr-m; $k = 0 \cdot 26 \times 10^{-3}$ kW/m-deg. 20

(c) A 4-cylinder, 4-stroke SI engine having 70 mm bore and 84 mm stroke runs at 4000 r.p.m. and uses a fuel having 84% carbon and 16% hydrogen by mass. The volumetric efficiency of the engine is 80%. The ambient conditions are 1·0 bar and 27 °C. The depression at the venturi throat is 0·65 bar. Assuming the stoichiometric A/F ratio, calculate the fuel flow rate, the air velocity at the throat and the throat diameter.

[Take, R_{air} = 287 J/kg-K, $R_{fuel\ vapour}$ = 98 J/kg-K] 20

3. *(a)* *(i)* Let us define a thermal time constant $\tau = \dfrac{mC_v}{C_q A}$; mass m with an initial uniform temperature T_0 and then lower into a water bath with temperature T_∞, and the heat transfer between mass and water has a heat transfer coefficient C_q with surface area A and C_v is specific heat at constant volume. Assume radiation to be negligible. Show, with the help of suitable equations, that for a quick response, thermocouple needs a small thermal time constant τ while for a house, a large thermal time constant is needed. 10

(ii) On a hot day of summer, a car is left in sunlight with all the windows closed. After some time, it is found that inside of the car is considerably warmer than the air outside. Why? 10

(b) *(i)* Establish a relation for the time taken to form a layer of ice on the surface of a pond. 12

(ii) Name the various types of insulating materials used in engineering and mention applications for which they are used. 8

(c) (i) A cylinder/piston setup contains 1 L of saturated liquid refrigerant (R-410A) at 40 °C. The piston now moves slowly, expands maintaining constant temperature to a final pressure of 500 kPa in a reversible process. Calculate the work done and heat transfer required to accomplish this process.

State–1

Temperature (°C)	Pressure (kPa)	Specific volume, m^3/kg			Enthalpy, kJ/kg			Entropy, kJ/kg-K			Internal energy, kJ/kg		
		v_f	v_{fg}	v_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	u_f	u_{fg}	u_g
40	2420·7	0·001025	0·00865	0·00967	124·09	159·04	283·13	0·4473	0·5079	0·9552	121·61	138·11	259·72

State–2

500 kPa, –13·89 °C

$v\ (m^3/kg) = 0{\cdot}06775$

u (kJ/kg) = 290·32

h (kJ/kg) = 324·20

s (kJ/kg-K) = 1·2398 10

(ii) (1) 1 kg of water at 100 kPa, 120 °C receives 50 kJ/kg in a reversible process by heat transfer. Which thermodynamic process, from the given below, will generate the largest entropy change? Justify your answer :

A. Constant temperature

B. Constant pressure

C. Constant volume 6

(2) How can you change entropy of a substance going through a reversible process? Keep in mind the second law of thermodynamics. 4

4. (a) A cooling tower cools water from 45 °C to 25 °C. Water enters the tower at a rate of 100000 kg/hr. Air enters the tower is at 20 °C with a relative humidity of 50%; the air leaving is at 40 °C with a relative humidity of 95%. The air enters at the bottom and leaves at the top. The barometric pressure is 92 kPa. Determine—

(i) the required flow rate of atmospheric air in kg/hr;

(ii) the amount of water lost by evaporation per hour. 20

Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat}, kPa	Specific volume, m³/kg: Sat. liquid, v_f	Specific volume, m³/kg: Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Internal energy, kJ/kg: Evap., u_{fg}	Internal energy, kJ/kg: Sat. vapor, u_g	Enthalpy, kJ/kg: Sat. liquid, h_f	Enthalpy, kJ/kg: Evap., h_{fg}	Enthalpy, kJ/kg: Sat. vapor, h_g	Entropy, kJ/kg·K: Sat. liquid, s_f	Entropy, kJ/kg·K: Evap., s_{fg}	Entropy, kJ/kg·K: Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
70	31.202	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6	1.0158	6.6655	7.6812
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0	1.0756	6.5355	7.6111
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4	1.1346	6.4089	7.5435
90	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6	1.1929	6.2853	7.4782
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647	7.4151
100	101.42	0.001043	1.6720	419.06	2087.0	2506.0	419.17	2256.4	2675.6	1.3072	6.0470	7.3542
105	120.90	0.001047	1.4186	440.15	2071.8	2511.9	440.28	2243.1	2683.4	1.3634	5.9319	7.2952
110	143.38	0.001052	1.2094	461.27	2056.4	2517.7	461.42	2229.7	2691.1	1.4188	5.8193	7.2382
115	169.18	0.001056	1.0360	482.42	2040.9	2523.3	482.59	2216.0	2698.6	1.4737	5.7092	7.1829
120	198.67	0.001060	0.89133	503.60	2025.3	2528.9	503.81	2202.1	2706.0	1.5279	5.6013	7.1292
125	232.23	0.001065	0.77012	524.83	2009.5	2534.3	525.07	2188.1	2713.1	1.5816	5.4956	7.0771
130	270.28	0.001070	0.66808	546.10	1993.4	2539.5	546.38	2173.7	2720.1	1.6346	5.3919	7.0265
135	313.22	0.001075	0.58179	567.41	1977.3	2544.7	567.75	2159.1	2726.9	1.6872	5.2901	6.9773
140	361.53	0.001080	0.50850	588.77	1960.9	2549.6	589.16	2144.3	2733.5	1.7392	5.1901	6.9294
145	415.68	0.001085	0.44600	610.19	1944.2	2554.4	610.64	2129.2	2739.8	1.7908	5.0919	6.8827

(b) For the velocity profile of laminar boundary layer

$$\frac{u}{U_{\alpha}} = \sin\left(\frac{\pi}{2} \cdot \frac{y}{\delta}\right)$$

find the expressions for—

(i) boundary layer thickness;

(ii) shear stress;

(iii) average coefficient of drag. 20

(c) (i) A 4-cylinder, 4-stroke engine has cylinder dia 10·0 cm and stroke length 10·0 cm. The engine is connected to an eddy current dynamometer, and 80·0 kW of power is dissipated by the dynamometer. Assuming engine mechanical efficiency as 85% at 4500 r.p.m. and the dynamometer efficiency as 95%, calculate—

(1) the frictional power lost;

(2) the brake mean effective pressure;

(3) the engine torque at 1500 r.p.m.;

(4) the engine specific volume. 10

(ii) A single-cylinder SI engine is operated with gasoline of calorific value 44 MJ/kg and density 780 kg/m^3. During each combustion cycle when the flame reaches up to a height of 2 cm, combustion reaction stops due to closeness of the wall and dampens out all fluid motion while conducts heat anyway. The boundary layer of unburnt charge is formed in the combustion chamber of 4 cm dia and fuel is distributed equally throughout the combustion chamber having unburnt charge layer of approximately 0·1 mm thickness. Find the fraction of the unburnt fuel and resulting heat loss. 10

SECTION—B

5. (a) Enumerate the advantages of using steam condenser in a steam power plant. Explain the significance of vacuum efficiency and condenser efficiency. 12

(b) Derive an expression for acceleration head impressed on the flow in case of a reciprocating pump. Assume that the piston has simple harmonic motion. 12

(c) What is the need of mine ventilation? Explain, with a sketch, the working of mine air-conditioning system. Also mention the various heat sources in mines. 12

(d) Briefly discuss the impact of the following variables on the performance of a concentrating solar collector :

(i) Fluid inlet temperature

(ii) Mass flow rate of fluid

(iii) Concentration ratio

(iv) Type of absorber surface 12

(e) (i) Mention any four advantages of a high-pressure boiler. 4

(ii) Briefly explain, with the aid of an illustrative sketch, the working principle of LaMont boiler. 8

6. (a) In a vapour compression refrigeration cycle based ice plant of 20 TR capacity using NH_3 as refrigerant, the following data are used for the calculations :

The temperatures of water entering and leaving the condenser are 20 °C and 27 °C, and the temperature of brine in the evaporator is –15 °C. Before entering the expansion valve, ammonia is cooled to 20 °C and ammonia enters the compressor dry saturated.

Calculate—

(i) the compressor power required;

(ii) the flow rate of cooling water circulated in the condenser;

(iii) the COP of the plant for 1 TR capacity.

Show the cycle on *t-s* and *p-h* diagrams. Use the properties given in the table :

Saturation temperature (°C)	*Entropy,* kJ/kg-K		*Enthalpy,* kJ/kg		*Sp. heat,* kJ/kg-K	
	Liquid	*Vapour*	*Liquid*	*Vapour*	*Liquid*	*Vapour*
–15	0·4572	5·5490	112·34	1426·54	4·396	2·303
25	1·1242	5·0391	298·90	1465·84	4·606	2·805

20

(b) For a hot and humid summer condition, an air-conditioning system needs to be designed for meeting an industrial demand and the following data are used :

Outside conditions : 32 °C DBT and 65% RH

Required inlet air conditions : 25 °C DBT and 60% RH

Amount of free air circulated is 250 m^3/min, coil dew point temperature is 13 °C. The required condition is achieved by cooling and dehumidification initially and then by heating.

Calculate the following :

(i) The cooling capacity of the cooling coil and its by-pass factor

(ii) The heating capacity of the heating coil in kW and surface temperature of the heating coil if the by-pass factor is 0·3

(iii) The mass of water vapour removed per hour

Show the psychrometric processes involved on Psychrometric Chart.

[Psychrometric Chart is given in Page No. 11] 20

(c) (i) Draw and explain in detail each of the constant head characteristics of Pelton, Francis and Kaplan turbines. 10

(ii) A Francis turbine was installed in a power plant system. For first few years of operation, it gave noise or vibration frequency around 15 Hz. But after 10 years of operation, the noise/frequency coming out of it is around 100 Hz. Can you explain the different causes of this increase in noise or vibration and suggest the remedies for it? Can you also suggest the places where the errors are located? 6

(iii) Describe the significance of specific speed in turbine sizing, if any. 4

7. (a) Compare running costs of winter heating system of a conference hall for which 50000 kJ/hr of heating is required using the following three methods of heating :

(i) Vapour compression cycle based heating

(ii) Direct heating using fuel

(iii) Electric heating

Take the following data for calculation :

COP of VCRC system = 3·0

Fuel charges for light diesel oil = ₹64/L

Specific gravity of oil = 0·87

Heating value of fuel = 42 MJ/kg

Combustion efficiency = 0·80

Electricity charges = ₹8·5/unit

Now-a-days in winter season, which is the most common system being used and why? 20

(b) Air enters a turbojet engine at 10×10^4 kg/hr at 25 °C and 1·03 bar, and is compressed adiabatically to 192 °C and four times the pressure. Products of combustion enter the turbine at 815 °C and leave the compressor at 650 °C to enter the nozzle. Calculate the isentropic efficiency of the compressor, the power required to drive the compressor, the exit speed of gases, and the thrust developed when flying at 900 km/hr. Assume that isentropic efficiency of turbine is same as that of compressor and the nozzle efficiency is 90%. Assume for air $\gamma_a = 1 \cdot 4$, $C_p = 1 \cdot 005$ kJ/kg-K and for gases assume $\gamma_g = 1 \cdot 3$ and $R = 1 \cdot 147$ kJ/kg-K. 20

(c) *(i)* A small rural village having 40 houses with 5 members each is located remotely. Design a solar photovoltaic system to meet the daily energy needs, considering 24×7 energy requirements. Assume the following data for solar panel :

Peak power = 80 W

Voltage at peak power = 17·6 V

Current at peak power = 4·55 A

Operating factor = 0·8

Mismatch factor = 0·85

Sunshine hours = 5 hr/day

State clearly, if any assumptions are made. 10

(ii) What are the important factors affecting the solar cell performance? Discuss in brief. 10

8. *(a)* *(i)* A blast furnace gas has the following volumetric compositions :

CO_2 = 10%

CO = 30%

H_2 = 1·5%

N_2 = 58·5%

Determine the theoretical volume of air required for the complete combustion of 1 m^3 of the gas. Also determine the percentage composition of dry flue gases by volume. Consider that air contains 21% of O_2 and 79% of N_2 by volume. 14

(ii) How does ash in the coal affect power plant economics? 6

(b) (i) What is the need of alternative fuels for transportation? Compare the utility of bio-diesel and bio-alcohol in Indian context. 10

(ii) A wind turbine is operating at wind speed of 7·0 m/s to pump water at a rate of 5·0 m^3/hr with a lift of 6·0 m. Calculate the radius of the rotor and the tip speed ratio.

Assume :

Water density = 1000 kg/m^3

Water pump efficiency = 45%

Efficiency of rotor to pump = 80%

Power coefficient = 0·25

Air density = 1·2 kg/m^3

Angular velocity of the rotor = 60 r.p.m. 10

(c) Gas at 8 bar and 300 °C expands to 4 bar in an impulse turbine stage. The nozzle angle is 65° with reference to the exit direction. The rotor blades have equal inlet and outlet angles, and the stage operates with optimum blade speed ratio. Assuming that the isentropic efficiency of the nozzle is 0·9 and velocity at entry to the stage is negligible, deduce the blade angle used and the mass flow required for this stage to produce 75 kW.

[Given, $C_p = 1{\cdot}15$ kJ/kg-K, $\gamma = 1{\cdot}333$] 20

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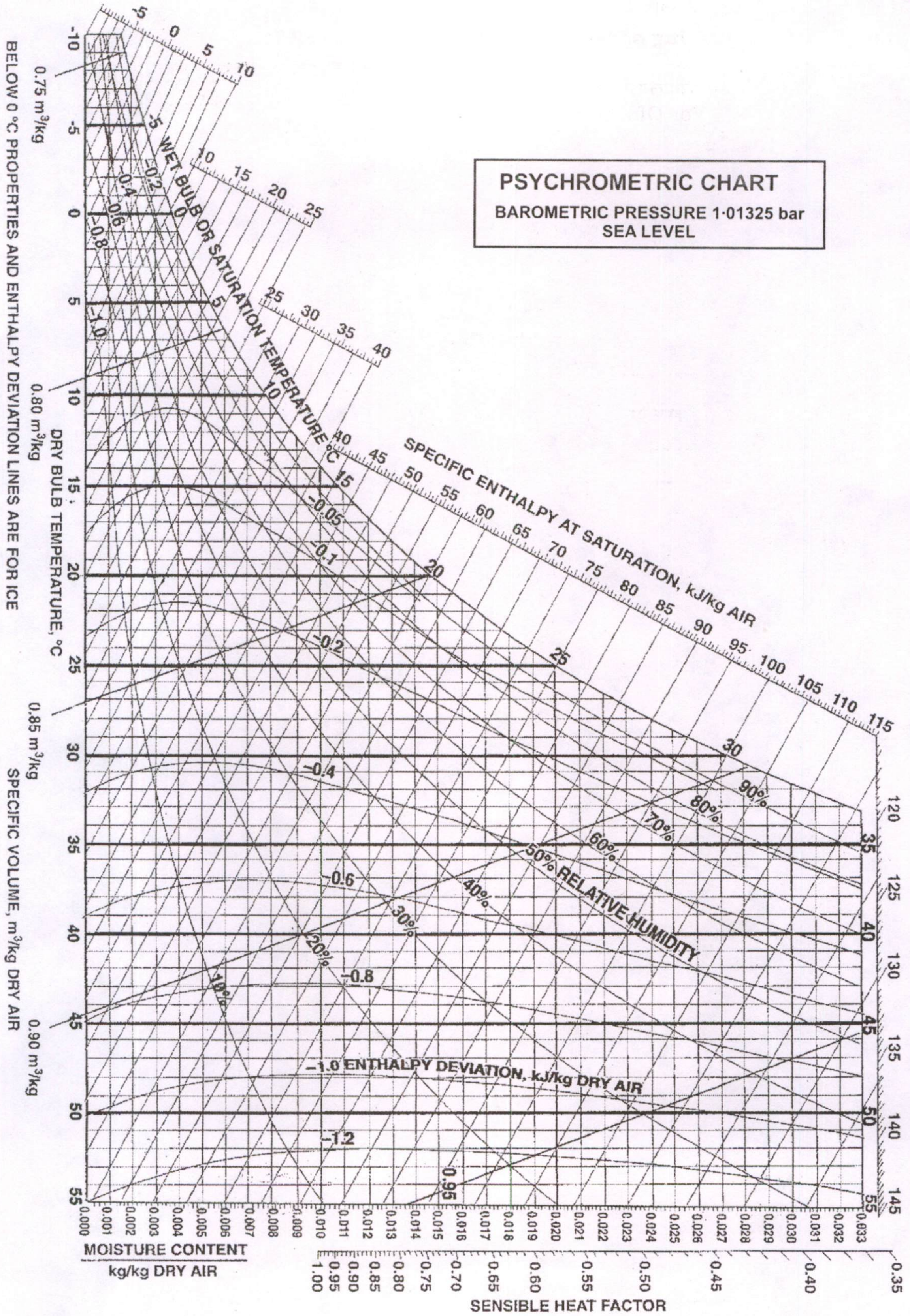
PSYCHROMETRIC CHART
BAROMETRIC PRESSURE 1·01325 bar
SEA LEVEL
WET BULB OR SATURATION TEMPERATURE °C
SPECIFIC ENTHALPY AT SATURATION, kJ/kg AIR
DRY BULB TEMPERATURE, °C
BELOW 0 °C PROPERTIES AND ENTHALPY DEVIATION LINES ARE FOR ICE
SPECIFIC VOLUME, m³/kg DRY AIR
0.75 m³/kg
0.80 m³/kg
0.85 m³/kg
0.90 m³/kg
50% RELATIVE HUMIDITY
−1.0 ENTHALPY DEVIATION, kJ/kg DRY AIR
MOISTURE CONTENT
kg/kg DRY AIR
SENSIBLE HEAT FACTOR