MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-3 : Fluid Mechanics and Turbo Machinery [All Topics]

Strength of Materials & Mechanics-1 + Thermodynamics-2 + IC Engine-2 + Refrigeration and Air-Conditioning-2 [Part Syllabus]

Name : ....

Roll No :

Test Centres	Student's Signature
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ Hyderabad ☐	

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	09
Q.2	—
Q.3	—
Q.4	08
Section-B	
Q.5	27+5
Q.6	—
Q.7	38
Q.8	52
Total Marks Obtained	134+5 =139

Signature of Evaluator .... Cross Checked by ....

Keep up this Consistent effort

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

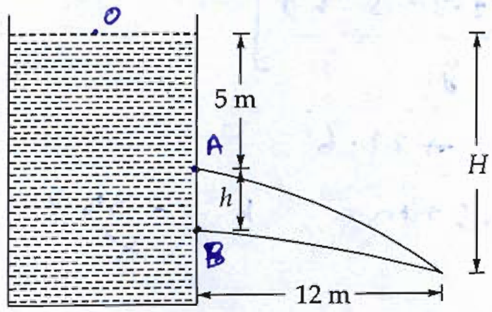
1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Section A : Fluid Mechanics and Turbo Machinery

1 (a) Two identical orifices are mounted on one side of a vertical tank as shown in the figure. The height of water above the upper orifice is 5 m. If the jets of water from the two orifices intersect at a horizontal distance of 12 m from the tank, estimate the vertical distance between the two orifices. Calculate the vertical distance of the point of intersection of the jets from the water level in the tank. Assume $C_V = 1$ for the orifices.



[12 marks]

~~$V_A = \sqrt{2g \times h_A}$~~ ~~{$h_A$ → distance of orifice A from top of}~~

Bernoulli's eqn betn point O & A

$$\frac{P_O}{\rho g} + \frac{V_O^2}{2g} + z_O = \frac{P_A}{\rho g} + \frac{V_A^2}{2g} + z_A$$

$$0 + 0 + 5 = 0 + \frac{V_A^2}{2g} + 0$$

$$V_A = \sqrt{2g \times 5} = 9.9045 \text{ m/s}$$

Similarly $V_B = \sqrt{2g \times (h+5)} = [49.05(h+5)]^{1/2}$.

time of travel will be calculated for both the orifices by y-dirn eqn.

For A :- $u_y t - \frac{1}{2} g t^2 = -S$.

$u_y = 0$

$$t_1 = \sqrt{\frac{2S}{g}} = \sqrt{\frac{2(H-5)}{g}}$$

Similarly, $t_2 = \sqrt{\frac{2(H-5-h)}{g}}$

$R = u_{x_A} \cdot t_1 = u_{x_B} \cdot t_2 \Rightarrow 9.9045 \times \sqrt{\frac{2(H-5)}{g}}$

$R = 12$ m

$$= \left(49.05(h+5) \times \frac{2(H-5-h)}{g}\right)^{1/2}$$

Do not write this margin

~~$98.1 \times (H-5) = 49.05 \times (H+5)^{2}\ 12$~~

~~$H = 5.1223$ m.~~

$9.9045 \times \sqrt{\frac{2(H-5)}{g}} = 12. \Rightarrow$ $\boxed{H = 12.2m}$ Ans

$\left[49.05\,(h+5) \times 2 \times \frac{(12.2-5-h)}{g}\right]^{1/2} = 12$

$-h^2 + 2.2h + 21.6 = 0$

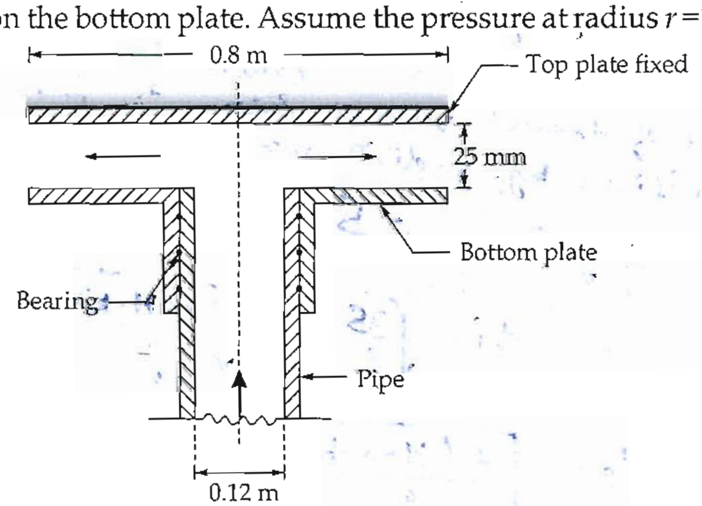
$\Rightarrow h = 5.8759$ m , $h = -3.6759$ X.

$\boxed{h = 5.8759 \text{ m}}$ Ans.

↑ vertical distance b/w the two orifices

7

Q.1 (b) Water flows in at a rate of 100 l/s from the pipe as shown in figure and flows outwards through the space between the top and bottom plates. The top plate is fixed. Determine the net force on the bottom plate. Assume the pressure at radius r = 0.06 m is atmospheric.



[12 marks]

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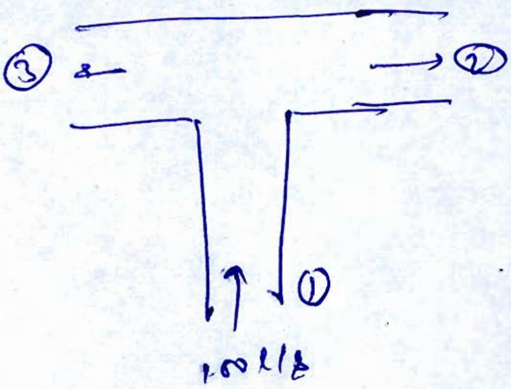

$\dot{m}_1 = \rho \dot{V}$

$= 10^3 \times 100 \times 10^{-3}$ kg/s

$= 100$ kg/s

$\dot{m}_2 = \dot{m}_3$ (by symmetry)

2

Rate of change of momentum in y-dir^n $= \Sigma F_y$

In y-dir^n as the top plate is fixed net force on it will be zero. ∴ F_{bottom} will be present in y-dir^n.

$\dot{m}_1 V_1 - 0 = F_{bottom}$

$100 \times \left(\frac{\dot{V}}{A_{entry}}\right) = F_{bottom}$

$100 \times \left(\frac{100 \times 10^{-3}}{\frac{\pi}{4} \times (0.12)^2}\right) = F_{bottom}$

$\boxed{F_{bottom} = 884.1941 \text{ N.}}$

Q.1 (c) In a stage of an impulse turbine provided with a single row wheel, the mean diameter of the blade ring is 800 mm and the speed of rotation is 3000 rpm. The steam issues from the nozzles with a velocity of 300 m/s and the nozzle angle is 20°. The rotor blades are equiangular and the blade friction factor is 0.86. Calculate the power developed in the blading when the axial thrust on the blades is 140 N.

[12 marks]

Q.1 (d) A nozzle is fitted at the end of a pipe of diameter D carrying water. Show that for maximum kinetic energy to be supplied by the nozzle, the diameter of the nozzle d is given by

$d = \left(\dfrac{D^5}{2fL}\right)^{1/4}$; where, f = friction factor and L = length of the pipe

[12 marks]

Q.1 (e) (i) Explain clearly the various factors affecting the performance of a Jet Propulsion device.

(ii) A turbojet power plant uses aviation kerosene having a calorific value of 43 MJ/kg. The fuel consumption is 0.25 kg per hour per N of thrust, when the thrust is 10 kN. The aircraft velocity is 500 m/s, the mass of air passing through the compressor is 27 kg/s. Calculate the air-fuel ratio and overall efficiency.

[6 + 6 = 12 marks]

Q.2 (a) A circular pipe of radius R_1 is placed concentrically inside another pipe of radius R_2. If the flow in the annular space between the pipes is laminar, show that the maximum velocity occurs at a radius r is given by

$$r = \sqrt{\frac{R_2^2 - R_1^2}{2\log_e\left[\frac{R_2}{R_1}\right]}}$$

[20 marks]

Q.2 (b) A straight conical draft tube attached to a Francis turbine has an inlet of diameter 2 m and its outlet area is 25 m^2. The velocity of water at inlet is 10m/s. The inlet is set 5 m above the tail race level. Assuming the loss of head in the draft tube equals half the velocity head at its outlet. Determine:

(i) the pressure head at the top of the draft tube.

(ii) total head at the top taking tail race level as datum.

(iii) power of water at outlet of runner.

(iv) power of water at the end of the draft tube.

(v) the power lost in the draft tube

[20 marks]

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Q.2 (c) **(i)** Explain stream line, streakline, pathline and timeline with neat sketch.

(ii) A velocity potential function for 2D flow is given by : $\phi = y^2 - x^2 + Axy$
Compute the value of the constant A when the discharge between the streamlines passing through the points (1, 3) and (1, 6) is 12 units.

[8 + 12 = 20 marks]

Q.3 (a) A single jet pelton turbine is required to drive a generator to develop 10 MW. The available head at the nozzle is 762 m. Assuming electric generator efficiency 95%, Pelton wheel efficiency 87%, coefficient of velocity for nozzle 0.97, mean bucket velocity 0.46 of jet velocity, outlet angle of the buckets 15° and the friction of the bucket reduces the relative velocity by 15 per cent, find the following:

(i) The rate of flow of water through the turbine

(ii) The diameter of the jet

(iii) The force exerted by the jet on the buckets.

If the ratio of mean bucket circle diameter to the jet diameter is not to be less than 10, find the best synchronous speed for generation at 50 cycles per second and the corresponding mean diameter of the runner.

[20 marks]

Q.3 (b) An 100 mm diameter composite solid cylinder consists of an 100 mm diameter 30 mm thick metallic plate having specific gravity 5, attached at the lower end of an 100 mm diameter wooden cylinder of specific gravity 0.85. Find the limits of the length of the wooden portion so that composite cylinder can float in stable equilibrium in water with its axis vertical.

[20 marks]

Q.3 (c) A centrifugal compressor runs at 12000 rpm and delivers 700 m^3/min of free air at a pressure ratio of 5 : 1. The isentropic efficiency of compressor is 82%. The outer radius of impeller is twice the inner one and neglect the slip coefficient. The inlet stagnation conditions are 1 bar and 293 K. The axial velocity of flow is 60 m/s and is constant throughout. Determine:

(i) Power input to the compressor

(ii) Impeller diameters at inlet and outlet and width at inlet,

(iii) Impeller and diffuser blade angles at inlet.

Assume radial blades at outlet and no swirl at inlet.

Take $(c_p)_{air}$ = 1005 J/kgK

[20 marks]

Q.4 (a) A single acting reciprocating pump has equal piston diameter and stroke length of 200 mm. The centre of the pump is 5 m above the level of water in sump and 35 m below delivery water level. The length of suction and delivery pipe are 6.5 m and 40 m respectively, and both the pipes have the same diameter of 75 mm. If the pump is working at 30 rpm find the absolute pressure head on the piston at the beginning, middle and end of both suction and delivery strokes. Also find the power required to drive the pump. Take atmospheric pressure as 10.3 m of water and Darcy's friction factor for both the pipes as 0.05.

[20 marks]

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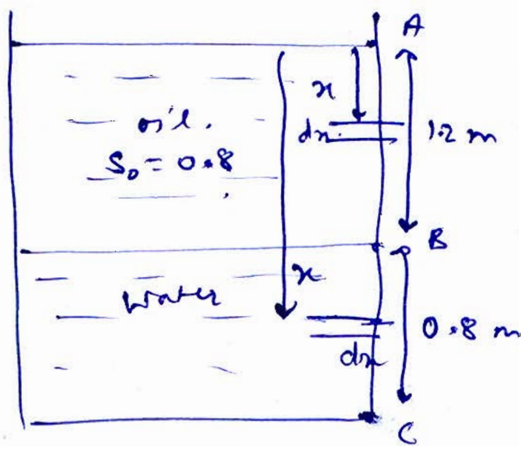
Q.4 (b) A cubical tank of side 2 m contains two immiscible liquids. The lower portion upto a depth of 0.8 m is filled with water, while the upper remaining part is filled with oil of specific gravity 0.8. For one vertical side of the tank, determine

(i) The total hydrostatic pressure force

(ii) The position of centre of pressure

[20 marks]

(i) $F = F_{AB} + F_{BC}$



$F_{AB} = \int_0 p \cdot dA$

$= \int_0^{1.2} \rho g x \cdot (2 \times dx)$

$= \rho_o \times g \times 2 \int_0^{1.2} x\, dx$

$= 0.8 \times 10^3 \times 9.81 \times 2 \times \left[\frac{x^2}{2}\right]_0^{1.2}$

$F_{AB} = 11301.12$ N.

$F_{BC} = \int p\, dA = \int_{1.2}^{2} (\rho g x) \cdot 2 \times dx$

$= \rho_w g \times 2 \times \int_{1.2}^{2} x\, dx$

$= 10^3 \times 9.81 \times 2 \times \left[\frac{(2)^2 - (1.2)^2}{2}\right]$

$= 25113.6$ N.

6

$F_T = F_{AB} + F_{BC}$

$= 36414.72$ N

$F_T = 36.4147$ kN $(\rightarrow)$

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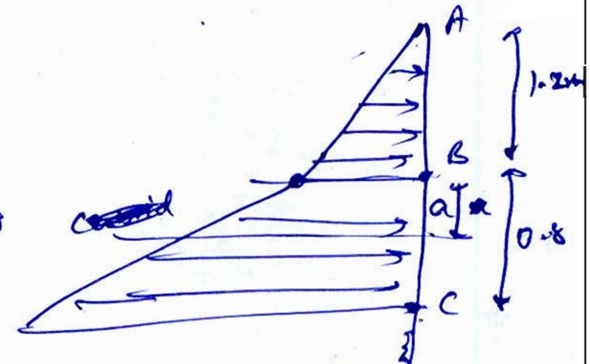
(ii). Let h be height from top where COP is located

~~$F_T \cdot h = F_{AB} \times$~~

Position of COP will be centroid of the pressure-prism

~~$h = F_{AB} \times \left(\frac{1.2 \times 2}{3}\right) + F_{BC} \times (1.2 +$~~



Variation of pressure with depth

$P_B = \rho_o g \cdot 1.2$

$= 0.8 \times 10^3 \times 9.81 \times 1.2$

$= 9417.6$ Pa

$P_C = \rho_o g \times 1.2 + \rho_w \times g \times 0.8$

$= 17265.6$ Pa.

$a = \left(\frac{P_C + P_B}{2P_C + P_B}\right) \times 0.8 = 0.4857$ m.

$\therefore h = \frac{F_{AB} \times \left(1.2 \times \frac{2}{3}\right) + F_{BC} \times (1.2 + 0.4857)}{F_T}$

$h = 1.41$ m

$\therefore$ centre of pressure is at a depth of 1.41 m from the free surface.

Q.4 (c) Given the velocity distribution in a laminar boundary layer on a flat plate as

$$\frac{u}{U} = 2\left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^3 + \left(\frac{y}{\delta}\right)^4$$

Obtain expressions for the boundary layer thickness, shear intensity and force on one side of the plate.

[20 marks]

Boundary layer thickness:

$$\delta^* = \int_0^\delta \frac{u}{U} \cdot dy = \int_0^\delta \left(2\left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^3 + \left(\frac{y}{\delta}\right)^4\right) dy$$

$$\delta^* = \left[\left(\frac{2}{\delta}\frac{y^2}{2} - \frac{2}{4}\frac{y^4}{\delta^3} + \frac{1}{\delta^4} \times \frac{y^5}{5}\right)\right]_0^\delta$$

$$\delta^* = \frac{\delta^2}{\delta} - \frac{\delta}{2} + \frac{\delta^5}{\delta^4 \times 5}$$

$$\delta^* = \delta - \frac{\delta}{2} + \frac{\delta}{5} = \frac{\delta}{2} + \frac{\delta}{5}$$

$$\boxed{\delta^* = \frac{7\delta}{10}}$$

2

Section B : Strength of Materials & Mechanics-1 + Thermodynamics-2 + IC Engine-2 + Refrigeration and Air-Conditioning-2

Q.5 (a) Explain the term human comfort in air conditioning. What are the factors governing optimum effective temperature? Discuss the various loads for estimating the cooling load of an air conditioned space?

[12 marks]

Human comfort in air-conditioning gives us the conditions at which the human would feel same in an AC room as in outside conditions.

Factors governing optimum effective temperature:

(a) Type of work:

for workers working near furnaces or inside mines would feel comfort at 2 - 3°C below that of normal

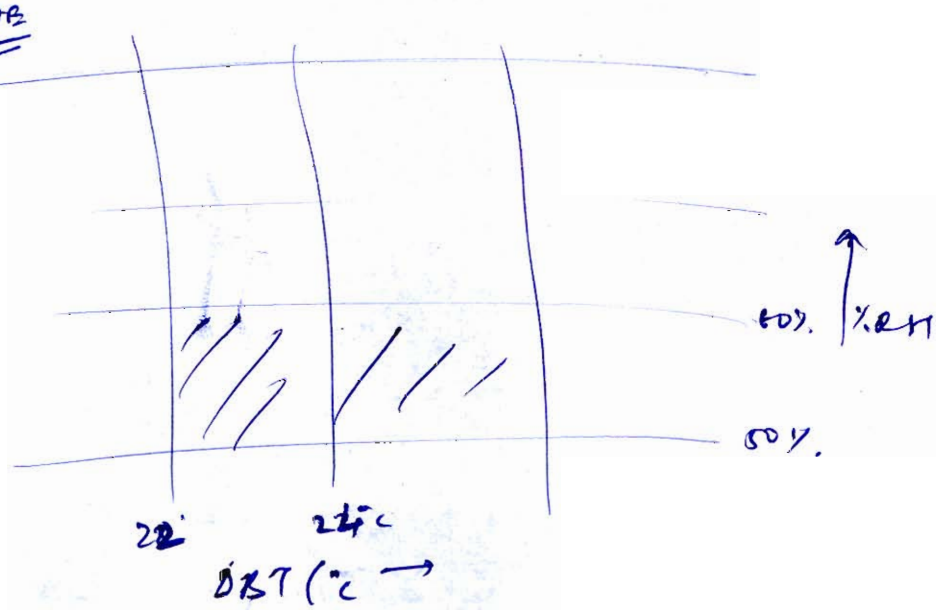
(b) Gender:

for women and old people the temp is 2° to 4° higher than normal comfort temp.

(c) climate :-

In summer we would feel comfort at higher temp than ~~at~~ in winter.

By ASHRAE



~~too dry~~ %R.H. < 50% would feel too dry

% RH > 60% would feel too ~~humid~~. sticky sensation

Various loads for estimating cooling load are:-

(i) RSHB - Room sensible heating

(ii) RLH - Room latent heat

(iii) GSH - Grand sensible heating

(iv) GLH - Grand latent heating.

6

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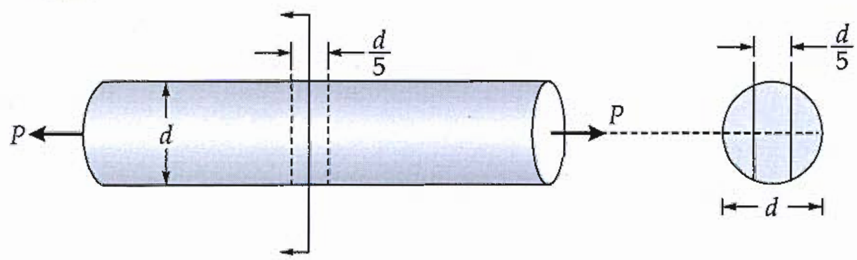
Q.5 (b) A solid bar of circular cross-section (diameter d) has hole of diameter $\frac{d}{5}$ drilled laterally through the center of the bar. The allowable average tensile stress on the net cross-section of the bar is σ_{allow}.

(i) Obtain a formula for the allowable load P_{allow} that the bar can carry in tension.

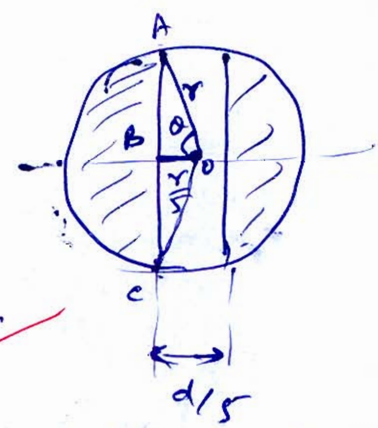
(ii) Calculate the value of P_{allow} if the bar is made of brass with diameter d = 50 mm, and σ_{allow} = 140 MPa.



[12 marks]

(i) Required area = Shaded Portion

$= 2 \times \left[\frac{2\theta}{2\pi} \times \pi \times r^2 - \frac{1}{2} \times 2 \times AB \times \frac{r}{5} \right]$ —(i)



$\theta = \cos^{-1}\left(\frac{r/5}{r}\right) = 1.3694 \text{ rad.}$

$AB = \sqrt{r^2 - \frac{r^2}{25}} = \frac{\sqrt{24}}{5} r.$

Req. area = $2.3468\, r^2$.

$\sigma_{allow} = \frac{P}{A_{req}} = \frac{P_{allow}}{2.3468\, r^2}$

12

$$P_{allow} = 2.3468\, \sigma_{allow} \times r^2.$$

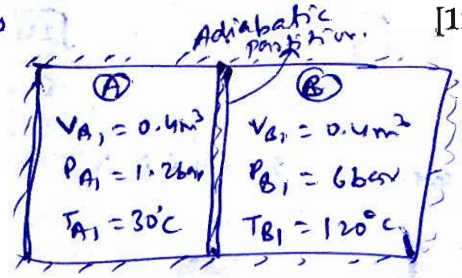
(ii) $P_{allow} = 2.3468 \times 140 \times (25)^2 \times 10^{-3}$ kN

$$P_{allow} = 205.345 \text{ kN}$$

Q.5 (c) A rigid insulated cylinder is divided into two compartments, each of volume 0.4 m^3 by an adiabatic partition. The two compartments contain air at 1.2 bar, 30°C and 6 bar, 120°C respectively. Estimate the final state of air in the cylinder when the partition is removed, and the irreversibility in the process.
Take, T_0 = 27°C

[12 marks]

Assumption :- Air is perfect gas



Let T_f be the final temp of air when partition is removed

From first law of thermodynamics on system :-

$$\cancel{Q} = \Delta U + \cancel{W}$$
Q → 0 (insulated), W → 0

$$\Delta U = 0$$

$$\Delta U_A + \Delta U_B = 0$$

$$m_A C_v (T_f - T_{A_1}) + m_B \times C_v \times (T_f - T_{B_1}) = 0 \quad \text{--- (1)}$$

$$m_A = \frac{P_{A_1} V_{A_1}}{R T_{A_1}} = \frac{120 \times 0.4}{0.287 \times 303} = 0.5519 \text{ kg}$$

$$m_B = \frac{P_{B_1} V_{B_1}}{R T_{B_1}} = \frac{600 \times 0.4}{0.287 \times 393} = 2.1278 \text{ kg.}$$

substituting in eqn (1)

$$0.5519 \times 0.718 \times (T_f - 303) + 2.1278 \times 0.718 \times (T_f - 393) = 0$$

$$\boxed{T_f = 374.46 \text{ K.}}$$

$$\boxed{V_f = V_A + V_B = 0.8 \text{ m}^3}$$

$$m_f = m_A + m_B = 0.5519 + 2.1278 \text{ kg}$$

$$m_f = 2.6797$$

$$P_f = \frac{m_f \times R \times T_f}{V_f} = \frac{2.6797 \times 0.287 \times 374.46}{0.8}$$

$$\boxed{P_f = 359.9842 \text{ kPa.}}$$

Final state:-
$P_f = 3.5998$ bar
$V_f = 0.8$ m³
$T_f = 374.46$ K $= 101.46°C$ **Ans**

12

$$\Delta S_{uni} = \Delta S_{sys} + \Delta S_{surr} \nearrow^{0}$$

$$= m_A \left[C_p \ln \frac{T_f}{T_{A_1}} - R \ln \frac{P_f}{P_{A_1}} \right] + m_B \left[C_p \ln \frac{T_f}{T_{B_1}} - R \ln \frac{P_f}{P_{B_1}} \right]$$

$$\Delta S_{uni} = 0.5519 \times \left[1.005 \ln \frac{374.46}{303} - 0.287 \ln \frac{3.5998}{1.2} \right]$$

$$+ 2.1278 \left[1.005 \ln \frac{374.46}{393} - 0.287 \ln \frac{3.5998}{6} \right]$$

$$\Delta S_{uni} = 0.152089 \text{ kJ/K.}$$

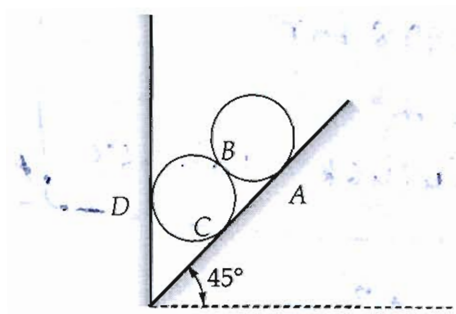
from Gouy - Stodola theorem:-

$$I = T_0 (\Delta S_{univ})$$

$I = 300 \times 0.152089$

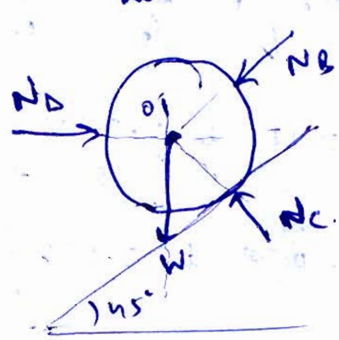
$\boxed{I = 45.6267 \text{ kJ}}$ Ans

Q.5 (d) Two identical rollers each weighing 150 N are supported by an inclined plane and a vertical wall as shown in the figure. Assuming all contact surfaces are smooth, find the reactions developed at the contact surfaces *A*, *B*, *C* and *D*.

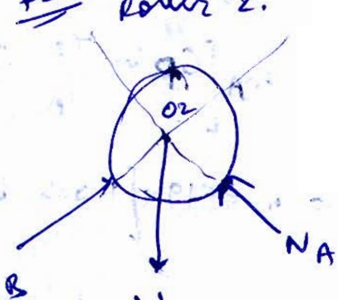


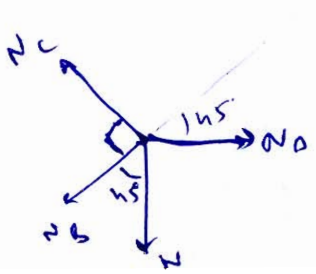
[12 marks]

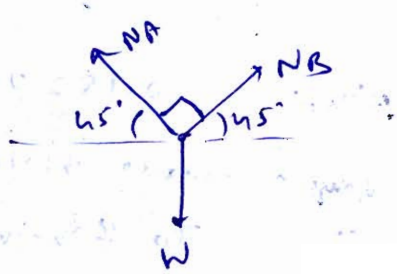
FBD Roller 1



FBD Roller 2







For Roller 2

$$\frac{N_A}{\sin(135^\circ)} = \frac{N_B}{\sin(135^\circ)} = \frac{W}{\sin 90^\circ}$$

$$\Rightarrow N_A = \frac{W \sin 135^\circ}{\sin 90^\circ} \Rightarrow N_A = 150 \times \sin 135^\circ$$

$$\boxed{N_A = 813.1728\ N}$$

$$N_B = \frac{W \sin 135^\circ}{\sin 90^\circ} \Rightarrow \boxed{N_B = 813.1728\ N}$$

2

For Roller 1

$$\Sigma F_V = 0 \Rightarrow N_C \sin 45^\circ = N_B \cos 45^\circ + W$$

$$N_C \sin 45^\circ = 813.1728 \cos 45^\circ + 150$$

$$\boxed{N_C = 1025.3048\ N}$$

$$\Sigma F_H = 0$$

$$\Rightarrow N_D = N_C \cos 45^\circ + N_B \sin 45^\circ$$

$$= 1025.3048 \times \cos 45^\circ + 813.1728 \sin 45^\circ$$

$$\boxed{N_D = 1299.9999\ N}$$

∴ Reactions developed will be,

$$N_A = 813.1728\ N$$
$$N_B = 813.1728\ N$$
$$N_C = 1025.3048\ N$$
$$N_D = 1299.9999\ N$$

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Q.5 (e) Explain the construction and functioning of catalytic converter.

[12 marks]

Q.6 (a) How does a thermoelectric refrigeration module works? Explain with the help of schematic of a thermoelectric cooler. What are the application areas of thermoelectric refrigeration system?

[20 marks]

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Q.6 (b) A closed rigid tank filled with water vapour, initially at 20.98 MPa, 633.22°C is cooled until its temperature reaches 439.03°C. Determine

(i) the specific volume of the water vapour in m^3/kg at the initial state.

(ii) the pressure in MPa at the final state

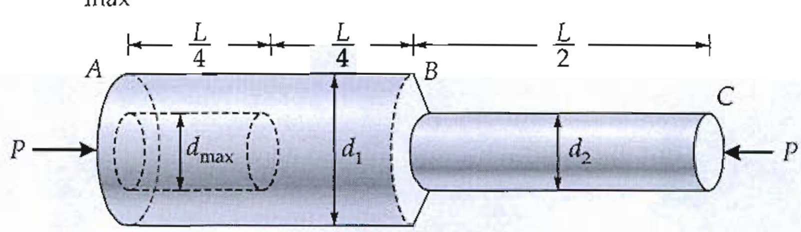
[Take molecular weight, critical temperature and critical pressure as 18.02 kg/Kmol, 647.3 K and 220.9 bar respectively]

[Use compressibility chart attached at the end]

[20 marks]

Q.6 (c) A bar ABC of length L consists of two parts of equal lengths but different diameters. Segment AB has diameter d_1 = 140 mm and segment BC has diameter d_2 = 80 mm. Both segments have length $\frac{L}{2} = 0.8$ m. A longitudinal hole of diameter d is drilled through segment AB for one-half of its length (distance $\frac{L}{4} = 0.4$ m). The bar is made of plastic having modulus of elasticity E = 6 GPa. Compressive loads P = 130 kN act at the ends of the bar.

(i) If the shortening of the bar is limited to 9.0 mm, what is the maximum allowable diameter d_{max} of the hole?



(ii) Now, if d_{max} is instead set at $\frac{d_2}{2}$, at what distance b from end C should load P be applied to limit the bar shortening to 3.0 mm?

(iii) Finally, if loads P are applied at the ends and d_{max} = 120 mm, what is the permissible length x of the hole if shortening is to be limited to 5.0 mm?

[20 marks]

Q.7 (a) An engine working on an Otto cycle having a compression ratio of 9, uses octane C_8H_{18} as a fuel. The lower heating value of the fuel is 44000 kJ/kg. The air fuel ratio is 14 : 1. Determine the maximum pressure and temperature reached in the cycle.

(i) Without considering the molecular expansion

(ii) With molecular expansion

Assume c_v = 0.71 kJ/kgK, compression follows the law $PV^{1.3}$ = constant, the pressure and temperature of the mixture at the beginning of the compression being 1.2 bar and 65°C respectively. Determine the percentage molecular expansion.

[20 marks]

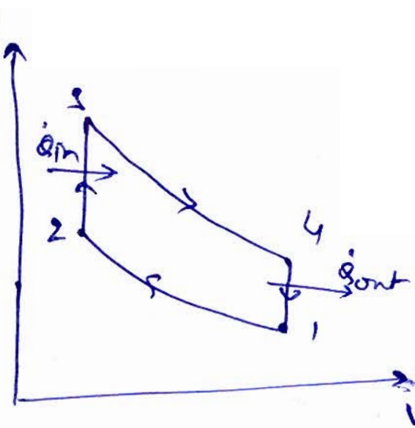
Given data:

$r = 9.$

$C.V. = 44000$ kJ/kg

$\frac{A}{F} = \frac{\dot{m}_a}{\dot{m}_f} = \frac{14}{1}$

$P_1 = 1.2$ bar, $T_1 = 338$ K.



(i) without considering molecular expansion.

Compression $\Rightarrow PV^{1.3} = C$

$P_1(V_1)^{1.3} = P_2(V_2)^{1.3}$

$P_2 = P_1 \times (r)^{1.3} = 1.2 \times (9)^{1.3}$

$P_2 = 20.8783$ bar

$\frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1}$

$\therefore T_2 = 653.41$ K

for process 2 → 3

$\dot{m}_f \times C.V. \times \eta_c = (\dot{m}_a + \dot{m}_f) \times C_v \times \Delta T.$

Assuming $\eta_c = 1.$ & dividing the eqn by $\dot{m}_f$.

$C.V. = \left(\frac{\dot{m}_a}{\dot{m}_f} + 1\right) \times C_v \times (T_3 - T_2)$

$44000 = (14 + 1) \times 0.71 \times (T_3 - 653.41)$

$\boxed{T_3 = 4784.86 \text{ K}}$ max temp. reached

$P \propto T$ (isochoric process)

$\frac{P_3}{P_2} = \frac{T_3}{T_2} \Rightarrow P_3 = \frac{4784.86}{653.41} \times 20.8783$

$\boxed{P_3 = 152.8898 \text{ bar}}$ max pressure reached.

10

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Q.7 (b) An air conditioned Hall is to be maintained at 26°C dry bulb temperature and 21°C wet bulb temperature. It has a sensible heat load of 48 kW and latent heat load of 18 kW. The air supplied from outside atmosphere at 40°C dry bulb temperature and 28°C wet bulb temperature is 28 m^3/min, directly into the room through ventilation and infiltration. Outside air to be conditioned is passed through the cooling coil whose apparatus dew point is 15°C. The quantity of recirculated air from the hall is 60%. This quantity mixed with the conditioned air after the cooling coil. Determine:

(i) Condition of air after the coil and before recirculated air mixes with it.

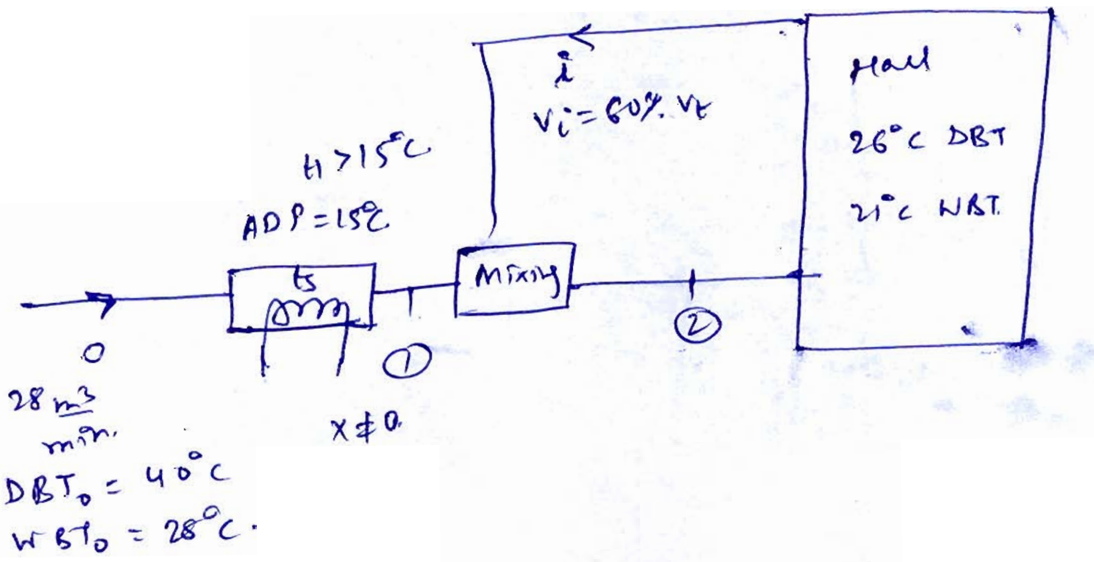
(ii) Condition of air entering the hall i.e. after mixing with recirculated air.

(iii) Mass of fresh air entering the cooler.

(iv) By-pass factor of cooling coil.

[Use Psychrometric chart attached at the end]

[20 marks]



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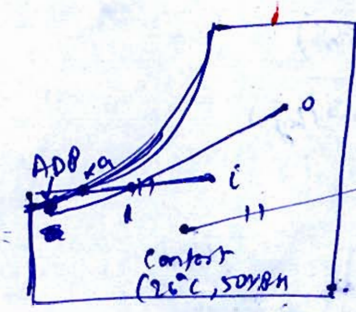
~~$1 \times t_1 = 0.6 \times t_i + 0.4 \times$~~

~~$t_1 = t_{ADP}$~~

$$RSHF = \frac{SH}{SH + LH} = \frac{48}{48+18} = 0.727$$



On psychrometric chart

(1) Draw line joining comfort point (26°C, 50% RH) with RSHF = 0.727.

(2) Draw line parallel to the above line from point i which intersects the sat. curve at a

(4) Draw line 'o' to ADP such that intersects the line i a on point 1

(i) ~~State~~ Point (1) ⇒

Data from psychrometric chart.

Ans: $t_1 = 22.5°C$, $h_1 = 57$ kJ/kg, $RH_1 = 78\%$, $t_{WBT} = 18°C$, $W_1 = 0.013$ kg/kg of air — Condn of air before mixing

(ii) $t_2 = 0.4 \times t_1 + 0.6 \times t_i = 0.4 \times 22.5 + 0.6 \times 26$

$= 24.6°C$

8

From Psychrometric chart, $h_2 = 59.5$ kJ/kg.

Condition of air after mixing:-

$t_2 = 24.6°C$	$t_{WBT} = 18.5°C$
$h_2 = 59.5$ kJ/kg	$W_2 = 0.0135$ kg/kg of air
$RH_2 = 68\%$	

Ans.

(iii) ~~mass of fresh~~

v_i from Psychrometric chart.

$= 0.915\ m^3/kg$

∴ mass of fresh air entering the cooler.

$= \frac{1}{v_i} \times V_i = \frac{(28\ m^3/min)}{(0.915\ m^3/kg)}$

$= \boxed{30.6\ \frac{kg}{min}}$ ans

(iv)

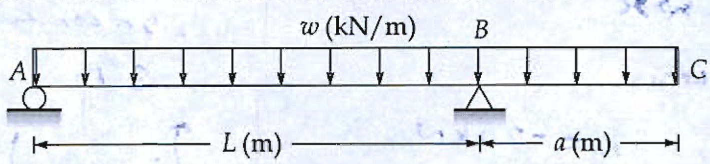
$X = \frac{t_1 - t_{ADP}}{t_0 - t_{ADP}} = \frac{22.5 - 15}{40 - 15}$

$\boxed{X = 0.3}$

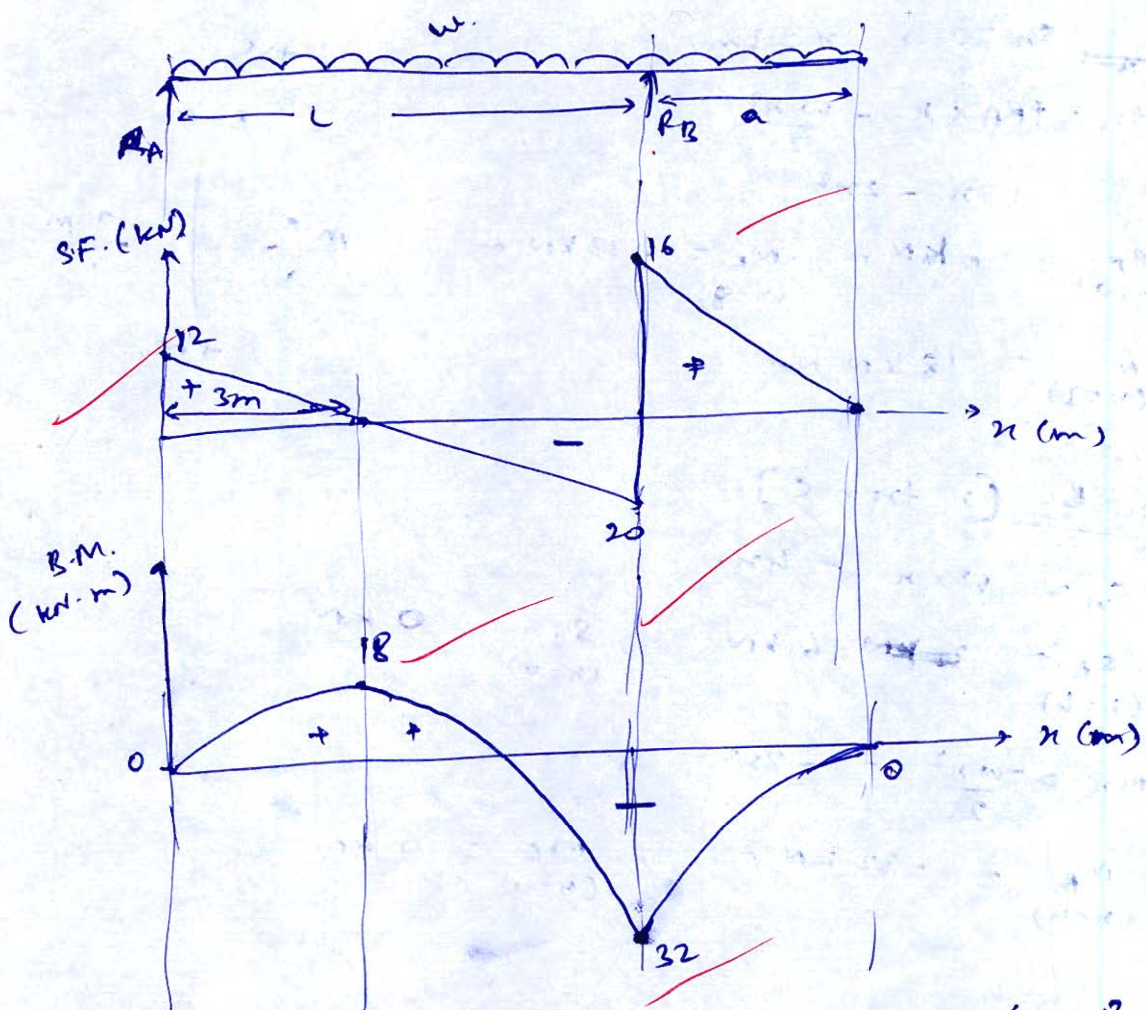
Bypass factor of cooling coil.

Refer the psychrometric chart at last page for location of points, and data taken from that is used in this question.

Q.7 (c) A simply supported beam with one side overhang is loaded with uniformly distributed load as shown in figure below. Comment your result on the variation of reaction forces at *A* and *B*, if '*L*' is less than, equal to and greater than '*a*'. Draw shear force and bending moment diagram for $w = 4$ kN/m, $L = 8$ m and $a = 4$ m.



[20 marks]



$\Sigma M_A = 0 \Rightarrow R_B \times L = \frac{w(L+a)^2}{2} \Rightarrow R_B = \frac{w(L+a)^2}{2L}$ — (1)

$R_A + R_B = w(L+a) \Rightarrow R_A = w(L+a) - R_B$

$R_A = \frac{w(L+a)(L-a)}{2L}$ — (2)

if $L < a \Rightarrow R_B = +ve$, $R_A = -ve$

∴ Reac^n at A is in downward dir^n & Reac^n at B is in upward dir^n

if $L = a \Rightarrow R_B = \frac{2wa}{}$ & $R_A = 0$.

if $L > a \Rightarrow R_B = +ve$, $R_A = +ve \Rightarrow$ Both reac^n forces in upward dir^n.

when $w = 4\ kN/m$, $L = 8\ m$, $a = 4\ m$

$\Downarrow$

$R_A = 12\ kN$, $R_B = 36\ kN$

For AB [x from A]

$S_x = +R_A - wx$

$= +12 - 4x$

$S_{A\,(x=0)} = +12\ kN$, $S_{B\,(x=8)} = -20\ kN$

$S_x = 0 \Rightarrow x = 3\ m$

$M_x = +R_A \times x - \frac{wx^2}{2}$

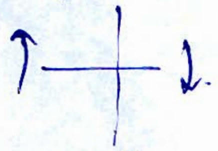
$= 12x - 2x^2$

$M_{A\,(x=0)} = 0\ kN\cdot m$, $M_{B\,(x=8)} = -32\ kN\cdot m$

$M_{(x=3)} = 18\ kN\cdot m$

Sign convention

S.F.



B.M.

for BC [x from C]

$S_x = w \times x = 4x$

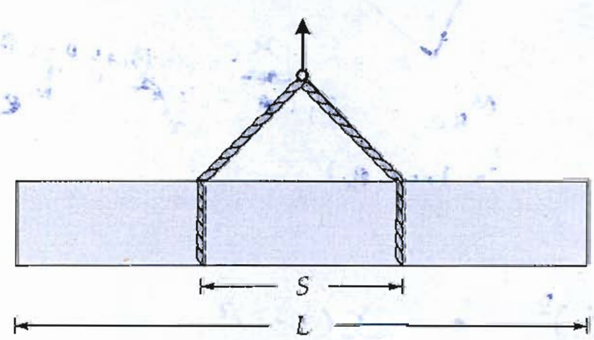
$S_{B\,(x=4)} = 16\ kN$, $S_{C\,(x=0)} = 0\ kN$

$M_x = \frac{-wx^2}{2} = -2x^2$

$M_{B\,(x=4)} = -32\ kN\cdot m$, $M_{C\,(x=0)} = 0\ kN$

20

Q.8 (a) A fiberglass pipe is lifted by a sling, as shown in the figure.



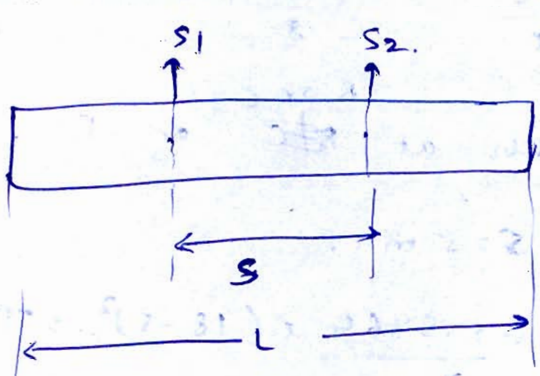
The outer diameter of the pipe is 180 mm, its thickness is 6 mm, and its weight density is 20 kN/m^3. The length of pipe is L =18 m and the distance between lifting points is S = 5 m.

(i) Determine the maximum bending stress in the pipe due to its own weight.

(ii) Find spacing S between lift points which will minimize the bending stress. What will be minimum bending stress?

(iii) What spacing S will lead to maximum bending stress? What is that stress?

[20 marks]

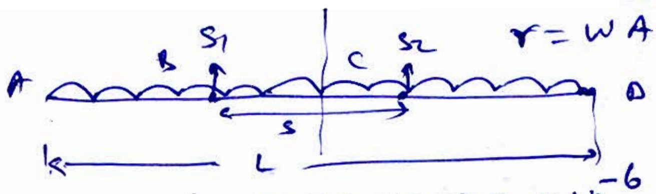


$w = 20 \frac{kN}{m^3}$

$d_o = 180mm.$

$d_i = 168 mm$

$A = \frac{\pi}{4}(d_o^2 - d_i^2) = 3279.8227 mm^2$



$\gamma = WA$ $\frac{N}{m}$

$\gamma = 20\times10^3 \times 3279.82273 \times 10^{-6}$. N/m.

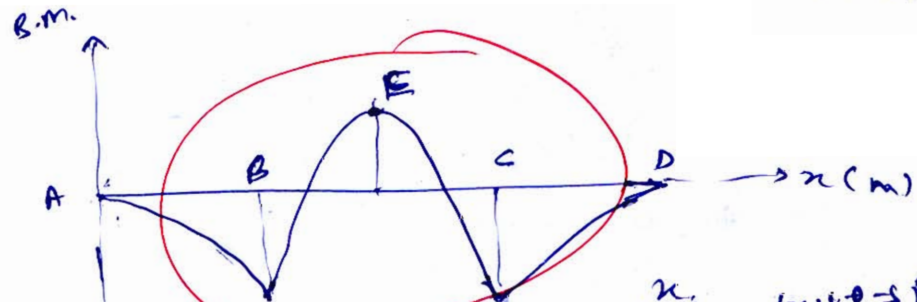
↑ weight density per unit length.

$\gamma = 65.5964$ N/m

$S_1 + S_2 = \gamma . L.$ —①

$\Sigma M_B = 0 \Rightarrow S_2 \times S = \gamma L \times \frac{S}{2} \Rightarrow S_2 = \frac{\gamma L}{2}.$

$\therefore S_1 = \frac{\gamma L}{2}$



$M_{AB} = -\frac{\gamma x^2}{2}$ (x from A), $M_{BC} = S_1 . x - \frac{\gamma (x+\frac{L}{2}-\frac{S}{2})^2}{2}$ (x from B), $M_{CD} = -\frac{\gamma x^2}{2}$ (x from C)

$M_B = -\frac{\gamma}{2}.\left(\frac{L-S}{2}\right)^2 = -\frac{\gamma}{8}(L-S)^2$

$M_C = -\frac{\gamma}{2}\left(\frac{L-S}{2}\right)^2. = -\frac{\gamma}{8}(L-S)^2.$

$M_E = \frac{\gamma L}{2}.\left(\frac{S}{2}\right) - \frac{\gamma}{2}.\left(\frac{L}{2}\right)^2.$

$= \frac{\gamma}{4}LS - \frac{\gamma L^2}{8} = \frac{\gamma L}{8}(2S-L)$

Max. moment is either at B or C or E.

(i) for L = 18, S = 5 m.

$M_B = M_C = -\frac{65.5964}{8} \times (18-5)^2 = -1385.7239$ N-m.

Do not write in this margin

$M_E = \frac{65.5964}{8} \times 18 \times (2 \times \sqrt{5} - 18) = -1180.7352$ N·m.

∴ max. Bending stress will be at point B & C.

$$\sigma_{max} = \frac{M}{I_z} = \frac{-1385.7239}{\frac{\pi}{32} d_o^3 (1-k^4)}$$

$$= \frac{-1385.7239}{\frac{\pi}{32} \times (0.18)^3 \times \left(1 - \left(\frac{0.168}{0.18}\right)^4\right)} \text{ N/m}^2.$$

$$\boxed{\sigma_{max} = -10.0356 \frac{N}{mm^2}}$$

(ii) For minimizing the bending stress there should be point of contraflexure & $|M_E| = |M_C|$

$$\therefore \frac{\gamma L}{8}(2S - L) = \frac{\gamma}{8}(L-S)^2.$$

$$2SL - L^2 = L^2 + S^2 - 2SL.$$

$$2L^2 + S^2 - 4SL = 0 \Rightarrow S^2 - (4L)S + 2L^2 = 0$$

$$S = \frac{4L \pm \sqrt{16L^2 - 8L^2}}{2 \times 1}$$

$$= 2L \pm \sqrt{2}L.$$

18

$S = (2+\sqrt{2})L$ or $S = (2-\sqrt{2})L$.

$$\therefore M_E = \frac{\gamma L}{8}(2S - L) = \frac{\gamma L}{8}((2-\sqrt{2})L \times 2 - L)$$

$$= \frac{\gamma L^2 (3 - 2\sqrt{2})}{8}$$

$$\sigma_{min} = \frac{\gamma L^2 (3 - 2\sqrt{2})}{8 \times \frac{\pi}{32} d_o^3 (1 - k^4)}$$

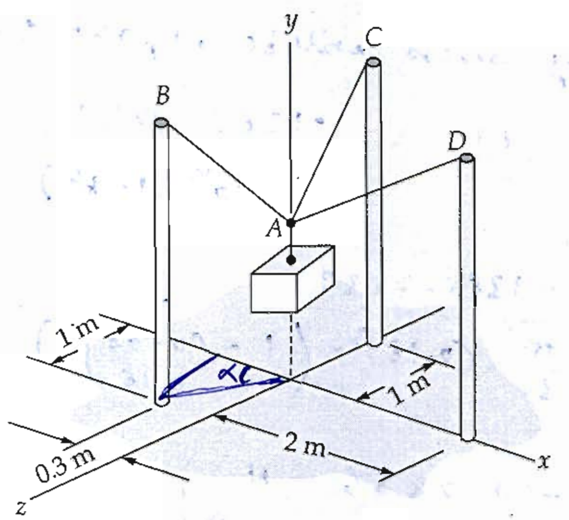
considering L = 18 m.

$$\boxed{\sigma_{min} = 3.3010 \text{ N/mm}^2}$$

(iii) σ_{max} will be when M_E = max ⇒ S = L and max stress will be at E

$$\sigma_{max} = \frac{\frac{\gamma}{8}(L)^2}{\frac{\pi}{32} \times d_o^3 (1-k^4)} \Rightarrow \boxed{\sigma_{max} = 19.2398 \text{ N/mm}^2}$$

Q.8 (b) The 15 kg mass is suspended by cables attached to three vertical 2 m posts. Point A is at (0, 1.4, 0) m. Determine the tensions in cables AB, AC and AD.

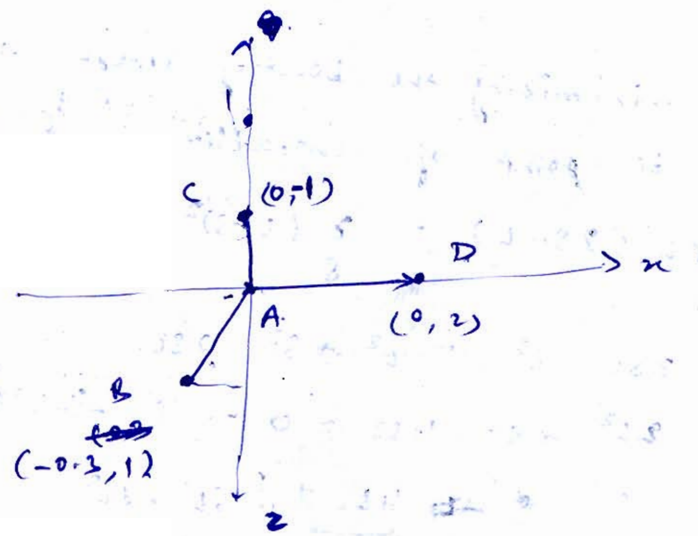


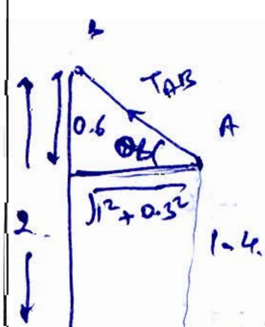
$\alpha = \tan^{-1} \frac{1}{0.3}$

$\alpha = 73.3°$

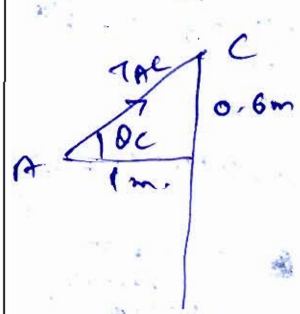
[20 marks]

Top view

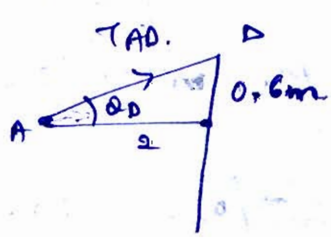




$\theta_B = \tan^{-1} \frac{0.6}{\sqrt{1^2+0.3^2}} = 29.8858°$



$\theta_C = \tan^{-1}\left(\frac{0.6}{1}\right) = 30.9637°$



$\theta_D = \tan^{-1}\left(\frac{0.6}{2}\right)$

$= 16.6992°$

$\Sigma F_y = 0 \Rightarrow T_{AB} \sin\theta_B + T_{AC} \sin\theta_C + T_{AD} \sin\theta_D = W.$ —(1)

$\Sigma F_x = 0. \Rightarrow T_{AD} \cos\theta_D = T_{AB} \cos\theta_B \times \cos\alpha.$

$T_{AD} \cos(16.6992) = T_{AB} \times \cos(29.8858) \times \cos(73.3)$

$T_{AD} = 0.26\, T_{AB}$ —(2)

$\Sigma F_z = 0 \Rightarrow T_{AC} \cos\theta_C = T_{AB} \cos\theta_B \times \sin\alpha.$

$T_{AC} \times \cos(30.9637^\circ) = T_{AB} \times \cos(29.8858) \times \sin(73.3)$

$T_{AC} = 0.9684\, T_{AB}$ —(3)

(2) & (3) in (1)

$T_{AB} \sin(29.8858) + 0.9184\, T_{AB} \sin(30.9637)$

$+ 0.26 \times T_{AB} \times \sin(16.6992) = 15 \times 9.81.$

$\boxed{T_{AB} = 137.3667 \text{ N.}}$

$T_{AC} = 0.9684 \times 137.3667 = \boxed{133.0259 \text{ N}}$

$T_{AD} = 0.26 \times 137.3667 \Rightarrow \boxed{T_{AD} = 35.7153 \text{ N.}}$

$\therefore$

$T_{AB} = 137.3667$ N

$T_{AC} = 133.0259$ N

$T_{AD} = 35.7153$ N.

Ans

20

Q.8 (c) (i) What do you understand by equivalence ratio? Explain its variation with respect to different types of mixtures.

(ii) An unknown hydrocarbon fuel has the following composition of dry products of combustion by volume:

CO_2 = 14%; CO = 0.6%; O_2 = 5% and the rest is N_2.

Determine :

(a) the air/fuel ratio.

(b) the percentage theoretical air.

(c) the percentage composition of fuel on mass basis.

[4 + 16 = 20 marks]

(i) Equivalence ratio is the ratio of actual fuel by air ratio to that of fuel by air ratio at stiotiometric reaction.

$$\phi = \frac{(F/A)_{actual}}{(F/A)_{stiometric}}$$

3

$\phi > 1 \Rightarrow$ Rich mixture.

$\phi = 1 \Rightarrow$ stiotiometric mixture.

$\phi < 1 \Rightarrow$ Lean mixture.

(ii) Let the hydrocarbon be $C_x H_y$.

Let the ~~composition~~ volume of dry product of combustion be $100\,m^3$.

$$m\,C_x H_y + n\left(O_2 + \frac{79}{21} N_2\right) \rightarrow 14\,CO_2 + 0.6\,CO + 5\,O_2 + 80.4\,N_2 + \frac{my}{2} H_2O$$

Carbon: $m x = 14 + 0.6 \Rightarrow m x = 14.6$ — (1)

Nitrogen:- $\frac{79}{21} n = 80.4 \Rightarrow n = 21.3721$

Oxygen: $n = 14 + \frac{0.6}{2} + 5 + \frac{m y}{4}$

$m y = 8.2884$ — (2)

(a) Air fuel ratio

$$\frac{A}{F} = \frac{n \times \left[32 + \frac{79}{21} \times 28\right]}{12 \times m x + 1 \times m y} = \frac{21.3721 \times [137.3333]}{12 \times 14.6 + 8.2884}$$

$$\boxed{\frac{A}{F} = 15.9961}$$

(b) % theoretical air $= \left(\frac{m_a}{m_a + m_f}\right) \times 100\%$

$$= \frac{1}{1 + \left(\frac{m_f}{m_a}\right)} \times 100\%$$

$$= \boxed{5.8836\%}$$

11

(c) Composition of fuel on mass basis $(C_x H_y)$

$m_C = m x \times 12 = 12 \times 14.6 = 175.2$ kg

$m_H = m y = 8.2884$ kg.

$$\% C = \frac{m_C}{m_T} \times 100\% = \frac{175.2}{175.2 + 8.2884} \times 100\% = \boxed{95.48\%}$$

$$\% H = \frac{m_H}{m_T} \times 100\% = \frac{8.2884}{175.2 + 8.2884} = \boxed{4.52\%}$$

on mass basis in fuel

$\% C = 95.48\%$

$\% H = 4.52\%$

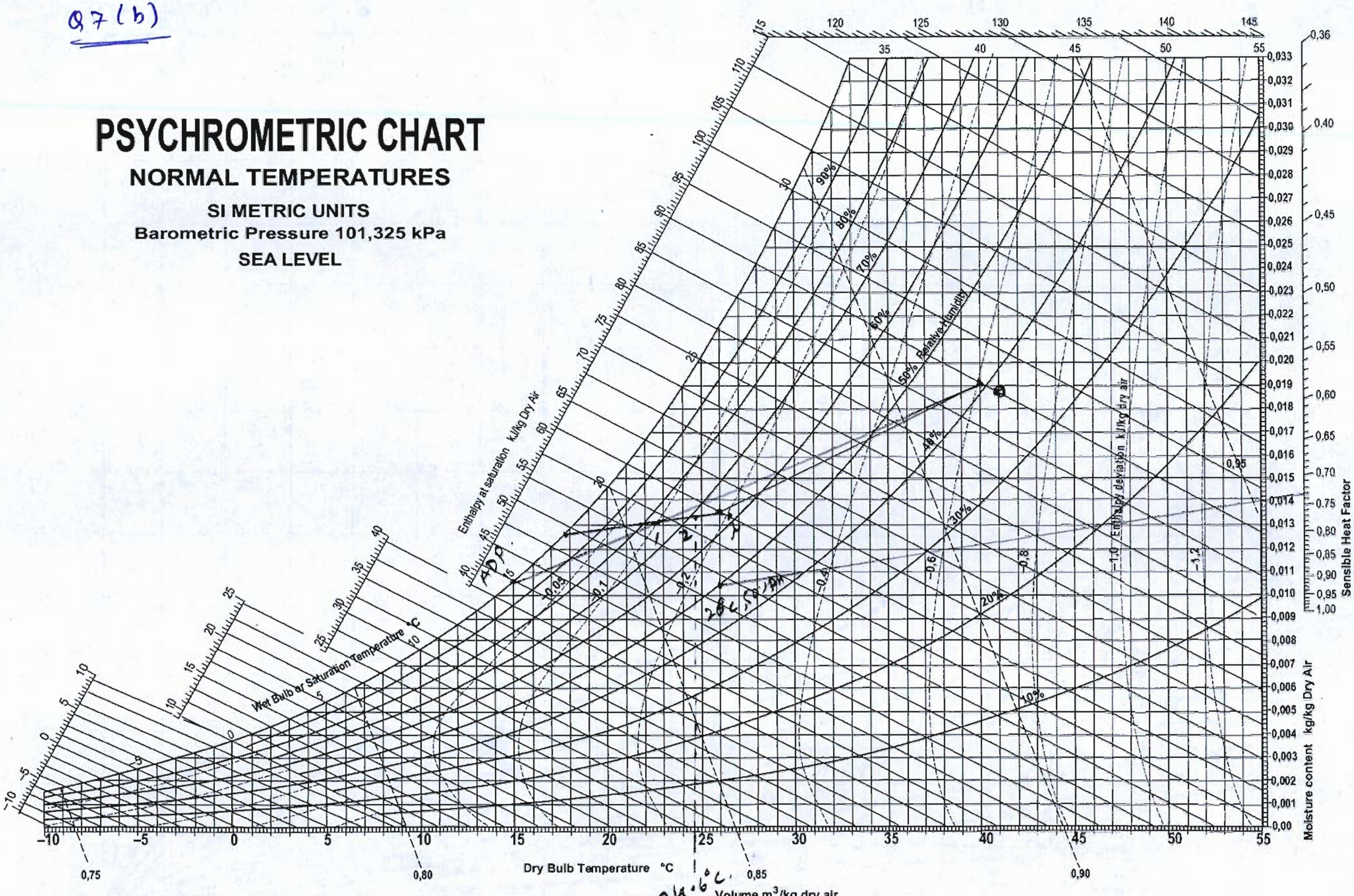
0000

Q7(b)

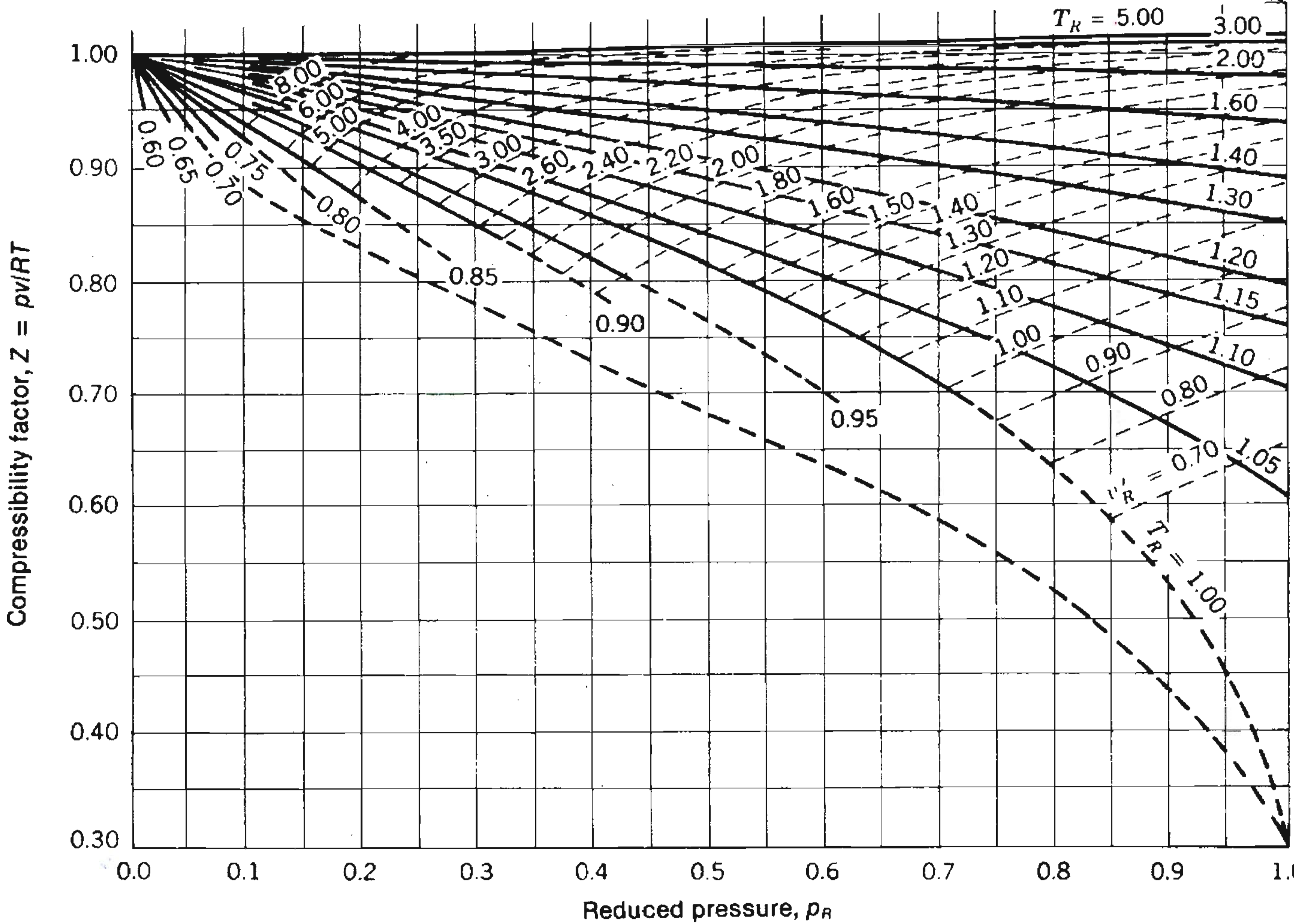
PSYCHROMETRIC CHART

NORMAL TEMPERATURES

SI METRIC UNITS
Barometric Pressure 101,325 kPa
SEA LEVEL



Below 0°C, Properties and Enthalpy Deviation Lines Are For Ice



Compressibility factor, Z = pv/RT
Reduced pressure, p_R
T_R = 5.00
T_R = 1.00
v'_R = 0.70

Space for Rough Work

Space for Rough Work