Indian Forest Service
(Main) Exam, 2020

JKLO-U-MCHE

MECHANICAL ENGINEERING

Paper – I

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.

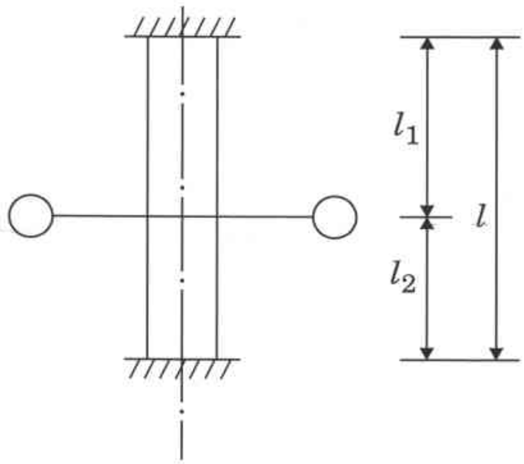
Neat sketch may be drawn, wherever required.

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

SECTION A

Q1. (a) A V-belt of 6·5 cm^2 cross-section has a groove angle of 30° and an angle of lap of 160° with coefficient of friction (μ) = 0·3. The mass of the rope is 1·5 kg/m. The maximum safe stress is 850 N/cm^2. Calculate the power that can be transmitted at 25 m/s. *8*

(b) A flywheel is mounted on a vertical shaft as shown in the figure. The ends of the shaft are being fixed. The shaft is 50 mm in diameter, the length l_1 is 900 mm and l_2 is 600 mm. The weight of the flywheel is 0·5 ton and its radius of gyration is 500 mm. Calculate the natural frequency of the longitudinal vibration of the system. Take Young's modulus (E) = 210 GPa. *8*

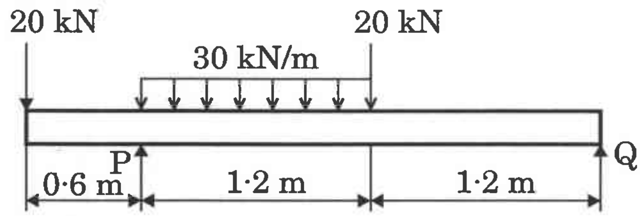


(c) A steel rod 5 m long and 20 mm in diameter is subjected to an axial pull of 50 kN. Determine the change in volume of the rod. Take Young's modulus (E) = 210 GPa and Poisson's ratio (ν) = 0·3. *8*

(d) What are the difficulties in hardening low carbon steel through heat treatment ? How can surface hardness be imparted through carburizing, nitriding and cyanide-hardening ? *8*

(e) What is the difference between an alloy and a composite ? Explain with the help of suitable examples. Also, cite the differences in strengthening mechanism for large particle and dispersion-strengthened composites. *8*

Q2. (a) Determine the deflection at a point 1·2 m from the left hand end of the overhanging beam loaded as shown in the figure below, using Macaulay's method. Take EI = 0·75 MNm^2. *15*



(b) A solid circular shaft is used to transmit simultaneously a twisting moment of 3000 Nm and a maximum bending moment of 2500 Nm. Determine the safe radius of the shaft that can be used if maximum $\sigma \leq 120$ MPa and maximum $\tau \leq 60$ MPa. *15*

(c) Explain strengthening in metals by way of grain size reduction. Also, discuss the mechanism of solid solution strengthening. *10*

Q3. (a) In a machine, the intermittent operations demand the torque to be applied as follows :

(i) During the first half-revolution, the torque increases uniformly from 800 Nm to 3000 Nm.

(ii) During the next one revolution, the torque remains constant.

(iii) During the next one revolution, the torque decreases uniformly from 3000 Nm to 800 Nm.

(iv) During the last one and a half revolution, the torque remains constant.

Thus, a cycle is completed in 4 revolutions. The motor to which the machine is coupled exerts a constant torque at a mean speed of 300 rpm. A flywheel of mass 2000 kg and radius of gyration of 500 mm is fitted to the shaft. Determine the power of the motor and total fluctuation of speed of the machine shaft. *15*

(b) A back gear is required for a lathe to give a reduction from cone-pulley speed to spindle speed of 9 to 1. The diametral pitch of the teeth on the high-speed pair is 7 and of those on the low-speed pair is 5. The centre distance is 7 cm. Determine the number of teeth on each of the four wheels if the pinions are to have as nearly as possible, equal number of teeth. Also, find the pitch circle diameter of the pinion on the cone pulley. *15*

(c) A cylinder has an internal diameter of 230 mm, has wall thickness of 5 mm and is 1 m long. It is found to change in internal volume by 12×10^{-6} m^3 when filled with a liquid at a pressure p. If Young's modulus (E) = 210 GPa and Poisson's ratio (v) = 0·3, and assuming rigid end plates, determine (i) the values of hoop and longitudinal stresses, and (ii) the modifications to the above values of stresses if joint efficiencies of 45% (hoop) and 85% (longitudinal) are assumed. *10*

Q4. (a) How can theoretical density of a material be calculated using the properties of the crystal structure ? Determine the density of BCC iron, which has a lattice parameter of 0·2866 nm by using the properties of crystal structure. If actual measured density is 7·850 g/cm^3, state the reason for this difference.

Avogadro's Number $N_A = 6{\cdot}02 \times 10^{23}$ atoms/mol.

Atomic Mass of Iron = 55·847 g/mol. *15*

(b) A uniform T-section beam is 100 mm wide and 150 mm deep with a flange thickness of 25 mm and a web thickness of 12 mm. If the limiting bending stresses for the material of the beam are 84 MPa in compression and 168 MPa in tension, find the maximum uniformly distributed load that the beam can carry over a simply supported span of 5 m. *15*

(c) A rotor has a mass of 15 kg and is mounted midway on a 24 mm diameter horizontal shaft supported at the ends by two bearings. The bearings are 1 m apart. The shaft rotates at 2500 rpm. If the centre of mass of the rotor is 0·11 mm away from the geometric centre of the rotor due to a manufacturing defect, find the amplitude of the steady-state vibration and the dynamic force transmitted to the bearing. Take Young's modulus (E) = 210 GPa. *10*

SECTION B

Q5. (a) In EDM process, why is the rate of material removal from the cathode comparatively less than that from anode ? State the basic requirements of an ideal dielectric fluid used in EDM process. *8*

(b) Enlist the difficulties encountered in conventional NC machines. Also, discuss the advantages of Computer Numerical Control (CNC) over conventional Numerical Control (NC). *8*

(c) The inter-arrival time of passengers at a railway ticket booking counter is exponentially distributed and is equal to 12 minutes. The ticket booking time for each passenger is 3 minutes and is exponentially distributed.

(i) What is the probability that a passenger arriving at the ticket counter will have to wait ?

(ii) The management will start a second ticket booking counter when each arrival would expect waiting for at least 3 minutes for ticket booking. By how much should the arrival rate of passengers increase to justify the second counter ?

(iii) What is the average length of the queue ?

(iv) What is the probability that the queue size will exceed 2 ? *8*

(d) The annual demand and unit price of some inventory items are given below :

Item No.	Annual Demand	Unit Price (₹)	Item No.	Annual Demand	Unit Price (₹)
1001	500	3·00	1009	500	1·20
1002	125	1·00	1010	300	1·80
1003	75	7·00	1011	15	30·00
1004	150	1·00	1012	5	20·00
1005	50	1·50	1013	500	5·00
1006	350	1·60	1014	1500	3·00
1007	250	7·00	1015	50	0·80
1008	10	5·00	—	—	—

Based on ABC analysis, classify these items in Class-A, Class-B and Class-C, considering A – 60 to 70%, B – 71 to 90%, C – 91 to 100%. *8*

(e) Draw a flowchart for finding the first 100 prime numbers. To determine whether a number is prime, you may call the function "Is This Number Prime" from the already made libraries. *8*

Q6. (a) In rolling operation, explain the condition of biting i.e. the condition for unaided entry of the workpiece in the rolls.

A 40 mm thick plate is to be reduced to 30 mm in one pass in a rolling operation. Entrance speed = 16 m/minute. Roll radius = 300 mm and Rotational speed = 18·5 rev/minute.

Determine : (a) the minimum required coefficient of friction that would make this rolling operation possible, (b) exit velocity under the assumption that the plate widens by 2% during the operation, and (c) forward slip. *15*

(b) Solve the following Linear Programming Problem using Big-M method : *15*

Maximize $z = 2x_1 + x_2$

subject to

$$3x_1 + x_2 = 3$$

$$4x_1 + 3x_2 \geq 6$$

$$x_1 + 2x_2 \leq 4$$

and $x_1, x_2 \geq 0$

(c) Write the C-program for the following series : *10*

$$\frac{1}{\lfloor\underline{1}} + \frac{2}{\lfloor\underline{2}} + \frac{3}{\lfloor\underline{3}} + \dots + \frac{N}{\lfloor\underline{N}}$$

Q7. (a) With the help of free body diagrams of forces, explain the construction of Merchant's circle. State all the assumptions that are made while deriving Merchant's circle equation. Also, derive this equation. *15*

(b) A production manager wants to fix the number of workstations required in an assembly line. The information related to the activities and time consumption (in seconds) are given below :

Activities	Immediate predecessor	Task time (sec)
A	None	50
B	A	20
C	A	32
D	B	57
E	C,D	12
F	E	18

If 50 products are to be assembled per hour, compute the following : *15*

(i) Draw the precedence (network) diagram

(ii) Cycle time

(iii) Theoretical and actual number of workstations required

(iv) The efficiency and balance delay

(c) The efficiencies of five different workers (A, B, C, D and E) on five different machines (I, II, III, IV and V) are recorded as given below :

Workers	Efficiencies (%)				
	I	II	III	IV	V
A	50	50	45	35	60
B	52	40	26	35	37
C	60	58	50	70	60
D	30	29	30	28	35
E	68	70	69	65	63

To maximize the overall efficiency, assign the workers on the different machines. (One worker is to be assigned on one machine only). *10*

Q8. (a) Explain the mechanism of material removal during ultrasonic machining process. With the help of neat sketches, show the effect of critical parameters (frequency, amplitude, tool material, grit size, abrasive material, feed force, slurry concentration, slurry viscosity) on material removal rate. Also, discuss its application and limitations. *15*

(b) A company is concerned with CPU (Central Processing Unit) manufacturing. The information related to manufacturing capacity, sales, and costs is given below :

Manufacturing capacity = 80,000 units

Margin of safety = 50% of Break-Even Point (BEP)

Contribution margin = 25%

Unutilized capacity at present is 5,000 units

Sales price = ₹ 1,500 per unit.

Find

(i) Break-even point in sales volume

(ii) Fixed and variable costs

(iii) Margin of safety

(iv) If the fixed cost is decreased by ₹ 1,00,000, to what extent can the price be reduced to maintain the same profit level. *15*

(c) Samples of fabric from a textile mill, each 100 m^2, are selected, and the number of occurrences of foreign matter is recorded. Data for 25 samples are shown in the following table. Construct a suitable control chart for the number of defects and plot the graph. *10*

Sample	Defects	Sample	Defects
1	5	14	11
2	4	15	9
3	7	16	5
4	6	17	7
5	8	18	6
6	5	19	10
7	6	20	8
8	5	21	9
9	16	22	9
10	10	23	7
11	9	24	5
12	7	25	7
13	8		

Indian Forest Service (Main) Exam, 2020

JKLO–B–MCHE

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

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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

1. *(a)* What is the reversible adiabatic work for a steady flow system when KE and PE changes are negligible? How is it different from a closed stationary system? 8

(b) Explain various methods to increase the power output of the IC engines with same volumetric capacity. 8

(c) The inner and outer surfaces of a spherical container are maintained at temperatures of $T_1 = 200\ ^\circ\text{C}$ and $T_2 = 80\ ^\circ\text{C}$, respectively. The container is having the following dimensions :

Inner radius = 8 cm, outer radius = 10 cm

The thermal conductivity of the container material is 45 W/m-K. Obtain a general relation for the temperature distribution inside the container under steady conditions and also, determine the rate of heat loss from the container. 8

(d) A Carnot refrigerator has working temperatures of –30 °C and 35 °C. If it operates with R12 as a working substance, calculate the work of isentropic compression and that of isentropic expansion. Also, calculate the refrigerating effect, heat rejected per kg of the refrigerant and COP of the cycle. 8

Thermodynamic properties of R12

Saturation Temp.	*Saturation Pressure*	*Saturated Liquid and Vapour*						*Vapour Superheated*			
								By 20 °C		By 40 °C	
t (°C)	p (bar)	v_f (kJ/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg-K)	s_g (kJ/kg-K)	h (kJ/kg)	s (kJ/kg-K)	h (kJ/kg)	s (kJ/kg-K)
–40	0·6417	0·66	0·2421	0	169·0	0	0·7274	180·8	0·7737	192·4	0·8178
–35	0·8069	0·67	0·1950	4·4	171·9	0·0187	0·7220	183·3	0·7681	195·1	0·8120
–30	1·0038	0·67	0·1595	8·9	174·2	0·0371	0·7171	185·8	0·7631	197·8	0·8068
–25	1·2368	0·68	0·1313	13·3	176·5	0·0552	0·7127	188·3	0·7586	200·4	0·8021
–20	1·5089	0·69	0·1089	17·8	178·7	0·0731	0·7088	190·8	0·7546	203·1	0·7979
–15	1·8256	0·69	0·0911	22·3	181·0	0·0906	0·7052	193·2	0·7510	205·7	0·7942
–10	2·1912	0·70	0·0767	26·9	183·2	0·1080	0·7020	195·7	0·7477	208·3	0·7909
–5	2·610	0·71	0·0650	31·4	185·4	0·1251	0·6991	198·1	0·7449	210·9	0·7879
0	3·086	0·72	0·0554	36·1	187·5	0·1420	0·6966	200·5	0·7423	213·5	0·7853
5	3·626	0·72	0·0475	40·7	189·7	0·1587	0·6942	202·9	0·7401	216·1	0·7830
10	4·233	0·73	0·0409	45·4	191·7	0·1752	0·6921	205·2	0·7381	218·6	0·7810
15	4·914	0·74	0·0354	50·1	193·8	0·1915	0·6902	207·5	0·7363	221·2	0·7792
20	5·673	0·75	0·0308	54·9	195·8	0·2078	0·6885	209·8	0·7348	223·7	0·7777
25	6·516	0·76	0·0269	59·7	197·7	0·2239	0·6869	212·1	0·7334	226·1	0·7763
30	7·450	0·77	0·0235	64·6	199·6	0·2399	0·6854	214·3	0·7321	228·6	0·7751
35	8·477	0·79	0·0206	69·5	201·5	0·2559	0·6839	216·4	0·7310	231·0	0·7741
40	9·607	0·80	0·0182	74·6	203·2	0·2718	0·6825	218·5	0·7300	233·4	0·7732
45	10·843	0·81	0·0160	79·7	204·9	0·2877	0·6812	220·6	0·7291	235·7	0·7724
50	12·193	0·83	0·0142	84·9	206·5	0·3037	0·6797	222·6	0·7282	238·0	0·7718
60	15·259	0·86	0·0111	95·7	209·3	0·3358	0·6777	226·4	0·7265	242·4	0·7706
70	18·859	0·90	0·0087	107·1	211·5	0·3686	0·6738	230·2	0·7240	246·2	0·7650

(e) Explain the phenomena of surge and choking in centrifugal compressors. 8

2. *(a)* Air at 10 °C and 80 kPa enters the diffuser of a jet engine steadily with a velocity of 200 m/s. The inlet area of the diffuser is 0·4 m^2. The air leaves the diffuser with a velocity that is very small compared with the inlet velocity. Determine—

(i) the mass flow rate of the air;

(ii) the temperature of the air leaving the diffuser. 15

Ideal gas properties of air at 1 atm pressure

Temp. *T*, °C	*Density* ρ, kg/m^3	*Specific Heat* C_p, J/kg-K	*Thermal Conductivity* *k*, W/m-K	*Thermal Diffusivity* α, m^2/s	*Dynamic Viscosity* μ, kg/m-s	*Kinematic Viscosity* ν, m^2/s	*Prandtl Number* Pr
−150	2·866	983	0·01171	$4{\cdot}158\times10^{-6}$	$8{\cdot}636\times10^{-6}$	$3{\cdot}013\times10^{-6}$	0·7246
−100	2·038	966	0·01582	$8{\cdot}036\times10^{-6}$	$1{\cdot}189\times10^{-5}$	$5{\cdot}837\times10^{-6}$	0·7263
−50	1·582	999	0·01979	$1{\cdot}252\times10^{-5}$	$1{\cdot}474\times10^{-5}$	$9{\cdot}319\times10^{-6}$	0·7440
−40	1·514	1002	0·02057	$1{\cdot}356\times10^{-5}$	$1{\cdot}527\times10^{-5}$	$1{\cdot}008\times10^{-5}$	0·7436
−30	1·451	1004	0·02134	$1{\cdot}465\times10^{-5}$	$1{\cdot}579\times10^{-5}$	$1{\cdot}087\times10^{-5}$	0·7425
−20	1·394	1005	0·02211	$1{\cdot}578\times10^{-5}$	$1{\cdot}630\times10^{-5}$	$1{\cdot}169\times10^{-5}$	0·7408
−10	1·341	1006	0·02288	$1{\cdot}696\times10^{-5}$	$1{\cdot}680\times10^{-5}$	$1{\cdot}252\times10^{-5}$	0·7387
0	1·292	1006	0·02364	$1{\cdot}818\times10^{-5}$	$1{\cdot}729\times10^{-5}$	$1{\cdot}338\times10^{-5}$	0·7362
5	1·269	1006	0·02401	$1{\cdot}880\times10^{-5}$	$1{\cdot}754\times10^{-5}$	$1{\cdot}382\times10^{-5}$	0·7350
10	1·246	1006	0·02439	$1{\cdot}944\times10^{-5}$	$1{\cdot}778\times10^{-5}$	$1{\cdot}426\times10^{-5}$	0·7336
15	1·225	1007	0·02476	$2{\cdot}009\times10^{-5}$	$1{\cdot}802\times10^{-5}$	$1{\cdot}470\times10^{-5}$	0·7323
20	1·204	1007	0·02514	$2{\cdot}074\times10^{-5}$	$1{\cdot}825\times10^{-5}$	$1{\cdot}516\times10^{-5}$	0·7309
25	1·184	1007	0·02551	$2{\cdot}141\times10^{-5}$	$1{\cdot}849\times10^{-5}$	$1{\cdot}562\times10^{-5}$	0·7296
30	1·164	1007	0·02588	$2{\cdot}208\times10^{-5}$	$1{\cdot}872\times10^{-5}$	$1{\cdot}608\times10^{-5}$	0·7282
35	1·145	1007	0·02625	$2{\cdot}277\times10^{-5}$	$1{\cdot}895\times10^{-5}$	$1{\cdot}655\times10^{-5}$	0·7268
40	1·127	1007	0·02662	$2{\cdot}346\times10^{-5}$	$1{\cdot}918\times10^{-5}$	$1{\cdot}702\times10^{-5}$	0·7255
45	1·109	1007	0·02699	$2{\cdot}416\times10^{-5}$	$1{\cdot}941\times10^{-5}$	$1{\cdot}750\times10^{-5}$	0·7241
50	1·092	1007	0·02735	$2{\cdot}487\times10^{-5}$	$1{\cdot}963\times10^{-5}$	$1{\cdot}798\times10^{-5}$	0·7228
60	1·059	1007	0·02808	$2{\cdot}632\times10^{-5}$	$2{\cdot}008\times10^{-5}$	$1{\cdot}896\times10^{-5}$	0·7202
70	1·028	1007	0·02881	$2{\cdot}780\times10^{-5}$	$2{\cdot}052\times10^{-5}$	$1{\cdot}995\times10^{-5}$	0·7177
80	0·9994	1008	0·02953	$2{\cdot}931\times10^{-5}$	$2{\cdot}096\times10^{-5}$	$2{\cdot}097\times10^{-5}$	0·7154
90	0·9718	1008	0·03024	$3{\cdot}086\times10^{-5}$	$2{\cdot}139\times10^{-5}$	$2{\cdot}201\times10^{-5}$	0·7132
100	0·9458	1009	0·03095	$3{\cdot}243\times10^{-5}$	$2{\cdot}181\times10^{-5}$	$2{\cdot}306\times10^{-5}$	0·7111
120	0·8977	1011	0·03235	$3{\cdot}565\times10^{-5}$	$2{\cdot}264\times10^{-5}$	$2{\cdot}522\times10^{-5}$	0·7073
140	0·8542	1013	0·03374	$3{\cdot}898\times10^{-5}$	$2{\cdot}345\times10^{-5}$	$2{\cdot}745\times10^{-5}$	0·7041
160	0·8148	1016	0·03511	$4{\cdot}241\times10^{-5}$	$2{\cdot}420\times10^{-5}$	$2{\cdot}975\times10^{-5}$	0·7014
180	0·7788	1019	0·03646	$4{\cdot}593\times10^{-5}$	$2{\cdot}504\times10^{-5}$	$3{\cdot}212\times10^{-5}$	0·6992
200	0·7459	1023	0·03779	$4{\cdot}954\times10^{-5}$	$2{\cdot}577\times10^{-5}$	$3{\cdot}455\times10^{-5}$	0·6974
250	0·6746	1033	0·04104	$5{\cdot}890\times10^{-5}$	$2{\cdot}760\times10^{-5}$	$4{\cdot}091\times10^{-5}$	0·6946
300	0·6158	1044	0·04418	$6{\cdot}871\times10^{-5}$	$2{\cdot}934\times10^{-5}$	$4{\cdot}765\times10^{-5}$	0·6935
350	0·5664	1056	0·04721	$7{\cdot}892\times10^{-5}$	$3{\cdot}101\times10^{-5}$	$5{\cdot}475\times10^{-5}$	0·6937
400	0·5243	1069	0·05015	$8{\cdot}951\times10^{-5}$	$3{\cdot}261\times10^{-5}$	$6{\cdot}219\times10^{-5}$	0·6948
450	0·4880	1081	0·05298	$1{\cdot}004\times10^{-4}$	$3{\cdot}415\times10^{-5}$	$6{\cdot}997\times10^{-5}$	0·6965
500	0·4565	1093	0·05572	$1{\cdot}117\times10^{-4}$	$3{\cdot}563\times10^{-5}$	$7{\cdot}806\times10^{-5}$	0·6986
600	0·4042	1115	0·06093	$1{\cdot}352\times10^{-4}$	$3{\cdot}846\times10^{-5}$	$9{\cdot}515\times10^{-5}$	0·7037
700	0·3627	1135	0·06581	$1{\cdot}598\times10^{-4}$	$4{\cdot}111\times10^{-5}$	$1{\cdot}133\times10^{-4}$	0·7092

800	0·3289	1153	0·07037	$1{\cdot}855\times10^{-4}$	$4{\cdot}362\times10^{-5}$	$1{\cdot}326\times10^{-4}$	0·7149
900	0·3008	1169	0·07465	$2{\cdot}122\times10^{-4}$	$4{\cdot}600\times10^{-5}$	$1{\cdot}529\times10^{-4}$	0·7206
1000	0·2772	1184	0·07868	$2{\cdot}398\times10^{-4}$	$4{\cdot}826\times10^{-5}$	$1{\cdot}741\times10^{-4}$	0·7260
1500	0·1990	1234	0·09599	$3{\cdot}908\times10^{-4}$	$5{\cdot}817\times10^{-5}$	$2{\cdot}922\times10^{-4}$	0·7478
2000	0·1553	1264	0·11113	$5{\cdot}664\times10^{-4}$	$6{\cdot}630\times10^{-5}$	$4{\cdot}270\times10^{-4}$	0·7539

(b) Why is the slope of the sublimation curve at the triple point on the *p-T* diagram greater than that of the vaporization curve at the same point? 10

(c) The fuel consumption of an SI engine is 0·5 kg of fuel per minute. The air-fuel ratio is 10. The air is supplied at 1 bar and 27 °C. The specific gravity of the fuel is 0·75. If the flow velocity of the choke is 100 m/s, velocity coefficient is 0·8 and the pressure drop across the fuel metering orifice is 0·80 to that of the choke, calculate the diameter of the orifice. Assume the orifice coefficient of discharge as 0·6. 15

3. *(a)* An 80 kW CI engine consumes 0·3 kg of fuel per minute consisting of 14% hydrogen and rest carbon. The calorific value of the fuel is 45·1 MJ/kg. The engine jacket cooling water is also passed through the exhaust calorimeter before discharge with the following observations. *(i)* Calculate the actual amount of the air supplied, *(ii)* find the mass of the exhaust gases discharged and *(iii)* draw the heat balance table of the engine :

(1) Amount of the water supplied per hr = 1000 kg

(2) Temperature of the water entering the engine jacket = 20 °C

(3) Temperature of the water leaving the engine jacket = 60 °C

(4) Temperature of the water leaving the exhaust calorimeter = 90 °C

(5) Temperature of the exhaust gases leaving the calorimeter = 150 °C

(6) Temperature of the exhaust gases leaving the engine = 400 °C

Assume the specific heat of the exhaust gases as 1·05 kJ/kg-K. Assume testing at full load. 15

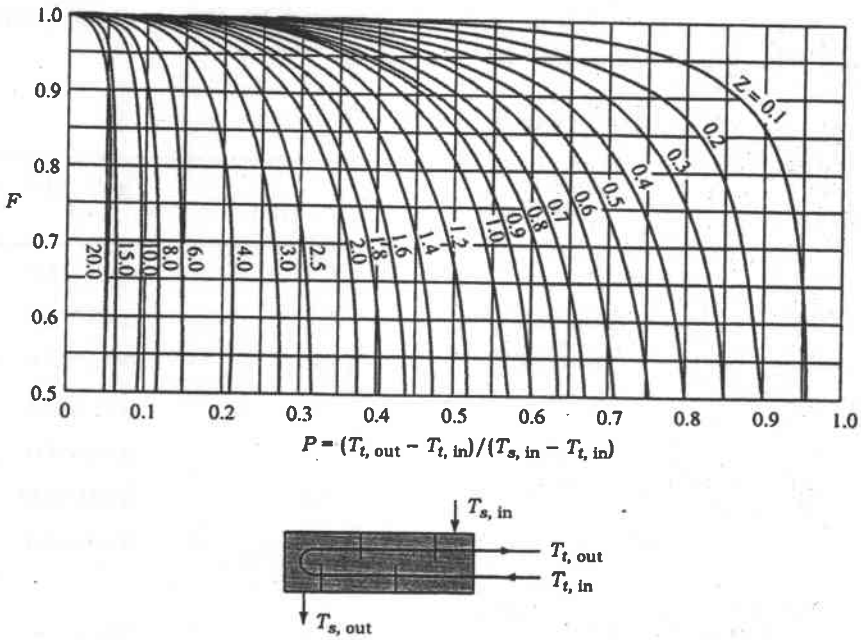
(b) What are the problems associated with cold weather operation of CI engines? Also, write in brief about their remedial measures. 15

(c) Calculate the decrease in available energy when 30 kg of water at 98 °C is mixed with 40 kg of water at 38 °C, the pressure being taken as constant and the temperature of the surroundings being 18 °C. (C_p of water = 4·2 kJ/kg-K) 10

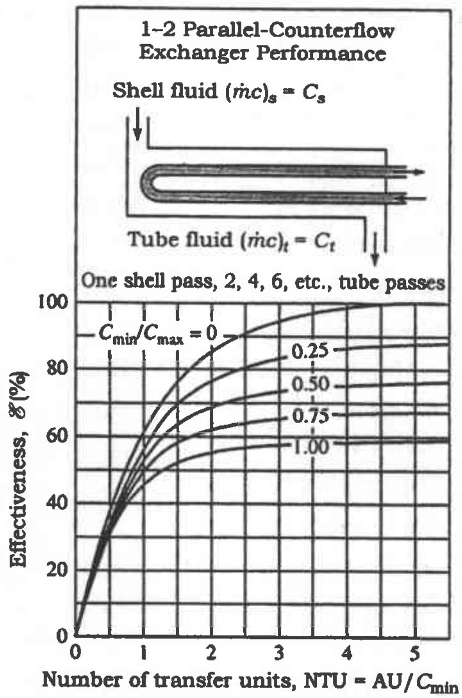
4. *(a)* From a performance test on a well-baffled single-shell, two-tube-pass heat exchanger, the following data are available :

Oil (C_p = 2100 J/kg-K) in turbulent flow inside the tubes entered at 340 K at the rate of 1 kg/s and left at 310 K; water flowing on the shell side entered at 290 K and left at 300 K

A change in service conditions requires the cooling of a similar oil from an initial temperature of 370 K but at three-fourths of the flow rate used in the performance test. Estimate the outlet temperature of the oil for the same water flow rate and inlet temperature as before. 15



Correction factor to counterflow LMTD for heat exchanger with one shell pass and two tube passes



Heat exchanger effectiveness for shell and tube heat exchanger with one well-baffled shell pass and two tube passes

(b) A large body of non-luminous gas at a temperature of 1100 °C has emission bands between 2·5 μm and 3·5 μm and between 5 μm and 8 μm. At 1100 °C, the effective emissivity in the first band is 0·8 and in the second band is 0·6. Determine the emissive power of this gas in W/m^2. 15

Blackbody radiation functions

λT(m-K $\times 10^3$)	$\frac{E_b(0-\lambda T)}{\sigma T^4}$	λT(m-K $\times 10^3$)	$\frac{E_b(0-\lambda T)}{\sigma T^4}$
0·2	$0{\cdot}341796\times10^{-26}$	6·2	0·754187
0·4	$0{\cdot}186468\times10^{-11}$	6·4	0·769234
0·6	$0{\cdot}929299\times10^{-7}$	6·6	0·783248
0·8	$0{\cdot}164351\times10^{-4}$	6·8	0·796180
1·0	$0{\cdot}320780\times10^{-3}$	7·0	0·808160
1·2	$0{\cdot}213431\times10^{-2}$	7·2	0·819270
1·4	$0{\cdot}779084\times10^{-2}$	7·4	0·829580
1·6	$0{\cdot}197204\times10^{-1}$	7·6	0·839157
1·8	$0{\cdot}393449\times10^{-1}$	7·8	0·848060
2·0	$0{\cdot}667347\times10^{-1}$	8·0	0·856344
2·2	0·100897	8·5	0·874666
2·4	0·140268	9·0	0·890090
2·6	0·183135	9·5	0·903147
2·8	0·227908	10·0	0·914263
3·0	0·273252	10·5	0·923775
3·2	0·318124	11·0	0·931956
3·4	0·361760	11·5	0·939027
3·6	0·403633	12	0·945167
3·8	0·443411	13	0·955210
4·0	0·480907	14	0·962970
4·2	0·516046	15	0·969056
4·4	0·548830	16	0·973890
4·6	0·579316	18	0·980939
4·8	0·607597	20	0·985683
5·0	0·633786	25	0·992299
5·2	0·658011	30	0·995427
5·4	0·680402	40	0·998057
5·6	0·701090	50	0·999045
5·8	0·720203	75	0·999807
6·0	0·737864	100	1·000000

(c) A nuclear reactor fuel rod is a circular cylinder of 6 cm diameter. The rod is to be tested by cooling it with a flow of sodium at 205 °C with a velocity of 5 cm/s perpendicular to its axis. If the rod surface is not to exceed 300 °C, estimate the maximum allowable power dissipation in the rod. 10

Properties of sodium

Temperature T			*Density* ρ (kg/m^3)	*Coefficient of Thermal Expansion* $\beta \times 10^3$ (1/K)	*Specific Heat* c_p (J/kg-K)	*Thermal Conductivity* k (W/m-K)	*Thermal Diffusivity* $\alpha \times 10^5$ (m^2/s)	*Absolute Viscosity* $\mu \times 10^4$ (N-s/m^2)	*Kinematic Viscosity* $\nu \times 10^7$ (m^2/s)	*Prandtl Number* Pr	$\frac{g\beta}{\nu^2} \times 10^{-9}$ (1/K-m^3)
°F	K	°C	$\times 6.243 \times 10^{-2}$ =(lb$_m$/ft^3)	$\times 0.5556$ =(1/R)	$\times 2.388 \times 10^{-4}$ =(Btu/lb$_m$-°F)	$\times 0.5777$ =(Btu/h-ft-°F)	$\times 3.874 \times 10^4$ =(ft^2/h)	$\times 0.6720$ =(lb$_m$/ft-s)	$\times 3.874 \times 10^4$ =(ft^2/h)		$\times 1.573 \times 10^{-2}$ =(1/R-ft^3)
200	367	94	929	0·27	1382	86·2	6·71	6·99	7·31	0·0110	4·96
400	478	205	902	0·36	1340	80·3	6·71	4·32	4·60	0·0072	16·7
700	644	371	860		1298	72·4	6·45	2·83	3·16	0·0051	
1000	811	538	820		1256	65·4	6·19	2·08	2·44	0·0040	
1300	978	705	778		1256	59·7	6·19	1·79	2·26	0·0038	

SECTION—B

5. (a) A 1 kW electric heating element is immersed in 25 kg of water initially at 12 °C in an insulated container. Determine the time required for the heater to raise the water temperature to 65 °C. Also, find the entropy generated during this process. 8

(b) It is a well-known fact that the two-stroke engines are more polluting than four-stroke engines. However, they are extensively used in some applications. Give the reasons and list these applications. 8

(c) A long steam pipe having 10 cm diameter and whose external surface temperature is 110 °C, passes through an open area that is not protected against winds. Determine the rate of heat loss from the pipe per unit of its length when the air is at 1 atmosphere pressure and 10 °C. The wind is blowing across the pipe at a velocity of 8 m/s.

Also, determine the rate of heat loss from the pipe if the length of the pipe is 25 m. 8

Properties of air at 1 atm pressure

Temp. T, °C	*Density* ρ, kg/m^3	*Specific Heat* C_p, J/kg-K	*Thermal Conductivity* k, W/m-K	*Thermal Diffusivity* α, m^2/s	*Dynamic Viscosity* μ, kg/m-s	*Kinematic Viscosity* ν, m^2/s	*Prandtl Number* Pr
–150	2·866	983	0·01171	$4·158\times10^{-6}$	$8·636\times10^{-6}$	$3·013\times10^{-6}$	0·7246
–100	2·038	966	0·01582	$8·036\times10^{-6}$	$1·189\times10^{-5}$	$5·837\times10^{-6}$	0·7263
–50	1·582	999	0·01979	$1·252\times10^{-5}$	$1·474\times10^{-5}$	$9·319\times10^{-6}$	0·7440
–40	1·514	1002	0·02057	$1·356\times10^{-5}$	$1·527\times10^{-5}$	$1·008\times10^{-5}$	0·7436
–30	1·451	1004	0·02134	$1·465\times10^{-5}$	$1·579\times10^{-5}$	$1·087\times10^{-5}$	0·7425
–20	1·394	1005	0·02211	$1·578\times10^{-5}$	$1·630\times10^{-5}$	$1·169\times10^{-5}$	0·7408
–10	1·341	1006	0·02288	$1·696\times10^{-5}$	$1·680\times10^{-5}$	$1·252\times10^{-5}$	0·7387
0	1·292	1006	0·02364	$1·818\times10^{-5}$	$1·729\times10^{-5}$	$1·338\times10^{-5}$	0·7362
5	1·269	1006	0·02401	$1·880\times10^{-5}$	$1·754\times10^{-5}$	$1·382\times10^{-5}$	0·7350
10	1·246	1006	0·02439	$1·944\times10^{-5}$	$1·778\times10^{-5}$	$1·426\times10^{-5}$	0·7336
15	1·225	1007	0·02476	$2·009\times10^{-5}$	$1·802\times10^{-5}$	$1·470\times10^{-5}$	0·7323
20	1·204	1007	0·02514	$2·074\times10^{-5}$	$1·825\times10^{-5}$	$1·516\times10^{-5}$	0·7309
25	1·184	1007	0·02551	$2·141\times10^{-5}$	$1·849\times10^{-5}$	$1·562\times10^{-5}$	0·7296
30	1·164	1007	0·02588	$2·208\times10^{-5}$	$1·872\times10^{-5}$	$1·608\times10^{-5}$	0·7282
35	1·145	1007	0·02625	$2·277\times10^{-5}$	$1·895\times10^{-5}$	$1·655\times10^{-5}$	0·7268
40	1·127	1007	0·02662	$2·346\times10^{-5}$	$1·918\times10^{-5}$	$1·702\times10^{-5}$	0·7255
45	1·109	1007	0·02699	$2·416\times10^{-5}$	$1·941\times10^{-5}$	$1·750\times10^{-5}$	0·7241
50	1·092	1007	0·02735	$2·487\times10^{-5}$	$1·963\times10^{-5}$	$1·798\times10^{-5}$	0·7228
60	1·059	1007	0·02808	$2·632\times10^{-5}$	$2·008\times10^{-5}$	$1·896\times10^{-5}$	0·7202
70	1·028	1007	0·02881	$2·780\times10^{-5}$	$2·052\times10^{-5}$	$1·995\times10^{-5}$	0·7177
80	0·9994	1008	0·02953	$2·931\times10^{-5}$	$2·096\times10^{-5}$	$2·097\times10^{-5}$	0·7154
90	0·9718	1008	0·03024	$3·086\times10^{-5}$	$2·139\times10^{-5}$	$2·201\times10^{-5}$	0·7132
100	0·9458	1009	0·03095	$3·243\times10^{-5}$	$2·181\times10^{-5}$	$2·306\times10^{-5}$	0·7111
120	0·8977	1011	0·03235	$3·565\times10^{-5}$	$2·264\times10^{-5}$	$2·522\times10^{-5}$	0·7073
140	0·8542	1013	0·03374	$3·898\times10^{-5}$	$2·345\times10^{-5}$	$2·745\times10^{-5}$	0·7041
160	0·8148	1016	0·03511	$4·241\times10^{-5}$	$2·420\times10^{-5}$	$2·975\times10^{-5}$	0·7014
180	0·7788	1019	0·03646	$4·593\times10^{-5}$	$2·504\times10^{-5}$	$3·212\times10^{-5}$	0·6992
200	0·7459	1023	0·03779	$4·954\times10^{-5}$	$2·577\times10^{-5}$	$3·455\times10^{-5}$	0·6974
250	0·6746	1033	0·04104	$5·890\times10^{-5}$	$2·760\times10^{-5}$	$4·091\times10^{-5}$	0·6946
300	0·6158	1044	0·04418	$6·871\times10^{-5}$	$2·934\times10^{-5}$	$4·765\times10^{-5}$	0·6935
350	0·5664	1056	0·04721	$7·892\times10^{-5}$	$3·101\times10^{-5}$	$5·475\times10^{-5}$	0·6937
400	0·5243	1069	0·05015	$8·951\times10^{-5}$	$3·261\times10^{-5}$	$6·219\times10^{-5}$	0·6948
450	0·4880	1081	0·05298	$1·004\times10^{-4}$	$3·415\times10^{-5}$	$6·997\times10^{-5}$	0·6965
500	0·4565	1093	0·05572	$1·117\times10^{-4}$	$3·563\times10^{-5}$	$7·806\times10^{-5}$	0·6986
600	0·4042	1115	0·06093	$1·352\times10^{-4}$	$3·846\times10^{-5}$	$9·515\times10^{-5}$	0·7037
700	0·3627	1135	0·06581	$1·598\times10^{-4}$	$4·111\times10^{-5}$	$1·133\times10^{-4}$	0·7092
800	0·3289	1153	0·07037	$1·855\times10^{-4}$	$4·362\times10^{-5}$	$1·326\times10^{-4}$	0·7149
900	0·3008	1169	0·07465	$2·122\times10^{-4}$	$4·600\times10^{-5}$	$1·529\times10^{-4}$	0·7206
1000	0·2772	1184	0·07868	$2·398\times10^{-4}$	$4·826\times10^{-5}$	$1·741\times10^{-4}$	0·7260
1500	0·1990	1234	0·09599	$3·908\times10^{-4}$	$5·817\times10^{-5}$	$2·922\times10^{-4}$	0·7478
2000	0·1553	1264	0·11113	$5·664\times10^{-4}$	$6·630\times10^{-5}$	$4·270\times10^{-4}$	0·7539

(d) Derive an expression for the COP of an ideal vapour absorption system in terms of temperatures at important points of the system. Also, comment on the relevance of COP of vapour absorption system with that of the COPs of Carnot refrigerator and Carnot engine. 8

(e) When is a natural draught cooling tower a good choice? What is the minimum temperature to which water can be cooled? Explain the functioning of induced draught counterflow cooling tower. 8

6. (a) The inside and outside conditions in an air-conditioning system are as :

Inside dry-bulb temperature—25 °C

Outside dry-bulb temperature—40 °C

Inside relative humidity—50%

Outside wet-bulb temperature—27 °C

The room sensible heat factor—0·8

Fifty percent of the room air is rejected to atmosphere and an equal quantity of fresh air is added before air enters the system. If the fresh air added is 100 m^3/minute, then find the following :

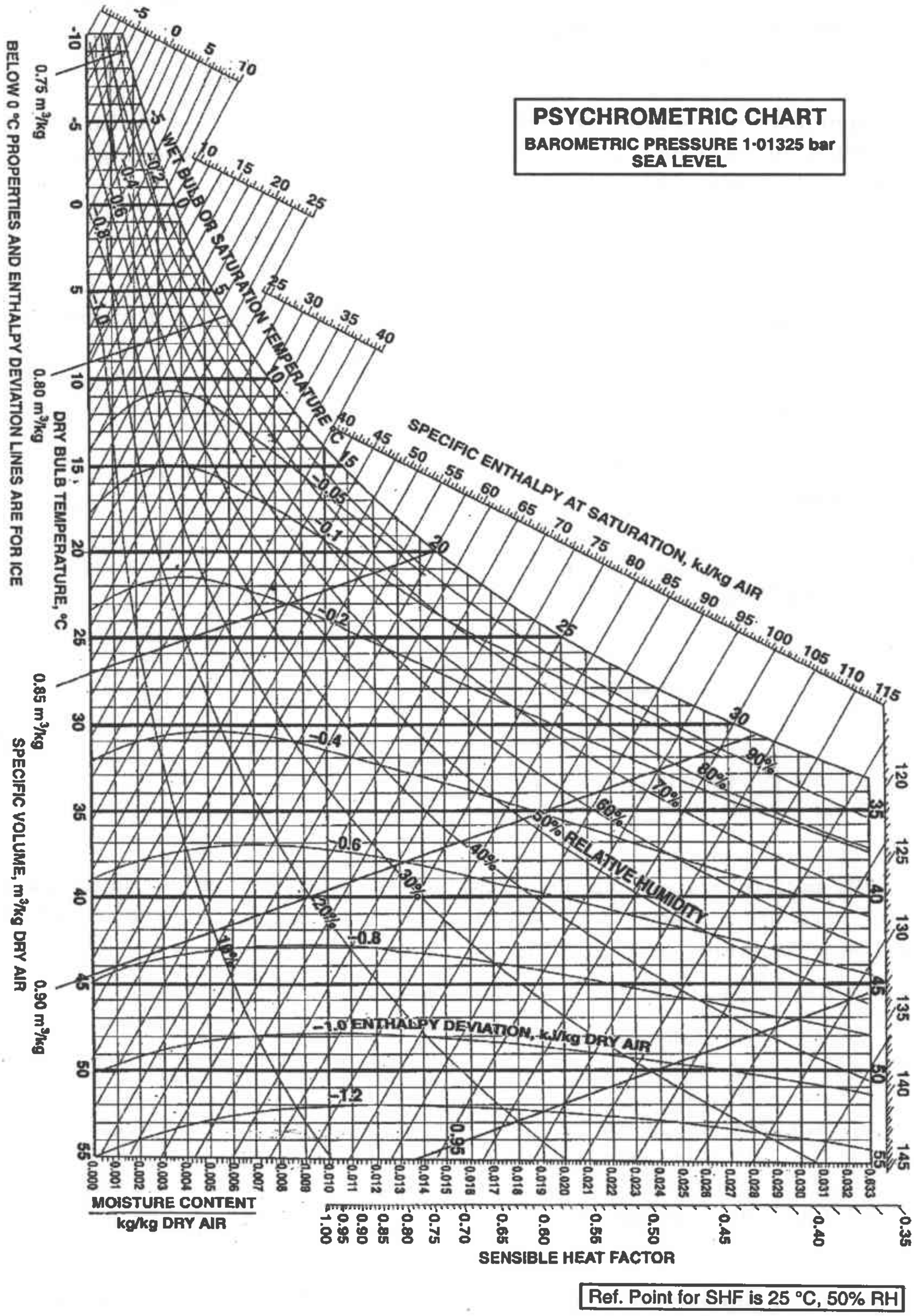
(i) Room sensible and latent load

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

(iii) Apparatus dew point

(iv) Humidity ratio and dry-bulb temperature of air entering the system

Assume by-pass factor as zero, density of air as 1·2 kg/m^3 at a total pressure of 1·01325 bar. 15



(b) An air-conditioning system has to be designed for a conference hall. The design conditions are as :

Inside conditions—25 °C DBT, 50% RH

Outside conditions—40 °C DBT, 28 °C WBT

Occupants—25 persons

Sensible heat gain per person—58 W

Latent heat gain per person—58 W

Solar heat gain through glass windows—5·52 kW

Solar heat gain through roof and walls—5·87 kW

Lighting load—15 lamps of 100 W each and 10 fluorescent lights of 80 W each

Sensible heat gain from other sources—11·63 kW

Infiltrated air—15 m^3/minute

If 75% recirculated air and 25% fresh air are mixed and passed through the air conditioner coil, then find the following :

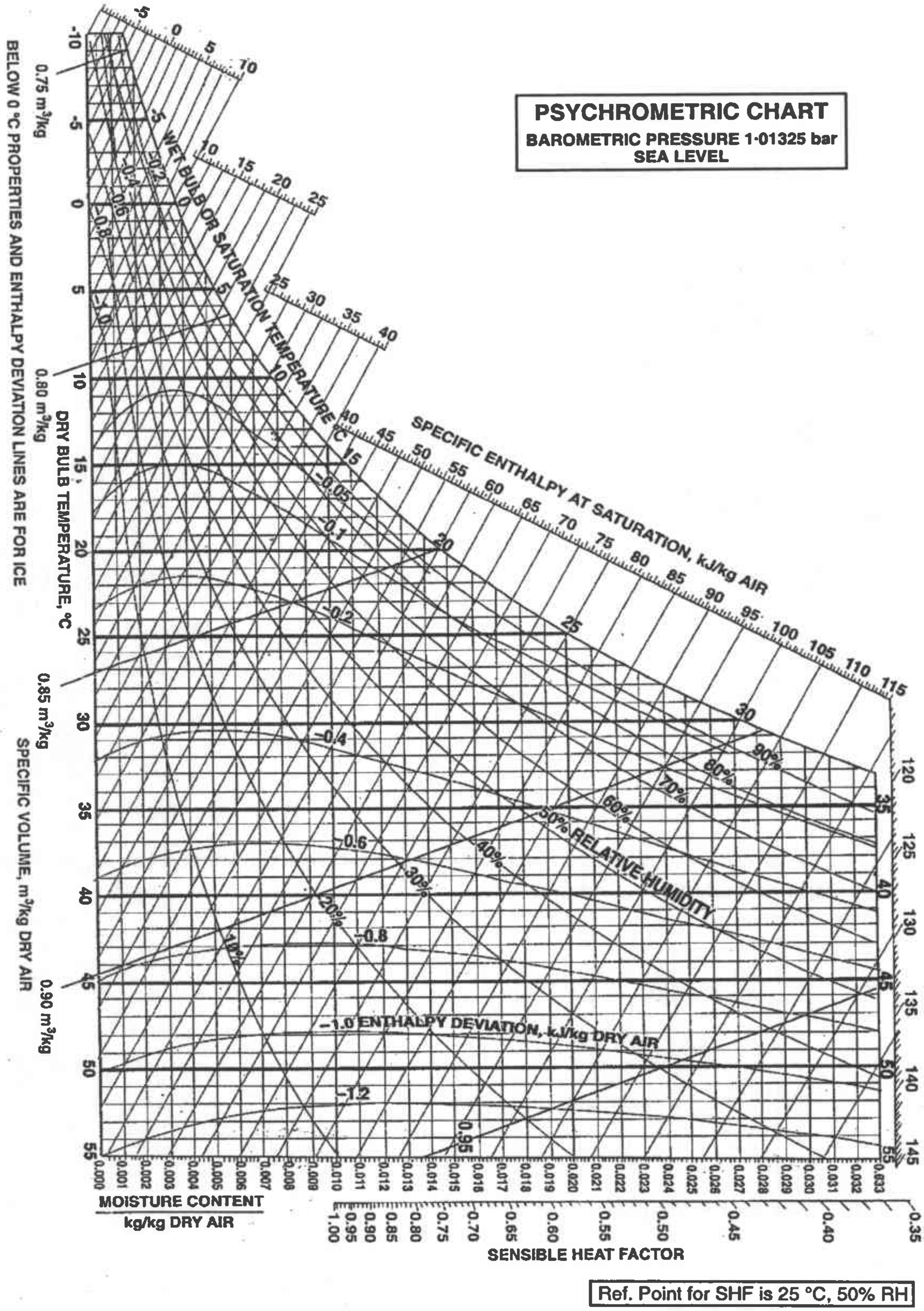
(i) Amount of total air required

(ii) Dew point temperature of the coil

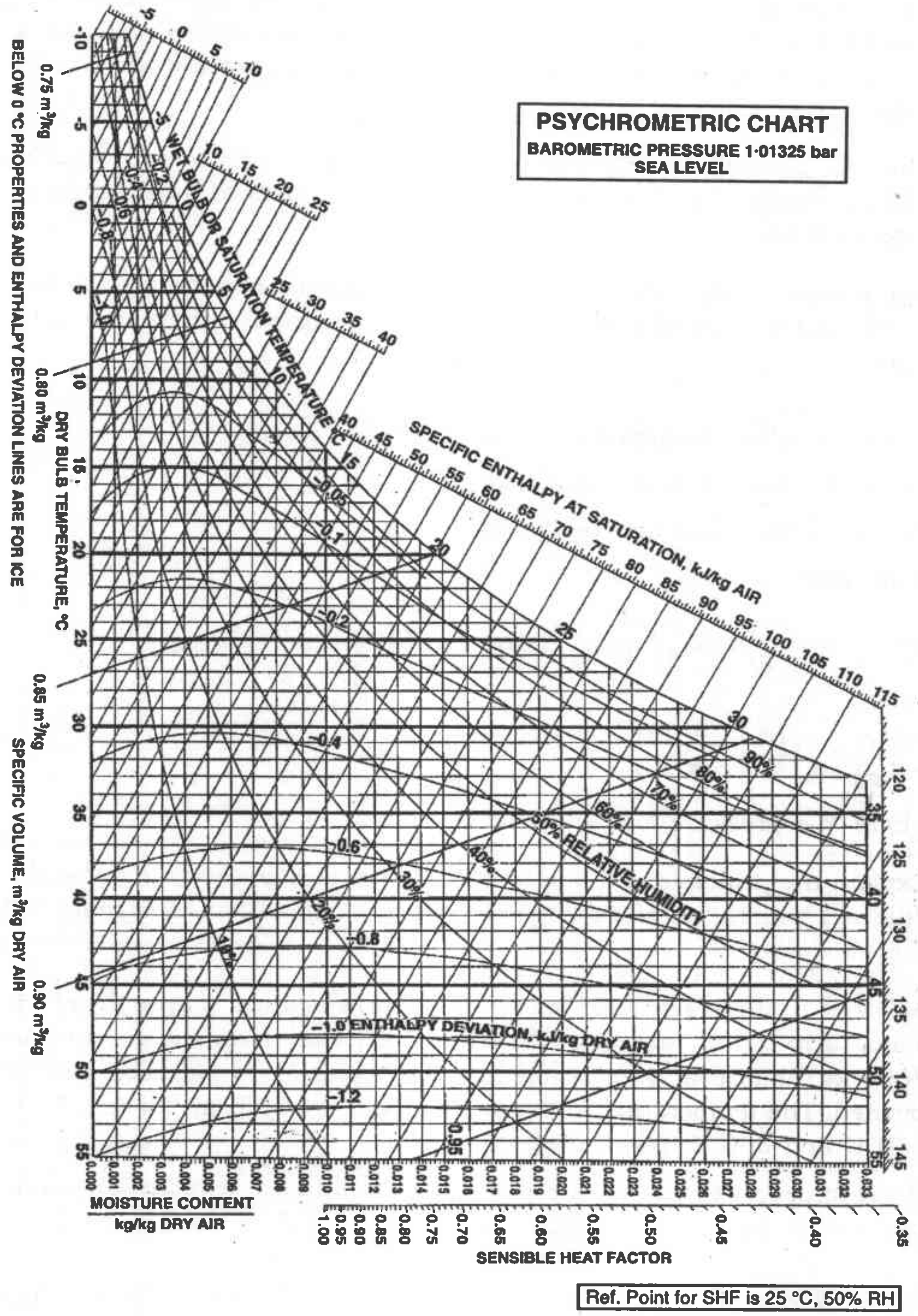
(iii) Condition of supply air to the room

(iv) Capacity of the conditioning plant

Assume by-pass factor as 0·2.



(c) A mixture of room air and fresh air enters a cooling coil at the rate of 39·6 m^3/minute. The dry-bulb and wet-bulb temperatures of the mixture are 31 °C and 18·5 °C, respectively. The surface area of the coil is such as would give 12·5 kW of refrigeration with the given entering air conditions. The effective surface temperature of the coil is 4·4 °C. Determine the exit conditions of the air and the by-pass factor. 10



7. *(a)* Air at ambient conditions of 1·01 bar and 288 K enters an axial flow compressor which has an overall pressure ratio of 4·0 and mass flow rate of 3·5 kg/s. If the polytropic efficiency is 90% and the stagnation temperature rise per stage is 28 K, calculate the number of stages required and the pressure ratio of the first and last stages. Assume equal temperature rise in all stages. If the absolute velocity approaching the last rotor is 170 m/s at an angle of 20° from the axial direction, the work done factor is 0·85, the velocity diagram is symmetrical and the mean diameter of the last stage rotor is 20 cm, calculate the rotational speed and the length of the last stage rotor blade at inlet to the stage. 20

(b) What is pressure coefficient for a centrifugal compressor stage? Derive $\psi = 1 - \phi_2 \cot\beta_2$ and plot ψ-ϕ_2 curves for radial, forward and backward swept impeller blades. 10

(c) Compare a 2-stage reaction turbine, a 2-stage impulse turbine and a Curtis wheel with 2 rows of rotating blades, and bring out merits and demerits of them. 10

8. *(a)* Show the following acting on a turbine blade cascade :

(i) Inlet, mean and outlet velocity triangles

(ii) Lift, drag, axial and tangential forces

Prove that

(iii) $C_L = 2\left(\frac{s}{l}\right)\cos\alpha_m(\tan\alpha_1 + \tan\alpha_2) + \left(\frac{s}{l}\right)Y\frac{\cos^2\alpha_m}{\cos^2\alpha_2}\sin\alpha_m$

(iv) $C_D = Y\left(\frac{s}{l}\right)\frac{\cos^3\alpha_m}{\cos^2\alpha_2}$

where Y = pressure loss coefficient. 15

(b) Explain the principle of fluidized bed combustion and working of a circulating fluidized bed boiler. List the advantages of such boilers over other solid fuel-fired boilers. 15

(c) A forced draught fan supplies air at 12 m/s against a draught of 25 mm of water across the fuel bed. Estimate the power required to run the fan if 3000 kg/hr of coal is consumed and 16 kg of air is supplied per kg of coal burned. The temperature of the flue gas and the ambient air may be taken as 650 K and 300 K, respectively.

If the forced draught fan is replaced by an induced draught fan, what will be the power required to drive the fan? 10

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