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# 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 | 26 |
| Q.2 | 28 |
| Q.3 | — |
| Q.4 | — |
| Section-B | |
| Q.5 | 33 |
| Q.6 | 24 |
| Q.7 | — |
| Q.8 | 41 |
| **Total Marks Obtained** | 152 |

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



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# IMPORTANT INSTRUCTIONS

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

## DONT'S

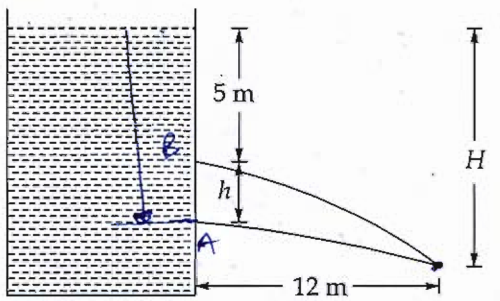
1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify 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]

Given: Take $g = 9.81$

$C_V = 1$

$V_A = \sqrt{2g h_A}$

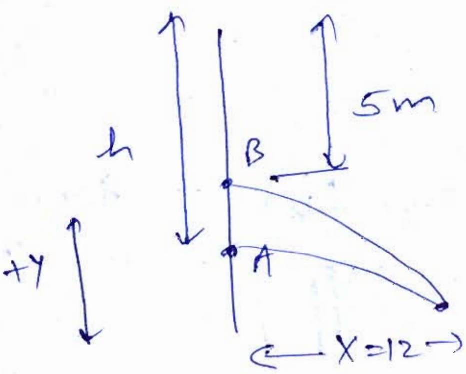
$h_A = (5+h)\,m$

$V_B = \sqrt{2g h_B}$

$h_B = 5$

$V_B = \sqrt{10 g}$

$V_B = 9.9045\ m/s$




In +Y direction

$s = \cancel{ut}^{\,0} + \frac{1}{2} g t^2$

$s = \frac{1}{2} g t^2$

from A-orific

$(H-5-h) = \frac{1}{2} \times 9.8\, t_1^2 \quad -①$

from B orific

$s = \frac{1}{2} g t^2$

$(H-5) = \frac{1}{2} 9.8\, t_2^2 \quad ②$

In horizontal direction there is no acceleration

$s_x = ut$ and

$12 = V_A \times t_1 \quad -③ \qquad 12 = V_B \times t_2 \quad -④$

(3)/(4)

$$V_A t_1 = V_B t_2$$

$$\sqrt{2g(h+5)} \times \sqrt{\frac{2(H-5-h)}{9.81}} = \sqrt{2g\times 5}\,\sqrt{\frac{2}{g}(H-5)}$$

Sq. both side

$$(h+5)(H-5-h) = 5(H-5) \quad —(5)$$

from eqn (4)

$$V_B \times t_2 = 12$$

$$\sqrt{2g\times 5} \times \sqrt{\frac{2}{g}(H-5)} = 12$$

10

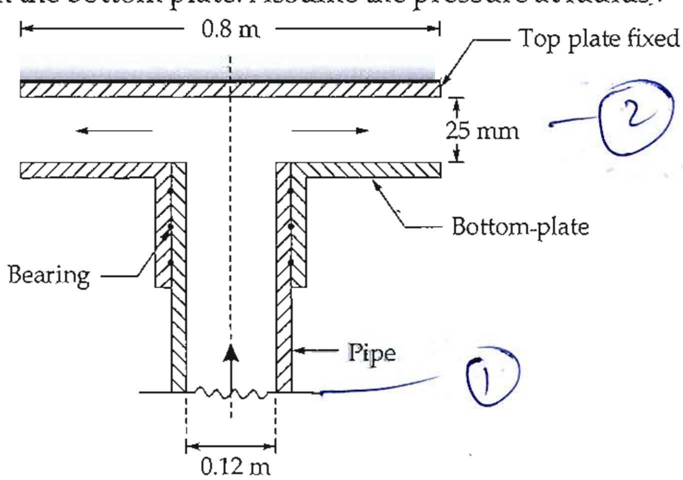
$$2\sqrt{5(H-5)} = \cancel{12}6$$

$$5(H-5) = 36$$

$$H = 12.2\,m$$

Vertical Distance from point of intersection from water level is ~~12.2m~~

**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]

$Q = 0.1 m^3/s$

Assumption
→ Water is incompressible

At section -1

$\frac{\pi}{4} d_1^2 \times V_1 = 0.1$

$\frac{\pi}{4} 0.12^2 \times V_1 = 0.1$

$V_1 = 8.8419 m/s$

At section - 2

$\pi d_2 L_2 V_2 = 0.1$

$\pi \times 0.8 \times 0.025 \times V_2 = 0.1$

$V_2 = \cancel{0.}1.59154 m/s$

1

Apply Bernoulli b/w S-1 & S-2

$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$

Assuming In same plane $Z_1 = Z_1$

$P_1 \to P_{atm}$ given

$+ \frac{8.84119^2}{2g} = \frac{P_2}{\rho g} + \frac{1.59154^2}{2g}$

$\frac{P_2}{\rho g} = 3.85556$

$P_2 = 37.823$ KPa

Top plate is fixed
so force ON bottom plate

$\frac{\pi}{4} \{d_2^2 - d_1^2\} P_2 = F$

$\frac{\pi}{4} \{0.8^2 - 0.12^2\} \times 37.823 = F$

$F = 18.584$ KN

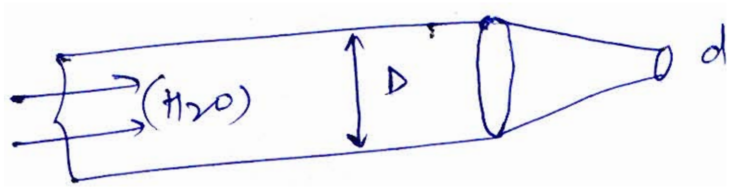
**Q.1 (c)** In a stage of an impulse turbine provided with a single row wheel, the mean diameter of the blade ring is 800 mm and the speed of rotation is 3000 rpm. The steam issues from the nozzles with a velocity of 300 m/s and the nozzle angle is 20°. The rotor blades are equiangular and the blade 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

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

**[12 marks]**




D → Diameter of pipe
d → Diameter of Nozzle
For max Power trasmission
$h_L = H/3 \Rightarrow H = 3h_L$

so for kinetic energy of water that can be given to stream ⇒ $h - h_L$ → Head loss due to friction

$H - H/3$

$= \underline{2H/3}$ — (I)

and $K.E = \frac{1}{2} m V^2$ $\quad (\frac{m}{V} = \rho)$

$\frac{1}{2} \rho \frac{\pi}{4} d^2 V^2$ — (II)

In eq^n — (I)

$K.E = \frac{2(3h_L)}{3} \Rightarrow \underline{2h_L}$ — (III)

and $h_L = \frac{fLQ^2}{12D^5}$ ie $\frac{fLQ^2}{12D^5}$ we know that

eq^n (II) and (3)

$\frac{1}{2} \rho Q V^2 = \frac{2 \times fLQ^2}{12 \cdot D^5} \times \rho Q$

Here = $V = \frac{Q}{\frac{\pi}{4} d^2}$

$$\frac{1}{2}\,\cancel{g}\,\cancel{Q}\times\frac{Q^2}{\left(\frac{\pi}{4}d^2\right)^2}=\frac{2fLQ^2\,\cancel{g}\,\cancel{Q}}{12.1\,D^5}$$

$$\frac{1}{2\left(\frac{\pi}{4}\right)^2 d^4}=\frac{fL}{12.1\,D^5}$$

$$\frac{D^5}{2fL}=\frac{2\times(\pi/4)^2 d^4}{12.1}$$

$$\boxed{\left(\frac{D^5}{2fL}\right)^{1/4}=d}\rightarrow \text{diameter of jet}$$

12

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

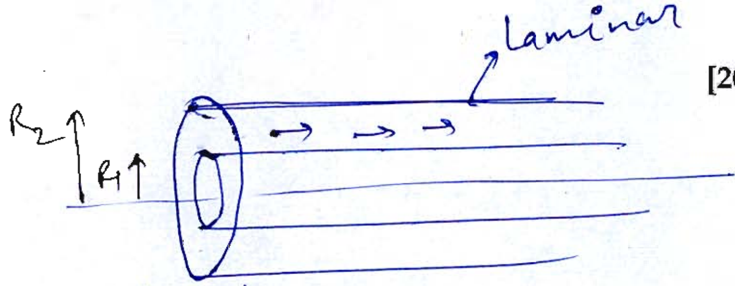
(ii) A turbojet power plant uses aviation kerosene having a calorific value of 43 MJ/kg. The fuel consumption is 0.25 kg per hour per N of thrust, when the thrust is 10 kN. The aircraft velocity is 500 m/s, the mass of air passing through the compressor is 27 kg/s. Calculate the air-fuel ratio and overall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

**[6 + 6 = 12 marks]**

**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]**




$Q$ = Area × velocity

We know that velocity profile in pipe flow is given by $= u = \frac{R^2}{4\mu}\left(\frac{\partial p}{\partial x}\right)\left\{1 - \frac{r^2}{R^2}\right\}$

2

**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

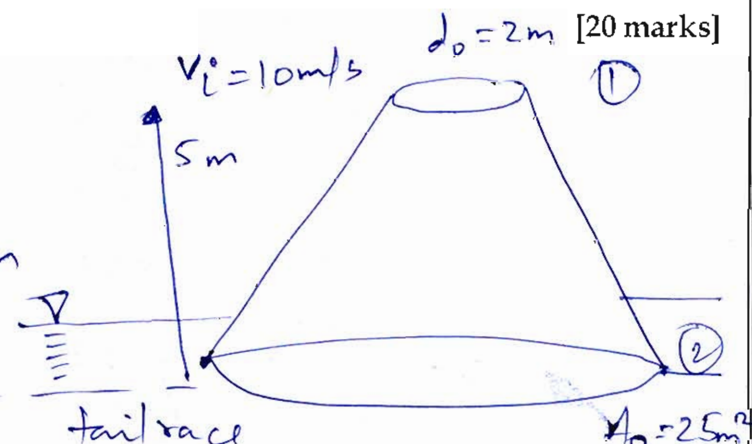
**[20 marks]**

Given

$h_L = \frac{1}{2}\left(\frac{V_o^2}{2g}\right)$

Mass. conservation

Assuming fluid i.e water to be incompressible




$\cancel{\rho_1} A_1 V_2 = \cancel{\rho_2} V_2 A_2$

$A_1 V_1 = A_2 V_2$

$\frac{\pi}{4}(2)^2 \times 10 = 25 \times V_0$

$V_0 = 1.2566$

$h_L = \frac{1}{2} V_0^2/2g$

$h_L = \frac{1}{2}(1.2566)^2/2g$

$h_L = 0.04024$ m

Apply Bernoulli b/w ① and ②

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + h_L$$

$$(P.H)_{Top} + \frac{10^2}{2g} + 5 = 0 + \frac{(1.2566)^2}{2g} + 0 + 0.04024$$

writing in term of gauge

$(PH)_{Top} + 10.096 = 0.120721$

$PH)_{Top} = -9.976$ m

$P_{top} = -9.976 \times \rho g$

{Take $\rho = 1000$ (water)}

$P_{Top} = -97.865$ kPa

or $P_{Top} = 3.4592$ kPa Absolute,

or $P_{Top} = 10.3 - 9.976$
$= 0.324$ m

9

ii Tail race as Datum

Total head at top $= \frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1$

$$\left(\frac{3.4592}{9.81} + \frac{10^2}{2g} + 5\right)$$

$= 10.44945$ m

Power at ~~outlet~~ inlet $= \rho g h Q$

$= 1000 \times 9.81 \times 10.44945 \times \frac{\pi}{4} \times 4 \times 10$

$\Rightarrow 3220.418$ kW

5 Power lost in draft tube

$= \rho g H_L Q$

$\Rightarrow 1000 \times 9.81 \times 0.04024 \times \frac{\pi}{4} \times 4 \times 10$

$= \underline{12.4015 \text{ kW}}$

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.

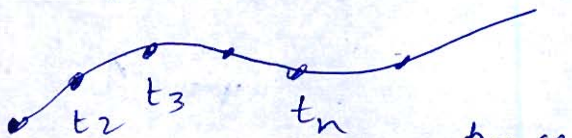
**[8 + 12 = 20 marks]**

1) Streamline : It is the Imaginary line inside the fluid flow on which tangent gives the direction of fluid particle

general mathematical eqn

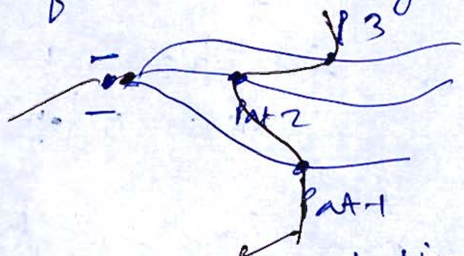
$$\frac{dx}{u} = \frac{dy}{v} = \frac{dw}{w} \quad -(1)$$


② Pathline :
It is the actual path trace by the fluid particle when it flows inside the fluid flow




same particle trace the path

③ Streakline :
It is the curve trace when we join the particles position at a given time which has passed from a single source




Same origin point

streakline at tim $t_1$

ii) $\phi = y^2 - x^2 + Axy$

And we know

$$\left.\begin{aligned}\frac{\partial \phi}{\partial x} &= \frac{\partial \psi}{\partial y}\\ \frac{\partial \phi}{\partial y} &= -\frac{\partial \psi}{\partial x}\end{aligned}\right\}$$ Cauchy Reimen equations

So
$$\frac{\partial \phi}{\partial x} = -2x + Ay = \frac{\partial \psi}{\partial y} \quad -(1)$$

Integrate eq$^n$ (1)

$$-2xy + \frac{Ay^2}{2} + c = \psi \quad -(A)$$

Now
$$\frac{\partial \phi}{\partial y} = 2y + Ax$$

$$2y + Ax = -\frac{\partial \psi}{\partial x}$$

Integrate both side

$$-\left\{2xy + \frac{Ax^2}{2} + c\right\} = \psi \quad -(B)$$

So stream function will be from (A) and (B)

$$\psi = A\left\{-\frac{x^2}{2} + \frac{y^2}{2}\right\} - 2xy + c$$

Now given is Discharge b/w points (1,3) (1,6) = 12 so $\psi_1 - \psi_2 = 12$

$$\left[ A\left\{ \frac{y^2}{2} - \frac{x^2}{2} \right\} - 2xy + c \right]_{(1,3)}^{(1,6)} = 12 \text{ units}$$

$$\left[ A\left\{ \frac{36-1}{2} \right\} - 2(6)(1) + c \right] - \left\{ A\left\{ \frac{9-1}{2} \right\} - 2(1)(3) + c \right] = 12$$

$$A\left(\frac{35}{2}\right) - 12 - A\left(\frac{8}{2}\right) + 6 = 12$$

$$A\left(\frac{27}{2}\right) - 6 = 12$$

$$A\left(\frac{27}{2}\right) = 18$$

$$A = \frac{4}{3}$$

12

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]**

Do not write in this margin

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]**

Do not write in this margin

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]**

Do not write in this margin

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]**

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]**

Do not write in this margin

**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 is determined with Air temperature, humidity Air velocity, odour, Oxygen Content etc. It is given and explain by ASRAEE committee. Generally, effective optimum temperature takes account of surrounding temperature humidity, Air velocity and serval other factor.

Comfort temperature = 22-26 °C

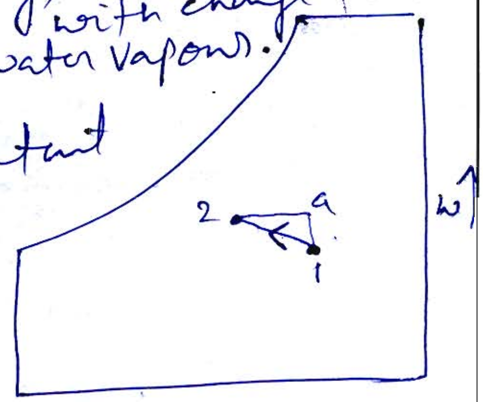
Humidity = 50-60 %

Air velocity = 15-25 m/min

optimum effective temperature is governed by surrounding temperature, climate condition.
It depends on velocity of air.
It depends on humidity of air etc

Different types of loads in A.C space

- Latent Load; It is load which takes account of ~~sensible~~ latent heat load during the Air Conditioning of space. It is associated with change in water vapour.
In psychrometric chart say, (Process occur as 1 to 2)
In this,
$(h_a - h_1)$ is taken as latent Load.



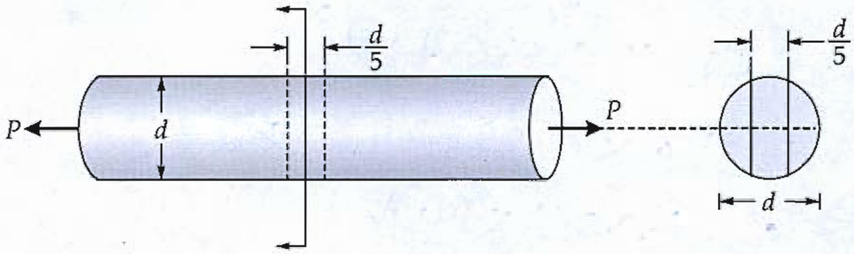

- Sensible load:
It is a load which takes account of sensible heat load ie heat load associated with temperature change
eg:- $(h_2 - h_a)$ is sensible heat load in diagram.

7

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 $\sigma_{allow}$.

(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 $\sigma_{allow}$ = 140 MPa.



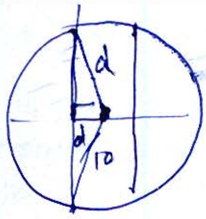

**[12 marks]**

Assumption

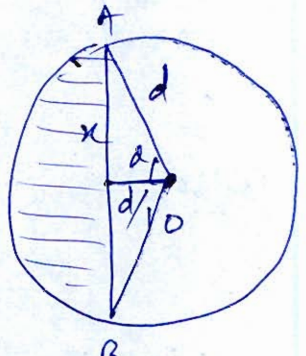
Bar is prismatic

Bar is homogeneous & Isotropic

Given, d → dia. of hole




$$\frac{P_{all}}{A} = \sigma_{all}$$




6

$\cos\theta = \frac{1}{10}$

$\theta = 84.2608$

$\left(\frac{d}{10}\right)^2 + n^2 = d^2$

$n = d^2 - \frac{d^2}{100} \rightarrow 0.99d^2$

$n = 0.99498d$

Shaded Area $= \frac{2\theta}{360} \times \pi r^2 -$ Area of $\Delta OAB$

$\Rightarrow \frac{2 \times 84.2608}{360} \times \frac{\pi \times d^2}{4} - \frac{1}{2} \times 1.98997 d \times \frac{d}{10}$

$0.11702 \frac{\pi}{4} d^2 - d^2(0.0994)$

$A = 0.26815 d^2$

Total area to resist load $= 2A$

$A_{resist} = 0.53631\, d^2$

$P = \sigma \times A$

$$\boxed{P_{allow} = \sigma_{allo} \times 0.53631\, d^2}$$

ii) If $d = 50$ mm

$\sigma = 140$ MPa

$P_{al} = \sigma_{all} \times 0.53631 \times d^2$

$= 140 \times 0.53631 \times 50^2$

$= 187.711 \times 10^3$ N

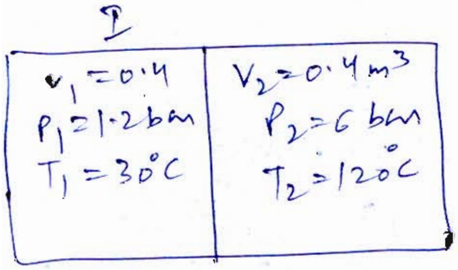
or $\underline{187.711 \text{ KN}}$

**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]**

$T_0 = 27°C$ or 300 K




Assumptions:

Treating Air as ideal gas

$C_p, C_v, \gamma$ donot change with temp

Given Insulated cylinder. so

$U_i = U_f$

or $\Delta U = 0$

$m_1 = \frac{P_1 V_1}{R T_1} \Rightarrow \frac{1200 \times 0.4}{0.287 \times 303} = \cancel{5.519\ \text{kg}}\ 0.55197$ kg

$m_2 = \frac{P_2 V_2}{R T_2} \Rightarrow \frac{600 \times 0.4}{0.287 \times 393} = 2.1278$ Kg

$m_1 c_v (T - T_1) = m_2 c_v (T_2 - T)$

Here, T is the final equilibrium temperature

$0.55197 \times 0.718 (T - 303) = 2.1278 \times 0.718 (393 - T)$

$0.55197 T - 167.24691 = 836.2254 - 2.1278 T$

$2.6786475 T = 1008.6945$

$T = 374.64$ K or

$T = 55.04°C \times 2$

$T = 101.632°C$

$V_{final} = 0.8 m^3$

$m_f = m_1 + m_2$

$= 2.6786475$ kg

$P_f \times 0.8 = 2.6786475 \times 0.287 \times 374.64$

~~$P_f = 899.99$ kPa or 8.99 bar~~

$P_f = 359.920$ kPa or 3.59 bar

Final state
$T = 101.632°C$
$P = 3.59$ bar
$V = 0.8 m^3$

Now,

$\Delta S|_{Part\ I} = m C_v \ln \frac{T_2}{T_1} + m R \ln V_2/V_1$

$= 0.55197 \{ 0.715 \ln \frac{374.64}{303} + 0.287 \ln 2 ]$

$0.151329 + 0.198933$

$\Delta S_1 = 0.19375$ KJ/K

$\Delta S|_{Part\ 2} = m C_v \ln T_2/T_1 + m R \ln V_2/V_1$

$= 2.1278 \{ 0.718 \ln \frac{374.64}{393} + 0.287 \ln 2 ]$

$2.1278 \times 0.164578$

$\Rightarrow 0.350195$ KJ/K

Irreversibility $= T_0 \times \dot{S}_{gn}$

$\dot{S}_{gn} = \Delta S|_I + \Delta S|_2$

$\dot{S}_{gn} = 0.54394$ KJ/K

Irre $= 300 \times 0.54394$

$= 163.183$ KJ

3

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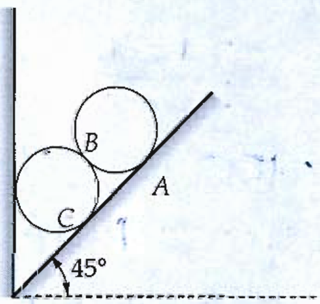
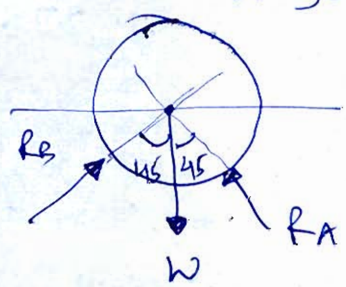
Q.5 (d) Two identical rollers each weighing 150 N are supported by an inclined plane and a vertical wall as shown in the figure. Assuming all contact surfaces are smooth, find the reactions developed at the contact surfaces *A*, *B*, *C* and *D*.

Given:
$W = 150$




[12 marks]

Body - I




$\Sigma F_n = 0$

$R_A \cos 45 = R_B \sin 45$

$R_A = R_B$

$\Sigma F_y = 0$

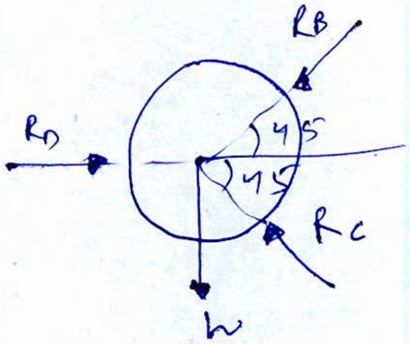
$R_A \sin 45 + R_B \cos 45 = W$

$(R_A + R_B)\frac{1}{\sqrt{2}} = 150$

$2R_A = 150\sqrt{2}$

$\underline{R_A = R_B = 75\sqrt{2}} \Rightarrow \underline{106.066\,N}$

$\Sigma F_x = 0$




$R_B \cos 45 + R_C \cos 45 = R_D$ — (11)

Body - 2

$\Sigma F_y = 0$

$R_B \sin 45 + W = R_C \sin 45$

Put value of $R_B$

$106.066 \times \frac{1}{\sqrt{2}} + 150 = \frac{R_C}{\sqrt{2}}$

$(75 + 150)\sqrt{2} = R_C$

$\underline{R_C = 318.198\ N}$

from eqn (2)

$R_B \cos 45 + R_C \cos 45 = R_D$

$75\cancel{\sqrt{2}} \times \frac{1}{\cancel{\sqrt{2}}} + (225)\frac{\cancel{\sqrt{2}}}{\cancel{\sqrt{2}}} = R_D$

$\underline{R_D = 300\ N}$

Direction is shown in Diagram.

12

Do not write in this margin

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]**

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]**

$M_m = 18.02$

$T_{cr} = 647.3K$

$P_{cr} = 220.9$ bar

$T_1 = 633.22°C$ or $906.22K$

$T_{reduced} = \cancel{\frac{T_{cr}}{T_{given}}} \Rightarrow \cancel{\frac{647.3}{906.22}} \Rightarrow \cancel{0.7142}$

$\boxed{T_{r_1} = 1.41}$

$P_{redu} = \cancel{\frac{P_{cr}}{P}} = \cancel{\frac{220.9}{209.8}}$

$\underline{P_{red_1} = 0.94975}$

$\left\{ T_r = \frac{T_{giv}}{T_{cr}} \quad P_r = \frac{P_{giv}}{P_{cr}} \right\}$

$T_2 = 439.03°C$ or $712.03K$

$\underline{T_{r_2} = 1.1}$

(1) $PV = ZRT$

from compressibility chart

$Z_1 = 0.9$

$$20.98 \times 10^3 \times v_1 = 0.9 \times \frac{8.314}{18.02} \times 906.22$$

$$v_1 = 0.017936 \ m^3/kg$$

Now water vapour is cooled
Since the tank is rigid
so specific volume remain same

$P_2 v_2 = Z_2 R T_2$

($T_r = 1.1$ for 2nd stat)

$T_r$ is 1.1

comp ($Z$) = 0.9

from chart $P_r = 0.4$

16

$$\frac{P}{P_{cr}} = 0.4$$

$P_{cr} = 220.9$ bar

$P = 220.9 \times 0.4$

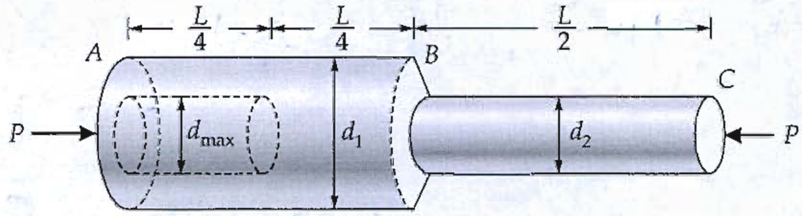
$P = 88.36$ bar

or

$P = 8.836$ MPa

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.

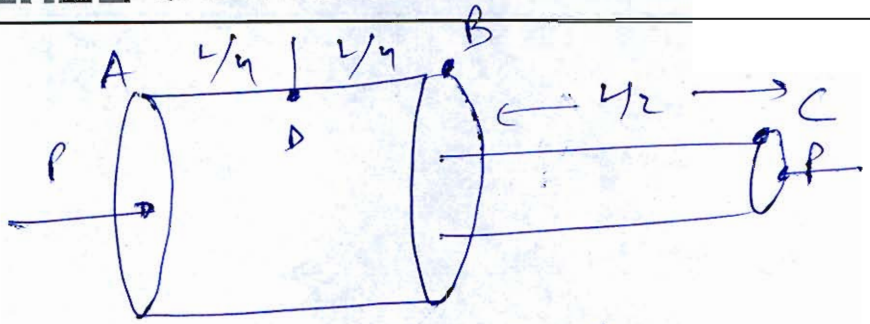
(i) If the shortening of the bar is limited to 9.0 mm, what is the maximum allowable diameter $d_{max}$ of the hole?




(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]**




Given, $d_1 = 140mm$ $L = 1.6 m$

$d_2 = 80 mm$ $L/2 = 0.8 m$

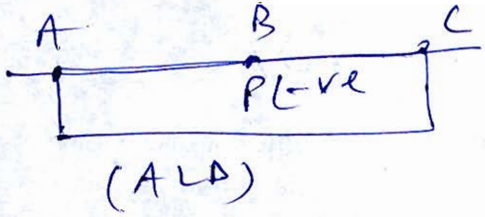
$G = 6 GPa$ $L/4 = 0.4 m$

$P = 130 kN$ comp

1) If $\Delta l = 0.9 mm$ shortening

$d_{max} = ?$

$\delta_{AD} + \delta_{DB} + \delta_{BC} = 0.9$




So,

$\sum \frac{PL}{AE} = 0.9 mm \times 10 = 9mm$

$\frac{P}{E} \sum L/A = 9mm$

$$\frac{130\times10^3}{6\times10^3}\left\{\frac{0.4\times1000}{\frac{\pi}{4}\{140^2-d_{max}\}^2} + \frac{0.4\times1000}{\frac{\pi}{4}140^2} + \frac{0.8\times1000}{\frac{\pi}{4}80^2}\right\} = 0.9$$

$$\left[\frac{509.2958}{140^2-d_m^2}\right] + 0.15915 + 0.02598 = \frac{9\times6000}{130\times10^3}$$

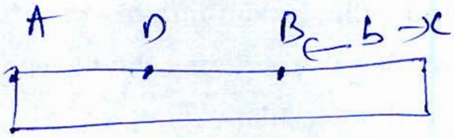
$2211.88 = 140^2 - d_m^2$

$d_m^2 = 17388.119$

$d_{max} = 131.864 mm$

2) If $d_{max} = \frac{d_2}{2} \Rightarrow \frac{80}{2} \Rightarrow 40mm$

As per given data,




$$\Sigma \frac{PL}{AE} = 3mm$$

$$\frac{130\times 10^3}{6\times 10^3}\left\{\frac{0.4\times 1000}{\frac{\pi}{4}\{140^2-40^2\}} + \frac{0.4\times 1000}{\frac{\pi}{4}\times 140^2} + \frac{b}{\frac{\pi}{4}\times 80^2}\right] = 3$$

$$\frac{b}{\frac{\pi}{4}80^2} + 0.028294 + 0.0259844 = 0.1384615$$

$$\frac{b}{\frac{\pi}{4}\times 80^2} = 0.0844615$$

$$\underline{b = 423.15mm}$$

from end C

3

(3) $\Sigma \frac{PL}{AE} = 5mm$

$d_{max} = 120mm$

(x)


$$\frac{130\times 10^3}{6\times 10^3}\left\{\frac{L}{\frac{\pi}{4}\{140^2-120^2]} + \frac{400}{\frac{\pi}{4}140^2} + \frac{800}{\frac{\pi}{4}80^2}\right) = 5$$

$$\frac{L}{1300\pi} + 0.02598 + 0.159154 = 0.230769$$

$$\underline{L = 186.3765mm}$$

from end $\underline{A}$

**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]**

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.

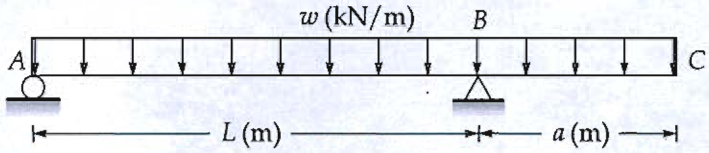
(iv) By-pass factor of cooling coil.

*[Use Psychrometric chart attached at the end]*

[20 marks]

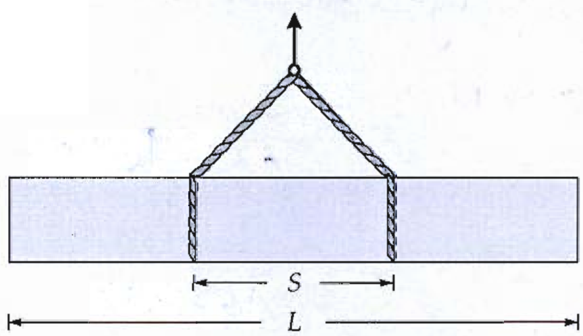
Do not write in this marg

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]**

.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]

$$\left.\begin{aligned} d_o &= 180\,mm \\ t &= 6\,mm \\ \gamma &= 20\,kN/m^3 \\ L &= 18\,m \\ S &= 5\,m \end{aligned}\right\} \text{given.}$$

$d_o = 180\,mm$

$d_i = 168\,mm$

$A_o = \frac{\pi}{4}[d_o^2 - d_i^2]$

$A_o \simeq 3.279822 \times 10^{-3}\,m^2$

$w = \gamma \times A$

$w = 20 \times 10^{3} \frac{N}{m^3} \times 3.27982 \times 10^{-3}$

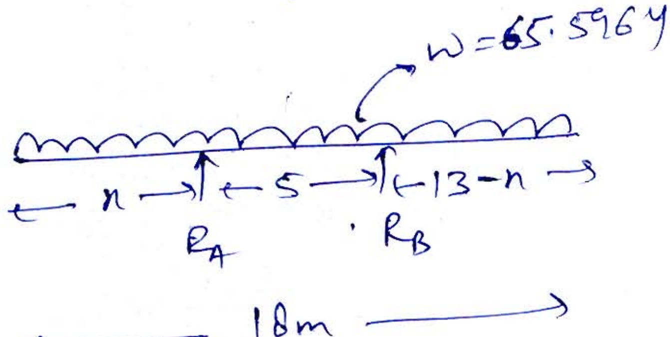
$w = 65.5964 \ N/m$

$\Sigma f_x = 0$

$w \times L = R_A + R_B$

$\Sigma M_A = 0$

$R_B \times 5 = wL\left(\frac{18}{2} - x\right)$

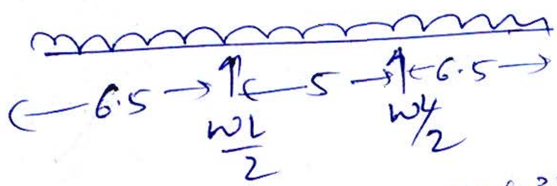



Since it has to be lift so it needs to be horizontal then Rxn must be half of the total load

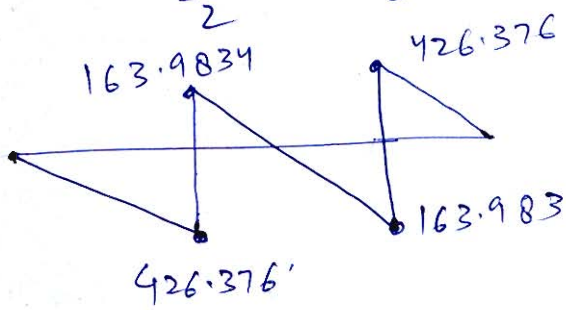
$R_A = R_B = wL/2$

It has to be evenly distributed.

$R_A = R_B = \frac{wL}{2} \Rightarrow 590.36 \ N$




(SF)

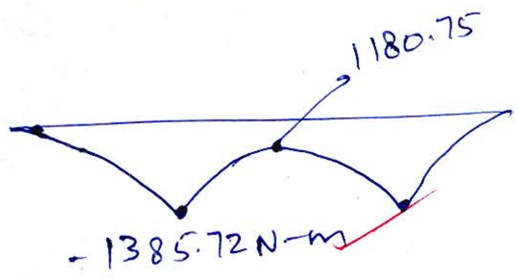



So Max Bending Moment

BM = 1385.72

$\sigma_B)_{max} = \frac{32M}{\pi d^3}$

But it is hollow

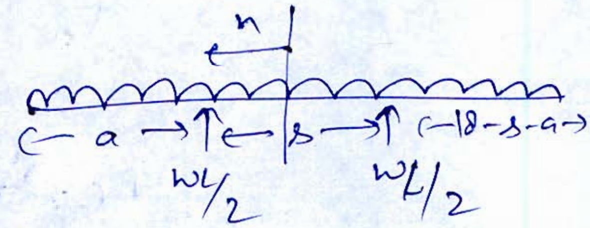



$\sigma_b|_{max} = \frac{M}{I} y$

$= \frac{1385.72 \times 10^3 \times d_o/2}{\frac{\pi}{64} d_o^4 \left[1 - \left(\frac{d_i}{d_o}\right)^4\right]} \Rightarrow \underline{10.1923 \ MPa}$

(ii) In order to Min Bending stress, point of contraflexure must be present in the beam

BM at mid eq




$\Rightarrow -\dfrac{w(n+a)^2}{2} + \dfrac{wL}{2}n$ — ①

(SF) in this region: $-w(n+a) + \dfrac{wL}{2}$

SF = 0

$n+a = L/2$

$n = \dfrac{L-2a}{2}$

Put in eqn ①

$BM\Big|_{mid} = -\dfrac{w}{2}\left(\dfrac{L}{2} - \cancel{a} + \cancel{a}\right)^2 + \dfrac{wL}{2}\left(\dfrac{L}{2} - a\right)$

$-\dfrac{wL^2}{8} + \dfrac{wL^2}{4} - \dfrac{wLa}{2}$

$\left(\dfrac{wL^2}{8} - \dfrac{wLa}{2}\right)$ (+ve)

Now -ve Bending Moment $= -wa^2/2$

This 2 should be equal and opposite in sign for Min Bending stress

$\dfrac{wL^2}{8} - \dfrac{wLa}{2} = \dfrac{wa^2}{2}$

$L^2 - 4La = 4a^2$

$4a^2 + 4La - L^2 = 0$

$a = \dfrac{-4L \pm \sqrt{16L^2 + 16L^2}}{8}$

$a = -L/2 + \dfrac{4L\sqrt{2}}{8}$

$a = \left(-L/2 + L/\sqrt{2}\right) \Rightarrow L\left(\dfrac{2-\sqrt{2}}{2\sqrt{2}}\right)$

so

$s = 18 - 2a$

$s = 18 - \dfrac{18}{\sqrt{2}}(2-\sqrt{2})$

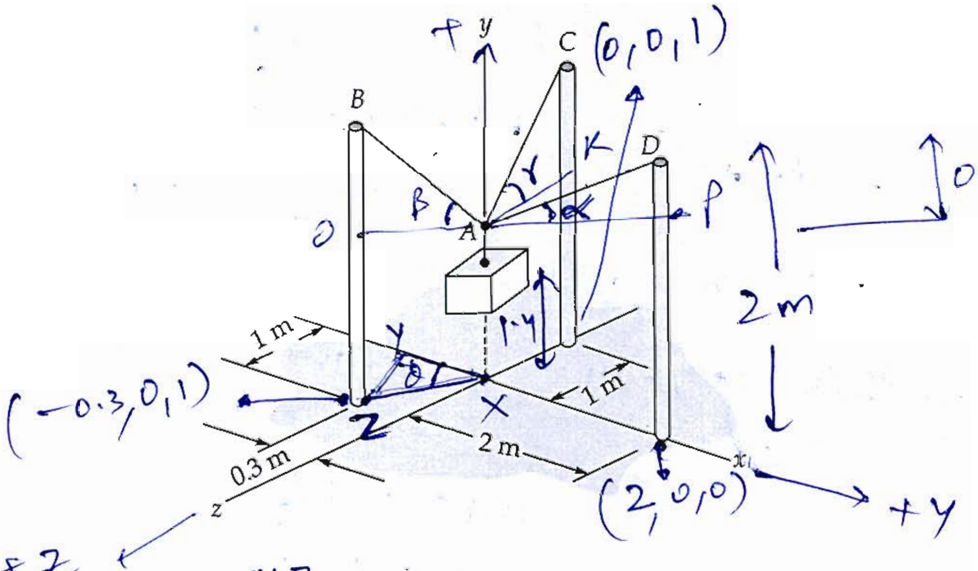
$s = +10.544$ m

for Min Bending stress

15

(iii) For Max Bending stress $s = 0$, that the sling is in the middle.

**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 $AD$.




**[20 marks]**

In $\Delta XYZ$

$\tan\theta = \frac{1}{0.3}$

$\underline{\theta = 73.3^\circ}$

$OA = \sqrt{0.3^2 + 1^2}$

$OA = 1.044$

$\tan\beta = \frac{OB}{OA}$ {In $\Delta OAB$)

$\tan\beta = \frac{0.6}{1.044}$

$\underline{\beta = 29.877}$

In $\Delta ADP$

$\cos\alpha = \frac{AP}{AD}$

$\tan\alpha = \frac{PD}{AD}$

$\tan\alpha = 0.6/2$

$\underline{\alpha = 16.699}$

$\Sigma F_x = 0$

$AB\cos\beta\cos\theta = AD\cos\alpha$

$AB\cos 29.877\cos 73.3 = AD\cos 16.699$

$\boxed{AB = 3.844\,AD}$ — (1)

$\Sigma F_z = 0$

$AB\cos\beta\sin\theta = AC\cos\gamma$

$\boxed{AB = 1.0324\,AC}$ — (2)

In $\Delta ACK$

$\tan\gamma = CK/AK$

$\tan\gamma = \frac{0.6}{1}$

$\gamma = 30.9637$

$\Sigma f_y = 0$

$AD \sin\alpha + AC \sin\gamma + AB \sin\beta = \text{Weight}$

$\text{Weight} = 15g$

taking $g = 9.81$

$AD \sin 16.9637 + AC \sin 30.96 + AB \sin 29.877$
$= 147.15$

$0.2917(AD) + 0.5144(AC) + 0.4981(AB) = 147.15$

$0.2917(0.26014)AB + 0.5144(0.9686)AB$
$+ 0.4981\, AB = 147.15$

$\boxed{AB = 137.2372\ N}$

$AD = \boxed{35.7016\ N}$

$\boxed{AC = 132.93\ N}$

In this, I balance force in x, y, z direction while taking component in that direction.

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]

a. Equivalence ratio is defined as fuel-air ratio of Actual to stoichiometric

$$\phi = \frac{(F/A)\ \text{Actual}}{(F/A)\ \text{stoich.}}$$

3

$\phi > 1$ Rich Mixture

$\phi = 1$ Stoichmetric Mixture

$\phi < 1$ Lean Mixture.

b

$$\cancel{C_xH_y + \left(x+\frac{y}{4}\right)\left(O_2 + \frac{79}{21}N_2\right) \longrightarrow xCO_2 + \frac{y}{2}H_2O + \underset{(x-1)}{CO} + O_2}$$

$$C_xH_y + \left(O_2 + \frac{79}{21}N_2\right) \longrightarrow 0.14\,CO_2 + 0.006\,CO + 0.05\,O_2 + \_\_N_2 + \underline{k}\,H_2O$$

on left side

$C \rightarrow 0.146$ k-mol

$$0.146\,C_xH_y + \underset{0.2295}{1}\left(O_2 + \frac{79}{21}N_2\right) \longrightarrow 0.14\,CO_2 + 0.006\,CO + 0.05\,O_2 + 0.8633\,N_2 + \underline{0.073}\,H_2O$$

B

In eqn (B)

$(0.146y)$ H on left side & $\frac{b}{2}(H_2)$ on right side so $b = 0.073$

Kmol of $N_2 = 1 - \Sigma$ of all other mol

$1 - 0.269$

$0.731$

3

So balanced eqn

$0.146\, C_xH_y + 0.2295\left(O_2 + \frac{79}{21}N_2\right) \rightarrow 0.14\, CO_2 + 0.006\, CO + 0.05\, O_2 + 0.8633\, N_2 + 0.073\, H_2O$

i)

OOOO

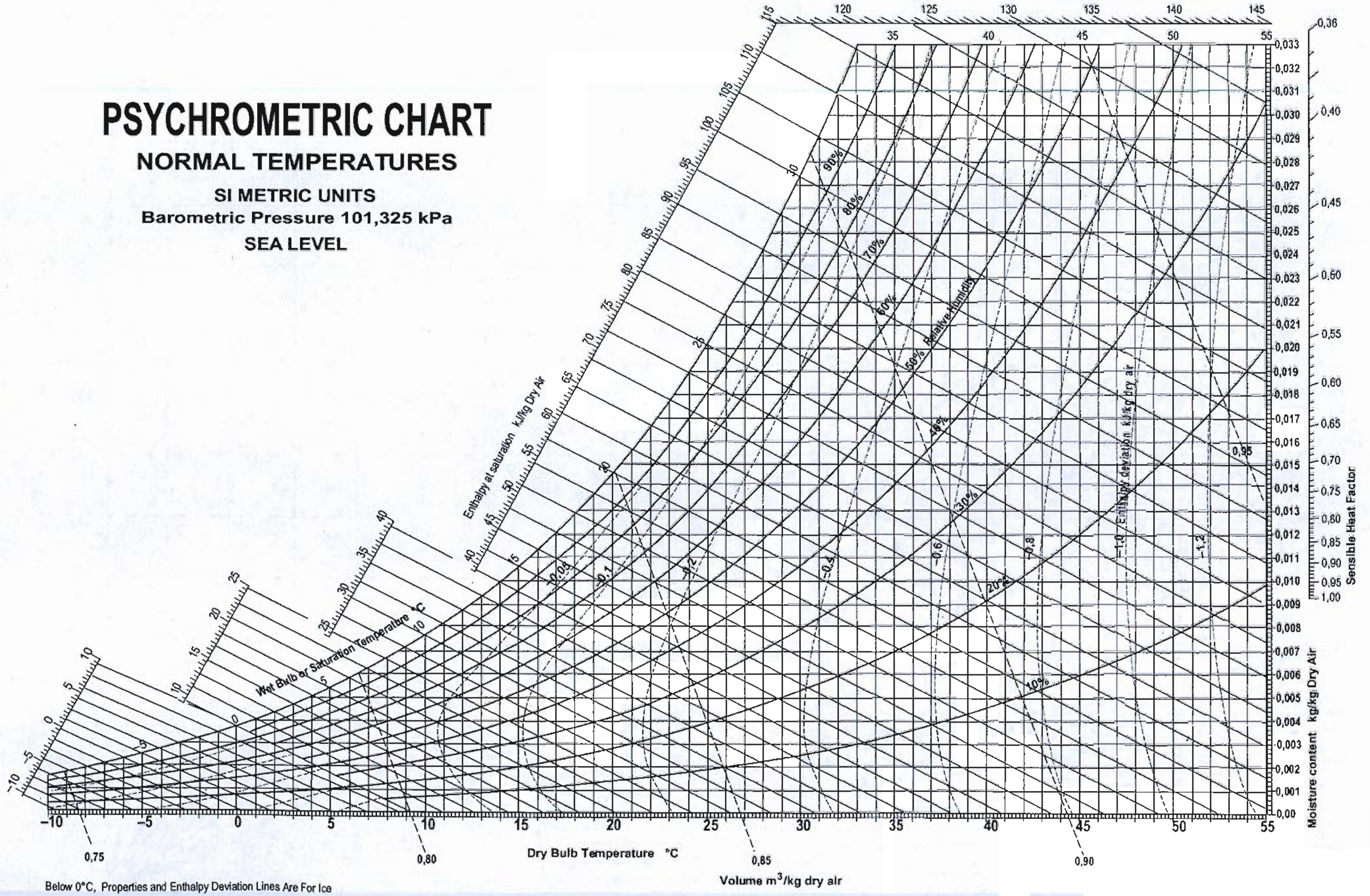
# PSYCHROMETRIC CHART

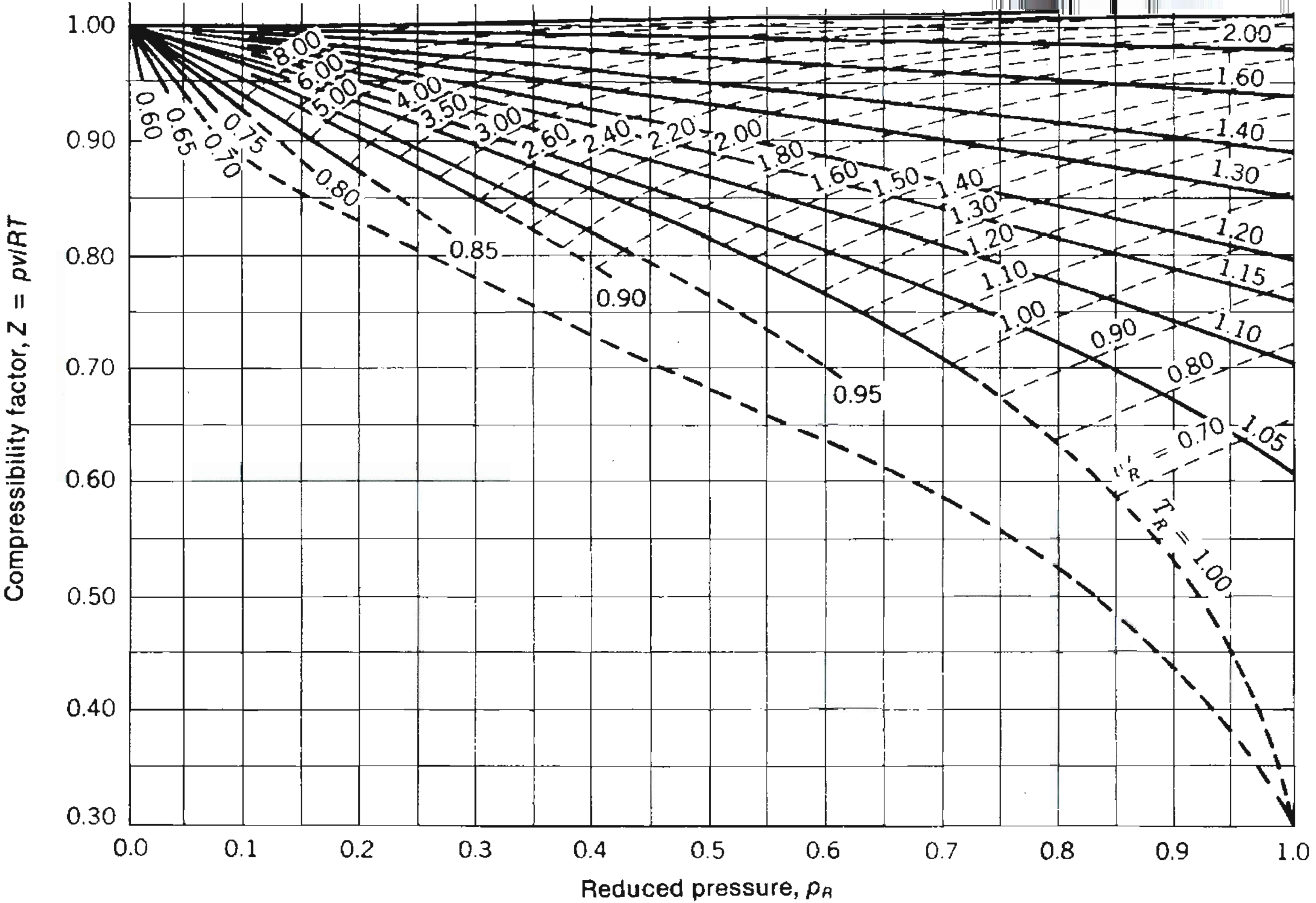
## NORMAL TEMPERATURES

**SI METRIC UNITS**

**Barometric Pressure 101,325 kPa**

**SEA LEVEL**




Compressibility factor, Z = pv/RT
Reduced pressure, p_R
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
8.00
6.00
5.00
4.00
3.50
3.00
2.60
2.40
2.20
2.00
1.80
1.60
1.50
1.40
1.30
1.20
1.15
1.10
1.05
1.00
T_R = 1.00
v'_R = 0.70

## Space for Rough Work

Space for Rough Work