



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 <input checked="" type="checkbox"/> Bhopal <input type="checkbox"/> Jaipur <input type="checkbox"/> Pune <input type="checkbox"/> Hyderabad <input type="checkbox"/>	

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	—
Q.2	—
Q.3	36
Q.4	60
Section-B	
Q.5	27
Q.6	26
Q.7	—
Q.8	—
Total Marks Obtained	149

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

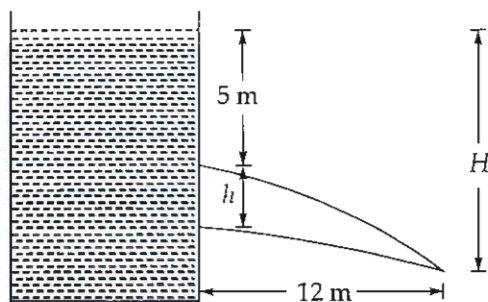
1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify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

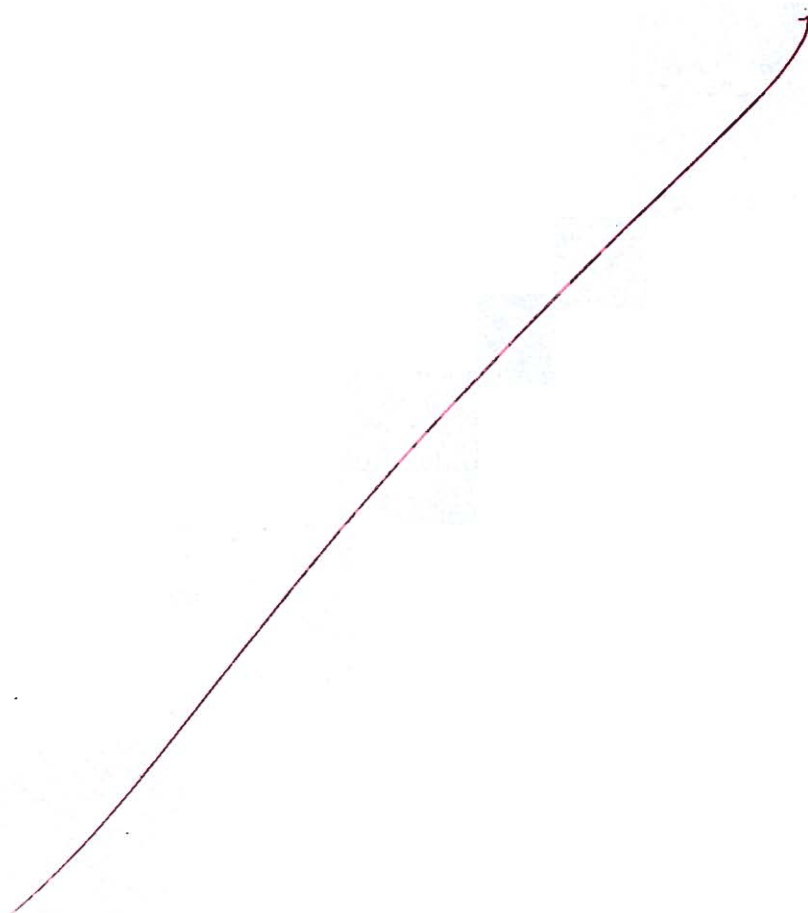
1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough 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.

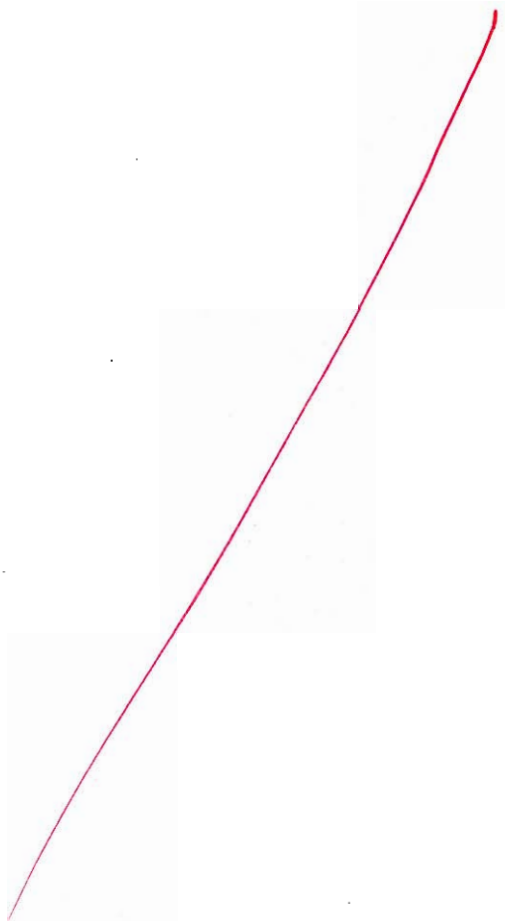
Section A : Fluid Mechanics and Turbo Machinery

- 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.

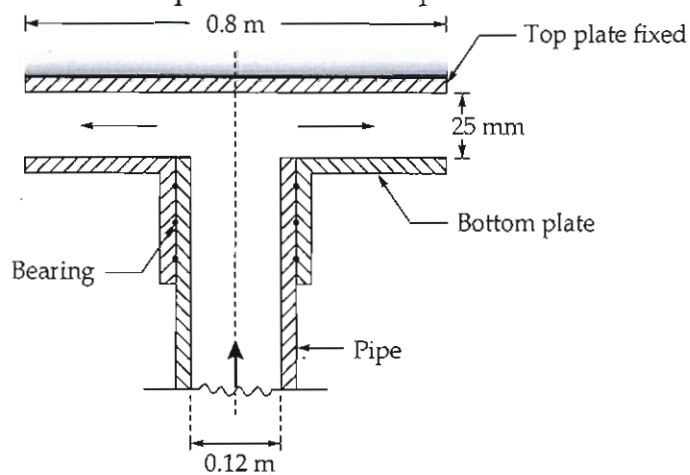


[12 marks]

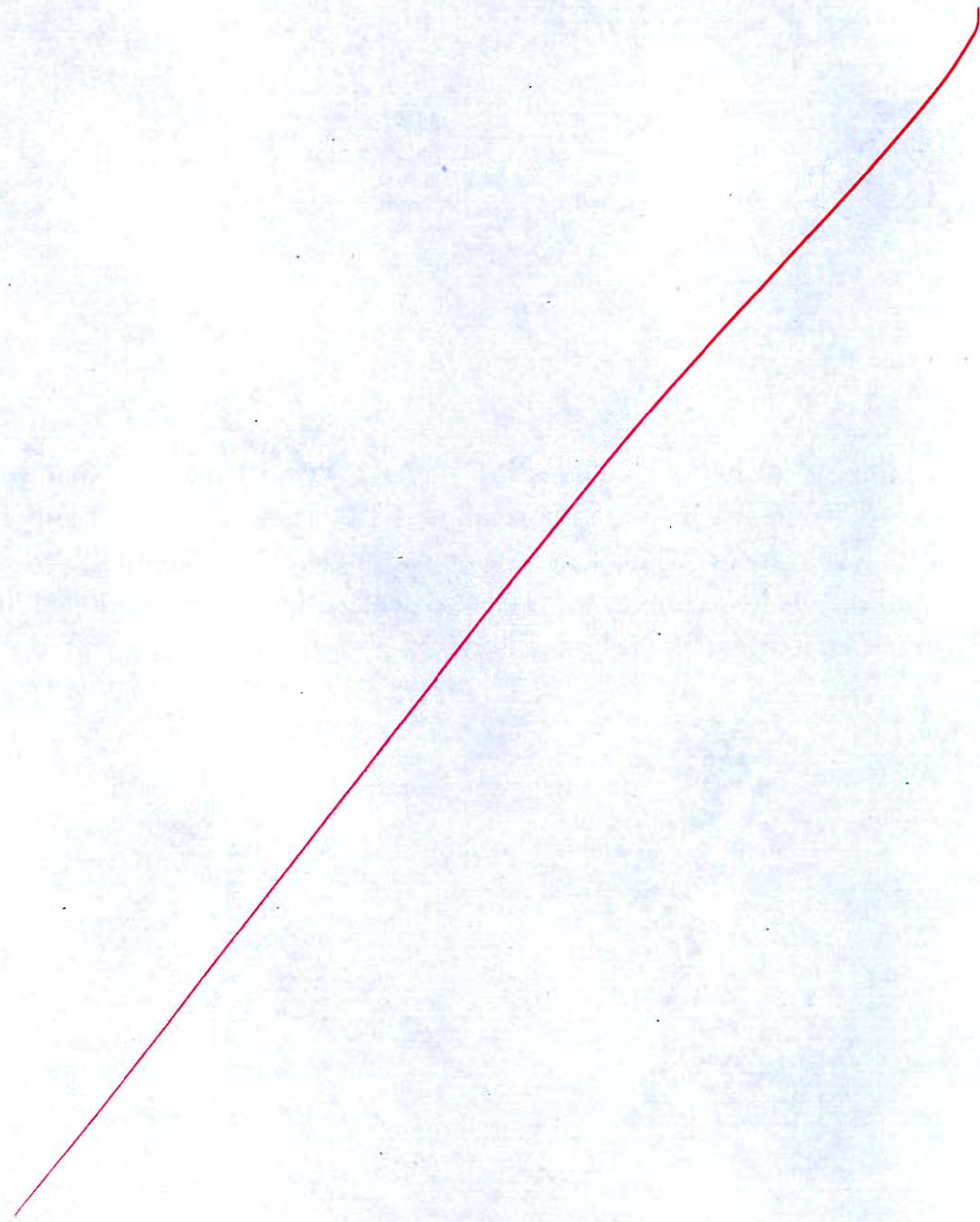




- Q.1 (b) Water flows in at a rate of 100 l/s from the pipe as shown in figure and flows outwards through the space between the top and bottom plates. The top plate is fixed. Determine the net force on the bottom plate. Assume the pressure at radius $r = 0.06 \text{ m}$ is atmospheric.

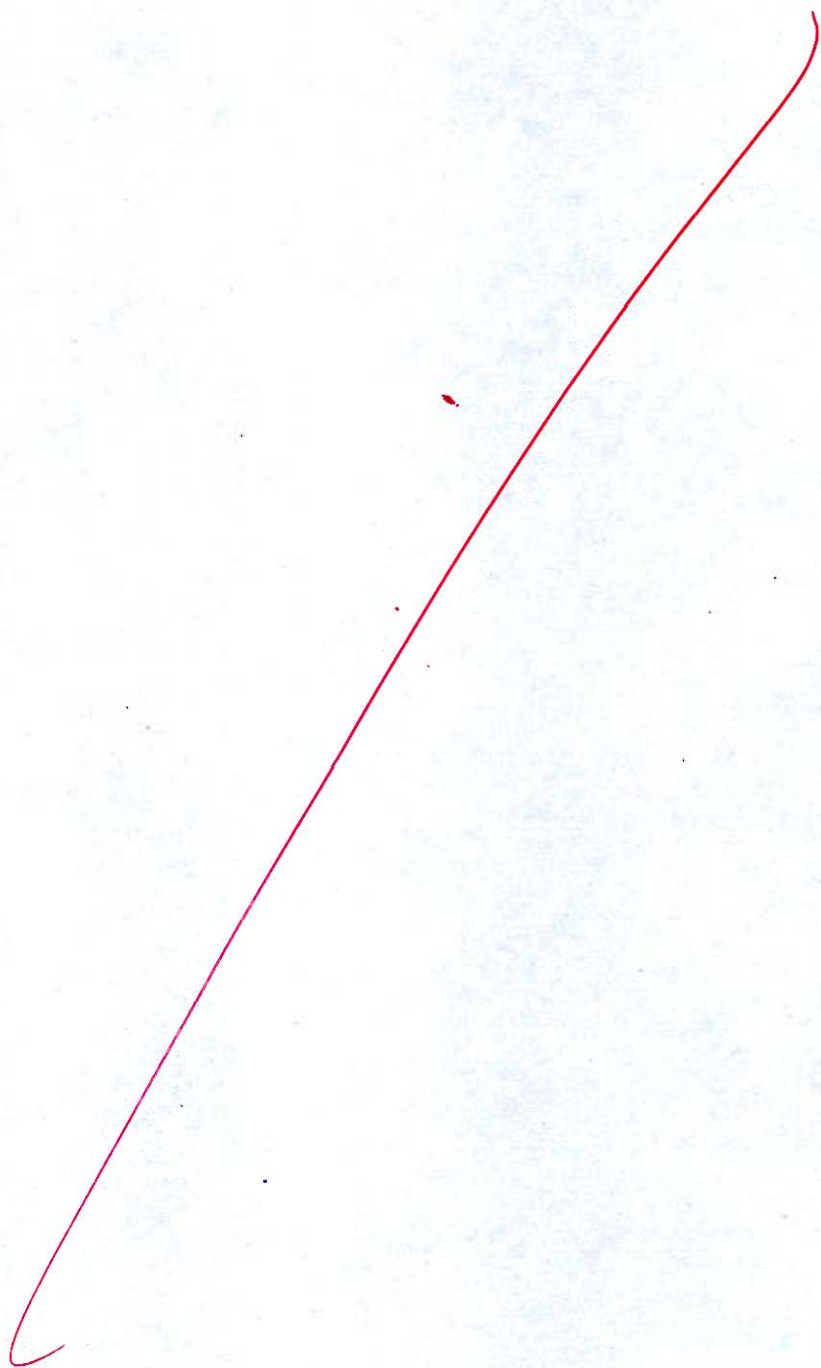


[12 marks]



- 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.

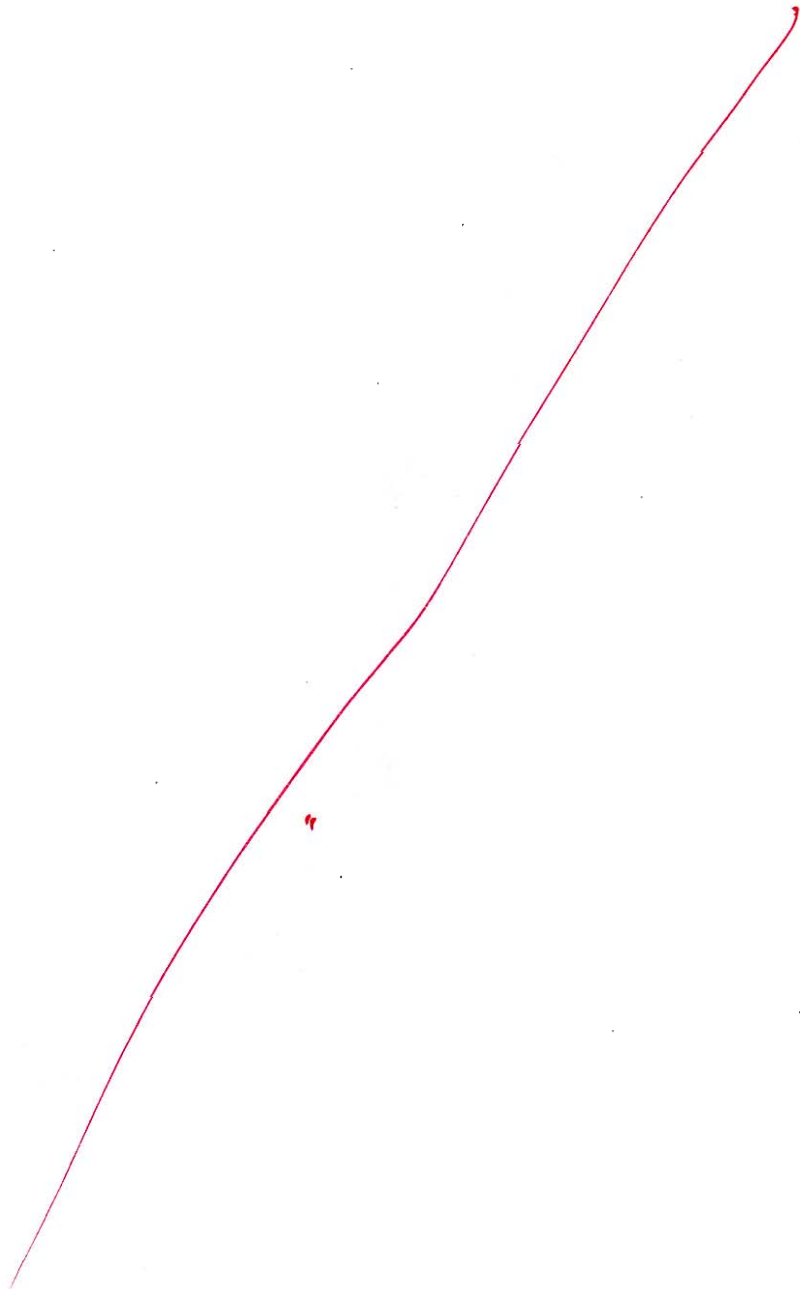
[12 marks]



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

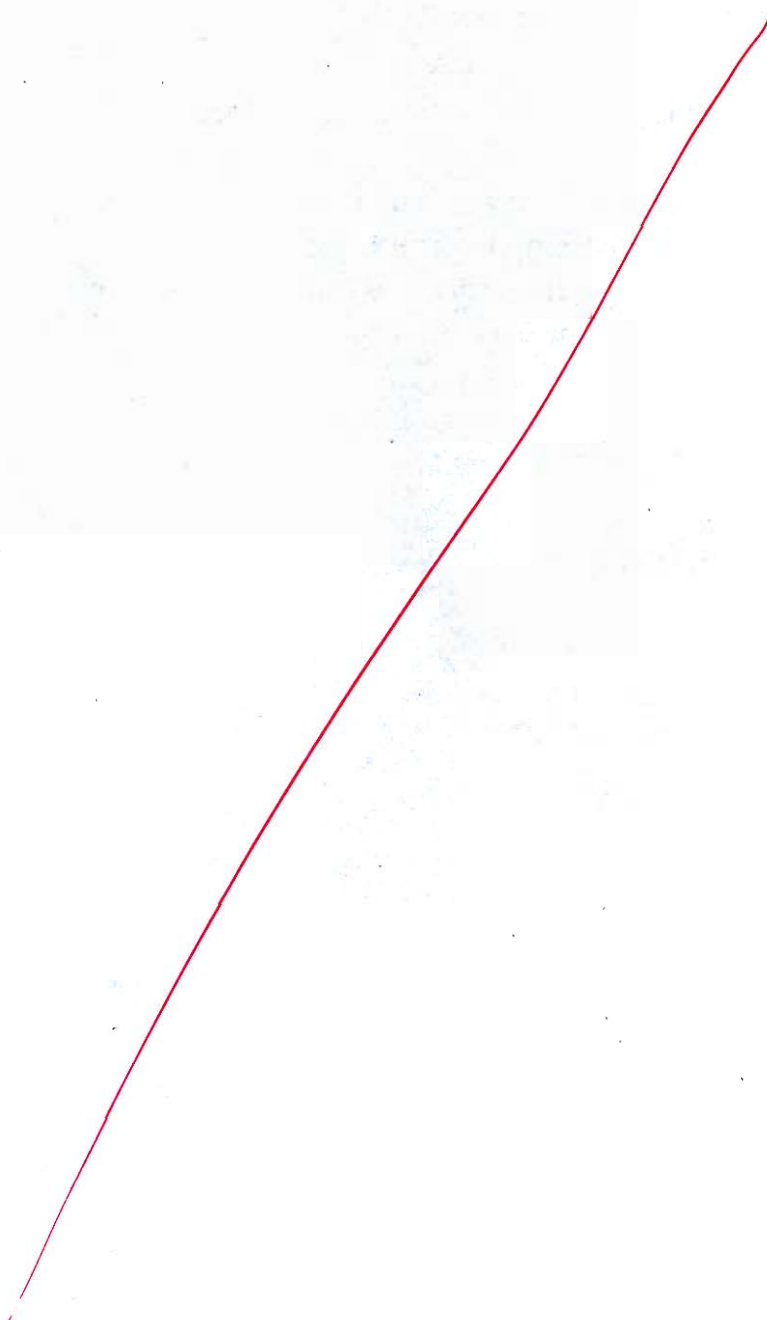
$$d = \left(\frac{D^5}{2fL} \right)^{1/4} ; \text{ where, } f = \text{friction factor and } L = \text{length of the pipe}$$

[12 marks]



- 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.

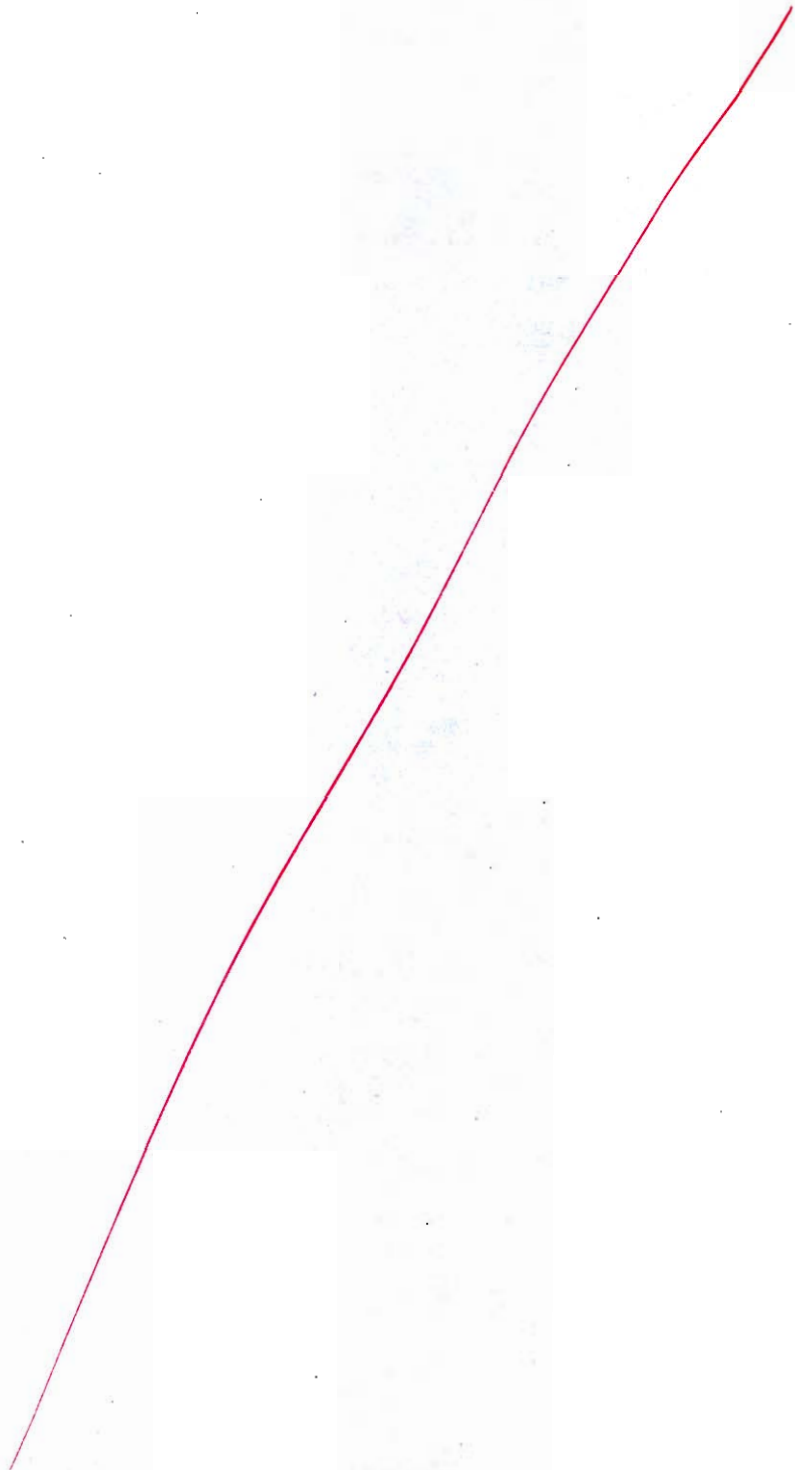
[6 + 6 = 12 marks]

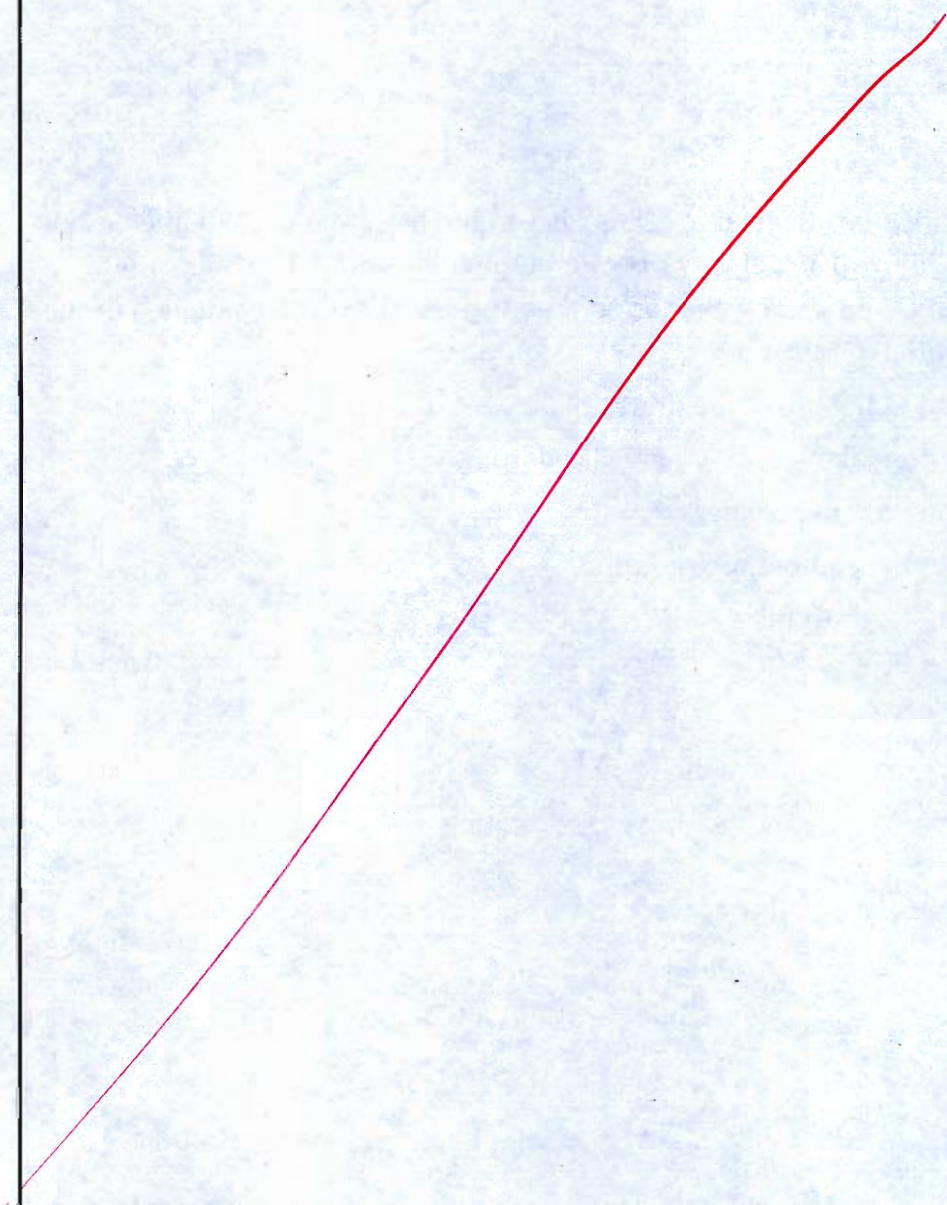


- 2 (a) A circular pipe of radius R_1 is placed concentrically inside another pipe of radius R_2 . If the flow in the annular space between the pipes is laminar, show that the maximum velocity occurs at a radius r is given by

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

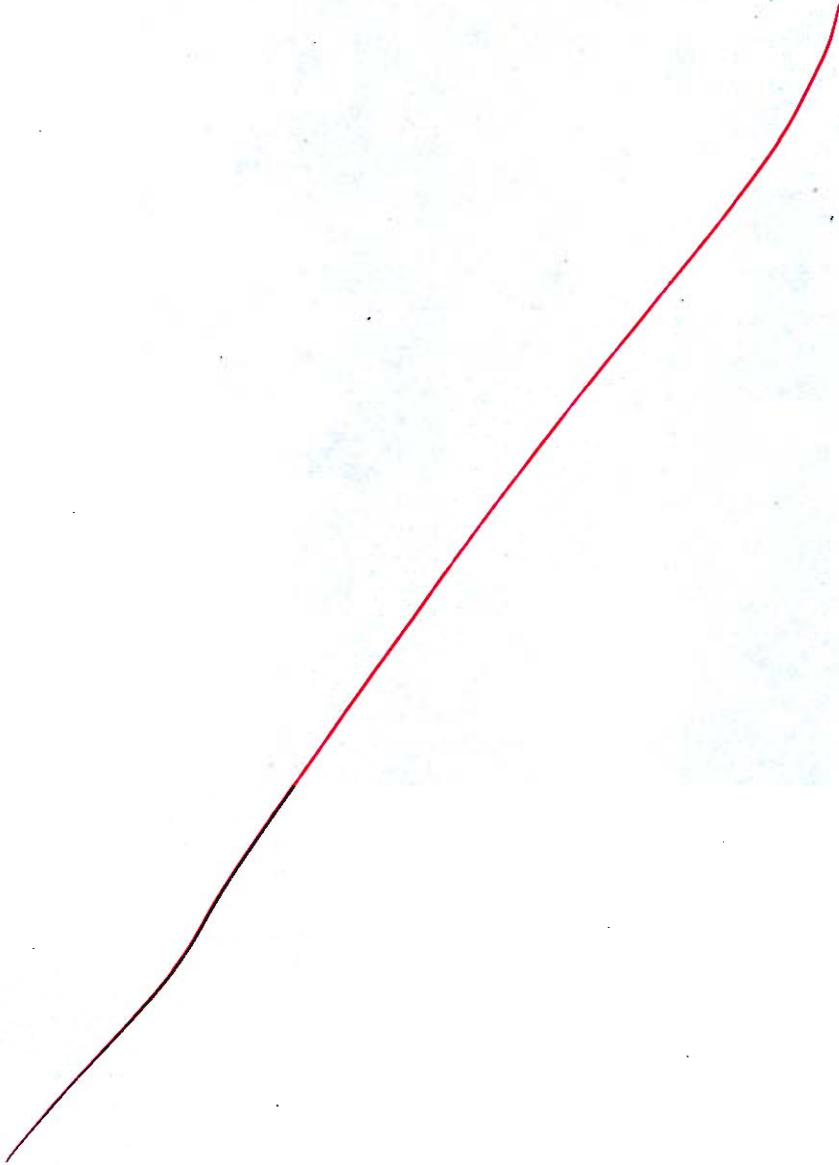
[20 marks]

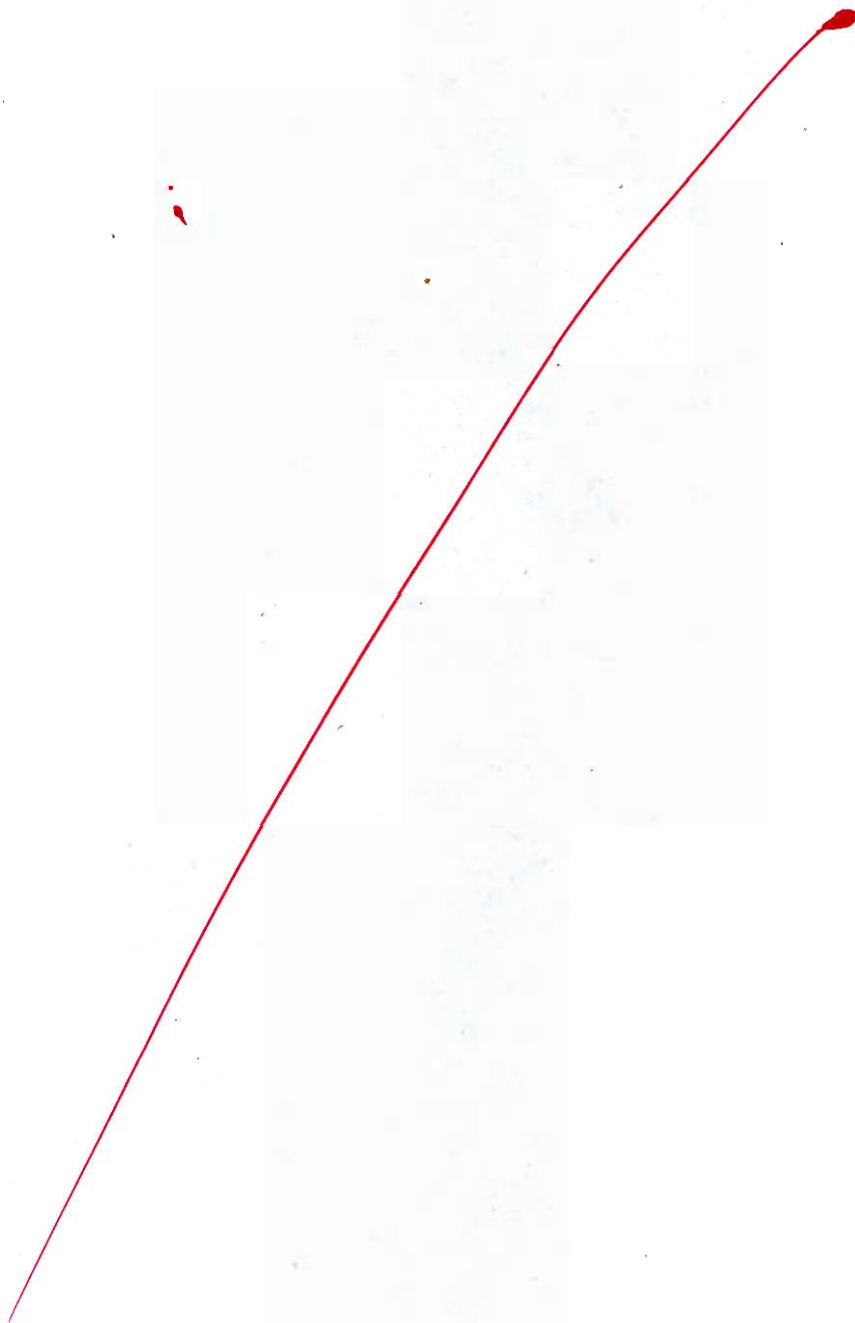




- Q.2 (b) A straight conical draft tube attached to a Francis turbine has an inlet of diameter 2 m and its outlet area is 25 m^2 . The velocity of water at inlet is 10 m/s . The inlet is set 5 m above the tail race level. Assuming the loss of head in the draft tube equals half the velocity head at its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

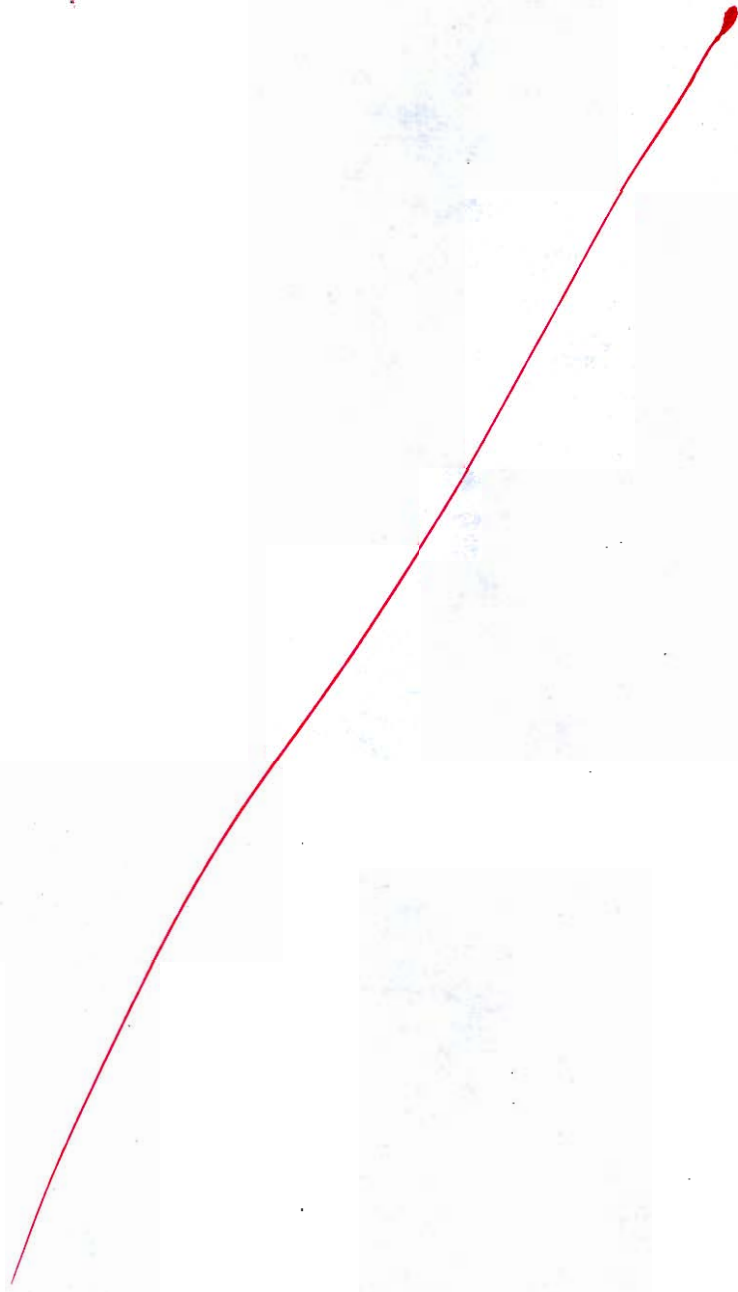
[20 marks]





- 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]



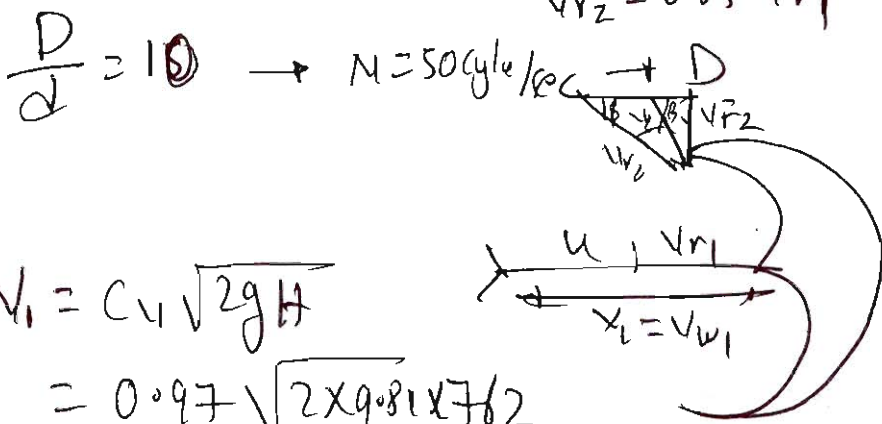
Q.3 (a) A single jet pelton turbine is required to drive a generator to develop 10 MW. The available head at the nozzle is 762 m. Assuming electric generator efficiency 95%, Pelton wheel efficiency 87%, coefficient of velocity for nozzle 0.97, mean bucket velocity 0.46 of jet velocity, outlet angle of 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]

Sol) $S.P = 10 \times 10^6 \text{ W}$ $\eta_H = 87\%$
 $H = 762 \text{ M}$ $C_v = 0.97$
 $\eta_G = 95\%$ $u = 0.46 V_1$
 $\phi = 15^\circ$
 $V_{r2} = 0.85 V_{r1}$



$V_1 = C_v \sqrt{2gH}$
 $= 0.97 \sqrt{2 \times 9.81 \times 762}$
 $V_1 = 118.60 \text{ m/s}$

$u = 0.46 \times 118.60 = 54.557 \text{ m/s}$

$\eta_H = \frac{R.P.}{\rho g Q H}$

$0.87 = \frac{\eta_G \times S.P.}{\rho g Q H} = \frac{10526315.79}{1000 \times 9.81 \times Q \times 762}$

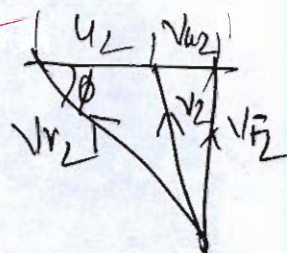
$\therefore Q = 1.6185 \text{ m}^3/\text{sec}$

→ ii) dia of jet 'd'

$$\dot{Q} = \frac{\pi}{4} d^2 \times v_1$$

$$1.06185 = \frac{\pi}{4} d^2 \times 118.60$$

$$\therefore d = 131.819 \text{ mm}$$



→ iii) $F = \dot{m}(v_{w1} + v_{w2})$

$$= 1.06185 \times 1000 [118.60 + (-1.9755)]$$

$$F = 188.757 \text{ kN}$$

$$v_2 \cos \phi = v_{w2} + u_2$$

$$v_{w2} = v_2 \cos \phi - u_2$$

$$= 0.85 v_2 \cos \phi - u_2$$

$$v_{w2} = -1.9753$$

$$\rightarrow \frac{D}{d} \rightarrow \frac{347.3}{131.819} < 10$$

16

$$\rightarrow 10 = \frac{D}{131.819}$$

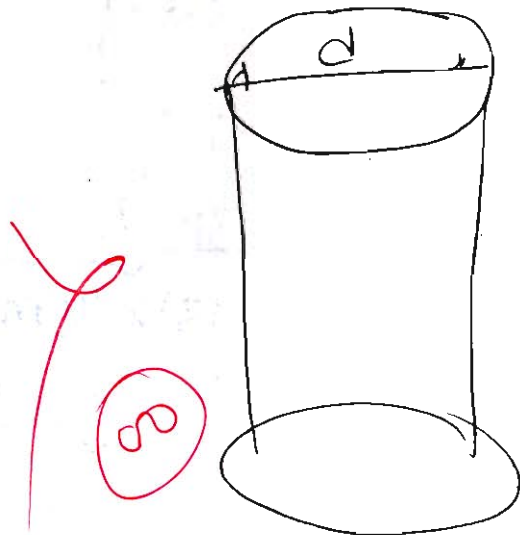
$$D = 1318.19 \text{ mm}$$

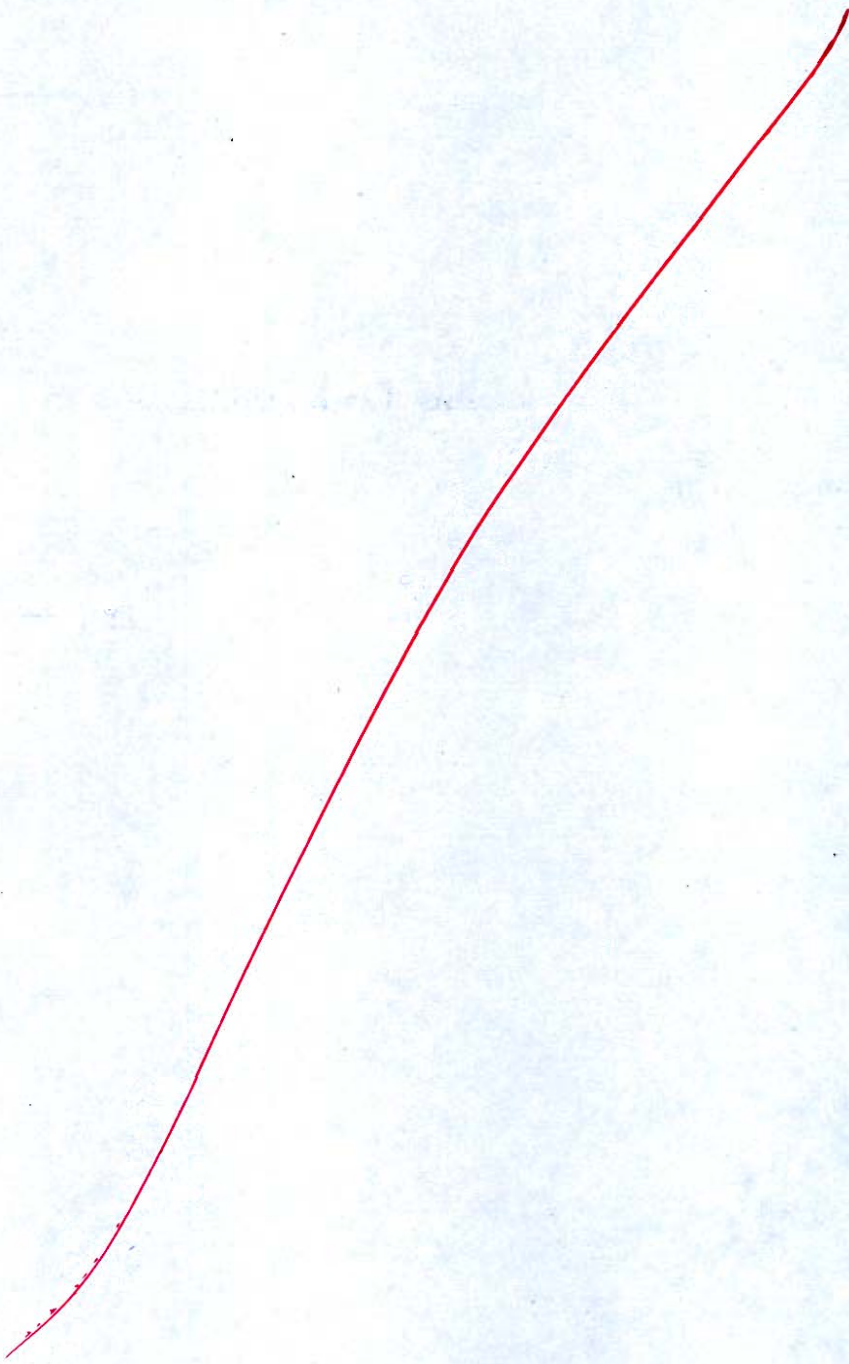
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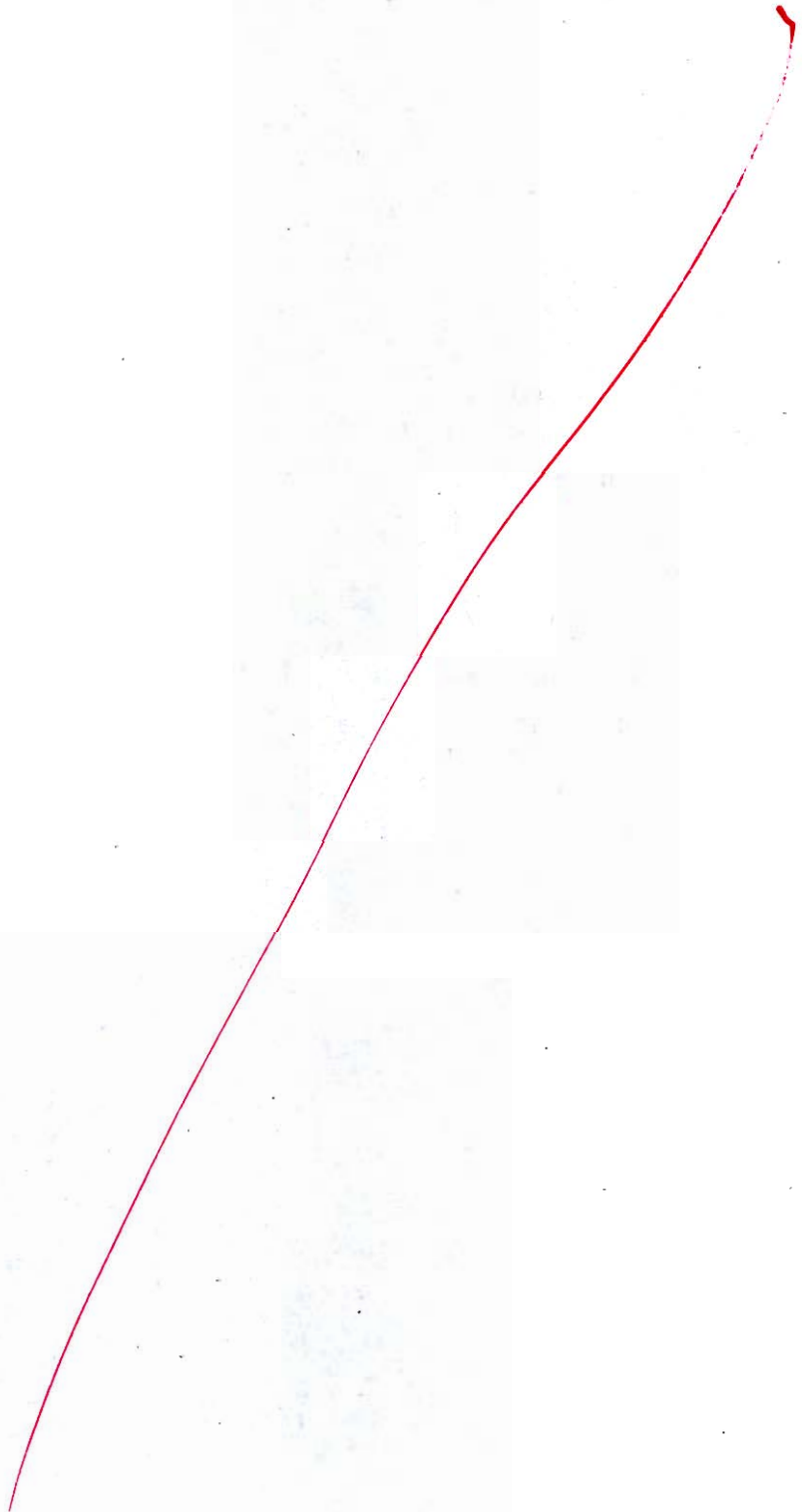
Q.3 (b) An 100 mm diameter composite solid cylinder consists of an 100 mm diameter 30 mm thick metallic plate having specific gravity 5, attached at the lower end of an 100 mm diameter wooden cylinder of specific gravity 0.85. Find the limits of the length of the wooden portion so that composite cylinder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

[20 marks]

→







1.3 (c) A centrifugal compressor runs at 12000 rpm and delivers $700 \text{ m}^3/\text{min}$ 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:

- Power input to the compressor
- Impeller diameters at inlet and outlet and width at inlet,
- Impeller and diffuser blade angles at inlet.

Assume radial blades at outlet and no swirl at inlet.

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

[20 marks]

Given data

$$N = 12000 \text{ rpm}$$

$$\omega = \frac{2\pi N}{60} = 1256.637 \text{ rad/s}$$

$$g_p = 5$$

$$P_1 = 100 \text{ kPa}$$

$$T_1 = 293 \text{ K}$$

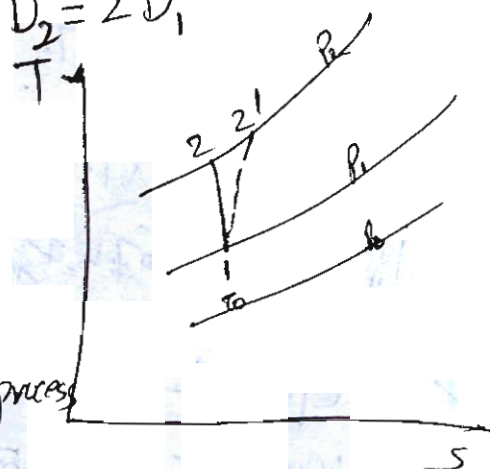
$$V_f = 60 \text{ m/s}$$

from Isentropic compression process

$$P V^{\gamma} = C$$

$$\eta_{\text{iso}} = 82\%$$

$$D_2 = 2 D_1$$



$$T_2 = T_1 (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = 293 [5]^{\frac{0.4}{1.4}}$$

$$T_2 = 464.05 \text{ K}$$

$$\rightarrow \eta_{is} = \frac{T_2' - T_1}{T_2' - T_1}$$

$$T_2' = T_1 + \frac{T_2 - T_1}{\eta_{is}}$$

$$T_2' = 293 + \frac{(464.05 - 293)}{0.82}$$

$$T_2' = 501.60 \text{ K}$$

$$\rightarrow \frac{P_0}{P_1} = \left(\frac{T_0}{T_1} \right)^{\frac{\gamma}{\gamma-1}}$$

$$P_0 = 100 \left(\frac{291.208}{293} \right)^{\frac{1.4}{0.4}}$$

$$P_0 = 97.725$$

→ power input to compressor

$$P_{\text{input}} = \dot{m} C_p (T_2' - T_1)$$

$$= 13.64 \times 1005 (501.60 - 293)$$

$$P_{\text{input}} = \cancel{844.74 \text{ kW}} \quad 2859.53 \text{ kW}$$

→

$$C_p (T_2' - T_1) = u_2^2$$

$$1005 (501.60 - 293) = u_2^2$$

[assuming air is ideal gas]

$$T_0 = T_1 - \frac{V^2}{2C_p}$$

$$= 293 - \frac{60^2}{2 \times 1005}$$

$$T_0 = 291.208 \text{ K}$$

→ for ideal gas equation

$$\dot{m} = \frac{P_0 \dot{V}}{R T_0}$$

$$\dot{m} = \frac{97.725 \times \frac{700}{60}}{0.287 \times 291.208}$$

$$\dot{m} = 13.641 \text{ kg/sec}$$

$$U_2 = 457.86 \text{ m/s}$$

$$\rightarrow U_2 = \frac{\pi D_2 N}{60}$$

$$457.86 = \frac{\pi D_2 \times 12000}{60}$$

outlet dia $D_2 = 0.7287 \text{ m} = 728 \text{ mm}$

inlet dia $D_2 = 2D_1 = 2 \times 364.35 \text{ mm}$

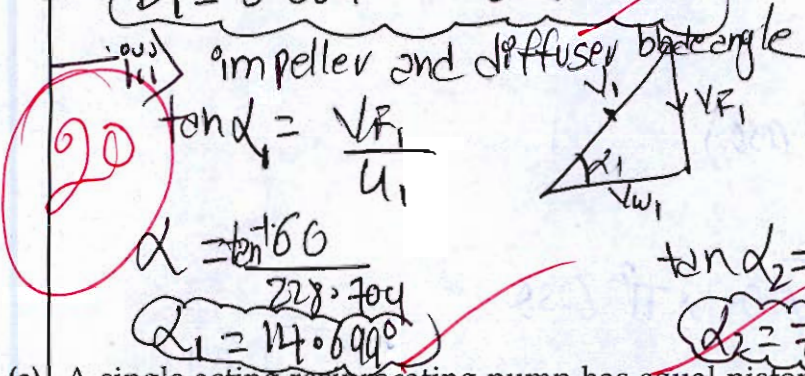
$$D_1 = 0.364 \text{ m} = 364.35 \text{ mm}$$

$$Q = \pi b_1 d_1 V F_1$$

$$\frac{700}{60} = \pi \times b_1 \times 0.364 \times 60$$

inlet width $b_1 = 0.17 \text{ m} = 170 \text{ mm}$

$$U_1 = \frac{\pi D_1 N}{60} = 228.7 \text{ m/s}$$



2.4 (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]

Sol $\rightarrow D = 200 \text{ mm} = 0.2 \text{ m}$ $h_s = 5 \text{ m}$

$L = 0.2 \text{ m}, g = 0.1 \text{ m}$ $h_d = 35 \text{ m}$

$l_s = 6.5 \text{ m}, l_d = 40 \text{ m}$

$d_s = d_d = 0.075 \text{ m}$

$N = 30 \text{ rpm} \rightarrow \omega = \frac{2\pi \times 30}{60} = \pi \text{ rad/sec}$

$f = 0.05$

Acceleration head suction

$$h_{as} = \frac{l_s}{g} \left(\frac{A}{A_s} g \omega^2 \cos \theta \right)$$

$$h_{as} = \frac{6.5}{9.81} \left(\left(\frac{0.2}{0.075} \right)^2 \times 0.1 \times \pi^2 \cos \theta \right)$$

$$h_{as} = 4.65 \cos \theta$$

$$\text{at } \theta = 0^\circ \rightarrow h_{as} = 4.65 \text{ m}$$

$$\theta = 90^\circ \rightarrow h_{as} = 0$$

$$\theta = 180^\circ \rightarrow h_{as} = -4.65 \text{ m}$$

→ Acceleration head
at delivery stroke

$$h_{ad} = \frac{l_d}{g} \left(\frac{A}{A_d} \omega^2 \cos \theta \right)$$

$$= \frac{46}{9.81} \left(\frac{0.2}{0.075} \right)^2 \times 0.1 \times \pi^2 \cos \theta$$

$$h_{ad} = 28.6172 \cos \theta$$

$$\text{at } \theta = 0^\circ \rightarrow h_{ad} = 28.6172 \text{ m}$$

$$\theta = 90^\circ \rightarrow h_{ad} = 0$$

$$\theta = 180^\circ \rightarrow h_{ad} = -28.6172$$

→ frictional head at suction pipe

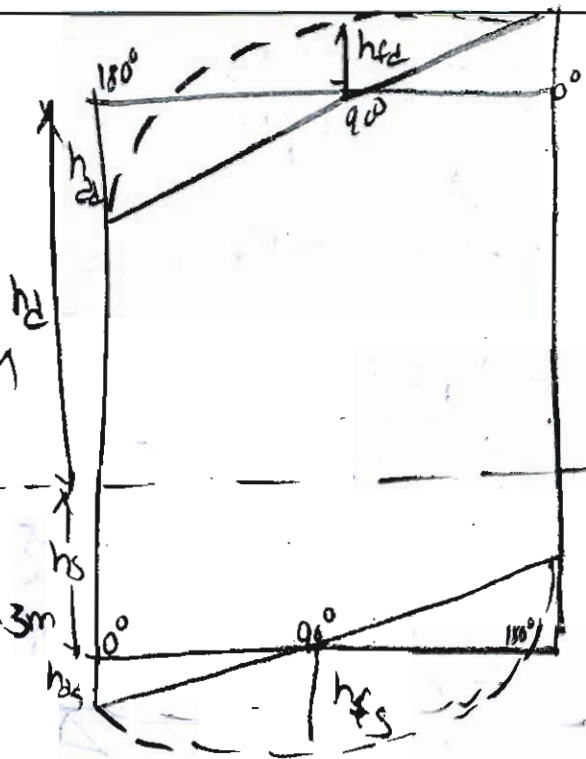
$$h_{fs} = \frac{f l_s \left(\frac{A}{A_s} \omega \sin \theta \right)^2}{2g d_s}$$

$$h_{fs} = \frac{0.05 \times 0.5 \left(\frac{0.2}{0.075} \right)^2 \times 0.1 \times \pi^2 \sin^2 \theta}{2 \times 9.81 \times 0.075}$$

$$h_{fs} = 1.1025 \sin^2 \theta$$

$$\text{at } \theta = 0^\circ \rightarrow h_{fs} = 0$$

$$\theta = 90^\circ \rightarrow h_{fs} = 1.1025 \text{ m}$$



$$Q = \frac{L A \omega}{60}$$

$$= \frac{0.2 \times \frac{\pi}{4} (0.2)^2 \times 30}{60}$$

$$Q = 3.14 \times 10^{-3} \text{ m}^3/\text{sec}$$

at $\theta = 180^\circ \rightarrow h_{fs} = 0$

→ frictional head at delivery pipe

$$h_{fd} = \frac{f L_d \left(\frac{A}{A_d} v \sin \theta \right)^2}{2g d_d}$$

$$h_{fd} = \frac{0.05 \times 40}{2 \times 9.81 \times 0.075} \left(\left(\frac{0.2}{0.075} \right)^2 \times 0.1 \times \pi \sin \theta \right)^2$$

$$h_{fd} = 6.7833 \sin^2 \theta$$

at $\theta \rightarrow 0^\circ \Rightarrow h_{fd} = 0$

$\theta = 90^\circ \Rightarrow h_{fd} = 6.7833 \text{ m}$

$\theta = 180^\circ \rightarrow h_{fd} = 0$

∴ Absolute pressure at suction stroke

at beginning → $P_{ob} = 10.3 - h_s - h_{as}$
 $= 10.3 - 5 - 4.065$
 $= 1.27 \text{ M}$

at middle → $P_{ob} = 10.3 - h_s - h_{fs}$
 $= 10.3 - 5 - 1.0102$
 $= 4.2898 \text{ M}$

at end → $P_{ob} = 10.3 - h_s + h_{as}$
 $= 10.3 - 5 + 4.065$
 $= 9.365 \text{ M}$

Power required

$$P = \rho g Q \left(h_s + h_d + \frac{2}{3} h_{fs} + \frac{2}{3} h_{fd} \right)$$

$$P = 1000 \times 9.81 \times 3.14 \times 0.075^2 \times \left(5 + 3.572 + \frac{2}{3} h_{fs} + \frac{2}{3} h_{fd} \right)$$

Power required to drive

$$P = 1394 \text{ W}$$

→ Absolute pressure at delivery stroke

at beginning $P_{ob} = 10.3 + h_d + h_{ad}$

$$= 10.3 + 35 + 28.017$$

$$= 73.317 \text{ M}$$

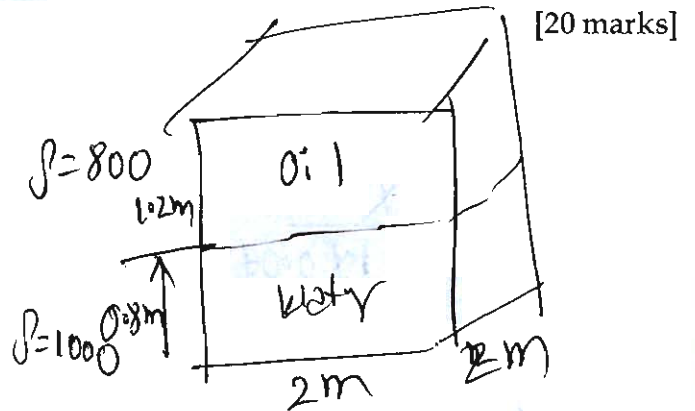
at middle

$$P_{ob} = 52.083 \text{ M}$$

at end

$$P_{ob} = 16.68 \text{ M}$$

- 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
- The total hydrostatic pressure force
 - The position of centre of pressure



sol

$$P_1 = \rho g h_1$$

$$= 800 \times 9.81 \times 1.2$$

$$= 9477.6 \text{ N/m}^2$$

$$P_2 = P_1 + 1000 \times 9.81 \times 0.8$$

$$P_2 = 23544 \text{ N/m}^2$$

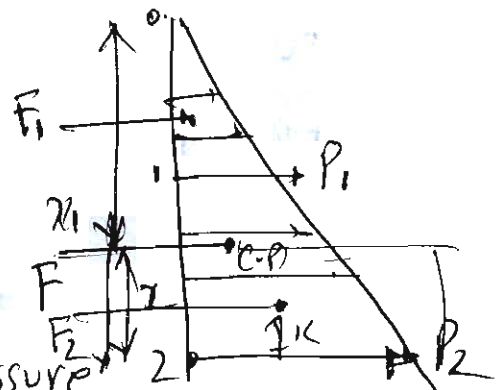
$$P_2 = 17265.6$$

i) total hydrostatic pressure force equal to volume of pressure prism

$$F_{\text{Hyd}} = \frac{1}{2} \times 9477.6 \times 1.2 \times 2 + \frac{1}{2} \times (9477.6 + 17265.6) \times 0.8 \times 2$$

$$F_{\text{Hyd}} = 50277.2$$

$$F_{\text{Hyd}} = 32647.68 \text{ N}$$



ii) position of centre of pressure (x) from botto

$$F_1 x_1 = F_1 x_1 + F_2 x_2$$

~~$$31342 \times x = 18835.2 \times 1.0 + 21346.56$$~~

~~$$50227.2$$~~

$$32647.6 x = 11301.2 \times 1.0 + 21346.56 \times 0.3607$$

$$x = 0.65124 \text{ m from bottom}$$

20

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]

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

for Momentum thickness ' θ '

$$\theta = \int_0^{\delta} \left(\frac{u}{U}\right) \left(1 - \frac{u}{U}\right)^2 \cdot dy$$

$$\theta = \int_0^{\delta} \left[2\left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^3 + \left(\frac{y}{\delta}\right)^4 \right] \left[1 - \left[2\left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^3 + \left(\frac{y}{\delta}\right)^4 \right] \right]^2 dy$$

$$\theta = \frac{37}{315} \delta$$

→ from Vonkarmen equation

$$\frac{\tau}{\rho U^2} = \frac{d\theta}{dx}$$

$$\tau = \rho U_0^2 \frac{d}{dx} \left(\frac{37}{315} \delta \right)$$

$$\tau = \rho \frac{37}{315} \rho U_0^2 \frac{d\delta}{dx} \quad \text{--- (A)}$$

→ from Newton law of viscosity

$$\tau = \mu \left. \frac{du}{dy} \right|_{y=0}$$

$$\tau = \mu \left. \frac{d}{dy} \left[U_0 \left(2\left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^3 + \left(\frac{y}{\delta}\right)^4 \right) \right] \right|_{y=0}$$

$$\tau = \mu U_0 \left[\frac{2}{\delta} - 6\left(\frac{y^2}{\delta}\right) + 4\frac{y^3}{\delta} \right]_{y=0}$$

$$\tau = \frac{\mu U_0 2}{\delta} \quad \text{--- (B)}$$

equation A and B

$$\frac{\mu U_0 2}{\delta} = \frac{37}{315} \rho U_0^2 \frac{d\delta}{dx}$$

$$\delta d\delta = \frac{2\mu U_0^2 \times 315}{37 \rho U_0^2} dx \quad \rightarrow \quad \delta d\delta = \frac{0.30 \mu U_0}{37 \rho U_0} dx$$

integrating above equation

$$\frac{\delta^2}{2} = \frac{0.30 \mu}{37 \rho U_0} x + C$$

at $x=0 \rightarrow \delta=0 \therefore C=0$

$$\frac{\delta^2}{2} = \frac{0.30 \mu x}{37 \rho U_0} \quad \rightarrow \quad \text{By multiply and divide by } x'$$

$$\frac{\delta^2}{2} = \frac{0.30 \mu x}{37 \rho U_0} \times \frac{x}{x}$$

$$\delta = \frac{5.835x}{\sqrt{Pex}} \quad \rightarrow \quad \text{boundary layer thickness}$$

→ By substituting τ' in eq (8)

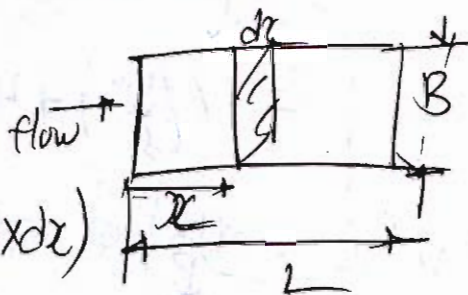
$$\tau = \frac{\mu U_\infty x}{5.835 x \sqrt{Re_x}}$$

$$\tau = \frac{0.3427 \mu U_\infty \sqrt{Re_x}}{x} \quad \text{shear intensity}$$

→ Drag force

Consider a element of dx at x distance on plate
 $B = \text{width of plate}$

Force on element $dF_D = \tau_w (B dx)$



$$dF_D = \frac{0.3427 \mu U_\infty \sqrt{Re_x}}{x} [B dx]$$

$$dF_D = 0.3427 \mu U_\infty \sqrt{\frac{\rho U_\infty}{\mu}} B \left(\frac{\sqrt{x}}{x} \right) dx$$

By integrating 0 to L

$$\int_0^L dF_D = 0.3427 \mu U_\infty \sqrt{\frac{\rho U_\infty}{\mu}} B \int_0^L \frac{1}{\sqrt{x}} dx$$

$$F_D = 0.6854 \mu U_\infty B \sqrt{Re_L} \quad \text{force on one side of plate}$$

20

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

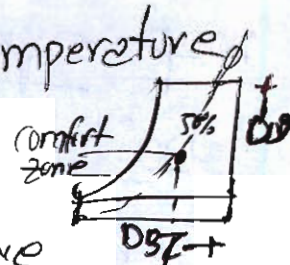
Q.5 (a) Explain the term human comfort in air conditioning. What are the factors governing optimum effective temperature? Discuss the various loads for estimating the cooling load of an air conditioned space?

[12 marks]

Sol) human comfort mean the effective temperature and relative humidity where human feels comfort is known as human comfort condition

→ Basically, it 22° - 23° Dry bulb temperature at 50%-60% relative humidity.

→ factor governing optimum effective temperature



→ density of occupancy :- human feels uncomfortable at more density of occupancy. For comfort human at highly density of occupancy require less effective temperature

2) climatic condition :- summer requires less effective temperature than in winter

3) gender & age :- older person requires less effective temperature than young person

4) wearing cloths

→ loads for estimating the cooling load

1) load due to solar heat gain → To avoid direct contact with sun, Glasses windows to be replace

2) infiltration :- To cool the air ventiated by exhaust air through heat exchanger pipe through ~~latent~~ latent heat

3) light and operating machine :- load raise due heat produce by light and equipments

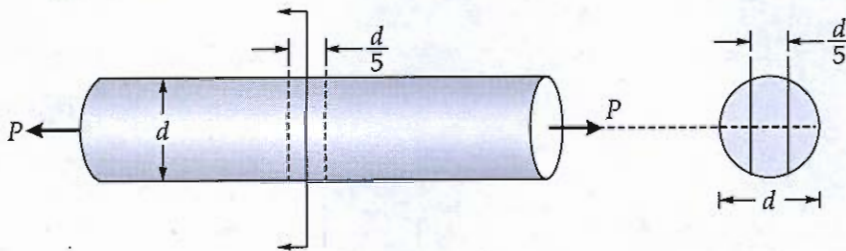
4) roof exposed to sun and thermal conductivity of building materials :- thickness of insulating material to be 6mm or more

5)

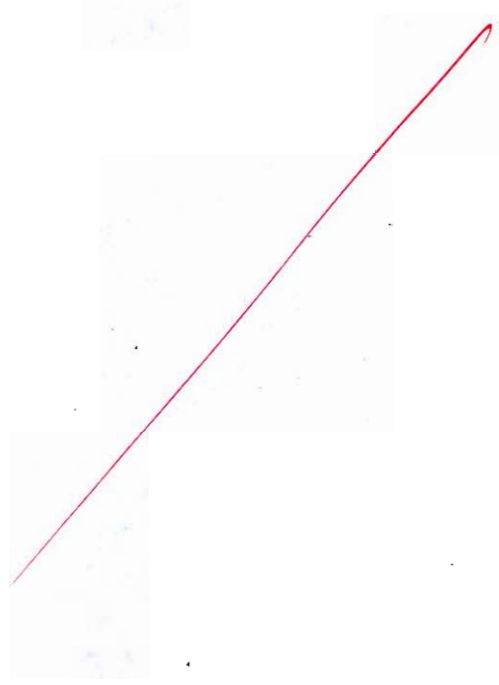
7

2.5 (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} .

- Obtain a formula for the allowable load P_{allow} that the bar can carry in tension.
- Calculate the value of P_{allow} if the bar is made of brass with diameter $d = 50$ mm, and $\sigma_{\text{allow}} = 140$ MPa.



[12 marks]



- 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, $T_0 = 27^\circ\text{C}$

[12 marks]

For A part \rightarrow right side

$$PV^n = C$$

P_2

\rightarrow Assume gas is ideal

$$(P_1)_A V_1 = m_A (T_1)_A R_1$$

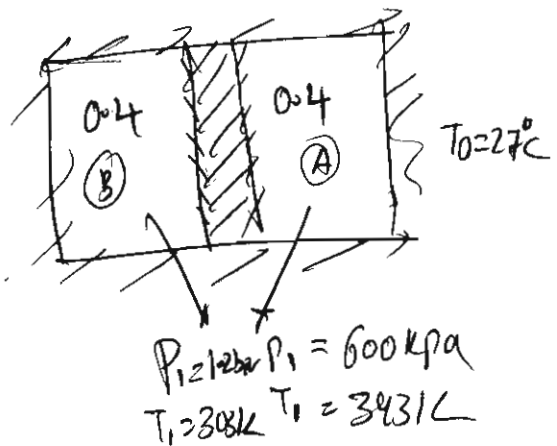
$$600 \times 0.4 = m_A \times 393 \times 0.287$$

$$m_A = 2.0127 \text{ kg}$$

$$\rightarrow (P_2)_B V_1 = m_B (T_1)_B R_1$$

$$1.2 \times 100 \times 0.4 = m_B \times 303 \times 0.287$$

$$\therefore m_B = 0.55 \text{ kg}$$



Final state

$$T_F = \frac{(T_{1A})M_A + (T_{1B})M_B}{M_{1A} + M_B}$$

$$V_F = (V_A + V_B)$$

$$V_F = 0.8 \text{ m}^3$$

$$T_F = \frac{2.127 \times 393 + 0.55 \times 303}{2.127 + 0.55}$$

$$T_F = 374.03 \text{ K}$$

→ from Ideal gas equation

$$P_F \times V_F = m R T_F$$

$$P_F \times 0.8 = (2.127 + 0.55) \times 0.287 \times 374.03$$

$$P_F = 359.72 \text{ kPa}$$

$$\rightarrow (\Delta S)_A = M_A \left[C_p \ln\left(\frac{T_F}{T_1}\right) - R \ln\left(\frac{P_F}{P_1}\right) \right]$$

$$= 2.127 \left[1.005 \ln\left(\frac{374.03}{393}\right) - 0.287 \ln\left(\frac{360}{800}\right) \right]$$

$$= 2.127 \left[-0.042 + 0.1466 \right]$$

$$(\Delta S)_A = 0.20943 \text{ kJ/K}$$

$$\rightarrow (\Delta S)_B = M_B \left[C_p \ln\left(\frac{T_F}{T_1}\right) - R \ln\left(\frac{P_F}{P_1}\right) \right]$$

$$= 0.55 \left[1.005 \ln\left(\frac{374.03}{303}\right) - 0.287 \ln\left(\frac{360}{120}\right) \right]$$

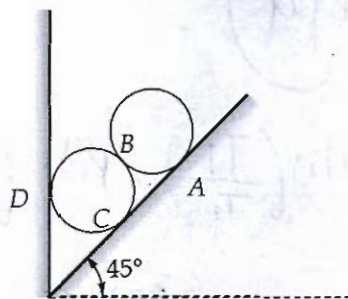
$$= 0.55 \left[0.21367 - 0.3153 \right]$$

$$= -0.05588 \text{ kJ/K}$$

$$\begin{aligned} \text{Irreversibility } (I) &= T_0 (\Delta S_A + \Delta S_B) \\ &= T_0 (0.20943 + (-0.05188)) \\ I &= 46.065125 \end{aligned}$$

12

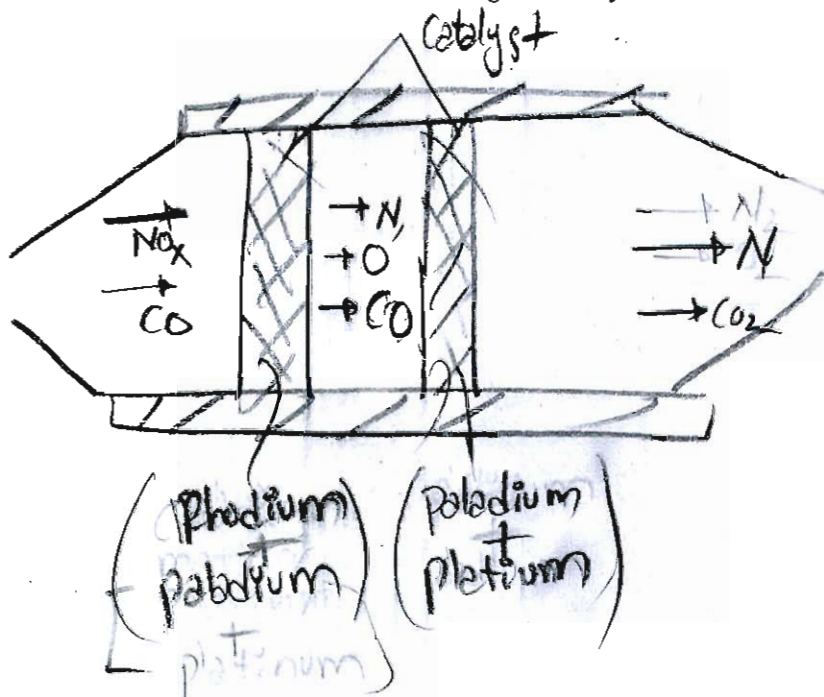
- Q.5 (d) Two identical rollers each weighing 150 N are supported by an inclined plane and a vertical wall as shown in the figure. Assuming all contact surfaces are smooth, find the reactions developed at the contact surfaces A, B, C and D.



[12 marks]

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

[12 marks]



→ Catalytic Converter is used to reduce the emission into atmosphere by reduction process and oxidation process

→ reduction reaction:- $\text{NO}_x \rightarrow \text{N}_2 + \text{O}_2$

Oxidation reaction - $\text{CO} + \text{O} \rightarrow \text{CO}_2$

→ initially the exhaust gas passes through reduction catalyst made of Rhodium + Palladium where NO_x is dissociated into Nitrogen and Oxygen (O_2)

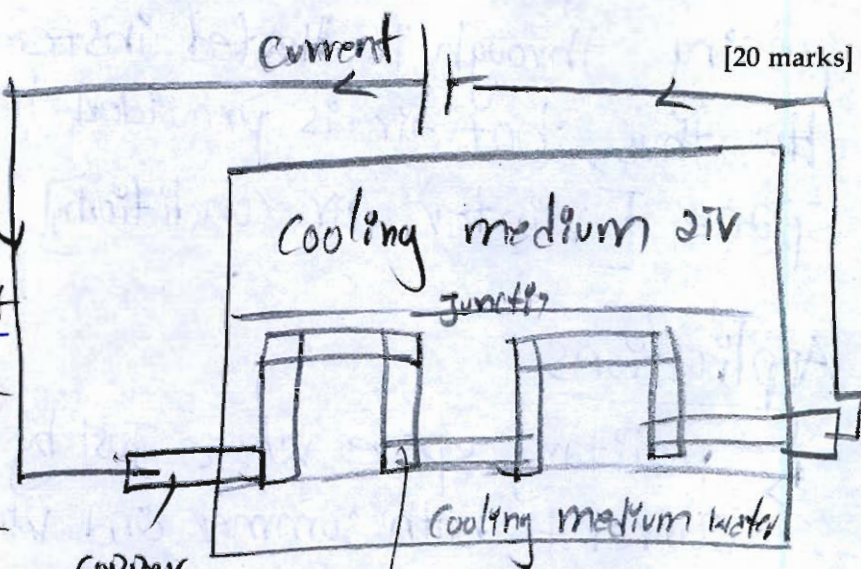
→ When ^{O_2 and} CO from reduction catalyst passes through the oxidation catalyst made up of Palladium and platinum, carbon monoxide get converted into carbon dioxide

→ at the end of the catalyst, NO_x and CO_2 get converted into Nitrogen and carbon dioxide

8

2.6 (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?

→ It works on the principle of Peltier effect i.e. when current passing through a junction of dissimilar material, strip like ~~Bismuth~~ Antimony and Bismuth,



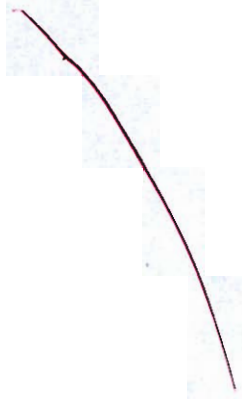
copper thermo-electric Module assembly
the heat absorbed at one side of junction is transferred to another side

- thermoelectric Module are assembled in series with the help of copper strip. each module consists of number of the thermo-couple
- When direct current passing through assembly modules, at the top of junction get cooled and observes the heat of flowing air, thus cooled air will go to Air conditioned space. the absorbed heat will transfer to bottom of junction which is cooled by cooled water. [summer air conditioning]
- When direction of current is reversed, at the top of junction is heated and air passing through is heated instead of cooling, thus, hot air is provided in Air conditioned space [winter air conditioning]

Applications

- 1) military space where just by reversing the current both summer and winter air conditioning possible
- 2) space application
- 3) Automobiles
- 4) Cinema halls

12



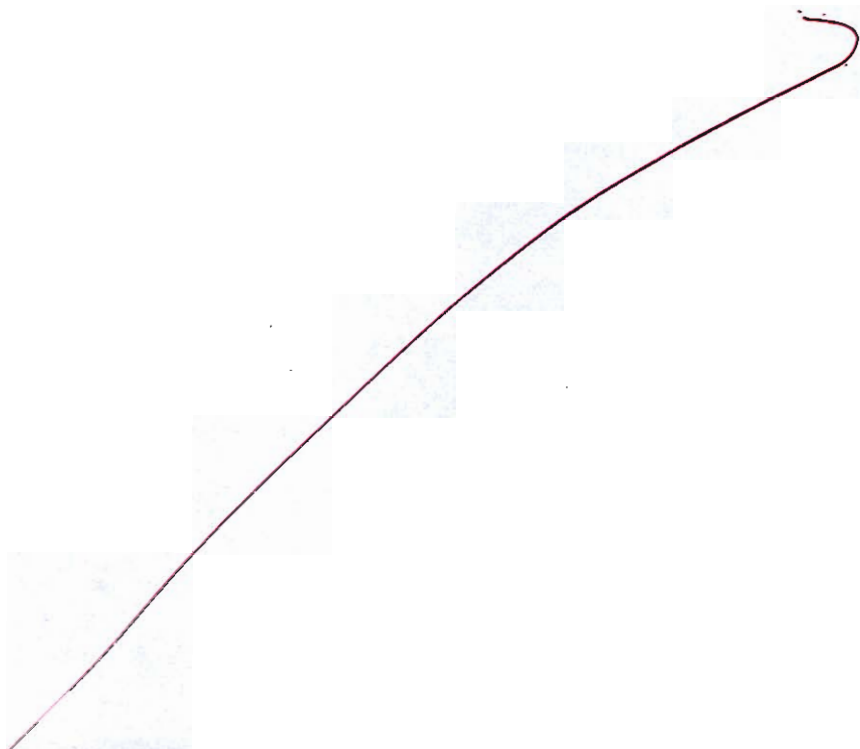
2.6 (b) A closed rigid tank filled with water vapour, initially at 20.98 MPa, 633.22°C is cooled until its temperature reaches 439.03°C. Determine

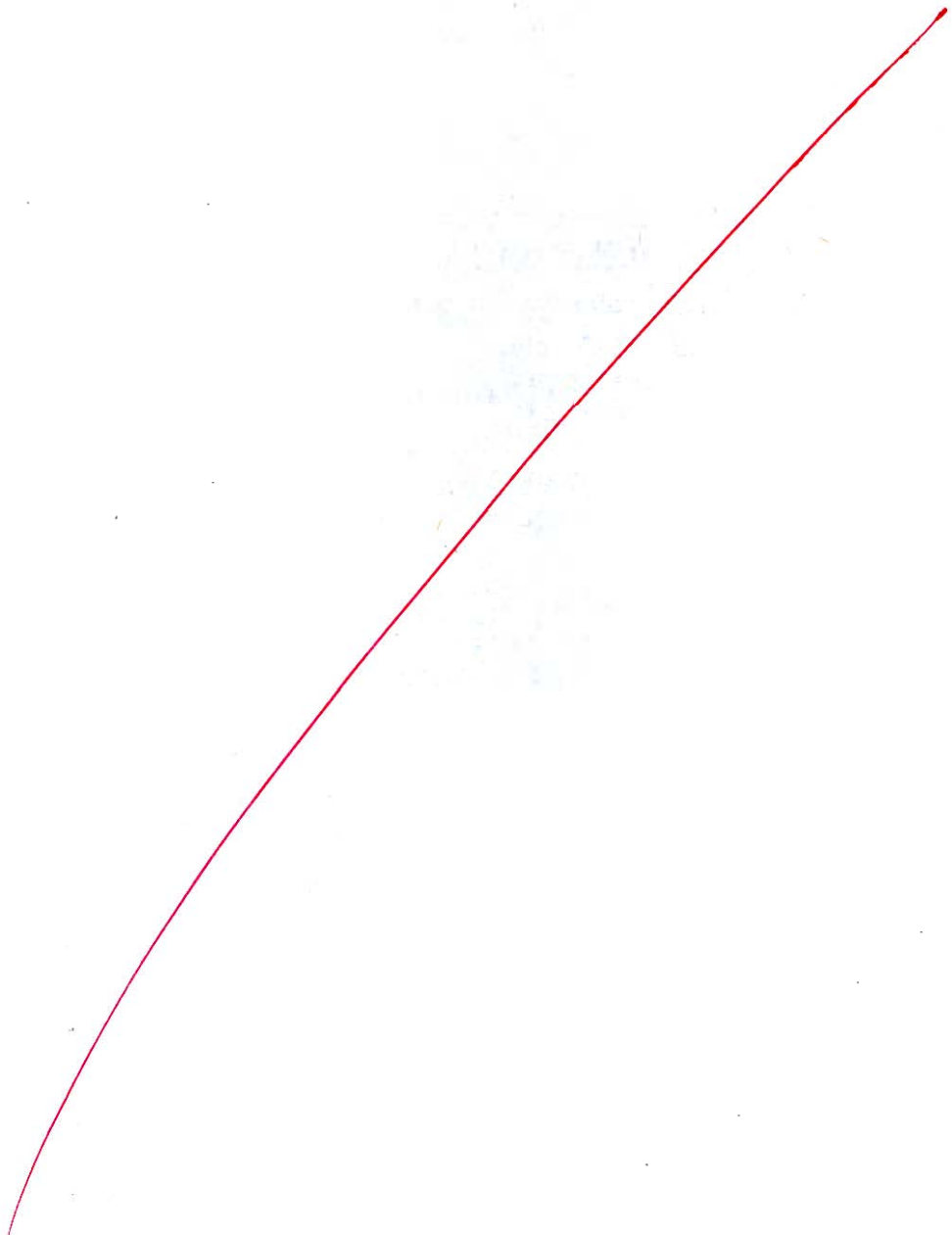
- (i) the specific volume of the water vapour in m^3/kg at the initial state.
- (ii) the pressure in MPa at the final state

[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]

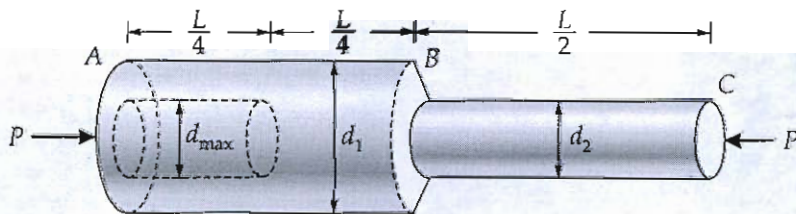
[20 marks]





- 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]

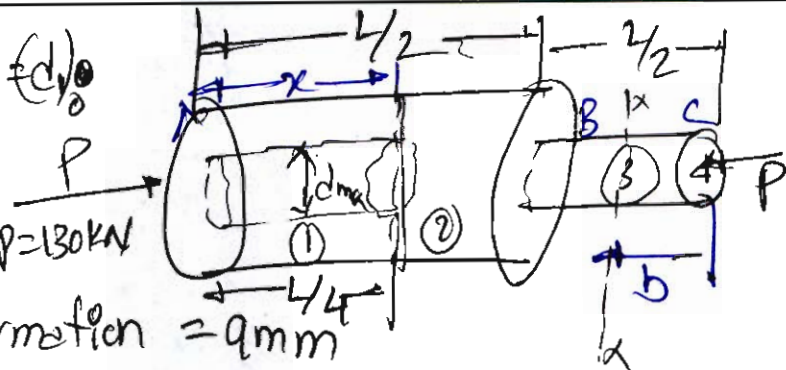
Given $d_2 = 140 \text{ mm}$ (d)

$$d_3 = 80$$

$$L = 106 \text{ M}$$

$$E = 6 \times 10^3 \text{ MPa} \quad P = 130 \text{ kN}$$

i) total deformation = 9 mm



$$-\frac{P_3 L_3}{A_3 E} + \frac{P_2 L_2}{A_2 E} + \frac{P_1 L_1}{A_1 E} = -9 \text{ mm}$$

$$\frac{1}{E} \left[\frac{130 \times 10^3 \times 800}{5026.542} + \frac{-130 \times 10^3 \times 400}{15393.84} + \frac{130 \times 10^3 \times 400}{\frac{\pi}{4}(d_0^2 - d_{\max}^2)} \right] = 9 \text{ mm}$$

$$20690.142 + 3377.982 + \frac{66208456.33}{140^2 - d_{\max}^2} = 54000$$

$$\therefore d_{\max} = 131.86 \text{ mm}$$

$$\therefore d_{\max} = \frac{d_3}{2} = 40 \text{ mm}$$

$$\frac{130 \times 10^3}{6 \times 10^3} \left[\dots \right]$$

14

$$\frac{130 \times 10^3}{8 \times 10^3} \left[\frac{800}{5026.5472} + \frac{800-x}{15393.804} + \frac{x}{4084.7} \right] = 5$$

$$0.0716142 = \frac{800}{15393.84} - \frac{x}{15393.8} + \frac{x}{4084.7}$$

$$0.01964544 = \frac{x}{\phi} (1.79855 \times 10^{-4})$$

$x \geq 109.22 \text{ mm}$ permissible length of hole

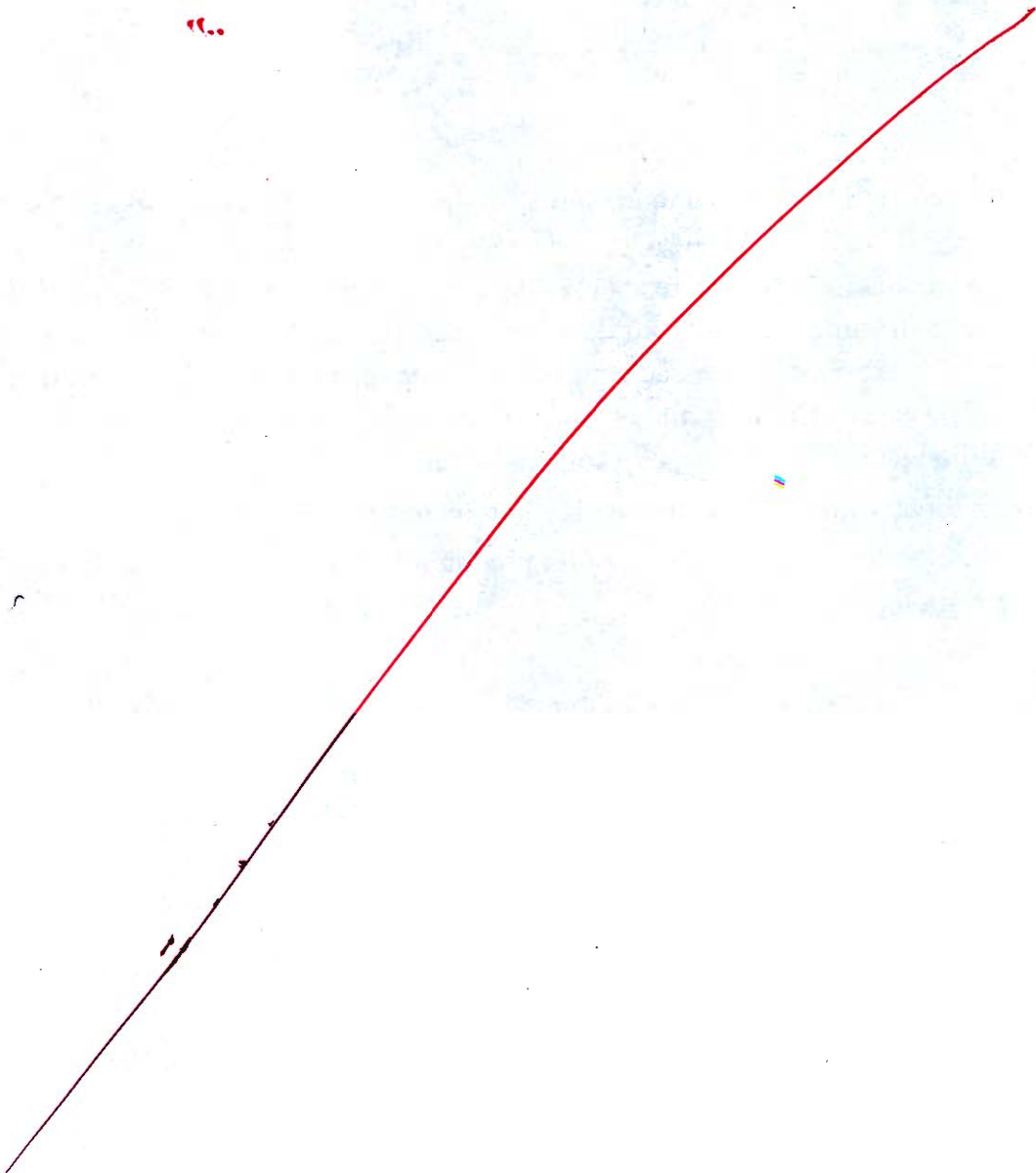
Q.7 (a) An engine working on an Otto cycle having a compression ratio of 9, uses octane C_8H_{18} as a fuel. The lower heating value of the fuel is 44000 kJ/kg. The air fuel ratio is 14 : 1. Determine the maximum pressure and temperature reached in the cycle.

(i) Without considering the molecular expansion

(ii) With molecular expansion

Assume $c_v = 0.71$ kJ/kgK, compression follows the law $PV^{1.3} = \text{constant}$, 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.

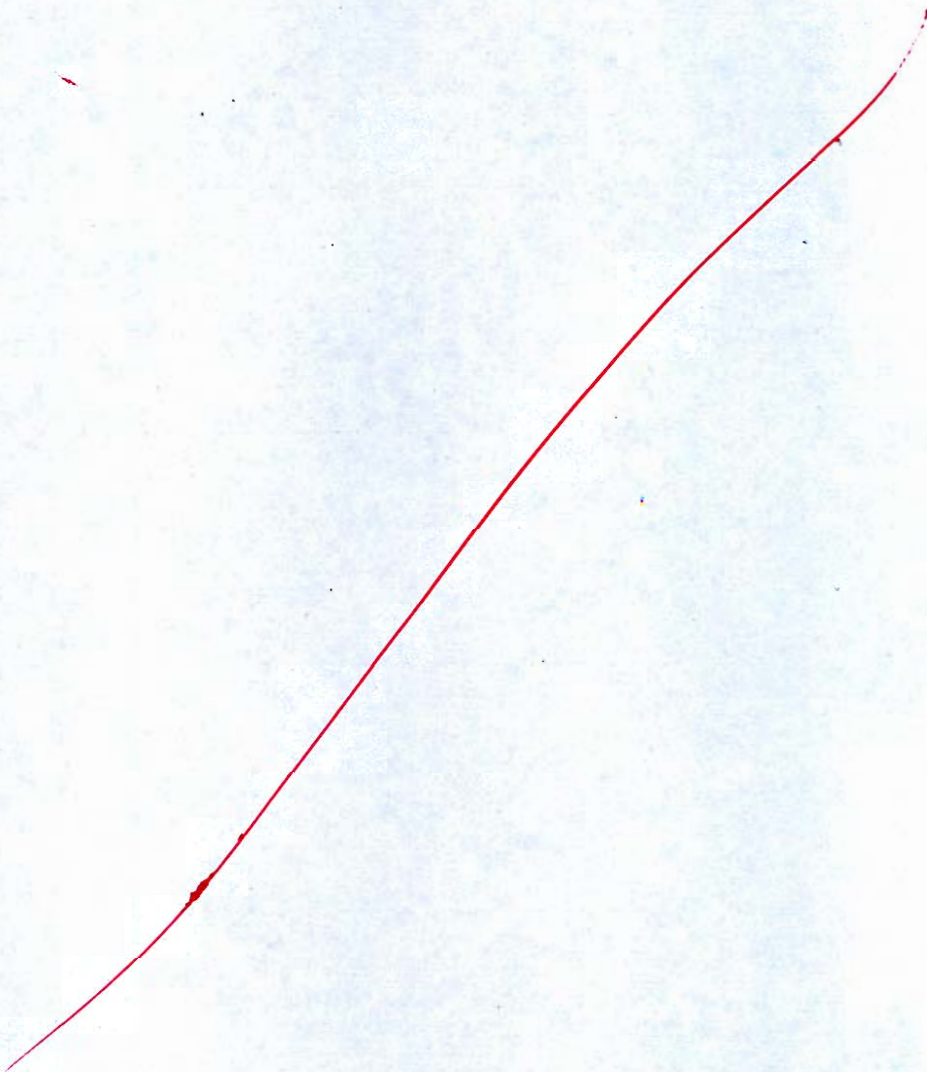
[20 marks]

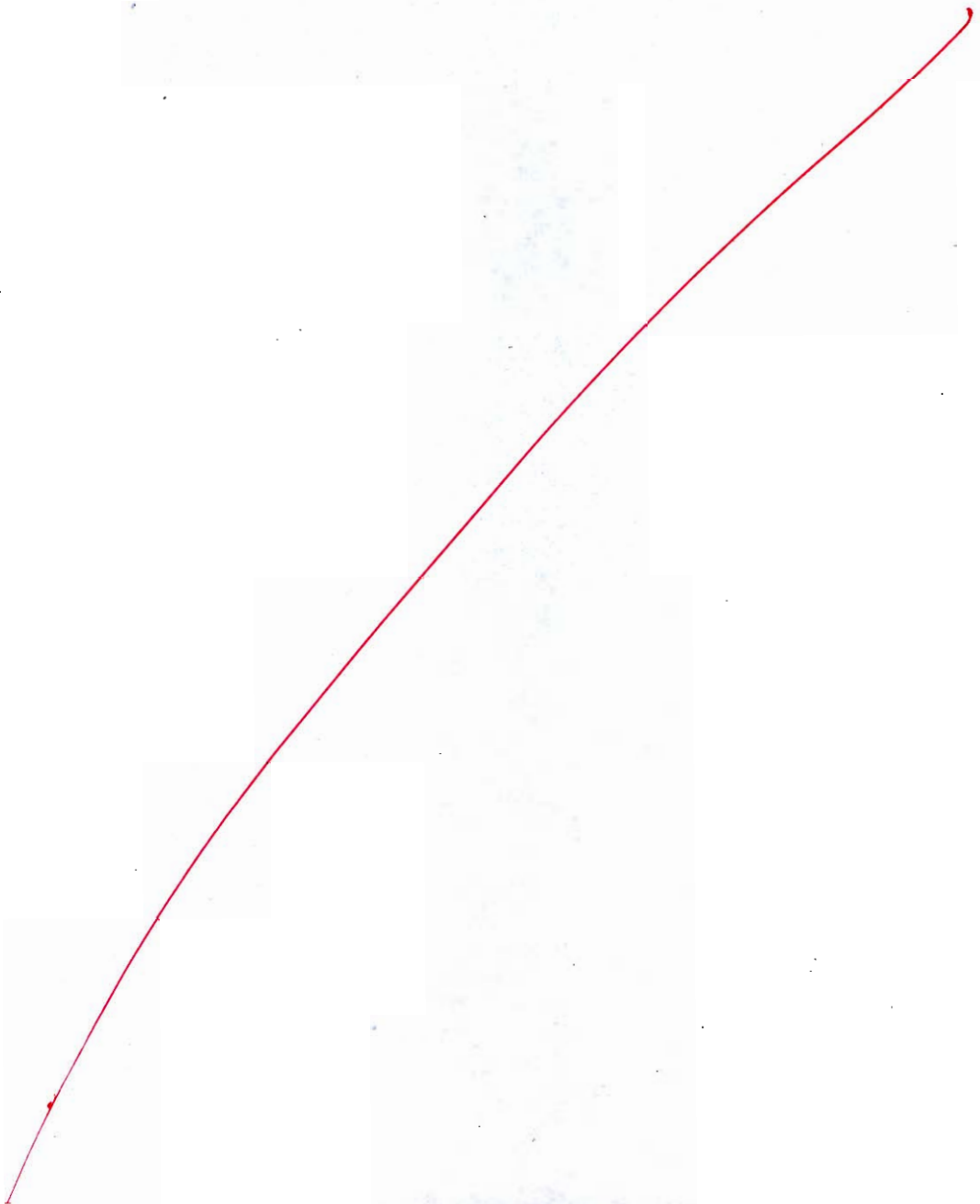


- Q.7 (b) An air conditioned Hall is to be maintained at 26°C dry bulb temperature and 21°C wet bulb temperature. It has a sensible heat load of 48 kW and latent heat load of 18 kW. The air supplied from outside atmosphere at 40°C dry bulb temperature and 28°C wet bulb temperature is $28\text{ m}^3/\text{min}$, 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:
- Condition of air after the coil and before recirculated air mixes with it.
 - Condition of air entering the hall i.e. after mixing with recirculated air.
 - Mass of fresh air entering the cooler.
 - By-pass factor of cooling coil.

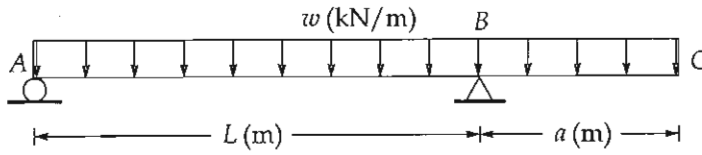
[Use Psychrometric chart attached at the end]

[20 marks]

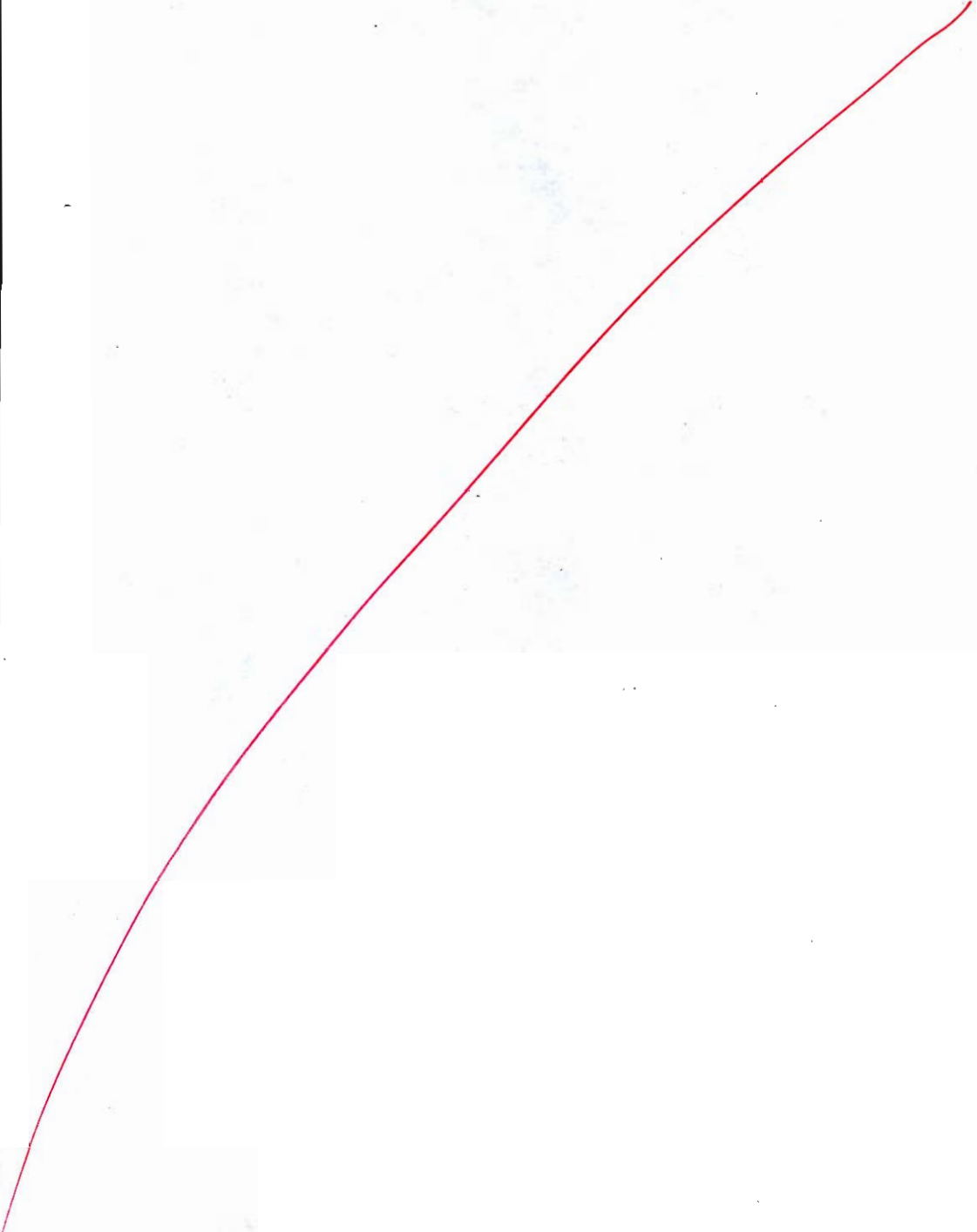


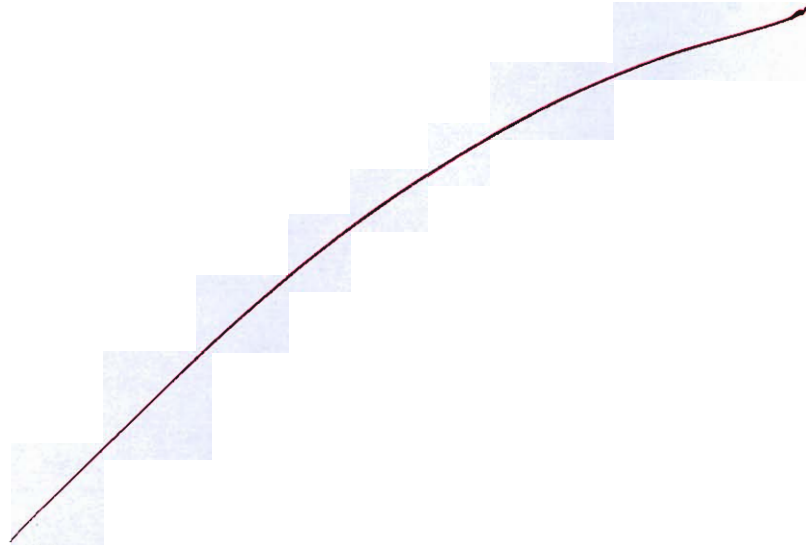


- 7 (c) A simply supported beam with one side overhang is loaded with uniformly distributed load as shown in figure below. Comment your result on the variation of reaction forces at A and B , if ' L ' is less than, equal to and greater than ' a '. Draw shear force and bending moment diagram for $w =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

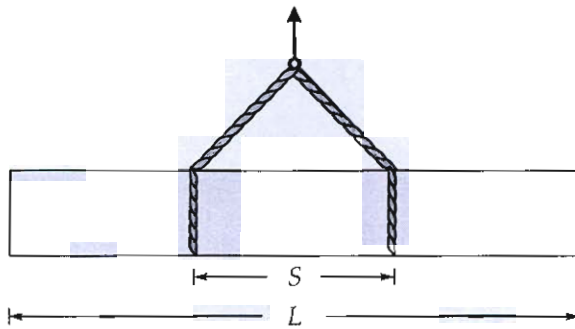


[20 marks]





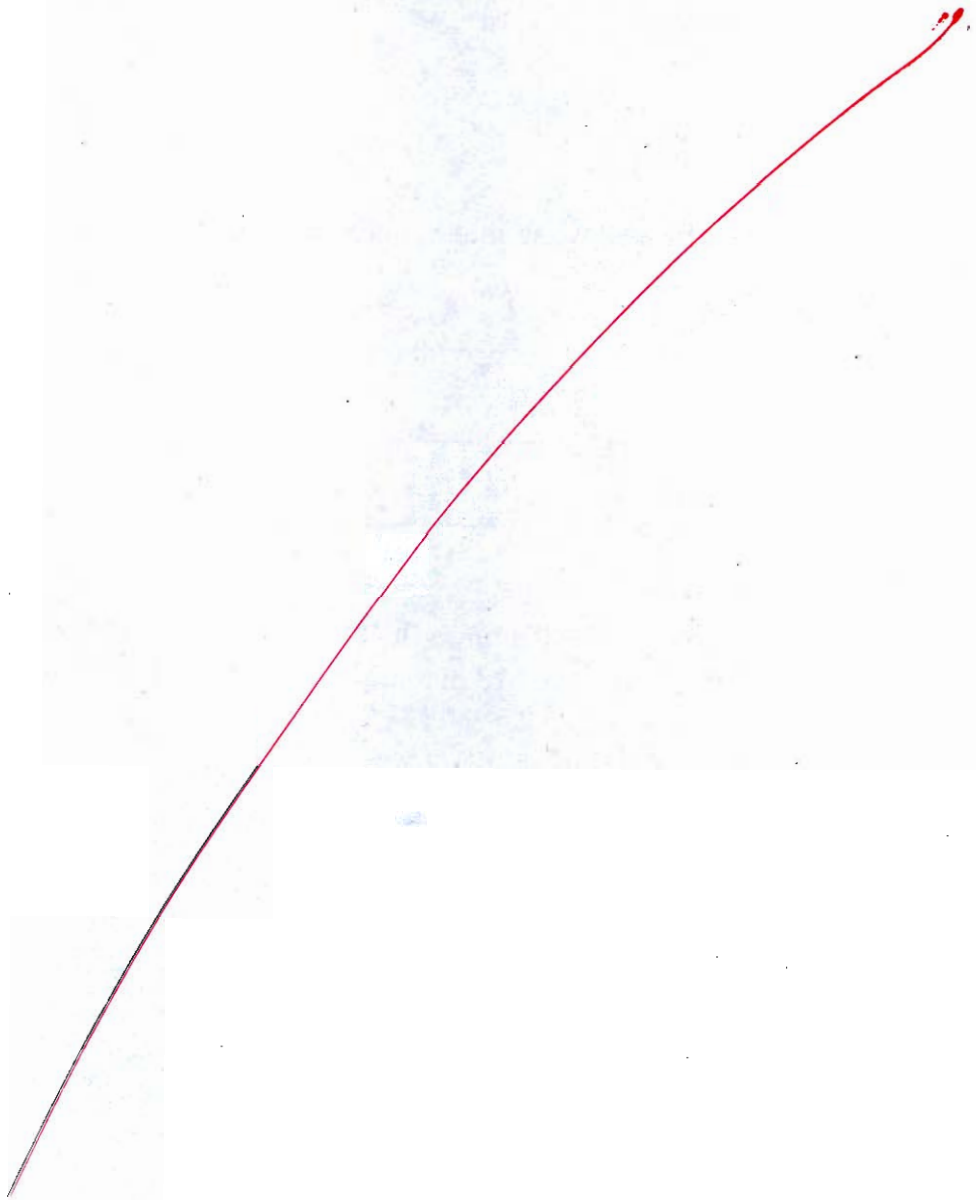
8 (a) A fiberglass pipe is lifted by a sling, as shown in the figure.

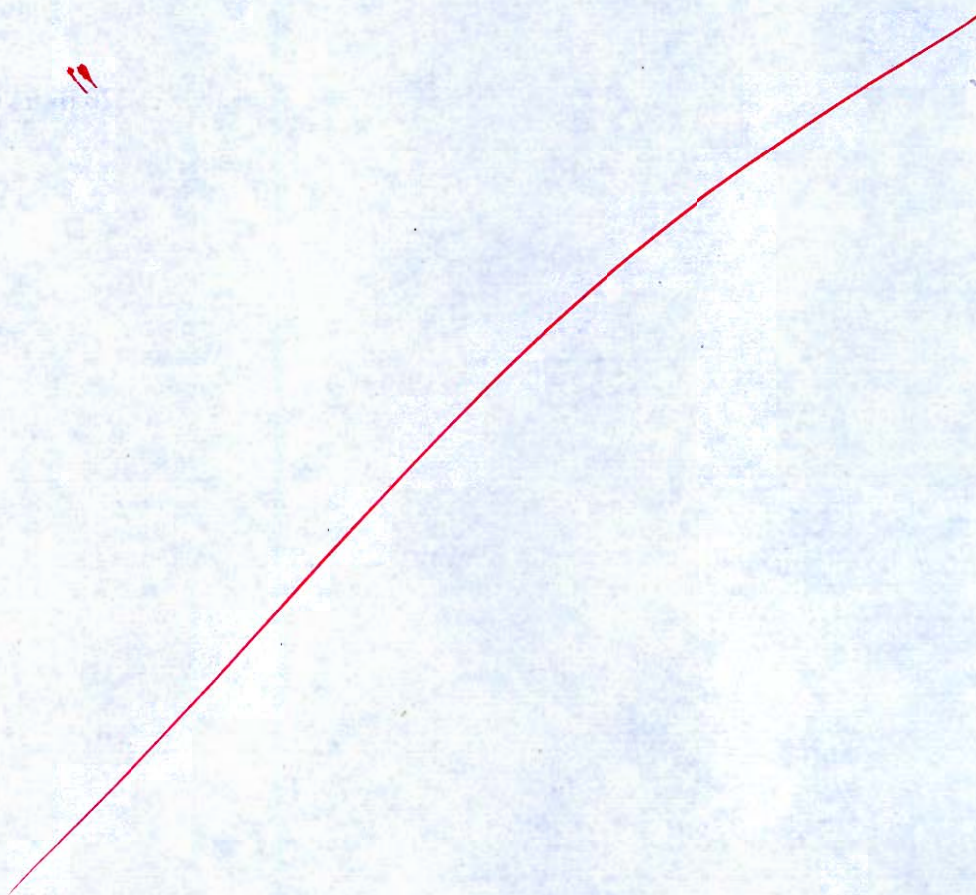


The outer diameter of the pipe is 180 mm, its thickness is 6 mm, and its weight density is 20 kN/m^3 . The length of pipe is $L = 18 \text{ m}$ and the distance between lifting points is $S = 5 \text{ m}$.

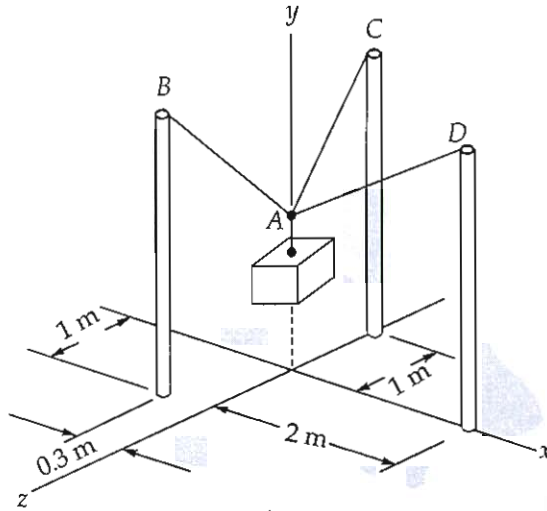
- (i) Determine the maximum bending stress in the pipe due to its own weight.
- (ii) Find spacing S between lift points which will minimize the bending stress. What will be minimum bending stress?
- (iii) What spacing S will lead to maximum bending stress? What is that stress?

[20 marks]

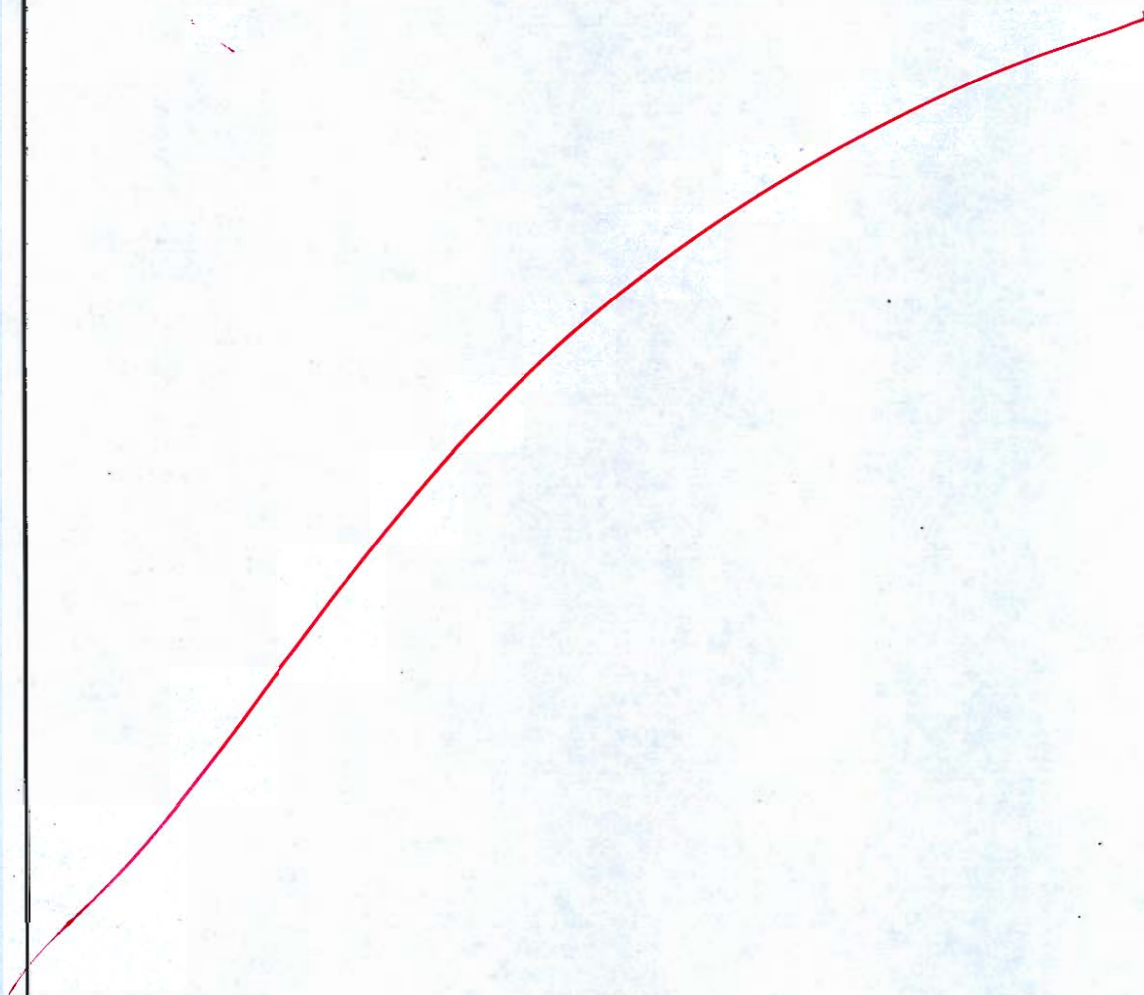




- Q.8 (b) The 15 kg mass is suspended by cables attached to three vertical 2 m posts. Point A is at $(0, 1.4, 0)$ m. Determine the tensions in cables AB, AC and AD.

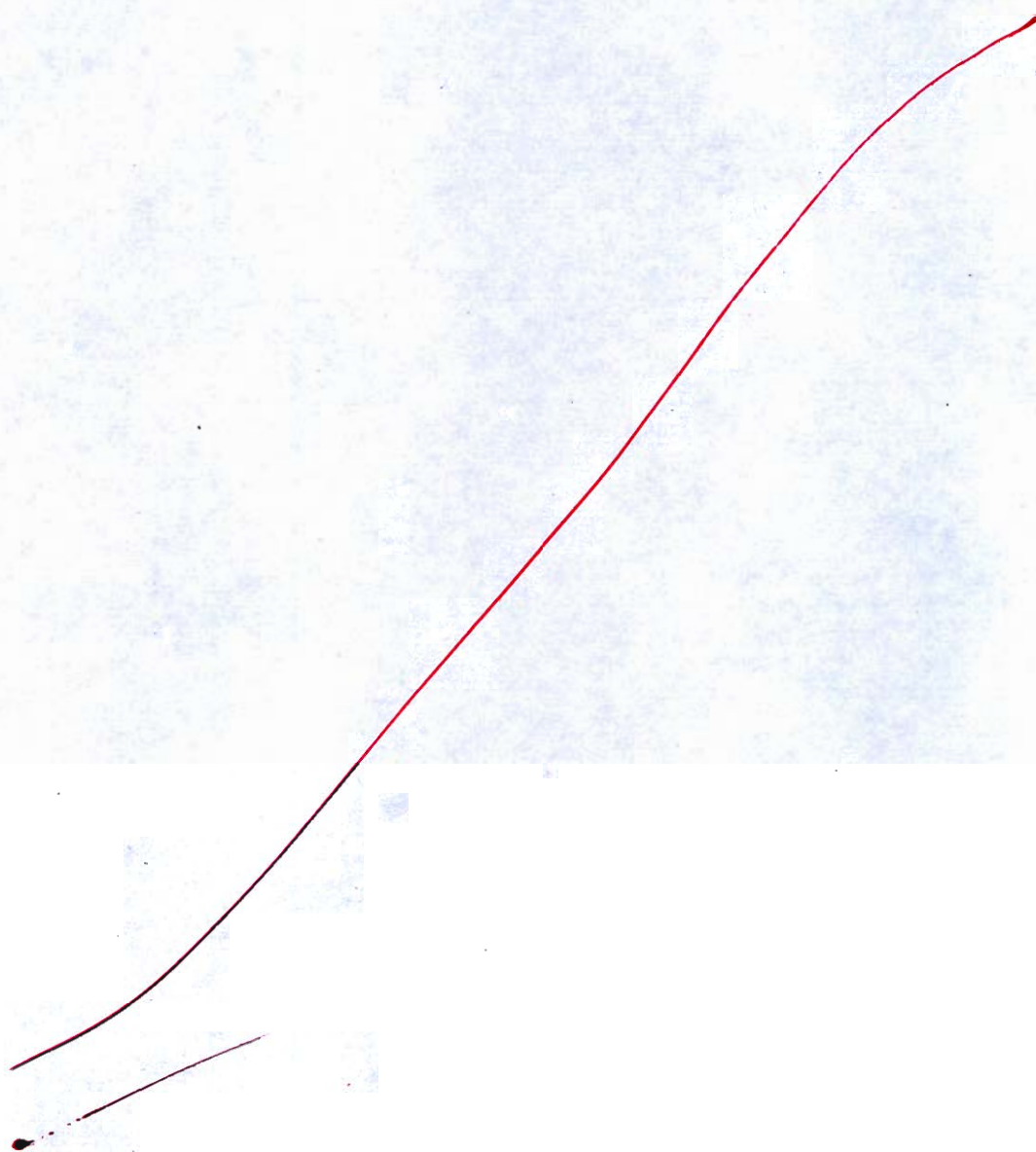


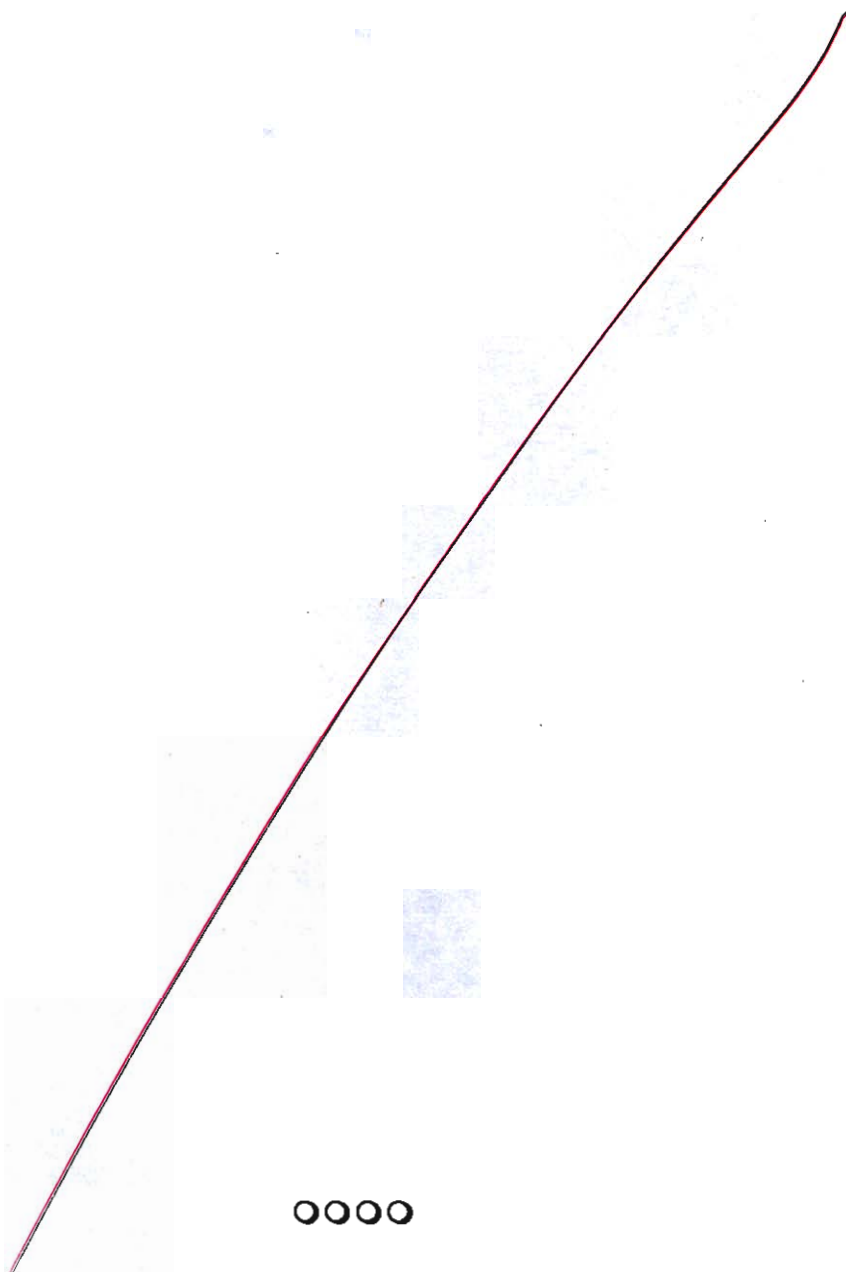
[20 marks]



- 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:
 $\text{CO}_2 = 14\%$; $\text{CO} = 0.6\%$; $\text{O}_2 = 5\%$ and the rest is N_2 .
Determine :
- the air/fuel ratio.
 - the percentage theoretical air.
 - the percentage composition of fuel on mass basis.

[4 + 16 = 20 marks]

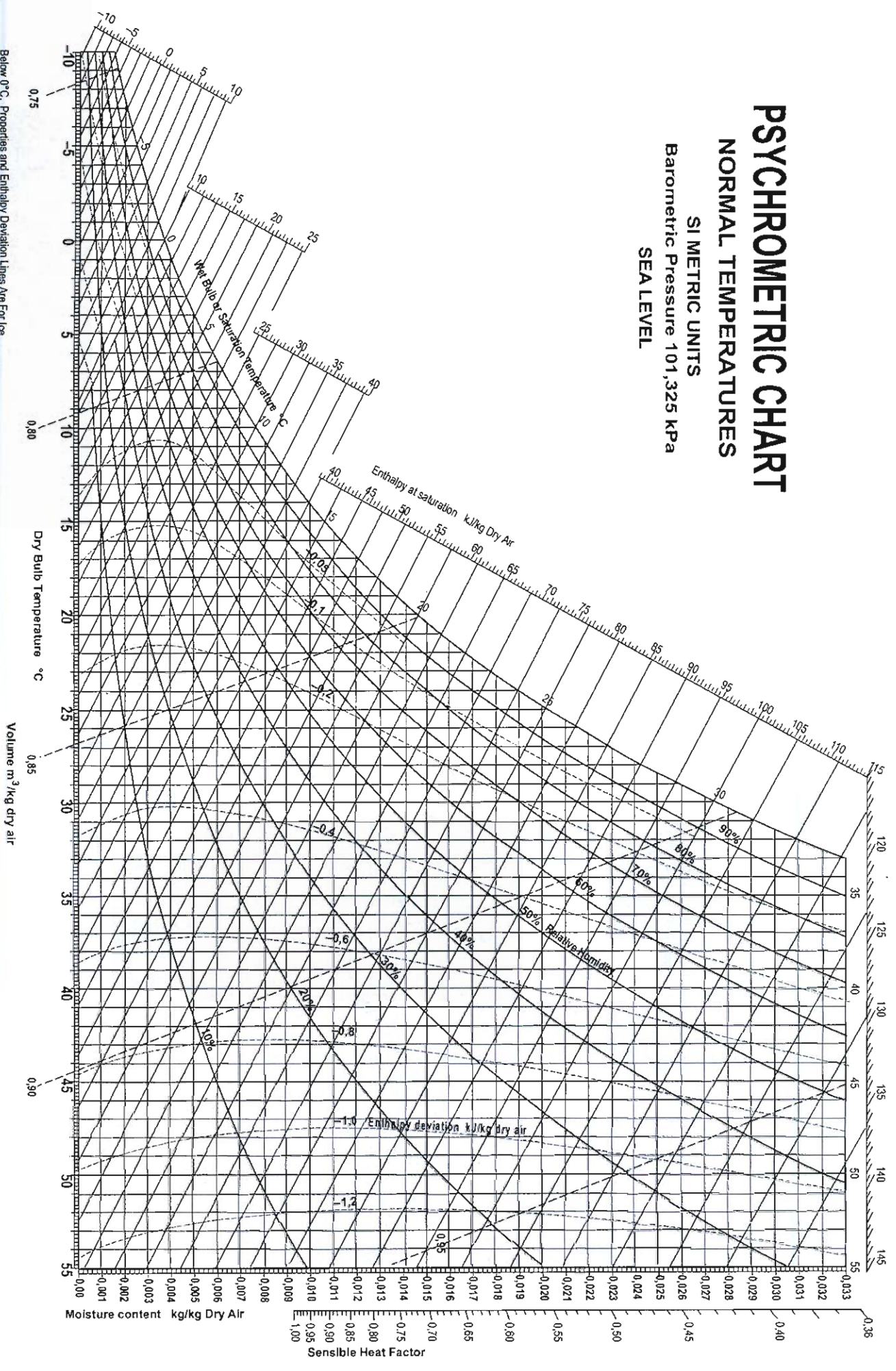




PSYCHROMETRIC CHART

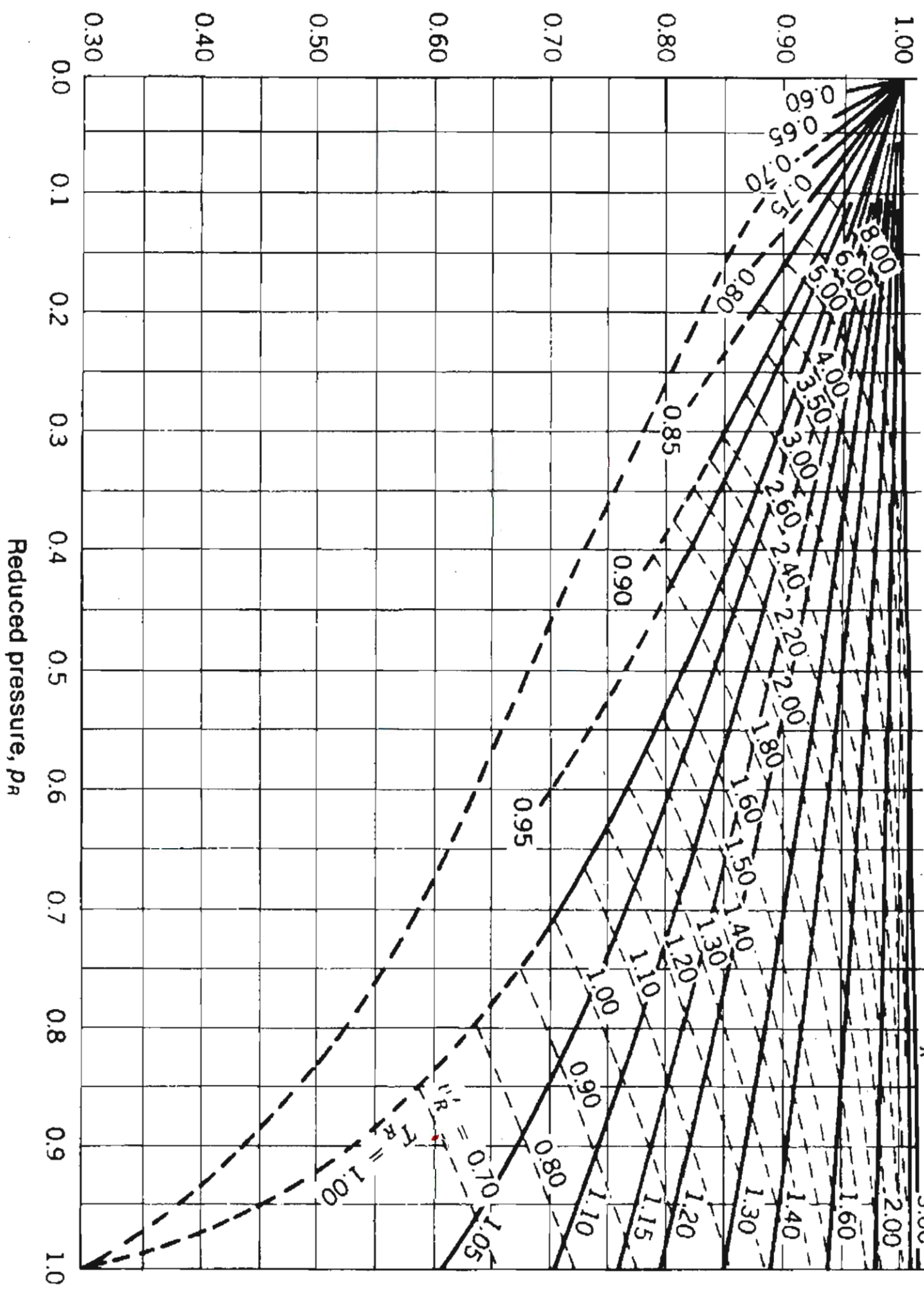
NORMAL TEMPERATURES

SI METRIC UNITS
Barometric Pressure 101,325 kPa
SEA LEVEL



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

Compressibility factor, $Z = pv/RT$



Space for Rough Work

Space for Rough Work

