



MADE EASY

India's Best Institute for IES, GATE & PSUs

ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

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

Section B : Heat Transfer-1 + Refrigeration and Air-Conditioning-1 [Part Syllabus]

Thermodynamics-2 + Strength of Materials & Mechanics-2 [Part Syllabus]

Name :

Roll No :

Test Centres

Delhi ☐ Bhopal ☒ Jaipur ☐
Pune ☐ Kolkata ☐ Bhubaneswar ☐ Hyderabad ☐

Student's Signature

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	13
Q.2	10
Q.3	16
Q.4	16
Section-B	
Q.5	50
Q.6	13
Q.7	58
Q.8	35
Total Marks Obtained	

Signature of Evaluator

Cross Checked by

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

- Q.1 (a) A tank of constant cross-sectional area of 3.2 m^2 has two orifices each $10.5 \times 10^{-4} \text{ m}^2$ in area in one of its vertical side at heights of 8 m and 2.0 m respectively above the bottom of the tank. Calculate the time taken to lower the water level from 11 m to 4.6 m above the bottom of the tank. Assume $c_d = 0.725$.

[12 marks]



- Q.1 (b) A centrifugal compressor runs at 12000 rpm and delivers $700 \text{ m}^3/\text{min}$ of free air at pressure ratio of 5 : 1. The isentropic efficiency of compressor is 85%. The outer radius of impeller (which has radial blades) is twice the inner one and the slip coefficient is negligible. Assume that the ambient air condition are 1.01 bar and 290 K. The axial velocity of flow is 70 m/s and is constant throughout. Determine
- Power input to the compressor.
 - Impeller diameters at inlet and outlet and width at inlet, and
 - Impeller and diffuser blade angles at inlet.

[12 marks]

Ans (b)

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

$$\dot{V}_{\text{delivered}} = 700 \text{ m}^3/\text{min}$$

→ Ambient conditions

$$r = \text{pressure ratio} = 5$$

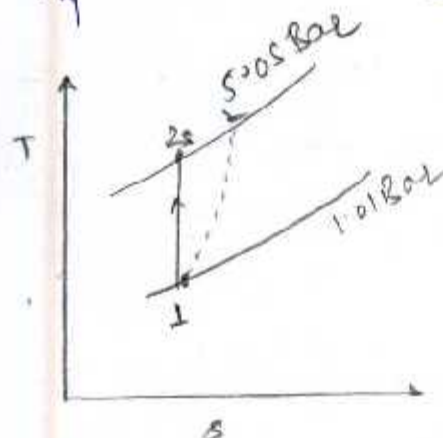
$$\eta_{\text{isen}} = 0.85$$

$$r_2 = 2r_1 \quad \& \quad C_s \approx \text{Negligible}$$

$$P_0 = 1.01 \text{ Bar}$$

$$T_0 = 290 \text{ K}$$

$$V_{F_1} = 70 \text{ m/s} = V_{F_2} \quad (\text{Axial velocity})$$



$$\eta_{\text{isen}} = \frac{T_{2s} - T_1}{T_2 - T_1} \quad \text{--- (1)}$$

$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \quad \gamma = 1.4 \quad (\text{Air})$$

$$\frac{T_{2s}}{290} = (5)^{\frac{0.4}{1.4}}$$

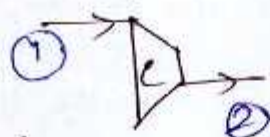
$$\frac{T_{2s}}{290} = 1.583$$

$$T_{2s} = 459.307 \text{ K}$$

Substituting the value of T_{2s} in (1)

$$0.85 = \frac{459.307 - 290}{T_2 - 290} \rightarrow T_2 = 489.85 \text{ K}$$

We know that power i/p to compressor is given by,



$$h_1 + w_{i/p} = h_2$$

$$w_{i/p} = h_2 - h_1$$

Assuming there is
No Heat Transfer.

$$\Delta K.E = 0, \Delta P.E = 0$$

$$\begin{aligned} \text{Power } w_{i/p \text{ to comp}} &= c_p (T_2 - T_1) \\ &= 1.005 \left(\frac{489.185}{489.185} - 290 \right) \end{aligned}$$

$$w_{i/p} = 200.181 \text{ kJ/kg}$$

Now, $P_1 V_1 = \dot{M} R T_1$

$$\dot{M}_a = \frac{P_1 V_1}{R T_1} = \frac{101 \times 700}{60 \times 0.287 \times 290}$$

$$\boxed{\dot{M}_a = 14.157 \text{ kg/s}}$$

$$\begin{aligned} \text{Power i/p to compressor} &= \dot{M}_a w_{i/p} \\ &= 14.157 \times 200.181 \end{aligned}$$

$$\boxed{P_{i/p} = 2834.073 \text{ kW}}$$

(ii) Impeller diameters at inlet & exit

Work done in centrifugal comp

$$\dot{M} (V_{w2} u_2 - V_{w1} u_1) = \dot{M} (u_2^2) \quad [V_{w2} = u_2]$$

$$\dot{M} u_2^2 = \dot{M} \times 200.181 \times 10^3$$

$$\boxed{u_2 = 447.41 \text{ m/s}}$$

$$V_2 = \frac{\pi d_2 N}{60} \rightarrow \frac{447.41 \times 60}{\pi \times 12000} = d_2$$

$$d_2 = 0.712 \text{ m}$$

$$d_1 = 0.356 \text{ m}$$

$$Q = A_1 V_1$$

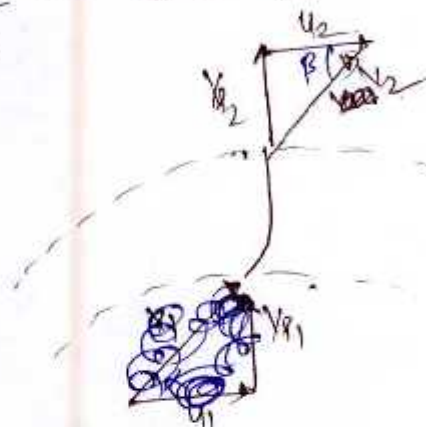
$$\frac{700}{60} = \pi b_1 d_1 \times V_1 \rightarrow \frac{700}{60 \pi \times 0.356 \times 70}$$

$$b_1 = 0.149 \text{ m}$$

$$\frac{700}{60} = \pi b_2 d_2 V_2$$

$$b_2 = 0.0745 \text{ m}$$

(c)



$$\tan \beta_2 = \frac{70}{447.41}$$

$$\beta = 8.892^\circ$$

Q.1 (c) The speed of rotation of a blade group of a 50% reaction turbine is 2500 rpm. The mean blade speed is 120 m/s. The velocity ratio is 0.6 and the exit angle of the blade is 25° . If the mean specific volume of the steam is $0.7 \text{ m}^3/\text{kg}$ and the mean height of the blade is 30 mm, calculate the mass flow of steam through the turbine in kg/h. Neglect the effect of blade thickness on the annulus area.

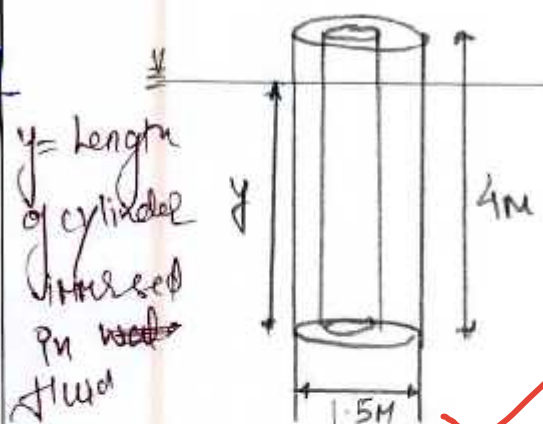
If there are six pairs of blades in the group, calculate the useful enthalpy drop required and the diagram power.

[12 marks]



- Q.1 (d) A hollow cylinder closed at both ends has an outside diameter of 1.5 m, length 4 m and specific weight 80 kN/m^3 . If the cylinder is to float just in stable equilibrium in sea water, find its minimum permissible thickness. Assume that sea water weighs 12 kN/m^3 .

[12 marks]

Ans 1dGiven

$$d_o = 1.5 \text{ m}$$

$$\rho_{\text{sea}} = 12 \text{ kN/m}^3$$

$$l = 4 \text{ m}$$

$$w_g = 80 \text{ kN/m}^3$$

Using principle of floatation
 $\uparrow B = \downarrow W$

$$\rho_g \times g \times V_g = \rho_f \times g \times V_{fd}$$

$$w_g \times V_g = w_{\text{sea}} \times V_{fd}$$

$$V_{fd} = \frac{w_g}{w_{\text{sea}}} \times V_g \rightarrow \frac{80}{12} \times \pi (1.5^2 - d_i^2) \times 4$$

$$V_{fd} = 20.933 (1.5^2 - d_i^2) \quad \text{--- (1)}$$

$$\frac{\pi (d_o^2 - d_i^2)}{4} xy = 20.933 \times \frac{\pi (d_o^2 - d_i^2)}{4}$$

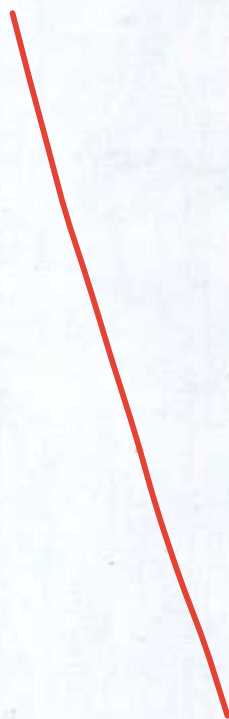
$$y = \frac{20.933 \times 4}{\pi}$$

??
- 0

3
12

1

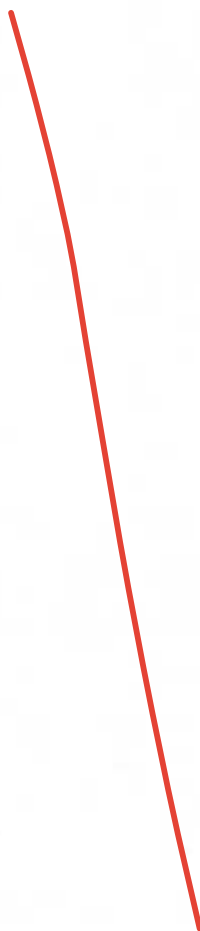
Q.1 (e) Briefly explain the working of pulse jet engine. Write its advantages and disadvantages. [12 marks]



- Q.2 (a) A jet propelled unit travels at 200 m/s in air at 0.7 bar at -5°C . Air first enters a diffuser in which it is brought to rest relative to the unit and it is then compressed in a compressor through a pressure ratio of 6.2 and fed to turbine at 975°C . The gas expands through the turbine and then through the nozzle to atmospheric pressure (i.e. 0.7 bar). The efficiencies of diffuser and nozzle are 0.92. The compressor and turbine efficiencies are 0.82. Pressure drop in combustion chamber is 0.15 bar. Find the fuel-air ratio and specific thrust of unit. If the inlet cross-section of the diffuser is 0.2 m^2 , calculate the total thrust. Assume calorific value of fuel as 44000 kJ/kg of fuel.

[20 marks]





- Q.2 (b) (i) Calculate the friction drag on a plate 0.2 m wide and 0.6 m long placed longitudinally in a stream of oil flowing with a free stream velocity of 8 m/s. Also find the thickness of the boundary layer and shear stress at the trailing edge. Specific gravity of oil is 0.945 and its kinematic viscosity is $1.2 \times 10^{-4} \text{ m}^2/\text{s}$.
- (ii) For turbulent flow in pipes (smooth as well as rough), show that
- $$\frac{V_{\max}}{V} = 1.33\sqrt{f} + 1$$
- (iii) Mean point velocities measured, with the help of a pitot tube at mid-point and quarter point of a 0.4 m diameter pipe were found to be 2 m/s and 1.85 m/s respectively. If the flow in the pipe is turbulent, determine the discharge, friction factor and average height of roughness projection.

[8 + 4 + 8 marks]

Ans(2)b

$$U_{\infty} = 8 \text{ m/s}$$

0.6 m

given

$$\text{length of plate} = 0.6 \text{ m}$$

$$\text{width of plate} = 0.2 \text{ m}$$

$$U_{\infty} = 8 \text{ m/s}$$

To find,

$$\delta = ?? \text{ (Trailing edge)}$$

$$\tau_{w,x} = ?? \text{ (Trailing edge)}$$

$$\rho_{\text{air}} = 0.945$$

$$\mu_{\text{air}} = 945 \text{ kg/m}^3$$

$$\nu = 1.2 \times 10^{-4} \text{ m}^2/\text{s}$$

$$Re_L = \frac{\rho U_{\infty} L}{\mu} = \frac{\rho L}{\nu} = \frac{8 \times 0.6}{1.2 \times 10^{-4}} = 40000 < 5 \times 10^5$$

↓
Flow is Laminar

Using Blasius Relations

$$\delta = \frac{5x}{\sqrt{Re_x}} \quad (\text{At Trailing Edge } x = 0.6)$$

$$\delta = \frac{5 \times 0.6}{\sqrt{40000}} = 15 \text{ mm}$$

$$\boxed{\delta = 15 \text{ mm}}$$

$$C_{f,x} = \frac{0.664}{\sqrt{Re_x}} = \frac{0.664}{\sqrt{40000}} = 3.32 \times 10^{-3}$$

(At $x=L$)

$$C_{f,x} = \frac{\tau_{w,x}}{\frac{1}{2} \rho U_{\infty}^2} \rightarrow$$

$$\tau_{w,x} = C_{f,x} \times \frac{1}{2} \rho U_{\infty}^2$$

$$\boxed{\tau_{w,x} = 100.3968 \text{ N/m}^2}$$

(ii) Velocity Relation in Turbulent flow is
given by

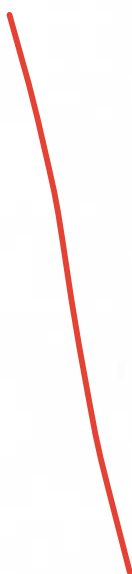
$$\frac{U-V}{V^*} = 5.75 \log_{10} \left(\frac{y}{r} \right) + 3.75$$

V^* = Shear
Velocity

y = Distance from pipe/wall

21.

10
26

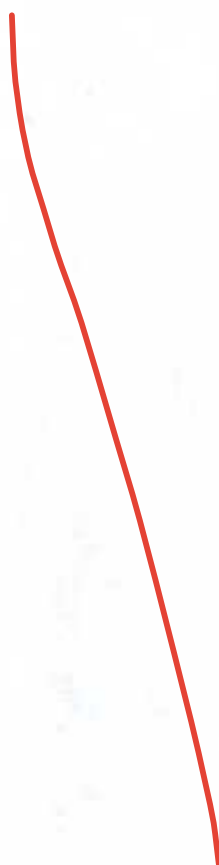


Q.2 (c) A single acting reciprocating pump has a stroke length of 50 cm and a cylinder diameter of 25 cm. The suction pipe is 7 m long and has diameter of 10 cm. The water level in the sump is 4.0 m below the cylinder.

- (i) Calculate the maximum speed of pump, if separation is known to occur at 2.6 m water (abs).
- (ii) If an air vessel is fitted on the suction side at a length of 2.5 m from the cylinder, calculate the admissible maximum speed and the percentage change in discharge.

Take Darcy-Weisbach friction factor, $f = 0.03$. Assume atmospheric pressure = 10.3 m water (abs).

[20 marks]

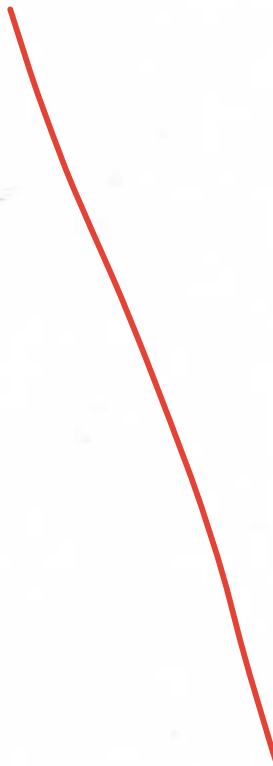


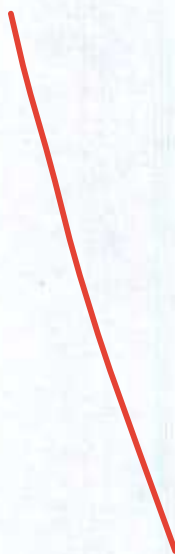
- Q.3 (a) A helicopter gas turbine requires an overall compressor pressure ratio of 12 : 1. This is to be obtained using a two-spool layout consisting of a five-stage axial compressor followed by a single-stage centrifugal compressor. The polytropic efficiency of the axial compressor is 90% and that of the centrifugal compressor is 84%.

The axial compressor has a stage temperature rise of 25 K, using a 50% reaction design with a stator outlet angle of 22° . If the mean diameter of each stage is 30 cm and each stage is identical. Calculate the required rotational speed. Assume a work done factor of 0.85 and a constant axial velocity of 170 m/s.

Assuming an axial velocity at the eye of the impeller, an impeller tip diameter of 36 cm, a slip factor of 0.92 and power input factor of 1.05, calculate the rotational speed required for the centrifugal compressor. Ambient conditions are 1 bar and 290 K.

[20 marks]





- Q.3 (b) A steam turbine is to operate between 160 bar, 560°C and 0.15022 bar. The bucket velocity is limited to 310 m/s and the average nozzle efficiency is expected to be 96%, except for a 2-row Curtis stage for which it will be 92%. Nozzle angles will be assumed as 16° for impulse stages and 26° for reaction stages.

All stages operate close to the speed of maximum efficiency. Estimate the number of stages required for each of the following arrangements.

- (a) All simple impulse stages.
 (b) All 50% reaction stages.
 (c) A 2-row Curtis stage followed by simple impulse stages.
 (d) A 2-row Curtis stages followed by 50% reaction stages.

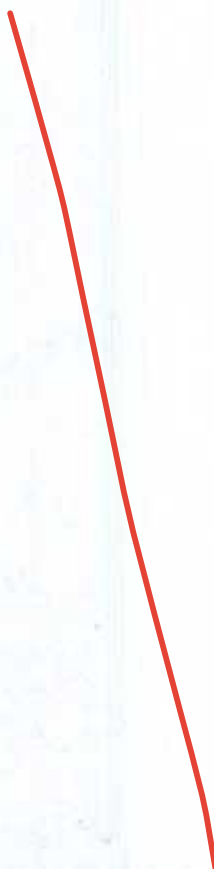
Saturated Water and Steam (Temperature-based), Contd.

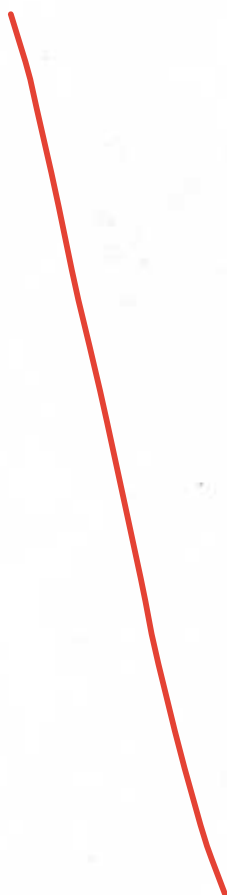
T °C	p_{sat} MPa	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
		v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
40	0.0073849	0.00100789	19.515	167.52	2429.4	167.53	2573.5	2406.0	0.57240	8.2555	7.6831
41	0.0077878	0.00100828	18.563	171.70	2430.7	171.71	2575.3	2403.6	0.58573	8.2368	7.6511
42	0.0082096	0.00100868	17.664	175.88	2432.1	175.89	2577.1	2401.2	0.59901	8.2182	7.6192
43	0.0086508	0.00100909	16.814	180.06	2433.4	180.07	2578.9	2398.8	0.61225	8.1998	7.5875
44	0.0091124	0.00100950	16.011	184.24	2434.7	184.25	2580.6	2396.4	0.62545	8.1815	7.5560
45	0.0095950	0.00100992	15.252	188.42	2436.1	188.43	2582.4	2394.0	0.63861	8.1633	7.5247
46	0.010099	0.00101036	14.534	192.61	2437.4	192.62	2584.2	2391.6	0.65173	8.1453	7.4936
47	0.010627	0.00101079	13.855	196.79	2438.8	196.80	2586.0	2389.2	0.66481	8.1275	7.4627
48	0.011177	0.00101124	13.212	200.97	2440.1	200.98	2587.8	2386.8	0.67785	8.1098	7.4320
49	0.011752	0.00101169	12.603	205.15	2441.4	205.16	2589.5	2384.4	0.69085	8.0922	7.4014
50	0.012352	0.00101215	12.027	209.33	2442.7	209.34	2591.3	2381.9	0.70381	8.0748	7.3710
51	0.012978	0.00101262	11.481	213.51	2444.1	213.52	2593.1	2379.5	0.71673	8.0576	7.3408
52	0.013631	0.00101309	10.963	217.70	2445.4	217.71	2594.8	2377.1	0.72961	8.0404	7.3108
53	0.014312	0.00101357	10.472	221.88	2446.7	221.89	2596.6	2374.7	0.74245	8.0234	7.2810
54	0.015022	0.00101406	10.006	226.05	2448.0	226.07	2598.3	2372.3	0.75526	8.0066	7.2513
55	0.015762	0.00101455	9.5643	230.24	2449.3	230.26	2600.1	2369.8	0.76802	7.9898	7.2218
56	0.016533	0.00101505	9.1448	234.42	2450.6	234.44	2601.8	2367.4	0.78075	7.9732	7.1925
57	0.017335	0.00101556	8.7466	238.60	2452.0	238.62	2603.6	2365.0	0.79344	7.9568	7.1633
58	0.018171	0.00101608	8.3683	242.79	2453.2	242.81	2605.3	2362.5	0.80610	7.9404	7.1343
59	0.019041	0.00101660	8.0089	246.97	2454.6	246.99	2607.1	2360.1	0.81871	7.9242	7.1055
60	0.019945	0.00101713	7.6672	251.16	2455.9	251.18	2608.8	2357.7	0.83129	7.9081	7.0769
61	0.020888	0.00101766	7.3424	255.35	2457.2	255.37	2610.6	2355.2	0.84384	7.8922	7.0484
62	0.021867	0.00101821	7.0335	259.53	2458.5	259.55	2612.3	2352.8	0.85634	7.8764	7.0200
63	0.022885	0.00101875	6.7396	263.72	2459.8	263.74	2614.0	2350.3	0.86882	7.8607	6.9918
64	0.023943	0.00101931	6.4598	267.91	2461.1	267.93	2615.8	2347.8	0.88125	7.8451	6.9638
65	0.025042	0.00101987	6.1935	272.09	2462.4	272.12	2617.5	2345.4	0.89365	7.8296	6.9359
66	0.026183	0.00102044	5.9399	276.27	2463.7	276.30	2619.2	2342.9	0.90602	7.8142	6.9082
67	0.027368	0.00102101	5.6984	280.46	2465.0	280.49	2621.0	2340.5	0.91835	7.7990	6.8807
68	0.028599	0.00102159	5.4682	284.65	2466.3	284.68	2622.7	2338.0	0.93064	7.7839	6.8532
69	0.029876	0.00102218	5.2488	288.84	2467.6	288.87	2624.4	2335.5	0.94291	7.7689	6.8260
70	0.031201	0.00102277	5.0395	293.04	2468.9	293.07	2626.1	2333.0	0.95513	7.7540	6.7989
71	0.032575	0.00102337	4.8400	297.23	2470.1	297.26	2627.8	2330.5	0.96733	7.7392	6.7719
72	0.034000	0.00102398	4.6496	301.42	2471.4	301.45	2629.5	2328.1	0.97949	7.7246	6.7451
73	0.035478	0.00102459	4.4680	305.60	2472.7	305.64	2631.2	2325.6	0.99161	7.7100	6.7184
74	0.037009	0.00102521	4.2945	309.80	2474.0	309.84	2632.9	2323.1	1.0037	7.6955	6.6918
75	0.038595	0.00102584	4.1289	313.99	2475.2	314.03	2634.6	2320.6	1.0158	7.6812	6.6654
76	0.040239	0.00102647	3.9708	318.18	2476.5	318.22	2636.3	2318.1	1.0278	7.6670	6.6392
77	0.041941	0.00102710	3.8197	322.38	2477.8	322.42	2638.0	2315.6	1.0398	7.6528	6.6130
78	0.043703	0.00102775	3.6752	326.58	2479.1	326.62	2639.7	2313.0	1.0517	7.6388	6.5871
79	0.045527	0.00102840	3.5372	330.76	2480.3	330.81	2641.3	2310.5	1.0637	7.6249	6.5612
80	0.047414	0.00102905	3.4052	334.96	2481.5	335.01	2643.0	2308.0	1.0756	7.6111	6.5355

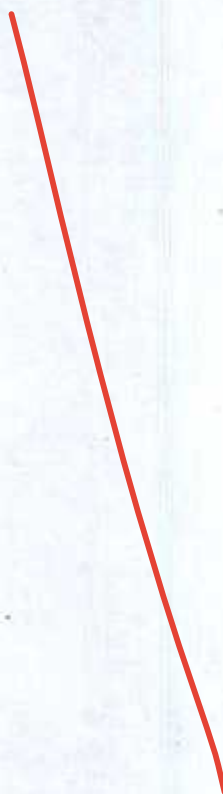
Water/Steam at $p = 16.0 \text{ MPa}$ ($T_{\text{sat}} = 347.355^\circ\text{C}$)

T $^\circ\text{C}$	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg K	T $^\circ\text{C}$	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg K
0	0.00099228	0.18	16.06	0.00046	270	0.00127925	1162.2	1182.7	2.9468
5	0.00099241	20.90	36.78	0.07563	280	0.00130718	1211.8	1232.7	3.0380
10	0.00099288	41.59	57.48	0.14939	290	0.00133865	1262.7	1284.1	3.1302
15	0.00099364	62.28	78.18	0.22182	300	0.00137464	1315.4	1337.4	3.2240
20	0.00099466	82.95	98.86	0.29300	310	0.00141665	1370.5	1393.2	3.3204
25	0.00099592	103.62	119.55	0.36297	320	0.00146711	1428.6	1452.1	3.4206
30	0.00099739	124.28	140.24	0.43180	330	0.00153044	1491.3	1515.8	3.5271
35	0.00099906	144.96	160.94	0.49952	340	0.00161630	1561.5	1587.4	3.6447
40	0.00100092	165.64	181.65	0.56617	347.355	0.00170944	1622.3	1649.7	3.7457
45	0.00100296	186.31	202.36	0.63180	347.355	0.00930880	2431.9	2580.8	5.2463
50	0.00100517	207.01	223.09	0.69644	350	0.00976580	2460.7	2617.0	5.3045
55	0.00100755	227.70	243.82	0.76012	360	0.0110610	2538.8	2715.8	5.4619
60	0.00101007	248.41	264.57	0.82288	370	0.0120460	2595.7	2788.4	5.5756
65	0.00101276	269.14	285.34	0.88474	380	0.0128780	2642.3	2848.3	5.6681
70	0.00101559	289.86	306.11	0.94573	390	0.0136130	2682.8	2900.6	5.7476
75	0.00101856	310.61	326.91	1.0059	400	0.0142810	2719.1	2947.6	5.8179
80	0.00102168	331.36	347.71	1.0652	410	0.0148990	2752.3	2993.7	5.8816
85	0.00102494	352.14	368.54	1.1238	420	0.0154780	2783.4	3031.0	5.9401
90	0.00102835	372.94	389.39	1.1816	430	0.0160260	2812.6	3069.0	5.9945
95	0.00103189	393.74	410.25	1.2387	440	0.0165480	2840.3	3105.1	6.0455
100	0.00103557	414.57	431.14	1.2950	450	0.0170490	2866.9	3139.7	6.0937
105	0.00103939	435.43	452.06	1.3507	460	0.0175310	2892.5	3173.0	6.1395
110	0.00104336	456.32	473.01	1.4057	470	0.0179980	2917.3	3205.3	6.1832
115	0.00104747	477.22	493.98	1.4601	480	0.0184510	2941.5	3236.7	6.2252
120	0.00105172	498.16	514.99	1.5139	490	0.0188920	2965.0	3267.3	6.2656
125	0.00105612	519.13	536.03	1.5671	500	0.0193230	2988.1	3297.3	6.3046
130	0.00106067	540.15	557.12	1.6197	520	0.0201570	3033.1	3355.6	6.3790
135	0.00106537	561.19	578.24	1.6718	540	0.0209610	3076.7	3412.1	6.4493
140	0.00107022	582.29	599.41	1.7233	560	0.0217390	3119.4	3467.2	6.5163
145	0.00107524	603.43	620.63	1.7744	580	0.0224970	3161.2	3521.2	6.5804
150	0.00108042	624.61	641.90	1.8250	600	0.0232380	3202.6	3574.4	6.6421
155	0.00108577	645.86	663.23	1.8751	620	0.0239630	3243.6	3627.0	6.7016
160	0.00109129	667.16	684.62	1.9247	640	0.0246750	3284.2	3679.0	6.7591
165	0.00109699	688.52	706.07	1.9740	660	0.0253760	3324.6	3730.6	6.8150
170	0.00110288	709.94	727.59	2.0228	680	0.0260670	3364.8	3781.9	6.8694
175	0.00110896	731.44	749.18	2.0713	700	0.0267490	3404.9	3832.9	6.9224
180	0.00111525	753.02	770.86	2.1194	720	0.0274230	3445.0	3883.8	6.9741
185	0.00112174	774.68	792.61	2.1671	740	0.0280910	3485.0	3934.5	7.0247
190	0.00112846	796.40	814.46	2.2145	760	0.0287520	3525.1	3985.1	7.0742
195	0.00113540	818.23	836.40	2.2617	780	0.0294070	3565.2	4035.7	7.1227
200	0.00114259	840.16	858.44	2.3085	800	0.0300580	3605.4	4086.3	7.1703
210	0.00115775	884.34	902.86	2.4014	820	0.0307030	3645.8	4137.0	7.2171
220	0.00117405	928.99	947.77	2.4934	840	0.0313450	3686.1	4187.6	7.2630
230	0.00119164	974.17	993.24	2.5847	860	0.0319830	3726.6	4238.3	7.3082
240	0.00121069	1020.0	1039.4	2.6754	880	0.0326170	3767.2	4289.1	7.3526
250	0.00123144	1066.5	1086.2	2.7658	900	0.0332470	3808.0	4340.0	7.3964
260	0.00125417	1113.8	1133.9	2.8562	920	0.0338750	3849.0	4391.0	7.4395
270	0.00127925	1162.2	1182.7	2.9468	940	0.0345000	3890.2	4442.2	7.4819
					960	0.0351230	3931.4	4493.4	7.5238
					980	0.0357430	3972.9	4544.8	7.5652
					1000	0.0363610	4014.5	4596.3	7.6060

[20 marks]







Q.3 (c) A Francis turbine is to be designed to develop 400 kW of power under a head of 100 m while running at a speed of 1000 rpm. Following are some data of turbine given:

- (i) Ratio of width of runner to outer diameter of the runner = 0.15
- (ii) Ratio of inner diameter to outer diameter of the runner = 0.6
- (iii) Flow ratio = 0.2
- (iv) Hydraulic efficiency = 92%
- (v) Mechanical efficiency = 86%
- (vi) Circumferential area occupied by thickness of vanes = 6%

Assuming constant flow velocity, calculate

- (a) Guide vane angle (b) runner blade angle at inlet (c) blade angle at outlet.

[20 marks]

Ans 3(c) Power developed = 400 kW

$$H = 100 \text{ m}$$

$$N = 1000 \text{ rpm}$$

1 - Inlet
2 - Exit

Given

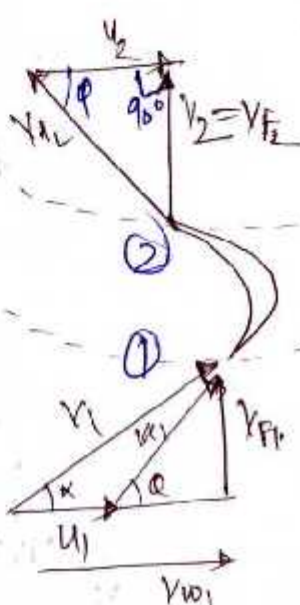
$$\frac{b_2}{d_2} = 0.15 ; \quad \frac{d_2}{d_1} = 0.6$$

$$K_f = \frac{V_{f1}}{\sqrt{2gH}} = 0.2 ; \quad \eta_H = 0.92$$

$$\eta_M = 86\%$$

$$K_{f2} = 0.84$$

Francis = Inward Flow Reaction Turbine



$$P = \dot{m} (V_{w1} u_1 + V_{w2} u_2)$$

$$P = \dot{m} (V_{w1} u_1)$$

$$400 \times 10^3 = \dot{m} g (V_{w1} u_1)$$

$$400 = g (V_{w1} u_1) \quad \text{--- (1)}$$

$$0.2 = \frac{V_{f1}}{\sqrt{2 \times 9.81 \times 100}}$$

$$V_{f1} = 8.858 \text{ m/s} = V_{f2}$$

$$\eta_H = 0.9 \rightarrow \frac{RP}{WP} = 0.92 \rightarrow WP = \frac{400}{0.92}$$

$$WP = 434.782 \text{ kW}$$

$$WP = \rho g H \rightarrow 434.782 \times 10^3 = 10^3 \times g \times H \times 100$$

$$g = 0.443 \text{ m/s}^2$$

$$A_H \times V_H = 0.443 \rightarrow$$

$$A_H = 0.05 \text{ m}^2$$

$$0.94 \times \pi b_1 d_1 = 0.05 = \pi b_2 d_2 \times 0.94$$

$$\frac{0.05}{\pi \times 0.94} = d_2 (0.15 d_2)$$

$$d_2 = 0.336 \text{ m}$$

$$d_1 = 0.56 \text{ m}$$

$$V_1 = \frac{\pi d_1 N}{60}$$

$$= \frac{\pi \times 0.56 \times 1000}{60} = 29.3 \text{ m/s}$$

$$V_1 = 29.3 \text{ m/s}$$

$$400 = Q (V_{w1} \times 29.3)$$

$$V_{w1} = 30.81 \text{ m/s}$$

$$\tan \alpha = \frac{V_H}{V_{w1}} = \frac{8.858}{30.81}$$

$$\alpha = 16.64^\circ$$

GUIDE
VANE
ANGLE

$$\textcircled{b} \quad \theta = ?$$

$$\tan \theta = \frac{V_H}{V_{w1} - V_1}$$

$$\tan \theta = \frac{8.858}{30.81 - 29.3}$$

$$\theta = 80.32^\circ$$

Runner blade
inlet angle

② $\phi = ?$ (Blade angle at outlet)

$$V_2 = \frac{\pi D_2 M}{60} = \frac{\pi \times 0.336 \times 1000}{60} \rightarrow \boxed{V_2 = 17.584 \text{ m/s}}$$

$$\tan \phi = \frac{V_{f2}}{V_2} = \frac{8.858}{17.584}$$

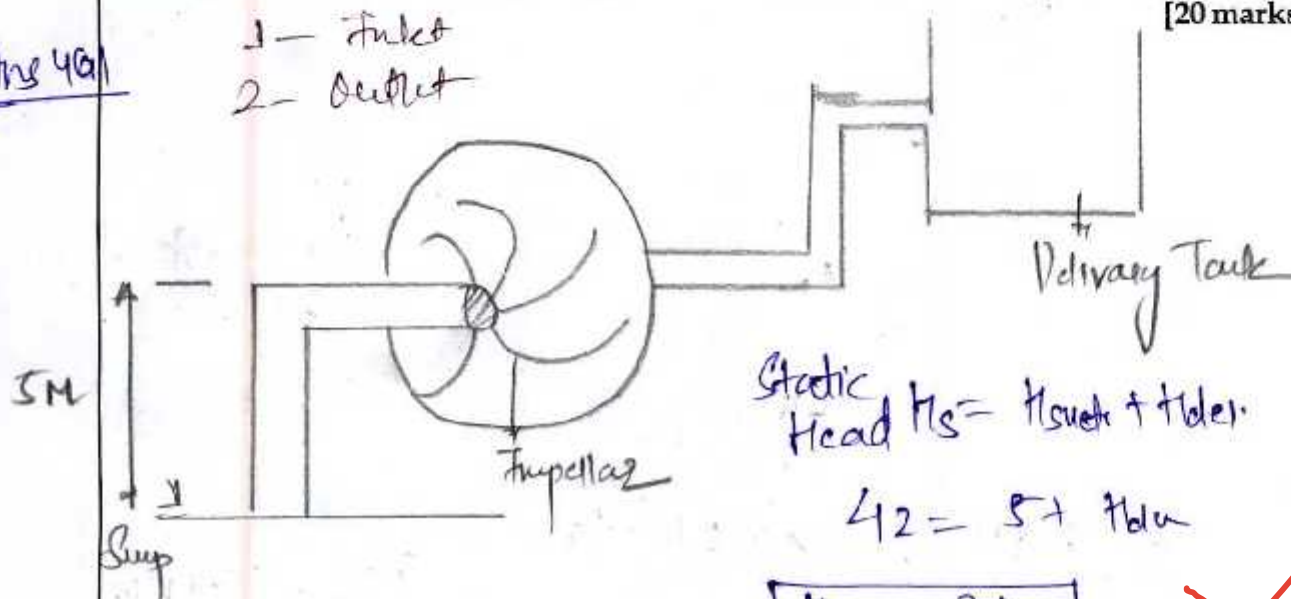
$$\boxed{\phi = 26.736^\circ}$$

- Q.4 (a) A centrifugal pump lifts water under a static lift of 42 m of which 5 m is suction lift. The suction and delivery pipes are both of 34 cm diameter. The friction loss in suction pipe is 2.5 m and in delivery pipe it is 7.0 m. The impeller is 0.6 m in diameter and 4 cm wide at outlet and runs at a speed of 1000 rpm. The exit blade angle is 25° . If the manometric efficiency of the pump is 86%, determine the pressures at the suction and delivery ends of the pump and the discharge. Neglect the velocity at the outlet of delivery pipe.

[20 marks]

Ans 401

1 - Inlet
2 - Outlet



$$\text{Static Head } H_s = H_{\text{suction}} + H_{\text{delivery}}$$

$$42 = 5 + H_{\text{deliv}}$$

$$\boxed{H_{\text{deliv}} = 37 \text{ m}}$$

$$(H)_{\text{static}} = 2.5 \text{ m}$$

$$(H)_{\text{delv}} = 7.0 \text{ m}$$

$$\eta_H = 0.86$$

$$Q_2 ??$$

$$P_{\text{static}} = ??$$

$$P_{\text{delv}} = ??$$

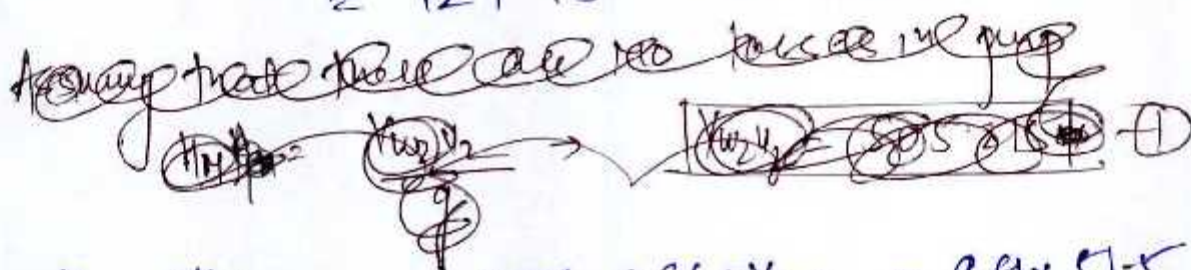
$$d_2 = 0.6 \text{ m}$$

$$b_2 = 0.04 \text{ m}$$

$$N = 1000 \text{ rpm}$$

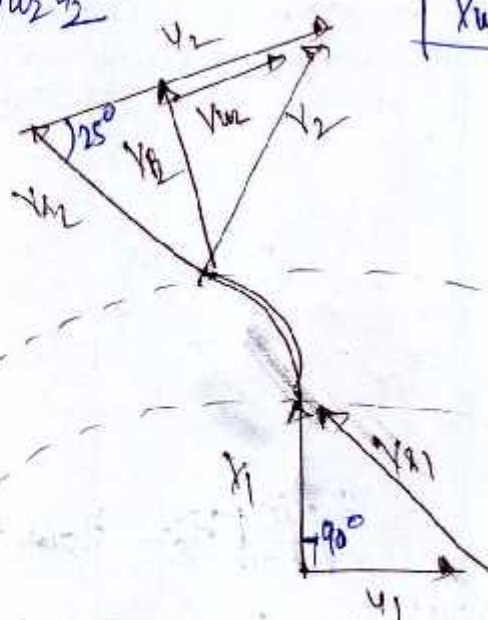
$$\phi = 25^\circ$$

$$\begin{aligned} \text{Manometric Head} &= H_s + H_f \\ &= 42 + 9.5 = 51.5 \text{ m} \end{aligned}$$



$$\eta_H = \frac{g H M}{V_{w2} V_2} \rightarrow 0.86 \times V_{w2} V_2 = 9.81 \times 51.5$$

$$V_{w2} V_2 = 587.459$$



$$\begin{aligned} V_{w1} &= 0 \\ \alpha &= 90^\circ \\ \text{For centrifugal pump} \end{aligned}$$

$$V_2 = \frac{\pi d_2 N}{60} = \frac{\pi \times 0.6 \times 1000}{60}$$

$$V_2 = 31.4 \text{ m/s}$$

$$V_{u2} = 18.7 \text{ m/s}$$

Apply B & B's equation & Bernoulli

$$\frac{P_{\text{suction}}}{\rho g} + \frac{V_1^2}{2g} + 0 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + 4.2 + 9.5$$

+ $V_1 \approx 0$.

$$\frac{P_{\text{suction}} - P_2}{\rho g} = 51.5$$

$$P_{\text{suction}} - P_2 = 505215$$

$$\tan 25^\circ = \frac{V_{F2}}{u_2 - V_{u2}} = \frac{V_{F2}}{31.4 - 18.7} = \tan 25^\circ$$

$$V_{F2} = 3.402 \text{ m/s}$$

$$Q = A_{F2} V_{F2} = \pi d_2^2 \times V_{F2}$$

$$Q = \pi \times 0.04^2 \times 0.6 \times 3.402$$

$$Q = 0.25644 \text{ m}^3/\text{s}$$

Assuming at suction orifice at atmospheric pressure, $\rightarrow P_{\text{suction}} = P_{\text{atm}} = 10^5 \text{ Pa}$.

~~$$P_{\text{suction}} = 505215$$~~

~~$$P_{\text{suction}} = 405215 \text{ Pa}$$~~

~~$$P_{\text{suction}} =$$~~

8/20

- Q.4 (b) The steam consumption in a Parson's reaction turbine running at 500 rpm is 7 kg/s. The pressure of the steam at a certain pair is 2 bar, its dryness fraction is 0.97 and power developed by the pair is 5.4 kW. The discharging blade tip angle is 22° for both fixed and moving blades and the axial velocity of flow is 0.75 of blade velocity. Calculate the drum diameter and the blade height, assuming the tip leakage as 7 percent and neglecting the blade thickness.

Take specific volume of saturated steam at 2 bar = $0.8851 \text{ m}^3/\text{kg}$

[20 marks]

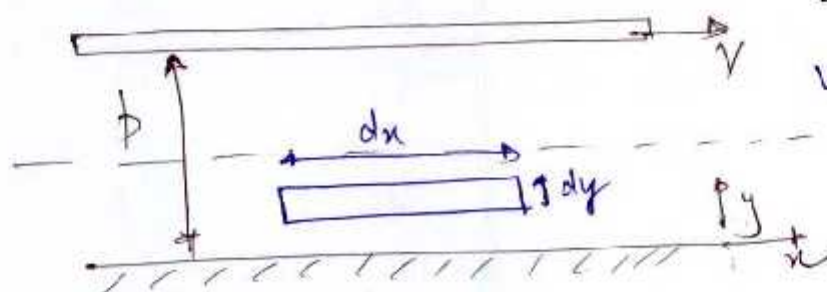


- Q.4 (c) (i) Show that the discharge per unit width between two parallel plates distance b apart, when one plate is moving at velocity V while the other one is held stationary, for the condition of zero shear stress at fixed plate is : $q = \frac{bV}{3}$.

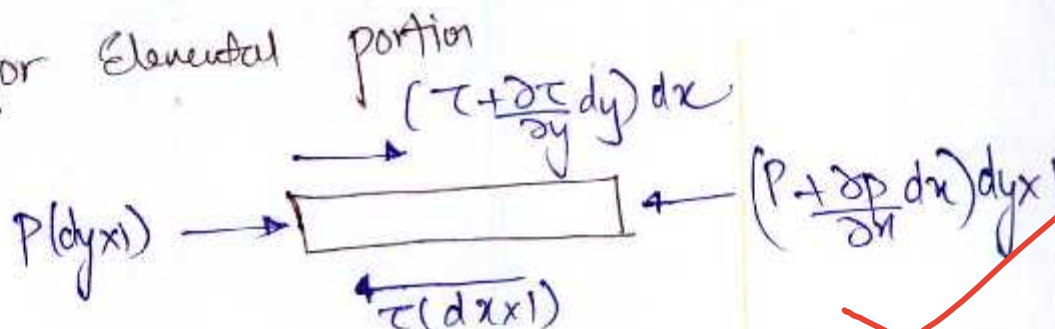
where q = Discharge per unit width

- (ii) Laminar flow of a fluid of viscosity 0.85 kg/ms and mass density 1150 kg/m^3 occurs between a pair of plates of extensive width : the plates are 12 mm apart and are inclined at 45° to the horizontal. Pressure gauge mounted at two points 1.5 m vertical apart on the upper plate record pressure of 85 kN/m^2 and 270 kN/m^2 . The upper plates moves with velocity of 2.5 m/s relative to the lower plate but in direction opposite to the fluid flow. Make calculation for
- the velocity and shear stress distribution between the plates.
 - the maximum flow velocity, and
 - the shear stress on the upper plate

[10 + 10 marks]



FBD for Elemental portion



From force Balancing $\rho dy - \rho dy - \frac{\partial p}{\partial x} du dy$
 $+ \tau dx + \frac{\partial \tau}{\partial y} dy dx - \tau dx = 0$

$$\boxed{\frac{\partial p}{\partial x} = \frac{\partial \tau}{\partial y}} \quad \text{--- (1)}$$

we know that

$$\tau = \mu \frac{du}{dy}$$

Substituting in (1), we get

$$\frac{\partial}{\partial y} \left(\mu \frac{du}{dy} \right) = \frac{\partial p}{\partial x}$$

$$\mu \frac{d^2 u}{dy^2} = \frac{\partial p}{\partial x} \rightarrow \frac{d^2 u}{dy^2} = \frac{1}{\mu} \frac{\partial p}{\partial x}$$

$$\frac{du}{dy} = \frac{1}{\mu} \frac{\partial p}{\partial x} y + C_1$$

$$\boxed{u = \frac{1}{2\mu} \frac{\partial p}{\partial x} y^2 + C_1 y + C_2}$$

At $y=0$, $u=0$ & At $y=b$, $u=V$.

$$0 = 0 + 0 + C_2 \quad \boxed{C_2 = 0}$$

$$V = \frac{1}{2\mu} \frac{\partial p}{\partial x} b^2 + C_1 b$$

$$\boxed{\frac{V}{b} - \frac{1}{2\mu} \frac{\partial p}{\partial x} b = C_1}$$

$$\boxed{u = \frac{1}{2\mu} \frac{\partial p}{\partial x} y^2 + \left[\frac{V}{b} - \frac{1}{2\mu} \frac{\partial p}{\partial x} b \right] y}$$

$$\phi = \int v dA$$

$$= \int_0^b \left[\frac{1}{2\mu} \frac{\partial p}{\partial x} y^2 + \left[\frac{V}{b} - \frac{1}{2\mu} \frac{\partial p}{\partial x} \right] y \right] dy \times 1$$

$$= \frac{1}{2\mu} \frac{\partial p}{\partial x} \frac{y^3}{3} + \frac{V}{b} y - \frac{1}{2\mu} \frac{\partial p}{\partial x} \frac{y^2}{2} \Big|_0^b$$

$$= \frac{1}{2\mu} \frac{\partial p}{\partial x} \frac{b^3}{3} + V - \frac{1}{2\mu} \frac{\partial p}{\partial x} \frac{b^2}{2}$$

$$= V + \frac{1}{2\mu} \frac{\partial p}{\partial x} b^2 \left(\frac{1}{3} - \frac{1}{2} \right)$$

$$= V + \frac{1}{2\mu} \frac{\partial p}{\partial x} b^2 \left(\frac{2-3}{6} \right)$$

$$q = V - \frac{1}{2\mu} \frac{\partial p}{\partial x} b^3 \times \frac{1}{6}$$

$$q = \left[\frac{V}{2} - \frac{b^3}{6\mu} \frac{\partial p}{\partial x} \right] \times 1$$

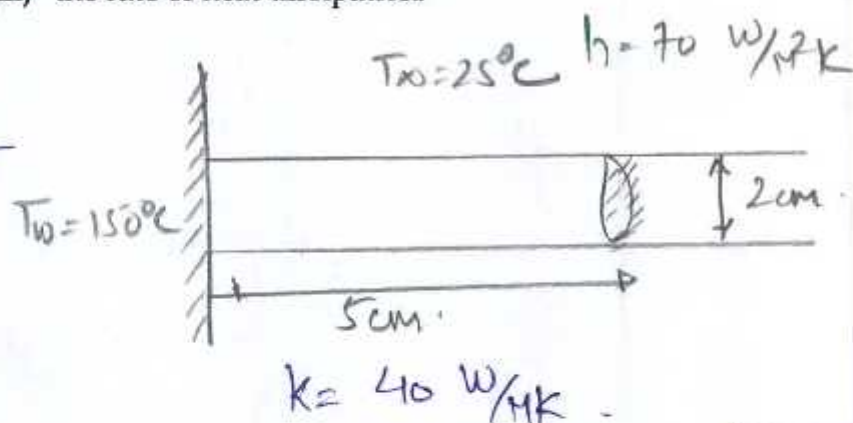
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Section : B

- Q.5 (a) A steel rod of 2 cm in diameter and 5 cm long protrudes from a wall which is maintained at 150°C . The rod is insulated at its tip and is exposed to an environment having heat transfer coefficient as $70 \text{ W/m}^2\text{K}$ and at 25°C temperature. The thermal conductivity of the rod is 40 W/mK . Calculate the
- fin efficiency
 - temperature at the tip of fin and
 - the rate of heat dissipation.

[12 marks]



$$M = \sqrt{\frac{hP}{KA_b}} = \sqrt{\frac{h \times \pi d \times L}{k \times \pi d^2}} = \sqrt{\frac{4 \times h}{k d}} = \sqrt{\frac{4 \times 70 \times 100}{40 \times 2}}$$

$$M = 18.7$$

$$ML = \frac{18.7 \times 5}{100} = 0.935$$

$$ML = 0.935$$

① Fin Efficiency

for insulated tip

$$\eta = \frac{q_{\text{act}}}{q_{\text{max}}}$$

$$\eta = \frac{\sqrt{hP} A_b \theta_b \tanh mL}{h P L \theta_b}$$

$$\eta = \frac{\tanh h(m)}{ML} = \frac{\tanh(0.935)}{0.935}$$

$$\eta = 0.783 \rightarrow$$

$$\eta = 78.3\%$$

(11) Temp at the Tip of fin $\rightarrow \frac{\theta}{\theta_0} = \frac{\cosh hM(T_i - T_\infty)}{\cosh hML}$

$$\frac{T - T_\infty}{T_i - T_\infty} = \frac{1}{\cosh(0.935)} \rightarrow \frac{T - T_\infty}{T_i - T_\infty} = 0.6803$$

$$(T - T_\infty) = 0.6803 \times (150 - 25) \quad T - T_\infty = 85.039$$

$$T_{\text{at tip}} = 110.03^\circ\text{C}$$

(11) Rate of Heat Dissipation

$$q = \sqrt{hPKA} \theta_0 \tanh hML$$

$$= \sqrt{70 \times \frac{\pi \times 2 \times 40 \times \pi}{4} \left(\frac{2}{100}\right)^2 \times (150 - 25) \times 0.7329}$$

$$q = 21.526 \text{ W}$$

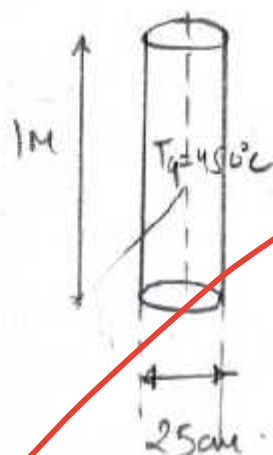
Q.5 (b) A 25 cm diameter pipe has been laid in an atmosphere of quiescent air at 15°C and conveys gas at 450°C . Calculate the heat loss per metre length of the bare pipe if the convection heat transfer coefficient from a hot cylindrical surface freely exposed to still air is prescribed the relation

$$h = 1.52 \left(\frac{\Delta t}{d} \right)^{0.25} \text{ W/m}^2\text{K}$$

where Δt is the temperature difference and 'd' is the diameter of the cylinder in metres, what percentage reduction in heat loss would occur if the pipe is covered with 10 cm thick layer of material whose thermal conductivity is 0.07 W/mK

[12 marks]

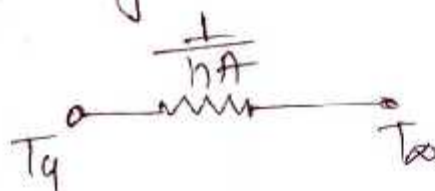
Ans (b)



$$T_\infty = 15^\circ\text{C}$$

$$q_{\text{lost}} = ??$$

Using Resistance concept



$$Q = \frac{T_q - T_o}{\frac{1}{hA}} = \frac{450 - 15}{\frac{1}{hA}}$$

$$h = 1.52 \left(\frac{\Delta T}{d} \right)^{0.25} = 1.52 \times \left(\frac{435}{0.25} \right)^{0.25}$$

$$h = 9.817 \text{ W/m}^2\text{K}$$

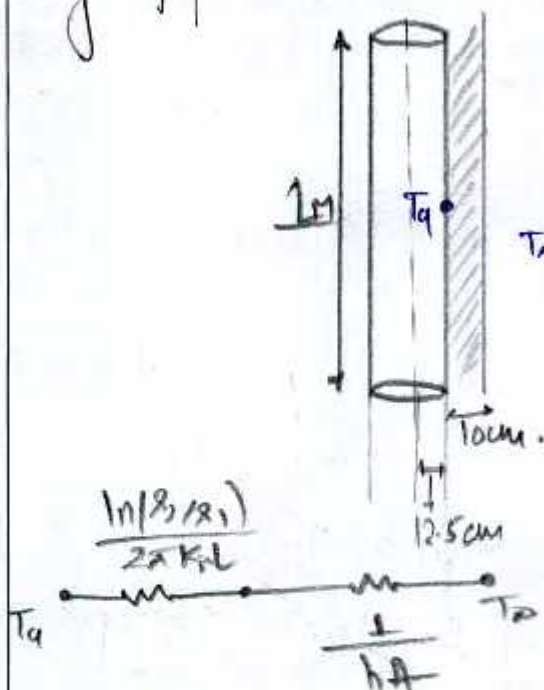
$$A = \pi \times 0.25 \times 1$$

$$A = 0.785 \text{ m}^2$$

$$Q = 435 \times 9.817 \times 0.785$$

$$Q = 3352.26 \text{ W} \quad (\text{Heat lost per metre length})$$

⇒ If pipe is covered with 10 cm Thick layer



$$Q = \frac{T_q - T_o}{\frac{1}{hA} + \frac{\ln(r_2/r_1)}{2\pi kL}}$$

$$Q = \frac{435}{\frac{1}{7.706} + \frac{\ln\left(\frac{22.5}{12.5}\right)}{2\pi \times 0.09 \times 1}}$$

$$Q = 296.55 \text{ Watt}$$

$$\begin{aligned} \underline{\% \text{ Reduct}^n} &= \frac{S_2 - S_1}{S_1} \times 100 \\ &= \frac{296.55 - 3352.26}{3352.26} \times 100 \\ &= -91.153\% \end{aligned}$$

$$\boxed{\% \text{ Reductio} = 91.1563\%}$$

- Q.5 (c) (i) Write down the functions of expansion devices in a refrigeration system and briefly explain their types.
- (ii) With a neat sketch explain the principle and working of automatic or constant pressure expansion valve.

[6 + 6 marks]

Ans (c) Expansion Devices = Expansion devices are the devices which helps in reducing the pressure of refrigerant by reducing its Temp.

Expansion Devices are mainly of two type

- ① Constant Area
- ② Constant Vol Type

- ① Constant Area - In constant Area, type Expansion device, area remains constant during Throttling process.

Eg - Capillary Tube.

Pressure drop in Capillary Tube directly proportion to length of Capillary tube & inversely proportion to Area

$$\Delta P \propto \frac{L}{A}$$

- ② Constant Vol - In constant Vol Type we have 2 further sub classifications

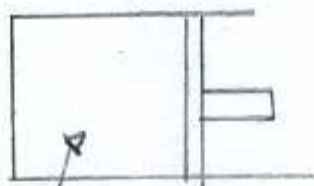
① Thermostatic - In thermostatic type expansion device, the degree of superheat remains least

② Automatic - In Automatic expansion device, the pressure remains constant throughout the process.



- Q.5 (d) Air in a piston-cylinder arrangement is heated at constant pressure by addition of 100 kJ/kg of air. The air is initially at atmospheric pressure and at a temperature of 40°C while the surroundings is at 27°C. Calculate the change in availability per kg of air. [Take, $c_p = 1.005$ kJ/kg-K and $P_{atm} = 1$ bar]

[12 marks]



$$q = 100 \text{ kJ/kg}$$

1 → Initial 2 → final

$$\text{Process } 1-2 \Rightarrow P = \text{constant}$$

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

$$T_0 = 300 \text{ K}$$

$$T_1 = 313 \text{ K}$$

Using First Law

$$q = du + sw$$

$$100 = C_v(T_2 - T_1) + sw$$

$$100 = 0.718(T_2 - T_1) + 100(V_2 - V_1) \quad \text{--- (1)}$$

$$P = \text{const} \rightarrow \left[\frac{V_1}{T_1} = \frac{V_2}{T_2} \right] \quad \text{--- (2)} \rightarrow T_2 = \frac{V_2 \times T_1}{V_1}$$

$$T_2 = 412.195 \text{ K}$$

Change in availability per kg of Air is given by

$$\Delta A.E = (u_1 - u_2) - T_0(s_1 - s_2) + P_0(V_1 - V_2)$$

$$\Delta A.E = (u_1 - u_2) + P_0(V_1 - V_2) - T_0(s_1 - s_2)$$

$$= -100 - T_0(s_1 - s_2)$$

$$s_1 - s_2 = c_p \ln \frac{T_1}{T_2} - R \ln \left(\frac{P_1}{P_2} \right)$$

$$s_1 - s_2 = 1.005 \ln \left(\frac{313}{412.195} \right)$$

$$= -0.2766$$

$$\Delta A.E = -100 - 300 \times (-0.2766)$$

$$\Delta A.E = -16.99 \text{ kJ/kg}$$

$$1 = \frac{PV_1}{RT_1}$$

$$\frac{1 \times 0.287}{100} = \frac{V_1}{T_1}$$

$$V_1 = 0.89831 \text{ m}^3$$

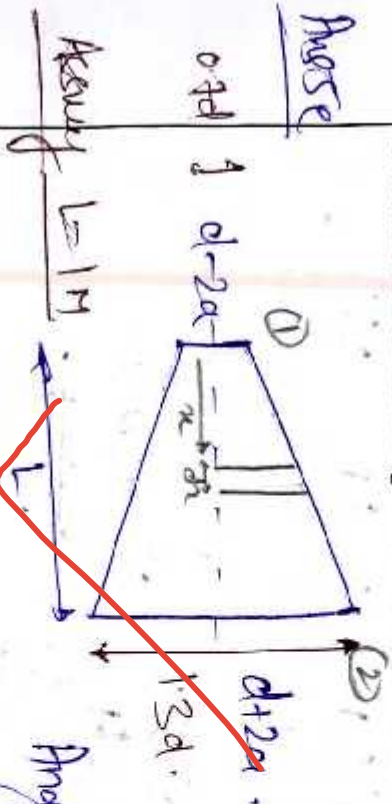
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$V_2 = 1.183 \text{ m}^3$$

Q.5 (c)

A shaft tapers uniformly from a diameter $(d - 2a)$ at one end to $(d + 2a)$ at the other is transmitting power under the action of an applied torque T . Assuming the value of $a = 0.15d$. Calculate the percentage error in the angle of twist for a given length, when evaluated on considering constant diameter d .

[12 marks]

Ans:

Applied Torque $= T$
 $a = 0.15d$

① for a const diameter, d

$$\theta = \frac{TL}{\frac{9}{32} \pi d^4} = \frac{32 TL}{9 \pi d^4} \quad \text{--- ①}$$

② for the tapered shaft

$$d\theta = \frac{T dx}{\frac{9}{32} \pi x^4}$$

$$x_1 = x_1 + \left(\frac{x_2 - x_1}{L} \right) x$$

$$x_2 = 0.35d + \frac{0.3d}{L} x$$

$$x_1 = 0.35d + 0.3d x$$

$$d\theta = T dx$$

$$\frac{9}{32} \pi x^4 (0.35d + 0.3d x)$$

$$\int d\theta = \int_0^L \frac{2T dx}{9 (0.35d + 0.3dx)^4}$$

$$0.35d + 0.3dx = k$$

$$(0.3d) dx = dk$$

$$\int d\theta = \int_0^L \frac{2T}{9} \frac{dk}{k^4} \times \frac{1}{(0.3d)}$$

$$0.35d$$

$$Q = \frac{2\pi}{9} \int_{0.35d}^{0.65d} k^{-4} dk \rightarrow Q = \frac{2\pi}{9} \frac{k^{-3}}{3} \Big|_{0.35d}^{0.65d}$$

$$Q = \frac{2\pi}{0.35d \cdot 3 \cdot 9} \left[\left(\frac{1}{0.35d} \right)^3 - \left(\frac{1}{0.65d} \right)^3 \right]$$

$$Q = \frac{2\pi \times 19.682}{3 \cdot 9} \rightarrow 43.737$$

$$Q_{at} = \frac{13.127}{0.49}$$

$$\% \text{ Error} = \frac{Q_{at} - Q_{car}}{Q_{car}} \times 100$$

$$= \frac{13.127}{0.49} - \frac{43.737}{0.49} - \frac{10.191}{0.49} \times 100$$

$$\frac{43.737}{0.49}$$

$$\% \text{ Error} = 76.70\%$$

- Q.6 (a) An engine cylinder system contains a gas mixture with volumetric analysis of 15% CO_2 , 17.5% O_2 and 67.5% N_2 . The temperature at the beginning of expansion is 1200°C and gas mixture expands reversibly through a volume ratio of 8 : 1 according to the law $p v^{1.25} = c$.

Calculate for per kg of gas:

- (a) The work done
- (b) The heat flow
- (c) The change in entropy

[Take the value of c_p for constituents CO_2 , O_2 and N_2 as 1.235 kJ/kg-K, 1.088 kJ/kg-K and 1.172 kJ/kg-K respectively]

[20 marks]

$$\text{(a) } \underline{\text{work done}} = \frac{p_1 V_1 - p_2 V_2}{n-1}$$

$$\Rightarrow \text{Mixture} = 15\% \text{ O}_2, 17.5\% \text{ O}_2, 67.5\% \text{ N}_2$$

$$T_1 = 1200^\circ\text{C} = 1473\text{K}$$

$$r = (\text{Vol Ratio}) = 8:1$$

$$p v^{1.25} = c$$

1
20

Q. 1. A particle of mass m is moving with a velocity v in a circular path of radius r . Find the centripetal force acting on the particle.

Sol. Centripetal force is the force that acts towards the center of the circular path.

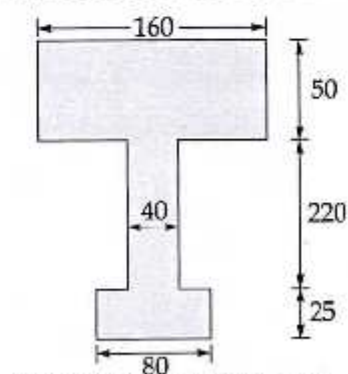
It is given by the formula:

$$F = \frac{mv^2}{r}$$

where F is the centripetal force, m is the mass of the particle, v is the velocity, and r is the radius of the circular path.

Ans.

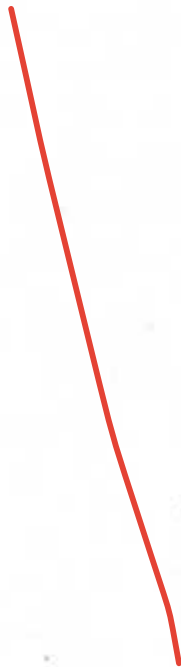
- Q.6 (b) A beam having cross-section as shown in figure is made of a material with permissible stress in compression and tension equal to 120 N/mm^2 and 160 N/mm^2 respectively. Calculate the moment of resistance of the cross-section, when subjected to a moment causing compression at the top and tension at the bottom. Also calculate the compressive force in the top flange and tensile force in the bottom flange corresponding to this moment.



(All dimensions are in mm)

[20 marks]

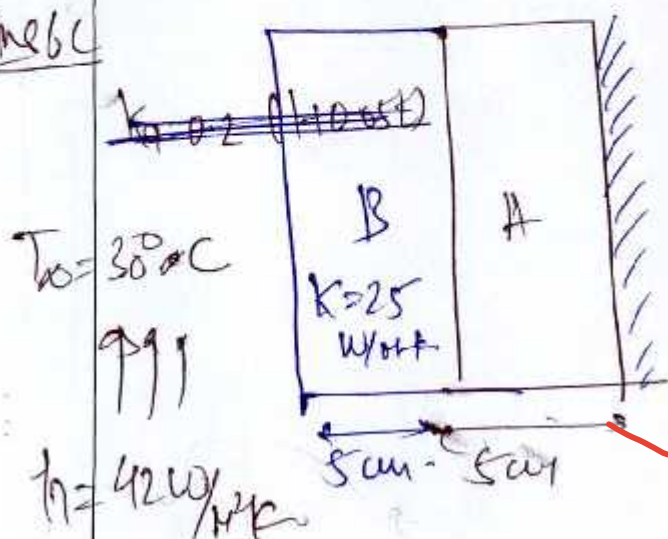




- Q.6 (c) An infinite composite slab is made of two layers A and B of different materials. The layer A is 5 cm thick, has variable thermal conductivity as $k_a = 0.2(1 + 0.05t)$, where 't' is temperature in $^{\circ}\text{C}$, and its exposed surface is insulated. The layer 'B' is 5 cm thick, has thermal conductivity 25 W/mK and its outside surface is exposed to a fluid at 30°C where the convective heat transfer coefficient is $42 \text{ W/m}^2\text{K}$. The temperature at the interface between the two layers is estimated to be 70°C . Determine
- Rate of heat flux from the slab to the fluid.
 - Maximum temperature in the system, and
 - Location of the point from the insulated surface where the temperature is 80°C .

[20 marks]

Ans 6c



$$A = 1 \text{ m}^2 \quad (\text{Assumed})$$

$$T_{\text{Interface}} = 70^{\circ}\text{C}$$

~~Between boundary & Exposed Surface, the amount of~~

$$q = \frac{30^{\circ}\text{C} - 70^{\circ}\text{C}}{\frac{1}{hA} + \frac{5 \times 10^{-2}}{25 \times 1}} \quad \text{Interface}$$

$$q = \frac{70 - 30}{\frac{1}{42 \times 1} + \frac{5 \times 10^{-2}}{25 \times 1}}$$

$$q = 1549.81 \text{ W/m}^2$$

① Maximum temp in system

using Fourier Law At interface

$$K_{\text{mean}} = 0.2 \left(1 + 0.05 \left(\frac{T_A + 70}{2} \right) \right)$$

$$1549.81 = 0.2$$

$$q = \frac{k_{\text{mean}} \Delta T}{5 \times 10^{-2}}$$

$$1549.81 = \frac{0.2 \left[1 + 0.025 (T_A + 70) \right] \times (T_A - 70)}{5 \times 10^{-2}}$$

$$386.4525 = 0.025 [T_A^2 - 4900]$$

$$T_A = 142.681^{\circ}\text{C}$$

Max Temp

(11)

Locatⁿ of pt from Insulated Surface
whe T_{280}°

~~1549.81~~

$$1549.81 = \frac{k_H \times 62.68}{\Delta L}$$

$$k_H = 0.2 (H + 0.05 (111.34))$$

$$k_H = 1.3134$$

$$1549.81 = \frac{1.313 \times 62.68}{\Delta L}$$

$$\Delta L = 0.053 \text{ m}$$

Therefore

$x = 4.688 \text{ cm}$
from Insulated
Surface

12
20

- Q.7 (a) A Freon 12 simple saturation cycle operates at temperature limits of 30°C and -10°C for the condenser and evaporator respectively. Determine work input and ton of refrigeration for unit mass flow rate of refrigerant.

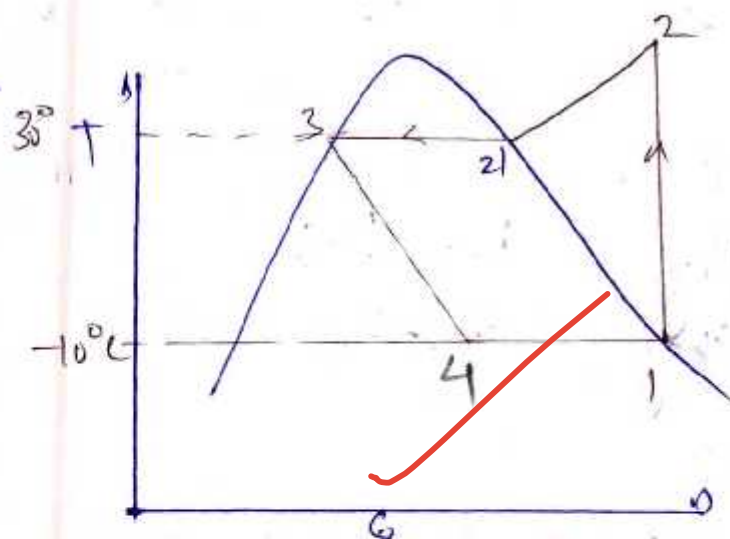
If a liquid-vapour heat exchanger is installed in the system, with the temperature of the vapour leaving the heat exchanger at 20°C , what will be the change in work input and ton of refrigeration? [Use R12 table property table as given]

Thermodynamic Properties of R12

Saturation Temp. t ($^\circ\text{C}$)	Saturation Pressure p (bar)	Saturated Liquid and Vapour						Vapour Superheated			
		v_f (m^3/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg.K)	s_g (kJ/kg.K)	By 20°C		By 40°C	
t ($^\circ\text{C}$)	p (bar)	v_f (m^3/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg.K)	s_g (kJ/kg.K)	h (kJ/kg)	s (kJ/kg.K)	h (kJ/kg)	s (kJ/kg.K)
-40	0.6417	0.66	0.2421	0	169.0	0	0.7274	180.8	0.7737	192.4	0.8178
-35	0.8069	0.67	0.1950	4.4	171.9	0.0187	0.7220	183.3	0.7681	195.1	0.8120
-30	1.0038	0.67	0.1595	8.9	174.2	0.0371	0.7171	185.8	0.7631	197.8	0.8068
-25	1.2368	0.68	0.1313	13.3	176.5	0.0552	0.7127	188.3	0.7586	200.4	0.8021
-20	1.5089	0.69	0.1089	17.8	178.7	0.0731	0.7088	190.8	0.7546	203.1	0.7979
-15	1.8256	0.69	0.0911	22.3	181.0	0.0906	0.7052	193.2	0.7510	205.7	0.7942
-10	2.1912	0.70	0.0767	26.9	183.2	0.1080	0.7020	195.7	0.7477	208.3	0.7909
-5	2.610	0.71	0.0650	31.4	185.4	0.1251	0.6991	198.1	0.7449	210.9	0.7879
0	3.086	0.72	0.0554	36.1	187.5	0.1420	0.6966	200.5	0.7423	213.5	0.7853
5	3.626	0.72	0.0475	40.7	189.7	0.1587	0.6942	202.9	0.7401	216.1	0.7820
10	4.233	0.73	0.0409	45.4	191.7	0.1752	0.6921	205.2	0.7381	218.6	0.7810
15	4.914	0.74	0.0354	50.1	193.8	0.1915	0.6902	207.5	0.7363	221.2	0.7792
20	5.673	0.75	0.0308	54.9	195.8	0.2078	0.6885	209.8	0.7348	223.7	0.7777
25	6.516	0.76	0.0269	59.7	197.7	0.2239	0.6869	212.1	0.7334	226.1	0.7763
30	7.450	0.77	0.0235	64.6	199.6	0.2399	0.6854	214.3	0.7321	228.6	0.7751
35	8.477	0.79	0.0206	69.5	201.5	0.2559	0.6839	216.4	0.7310	231.0	0.7741
40	9.607	0.80	0.0182	74.6	203.2	0.2718	0.6825	218.5	0.7300	233.4	0.7732
45	10.843	0.81	0.0160	79.7	204.9	0.2877	0.6812	220.6	0.7291	235.7	0.7724
50	12.193	0.83	0.0142	84.9	206.5	0.3037	0.6797	222.6	0.7282	238.0	0.7718
60	15.259	0.86	0.0111	95.7	209.3	0.3358	0.6777	226.4	0.7265	242.4	0.7706
70	18.859	0.90	0.0087	107.1	211.5	0.3686	0.6738	230.2	0.7243	246.2	0.7690

*Haywood R W, Thermodynamics Tables in S.I. Units, Cambridge University Press, 1968, p.22.

Ans 7ed



[20 marks]

$$h_1 = 183.2 \text{ kJ/kg}$$

$$s_1 = 0.7020 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$h_3 = h_4 = 64.6 \text{ kJ/kg}$$

$$s_1 = s_2$$

$$s_2 = 0.7020 \rightarrow s_2 = s_2' + (p \ln(t_2/t_2'))$$

$$0.7020 = 0.6854 + (p \ln(t_2/t_2'))$$

$$R_{\text{ref}} = m(h_1 - h_4)$$

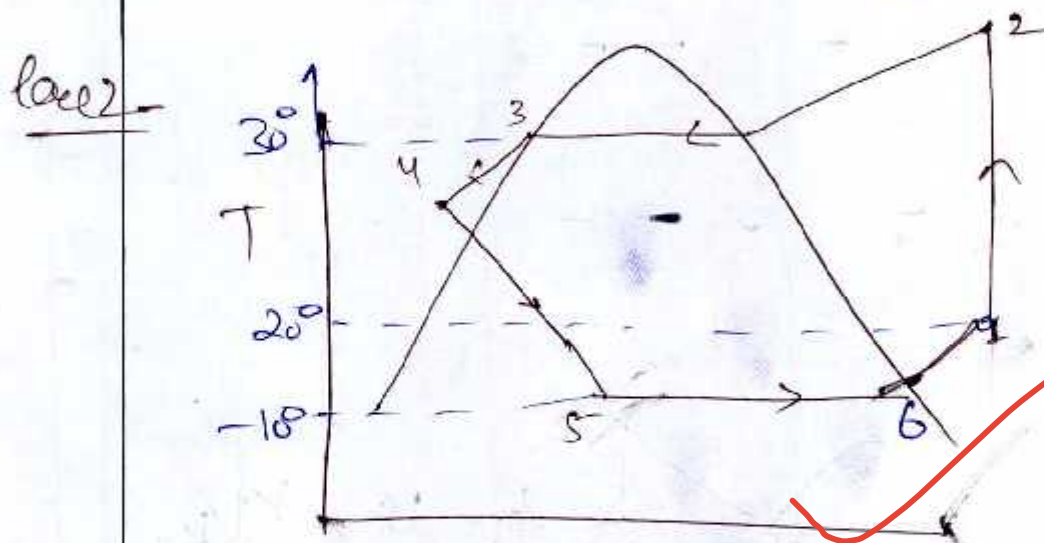
$$= 1(183.2 - 64.6) = 118.6 \text{ kW}$$

$$= 33.885 \text{ TR}$$

Assuming $\odot$ vapour superheated 20° more than condenser pressure, as Data given is not sufficient,

$$\therefore h_2 = 214.3 \text{ kJ/kg}$$

$$\frac{W_{i/p}}{P} = \dot{M} (h_2 - h_1) = 1 \times (214.3 - 183.2) \\ = \underline{31.1 \text{ kW}}$$



$$h_1 = 195.7 \text{ kJ/kg}$$

$$h_2 = 214.3 \text{ kJ/kg}$$

$$h_6 = 183.2$$

$$h_3 = 64.6$$

$$h_4 = h_5$$

From heat Balance in Heat Exch

$$h_1 - h_6 = h_3 - h_4$$

$$12.5 = 64.6 - h_4$$

$$\boxed{h_4 = 52.1 \text{ kJ/kg}}$$

$$\frac{W_{1/p}}{P} = \dot{m}(h_2 - h_1) = 1 \times (214.3 - 195.7)$$

$$W_{1/p} = 18.6 \text{ kW}$$

$$I.R. = \frac{\dot{m}(h_6 - h_5)}{3.5} = \frac{1 \times (183.2 - 52.51)}{3.5}$$

$$I.R. = 37.45 \%$$

Hence, from the results obtained, it shows that with the use of Heat Exchanger in VCR cycle, the R.E of the cycle ↑ & W_{1/p} to compressor ↓. Therefore the net COP will ↑.

18
20

(1) $(1 - 2 + 1) \times 1 = 0$

(2) $(1 - 2 + 1) \times 1 = 0$

(3) $(1 - 2 + 1) \times 1 = 0$

(4) $(1 - 2 + 1) \times 1 = 0$

(5) $(1 - 2 + 1) \times 1 = 0$

(6) $(1 - 2 + 1) \times 1 = 0$

(7) $(1 - 2 + 1) \times 1 = 0$

(8) $(1 - 2 + 1) \times 1 = 0$

(9) $(1 - 2 + 1) \times 1 = 0$

(10) $(1 - 2 + 1) \times 1 = 0$

(11) $(1 - 2 + 1) \times 1 = 0$

(12) $(1 - 2 + 1) \times 1 = 0$

(13) $(1 - 2 + 1) \times 1 = 0$

(14) $(1 - 2 + 1) \times 1 = 0$

(15) $(1 - 2 + 1) \times 1 = 0$

(16) $(1 - 2 + 1) \times 1 = 0$

(17) $(1 - 2 + 1) \times 1 = 0$

(18) $(1 - 2 + 1) \times 1 = 0$

(19) $(1 - 2 + 1) \times 1 = 0$

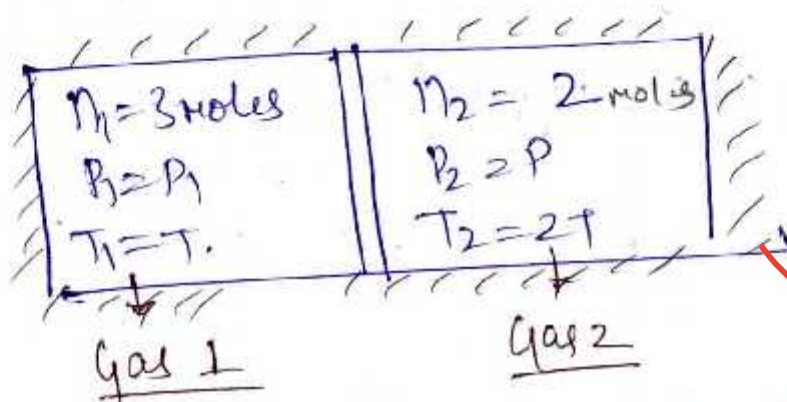
- Q.7(b) Three moles of an ideal gas at temperature T and pressure P are contained in a compartment. In an adjacent compartment is two moles of an another ideal gas at temperature $2T$ and pressure P . The gases mix adiabatically but do not react chemically when a partition separating the compartments is withdrawn. Show that the entropy increase due to mixing process is given by

$$\Delta s = R \left(\ln \frac{3125}{108} + \frac{\gamma}{\gamma-1} \ln \frac{16807}{12500} \right)$$

where R is the universal gas constant and the ratio of specific heats i.e., γ is same for both the gases and remains constant.

[20 marks]

Ans: (b)



Now using first Law after the partition is removed,

$$\oint \delta q = du + \oint \delta p$$

$$\boxed{du = 0}$$

$$\cancel{(\delta q)} \cdot [(U_1)_f - (U_1)_i] + [(U_2)_f - (U_2)_i] = 0$$

$$\cancel{(\delta q)} \cdot (n_1 \bar{C}_v T_f - n_1 \bar{C}_v T_1)$$

$$+ (n_2 \bar{C}_v T_f - n_2 \bar{C}_v T_2) = 0$$

$$T_f = \frac{n_1 \bar{C}_v T_1 + n_2 \bar{C}_v T_2}{n_1 \bar{C}_v + n_2 \bar{C}_v}$$

$$T_f = \frac{3T + 2 \times 21}{5} = \frac{71}{5} = 14.2$$

$$(\Delta G)_{\text{mix}} = \Delta G_1 + \Delta G_2$$

$$\left(n_1 C_{p1} \ln\left(\frac{T_f}{T_1}\right) - n_1 R \ln\left(\frac{P_f}{P_1}\right) \right) +$$

$$\left(n_2 C_{p2} \ln\left(\frac{T_f}{T_2}\right) - n_2 R \ln\left(\frac{P_f}{P_2}\right) \right)$$

$$= n_1 C_{p1} \ln(1.4) - n_1 R \ln\left(\frac{3 \times P_f}{P_1}\right) +$$

$$\left(n_2 C_{p2} \ln(0.7) - n_2 R \ln\left(\frac{2 \times P_f}{P_2}\right) \right)$$

$$P_f = \frac{P_1 n_1 + P_2 n_2}{n_1 + n_2} = \frac{n_1 P_1 T_1 + n_2 P_2 T_2}{\frac{n_1 R T_1}{P} + \frac{n_2 R T_2}{P}}$$

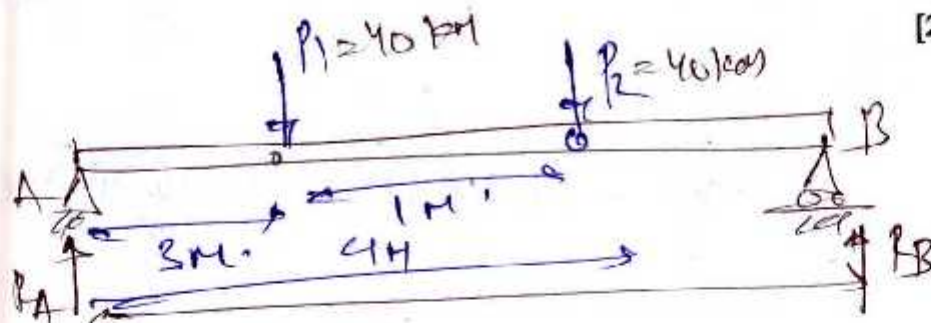
$$\frac{3 \times T + 2 \times 21}{\frac{3 \times T}{P} + \frac{2 \times (21)}{P}} = \frac{71 T P}{71} \quad [P_f = P]$$

Therefore, after rearranging the terms, we get

$$\Delta S_2 = R \left[\ln\left(\frac{3125}{108}\right) + \frac{4}{4-1} \frac{16807}{12500} \right]$$

- Q.7 (c) A beam 8 m in length simply supported at ends A and B is loaded with two point loads of 40 kN each at a distance of 3 m and 4 m respectively from end A. Determine the position and magnitude of the maximum deflection. Take $E = 2.5 \times 10^5 \text{ N/mm}^2$ and $I = 15000 \text{ cm}^4$.

[20 marks]

Ans 7(c)

Verify & find R_x at A & B

$$R_A + R_B = 80 \text{ kN}$$

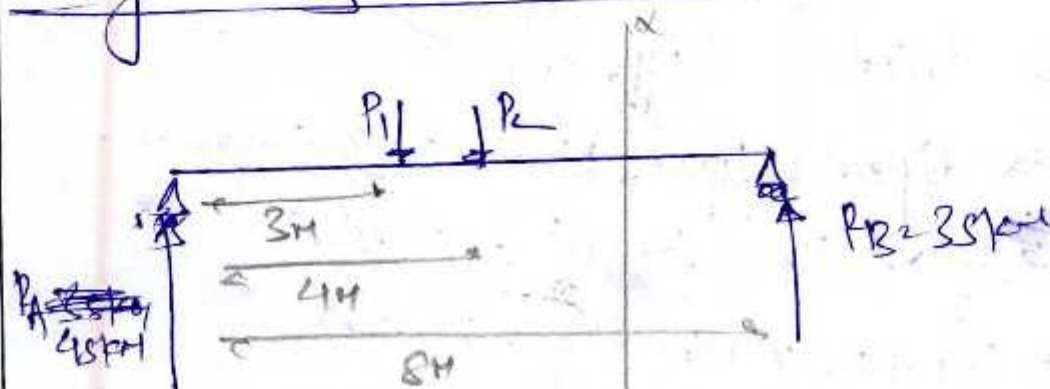
Take moments about A

$$P_1 \times 3 + P_2 \times 4 = R_B \times 8$$

$$40(7) = R_B \times 8$$

$$\boxed{R_B = 35 \text{ kN}} \\ \boxed{R_A = 45 \text{ kN}}$$

Using Macaulay Method



$$EI \frac{d^2y}{dx^2} = +45(x) - 40(x-3) - 40(x-4)$$

Differentiating the Equation we get

$$E \frac{dy}{dx} = \frac{45x^2}{2} - \frac{40(x-3)^2}{2} - \frac{40(x-4)^2}{2} + C_1$$

Differentiating again

$$E \frac{d^2y}{dx^2} = \frac{45 \times 2x}{2} - \frac{20(x-3)^2}{3} - \frac{20(x-4)^2}{3} + C_1 + C_2$$

$$E \frac{d^2y}{dx^2} = 7.5x^2 - \frac{20}{3}(x-3)^2 - \frac{20}{3}(x-4)^2 + C_1 + C_2$$

At $x=0$, $y=0 \rightarrow \boxed{C_2=0}$

At $x=8$, $y=0$

$$0 = 7.5 \times 8^3 - \frac{20}{3} \times 5^3 - \frac{20}{3} \times 4^3 + C_1 \times 8$$

$$\boxed{C_1 = -322.5}$$

Eq of Deflection

$$\boxed{E \frac{d^2y}{dx^2} = 7.5x^2 - \frac{20}{3}(x-3)^2 - \frac{20}{3}(x-4)^2 - 322.5x}$$

For max deflection $\frac{dy}{dx} = 0$

Let max deflection lies b/w $x=3$ to $x=4$,

$$20(x-3)^2 + 20(x-4)^2 = 22.5x^2$$

$$20(x^2 + 9 - 6x) + 20(x^2 + 16 - 8x) = 22.5x^2$$

$$17.5x^2 - 280x + 500 = 0$$

$$x = 2.04$$

(Assumption is wrong)

20
20

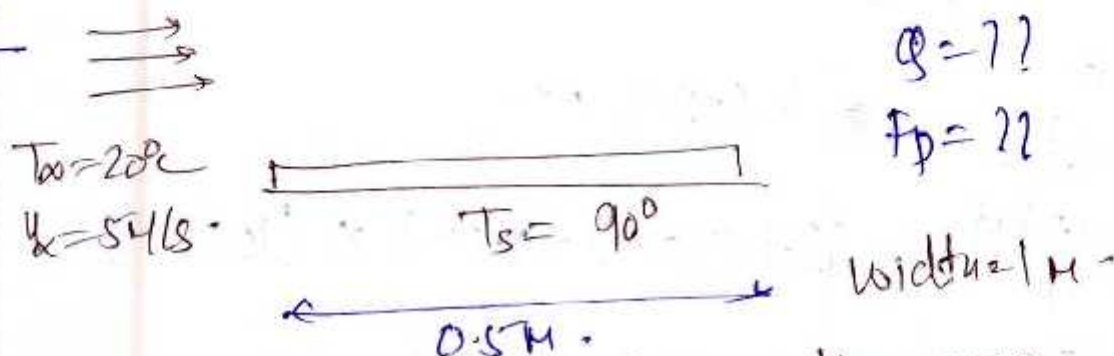
- Q.8 (a) Air at 20°C and at atmospheric pressure is flowing past a flat plate at 5 m/s velocity. The plate is heated over its entire length to a uniform temperature of 90°C . Calculate the heat transfer and the drag force for 50 cm length of the plate. The relevant thermo-physical properties of air are:

Density, $\rho = 1.2\text{ kg/m}^3$; Specific heat, $c_p = 1.005\text{ kJ/kg-K}$; Thermal conductivity, $k = 0.0275\text{ W/mK}$; Viscosity, $\mu = 19.13 \times 10^{-6}\text{ kg/m-s}$

[Assume unit width for the plate and air flow over both sides of the plate]

[20 marks]

Ans 89



Given

$$\begin{aligned}\rho &= 1.2\text{ kg/m}^3 \\ c_p &= 1.005\text{ kJ/kg-K} \\ k &= 0.0275\text{ W/mK} \\ \mu &= 19.13 \times 10^{-6}\end{aligned}$$

flow over
both sides
of plate

$$Re = \frac{\rho V L}{\mu} = \frac{1.2 \times 5 \times 0.5}{19.13 \times 10^{-6}}$$

$$Re = 156821.74 < 5 \times 10^5$$

(flow is laminar)

$$Nu = 0.664 Re_L^{1/2} Pr^{1/3}$$

$$Pr = \frac{\mu c_p}{k} = \frac{19.13 \times 10^{-6} \times 1005}{0.0275} = 0.699$$

$$Nu = 0.664 \times (156821.74)^{0.5} (10.699)^{1/3}$$

$$Nu = 233.374$$

$$\frac{h \times 0.5}{0.0275} = 233.374$$

$$h = 12.834 \text{ W/m}^2\text{K}$$

Heat Transfer = $h(2A) \Delta \theta$

for plate $12.834 \times 2 \times 0.5 \times 1 \times (90 - 20)$

$$Q = 898.443 \text{ W}$$

⑪ Drag force $C_p = \frac{1.328}{\sqrt{Re_L}}$

$$C_p = \frac{1.328}{\sqrt{156821.74}} \quad C_p = 3.353 \times 10^{-3}$$

$$F_D = C_p \times \frac{1}{2} \rho A u_\infty^2 = \frac{3.353 \times 10^{-3}}{2} \times 1.2 \times 0.5 \times 25^2$$

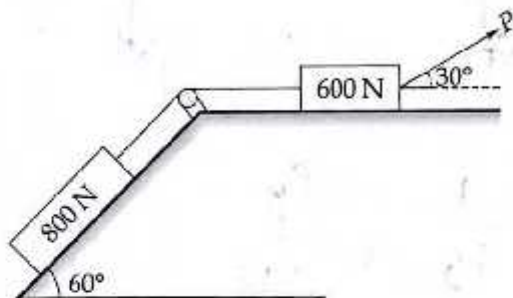
$$F_D = 0.0251 \text{ N}$$

20
20

- Q.8 (b) (i) Show that the slope of a reversible adiabatic process on P - v coordinates is

$$\frac{dP}{dv} = \frac{-1}{k_T v c_v} \frac{c_p}{c_v}; \text{ where } k_T = \frac{-1}{v} \left(\frac{\partial v}{\partial P} \right)_T$$

- (ii) Assuming the pulley to be smooth and coefficient of friction between the other surfaces to be 0.25, what is the value of P in Newton as shown in the figure to cause the system to impend?



[10 + 10 marks]

Ans (b) Reversible Adiabatic process $=$ $z = \text{const}$

$$P v^\gamma = \text{const} \quad \checkmark \quad \cancel{P v^{\gamma-1} = \text{const}}$$

$$\gamma P dp + P \gamma v^{\gamma-1} dv = 0$$

$$\gamma P dp = -P \frac{\gamma v^{\gamma-1}}{v} dv \quad \checkmark$$

$$\frac{dp}{dv} = - \frac{P \gamma v^{\gamma-1}}{v \gamma}$$

$$\frac{dp}{dv} = - \left[\frac{\gamma P}{v} \right]$$

$$\frac{dp}{dv} = - \left[\frac{c_p}{c_v} \frac{P}{v} \right] \left(\frac{\gamma v^{\gamma-1}}{v} \right)$$

$$k_T = \frac{-1}{v} \left(\frac{\partial v}{\partial P} \right)_T$$

$$k_T P v = R T \rightarrow$$

Differentiating we get

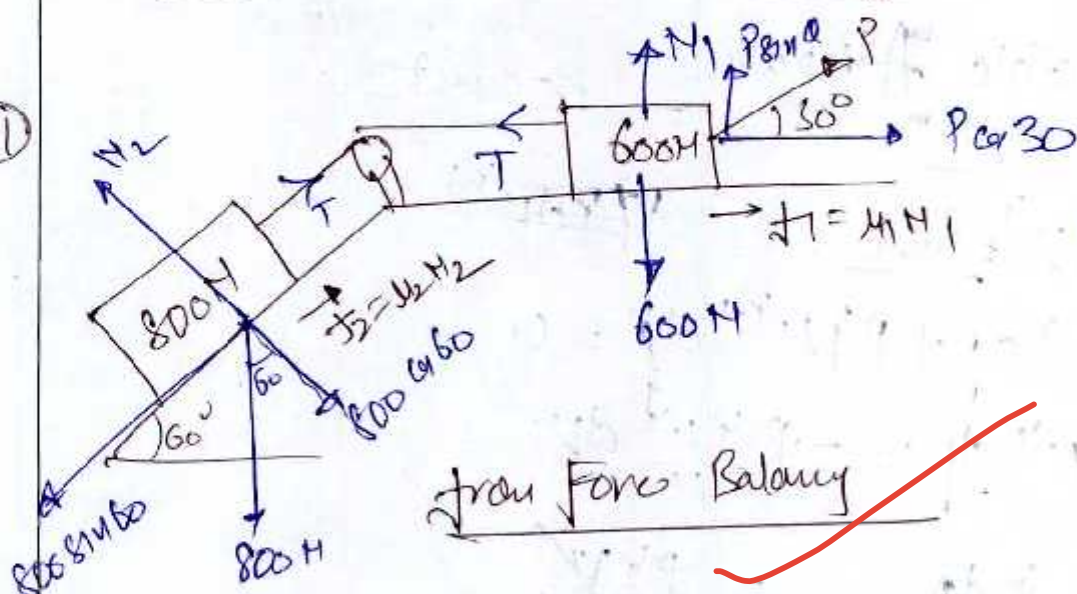
$$\frac{dp}{d\alpha} = \frac{1}{k_t \mu}$$

$$\frac{dp}{d\alpha} = -\frac{1}{k_t \mu} \frac{C_p}{C_v}$$

Substituting the value
we get

$$\frac{dp}{d\alpha} = -\frac{1}{k_t \mu} \frac{C_p}{C_v}$$

⑪



from Force Balance

For 600 N Block

$$T = P \cos 30 + \frac{H_1}{4} \quad \text{--- (1)}$$

$$N_1 + P \sin 30 = 600 \quad \text{--- (2)}$$

For 800 N Block

$$T + \frac{H_2}{4} = 800 \sin 60 = 692.82$$

$$T + \frac{H_2}{4} = 692.82 \quad \text{--- (3)}$$

$$N_2 = 400 \quad \text{--- (4)}$$

15
20

$$T = 692.82 - \frac{400}{4} = 592.82 \quad [T = 592.82 \text{ K}]$$

$$\text{from (1)} \quad 592.82 = P \times 0.866 + 0.25 N_1$$

$$600 = P \times 0.5 + N_1$$

$$P = 597.597$$

$$N_1 = 301.201$$

$$[P = 597.597 \text{ N}]$$

- Q.8 (c) (i) A simply air-cooled system is used for an aeroplane to take the load of 25 tons. Atmospheric temperature and pressure conditions are 25°C and 1 bar respectively. The pressure of air is increased due to isentropic ramming from 1 bar to 1.1 bar. The pressure of air leaving the main compressor is 4 bar and its 65% heat is removed in the air-cooled heat exchanger and then it is passed through an evaporator for further cooling. The temperature of air is reduced by 6°C in the evaporator. Lastly the air is passed through cooling turbine and then it is supplied to the cooling cabin in which the pressure is maintained at 1.05 bar. Assuming isentropic efficiencies of the compressor and turbine are 85% and 82% find
- kW-capacity required to take the load in the cooling cabin.
 - COP of the system
- The temperature of the air leaving the cabin should not exceed 27°C .
[Take specific heat of air as 1 kJ/kgK]
- (ii) With neat sketch, briefly explain the working of steam ejector system.

[15 + 5 marks]

2) $52.5^\circ - 9^\circ$

