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				Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐		
Pune ☐	Kolkata ☐	Bhubaneswar ☐	Hyderabad ☐	

Instructions for Candidates

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

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	20
Q.2	
Q.3	
Q.4	17
Section-B	
Q.5	51
Q.6	44
Q.7	42
Q.8	
Total Marks Obtained	174

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.

- Avoid silly conceptual and calculation mistake.
- Try to attempt all mandatory question.
- Do not write anything in margin.
- Draw diagram properly.
-

Section : A

Q.1 (a) A tank of constant cross-sectional area of 3.2 m^2 has two orifices each 10.5×10^{-4} m^2 in area in one of it's 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 $c_d = 0.725$.

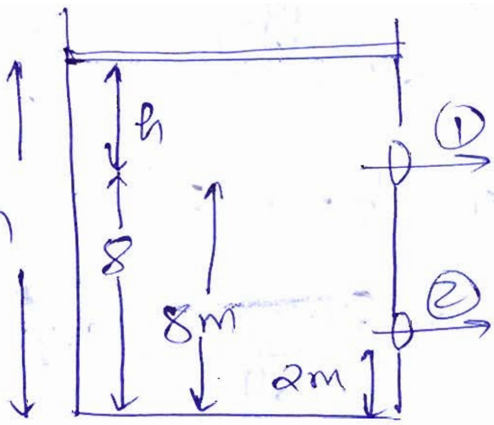
[12 marks]

Given,

Area cross → $3.2 m^2$,

When water is at h m,

By applying Bernaulli's,



$V_1 = C_d\sqrt{2gh}$

$A_1V_1 = 10.5\times10^{-4}\times V_1$

and $V_2 = C_d\sqrt{2g(h+6)}$

silly conceptual mistake refer solution

by mass conservation,

$A_1V_1 + A_2V_2 = -A_{c/s} \times \frac{dh}{dt}$

6

$\Rightarrow C_d A\left[\sqrt{2gh} + \sqrt{2g(h+6)}\right] = -3.2\times\frac{dh}{dt}$

$\Rightarrow \frac{0.725\times10.5\times10^{-4}}{3.2}\times\sqrt{2g}\left[\sqrt{h}+\sqrt{h+6}\right] = \frac{dh}{dt}$

$\Rightarrow 10.537\times10^{-4}\int_0^t dt = \int\frac{-dh}{\sqrt{h}+\sqrt{h+6}}$

$\Rightarrow \frac{10.537}{10^4}\left[t\right]_0^t = -\int\frac{dh\left[\sqrt{h}-\sqrt{h+6}\right]}{\left[\sqrt{h}+\sqrt{h+6}\right]\left[\sqrt{h}-\sqrt{h+6}\right]}$

$$\frac{10.537}{10^4}[t]_0^t = -\int \frac{\sqrt{h}+\sqrt{h+6}}{[h]-[h+6]}\,dh.$$

$$\Rightarrow \frac{63.22}{10^4}(t) = \frac{2}{3}\left[h^{3/2}\right]_8^{11} + \frac{2}{3}\left[h+6\right]_8^{11\ 3/2}$$

from $h \rightarrow 11$ m to 8m,

$$t_1 \times \frac{63.22}{10^4} = 9.236 + \frac{2}{3}\left[70.092 - 52.383\right]$$

$$t_1 \rightarrow 3328.3\text{sec}$$

Similarly for 8m to 4.6 m drainage,

$$A_2 V_2 = -A_c \frac{dh}{dt} \quad \{\text{By mass conservation}\}$$

$$\Rightarrow 10.5\times10^{-4}\times\sqrt{2gh} = -3.2\times\frac{dh}{dt}.$$

$$\Rightarrow \int_0^t -3.28125\times10^{-4}\times\sqrt{2g}\,dt = \int_{2.6}^{6}\frac{dh}{\sqrt{h}}$$

$$\Rightarrow \frac{16.88}{10^4}[t]_0^t = \frac{2}{3}\left[t^{3/2}\right]_{2.6}^{6}$$

$$\Rightarrow \frac{16.88}{10^4}\times t = 7 \Rightarrow t_2 = 4148.72\text{se}$$

Total time $= t_1 + t_2$

$\Rightarrow$ 7477.027 seconds.

Q.1 (b) A centrifugal compressor runs at 12000 rpm and delivers 700 m^3/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

(i) Power input to the compressor.

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

(iii) Impeller and diffuser blade angles at inlet.

[12 marks]

Given, Centrifugal compressor,

Axial velocity $V_{f2} = V_{f1} = 70 m/s$,

$Q_{input} = \frac{700}{60} m^3/sec$, $N = 12000 rpm$,

$r_p \to 5:1$, $\eta_{iso} = 0.85$, $r_2 = 2r_1$

and $V_{w2} \to 0$ {radial at outlet].

$T_1 = 290 K$, $P_1 = 1.01 bar$

so, $\frac{T_2}{T_1} = (r_p)^{\frac{\gamma-1}{\gamma}} \Rightarrow \frac{T_2}{290} = (5)^{0.2857}$

$\Rightarrow T_2 = 459.297 K$,

$\eta_{iso} = \frac{T_2 - T_1}{T_2' - T_1} = 0.85 \Rightarrow \frac{459.297 - 290}{T_2' - 290}$

$T_2' = 489.17 K$

and at inlet, $P_1 = \rho_1 R T_1$

$\Rightarrow 101 = \rho_1 \times 0.287 \times 290 \Rightarrow \rho_1 = \frac{1}{v_1} = 1.213$

so, mass flow rate $= \rho_1 \times Q_1$

$\Rightarrow 1.213 \times \frac{700}{60} = 14.157 kg/sec$

Power input $= \dot{m} \times C_p [T_2' - T_1]$

$= 14.157 \times 1.005 [489.17 - 290]$

$= \boxed{2833.7 \text{ KW}}$

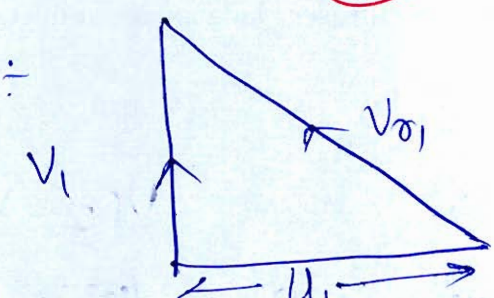
8

At inlet,

and

W done on compressor :

$= \sigma U_2^2$



$=$ [No slip $\sigma = 1$]

$200.165 = U_2^2$

$\Rightarrow U_2 = 447.398$ m/s

so, $U_1 = \frac{U_2}{2} = 223.699$ m/s.

so, $U_1 = \frac{\pi D_1 N}{60} = 223.699 = \frac{\pi \times D \times 12000}{60}$

$\boxed{D_1 = 0.356 m}$

and $Q = \pi D_1 B_1 V_{f_1}$ {Assume no vane thickness}

$\Rightarrow \frac{700}{60} = \pi \times 0.356 \times B_1 \times 70 \times B_1$

$\boxed{B_1 = 0.149 \text{ m}}$

$D_2 = 2D_1 \Rightarrow \boxed{D_2 = 0.712 m}$

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 m^3/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]

Given [DOR = 50%]

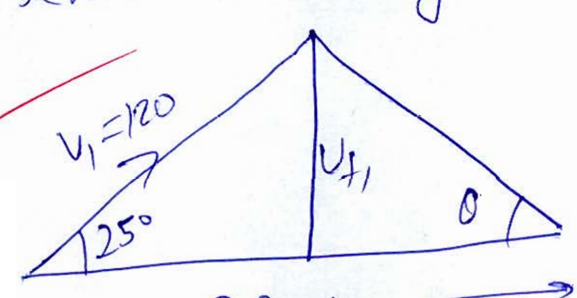
$V_{r_1} = V_2$, $V_{r_2} = V_1$, $\alpha = \phi$, $\beta = \theta$,

$U_1 = 120$ m/s and $V_{f_1} = 0.6 \times 120 = 72$ m/s

$N = 2500$ rpm, $v_{steam} = 0.7$ m^3/kg

$Q = \pi D_1 B_1 V_{f_1}$

V_f



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/m³. If the cylinder is to float just in stable equilibrium in sea water, find it's minimum permissible thickness. Assume that sea water weighs 12 kN/m³.

[12 marks]

Given, Cylinder is just in stable Equil.

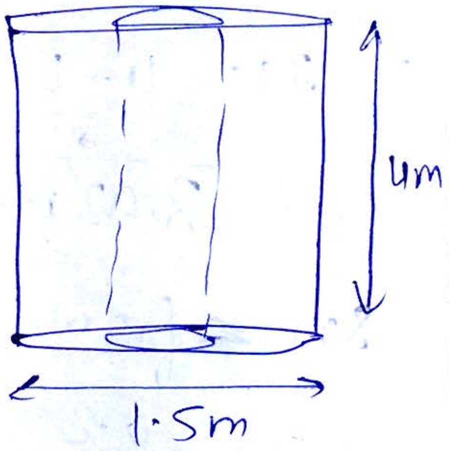
For floating body,

at this condition,

M is just above G,

$(\rho g)_{body} = 80 \times 10^3$ N/m3,

$(\rho g)_{water} = 12 \times 10^3$ N/m³



so, $F_b = mg$.

$V_{inside} \times \rho_w \times g = V_{Total} \times \rho_{bod} \times g.$

$\Rightarrow$ ~~$\frac{\pi}{4} \times (D_o^2 - D_i^2) \times L \times 12 = \frac{\pi}{4}(D_o^2 - D_i^2) \times 4 \times 80$~~

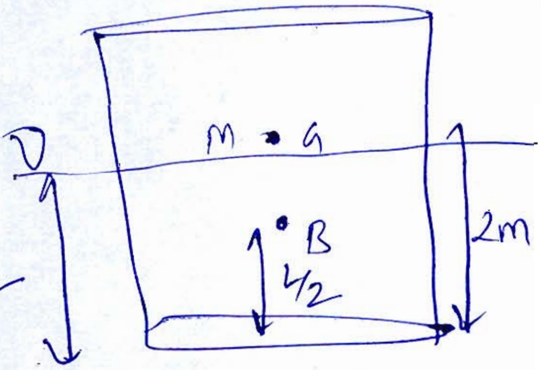
$\Rightarrow \frac{\pi}{4}(D_o^2) \times L \times 12 = \frac{\pi}{4}[D_o^2 - D_i^2] \times 4 \times 80$

$\Rightarrow \frac{D_o^2 - D_i^2}{D_o^2} = \frac{L \times 12}{320} = \frac{L}{26.66}$ — (i)

$BG = 2 - \frac{L}{2}$

5

and



$MB = \frac{I}{\forall_{submerged}}$.

$\Rightarrow MB = \frac{\frac{\pi}{64} \times [D_o^4]}{\frac{\pi}{4}[D_o^2] \times L} = \frac{D_o^2}{16 \times L} = \frac{1.5 \times 1.5}{16L}$

$\Rightarrow$ So, $2 - \frac{L}{2} = \frac{2.25}{16L} = \frac{0.1406}{L}$

$\Rightarrow \frac{4 - L}{2} = \frac{0.281}{L} \Rightarrow L^2 - 4L + 0.281 = 0$

By solving,

$L = 3.92\ m$

refer solution.

So, from (i)

$\frac{D_o^2 - D_i^2}{D_o^2} = \frac{3.92}{26.66} = 1 - \frac{D_i^2}{D_o^2}$

$$0.853 = \frac{D_i^2}{D_o^2} \Rightarrow \frac{D_i}{D_o} = 0.9235$$

$$\Rightarrow D_i = 0.9235\, D_o \Rightarrow \boxed{D_i = 1.385\ m}$$

$$\text{Thickness} = \frac{D_o - D_i}{2}$$

$$= 0.0573\ m = 57.3\ mm$$

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 it's kinematic viscosity is 1.2×10^{-4} m²/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]

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 25K, 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]

Do not write in this margin

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	p_{sat}	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
°C	MPa	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	0.017336	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	0.019946	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 $p = 16.0$ MPa ($T_{sat} = 347.355$°C)

T	v	u	h	s
°C	m³/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00099228	0.18	16.06	0.00046
5	0.00099241	20.90	36.78	0.07563
10	0.00099288	41.59	57.48	0.14939
15	0.00099364	62.28	78.18	0.22182
20	0.00099466	82.95	98.86	0.29300
25	0.00099592	103.62	119.55	0.36297
30	0.00099739	124.28	140.24	0.43180
35	0.00099906	144.96	160.94	0.49952
40	0.00100092	165.64	181.65	0.56617
45	0.00100296	186.31	202.36	0.63180
50	0.00100517	207.01	223.09	0.69644
55	0.00100755	227.70	243.82	0.76012
60	0.00101007	248.41	264.57	0.82288
65	0.00101276	269.14	285.34	0.88474
70	0.00101559	289.86	306.11	0.94573
75	0.00101856	310.61	326.91	1.0059
80	0.00102168	331.36	347.71	1.0652
85	0.00102494	352.14	368.54	1.1238
90	0.00102835	372.94	389.39	1.1816
95	0.00103189	393.74	410.25	1.2387
100	0.00103557	414.57	431.14	1.2950
105	0.00103939	435.43	452.06	1.3507
110	0.00104336	456.32	473.01	1.4057
115	0.00104747	477.22	493.98	1.4601
120	0.00105172	498.16	514.99	1.5139
125	0.00105612	519.13	536.03	1.5671
130	0.00106067	540.15	557.12	1.6197
135	0.00106537	561.19	578.24	1.6718
140	0.00107022	582.29	599.41	1.7233
145	0.00107524	603.43	620.63	1.7744
150	0.00108042	624.61	641.90	1.8250
155	0.00108577	645.86	663.23	1.8751
160	0.00109129	667.16	684.62	1.9247
165	0.00109699	688.52	706.07	1.9740
170	0.00110288	709.94	727.59	2.0228
175	0.00110896	731.44	749.18	2.0713
180	0.00111525	753.02	770.86	2.1194
185	0.00112174	774.66	792.61	2.1671
190	0.00112846	796.40	814.46	2.2145
195	0.00113540	818.23	836.40	2.2617
200	0.00114259	840.16	858.44	2.3085
210	0.00115775	884.34	902.86	2.4014
220	0.00117405	928.99	947.77	2.4934
230	0.00119164	974.17	993.24	2.5847
240	0.00121069	1020.0	1039.4	2.6754
250	0.00123144	1066.5	1086.2	2.7658
260	0.00125417	1113.8	1133.9	2.8562
270	0.00127925	1162.2	1182.7	2.9468

T	v	u	h	s
°C	m³/kg	kJ/kg	kJ/kg	kJ/kg K
270	0.00127925	1162.2	1182.7	2.9468
280	0.00130718	1211.8	1232.7	3.0380
290	0.00133865	1262.7	1284.1	3.1302
300	0.00137464	1315.4	1337.4	3.2240
310	0.00141665	1370.5	1393.2	3.3204
320	0.00146711	1428.6	1452.1	3.4206
330	0.00153044	1491.3	1515.8	3.5271
340	0.00161630	1561.5	1587.4	3.6447
347.355	0.00170944	1622.3	1649.7	3.7457
347.355	0.00930880	2431.9	2580.8	5.2463
350	0.00976580	2460.7	2617.0	5.3045
360	0.0110610	2538.8	2715.8	5.4619
370	0.0120460	2595.7	2788.4	5.5756
380	0.0128780	2642.3	2848.3	5.6681
390	0.0136130	2682.8	2900.6	5.7476
400	0.0142810	2719.1	2947.6	5.8179
410	0.0148990	2752.3	2990.7	5.8816
420	0.0154780	2783.4	3031.0	5.9401
430	0.0160260	2812.6	3069.0	5.9945
440	0.0165480	2840.3	3105.1	6.0455
450	0.0170490	2866.9	3139.7	6.0937
460	0.0175310	2892.5	3173.0	6.1395
470	0.0179980	2917.3	3205.3	6.1832
480	0.0184510	2941.5	3236.7	6.2252
490	0.0188920	2965.0	3267.3	6.2656
500	0.0193230	2988.1	3297.3	6.3046
520	0.0201570	3033.1	3355.6	6.3790
540	0.0209610	3076.7	3412.1	6.4493
560	0.0217390	3119.4	3467.2	6.5163
580	0.0224970	3161.2	3521.2	6.5804
600	0.0232380	3202.6	3574.4	6.6421
620	0.0239630	3243.6	3627.0	6.7016
640	0.0246750	3284.2	3679.0	6.7591
660	0.0253760	3324.6	3730.6	6.8150
680	0.0260670	3364.8	3781.9	6.8694
700	0.0267490	3404.9	3832.9	6.9224
720	0.0274230	3445.0	3883.8	6.9741
740	0.0280910	3485.0	3934.5	7.0247
760	0.0287520	3525.1	3985.1	7.0742
780	0.0294070	3565.2	4035.7	7.1227
800	0.0300580	3605.4	4086.3	7.1703
820	0.0307030	3645.8	4137.0	7.2171
840	0.0313450	3686.1	4187.6	7.2630
860	0.0319830	3726.6	4238.3	7.3082
880	0.0326170	3767.2	4289.1	7.3526
900	0.0332470	3808.0	4340.0	7.3964
920	0.0338750	3849.0	4391.0	7.4395
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]

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]

Given. Centrifugal pump,

$H_{Lif} = 42\,m$ and $h_s = 5\,m$, $d_s = d = 34\,cm$

$h_{fs} = 2.5\,m$, $h_{fd} = 7\,m$, $D_2 = 0.6\,m$,

$B_2 = 0.04\,m$, $N = 1000\,rpm$, $\phi \rightarrow 25°$,

$\eta_{mano} = 86\%$,

~~η_{mano}~~ =

$H_{mano} = H_s + H_d + h_{fs} + h_{fd}$

$h_{os} = \frac{L_s \times A_p}{g \times A_s} \times r\omega^2 \cos\theta$.

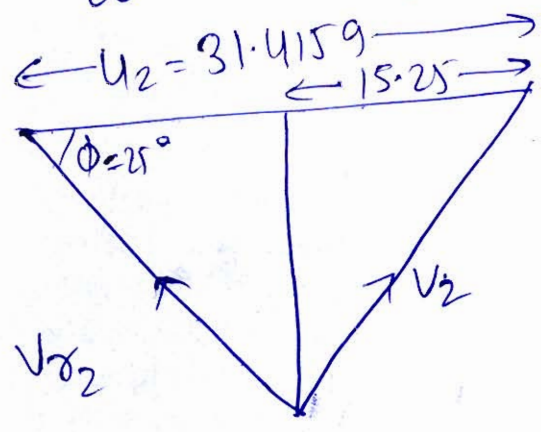
$\eta_{mano} = \frac{H_{mano}}{H_{impeller}} = \frac{42}{H_{impeller}} \Rightarrow H_{imp} = 48.83m$

$(V_{pipe})_{suction} = (V_{pipe})_{delivery}$.

$(V_{pip})_{suction} = \frac{r\omega \sin\theta \times A_{piston}}{A_{pipe}}$.

$U_2 = \frac{\pi \times D \times N}{60} = \frac{\pi \times 0.6 \times 1000}{60} = 31.4159 m/s$,

7



(Exit velocity Triangle)

$V_{w2} U_2 = 48.83 \times g$.

$\Rightarrow V_{w2} = 15.25 m/s$,

$\Rightarrow$ So, $\tan 25° = \frac{V_f}{31.4159 - 15.25}$

$\Rightarrow \tan 25 = \frac{V_f}{16.165} \Rightarrow V_f = 7.538 m/s$

$Q = \pi D_2 B_2 V_f$.

$\Rightarrow \pi \times 0.6 \times 0.04 \times 7.538$

$= 0.5638 m^3/sec$

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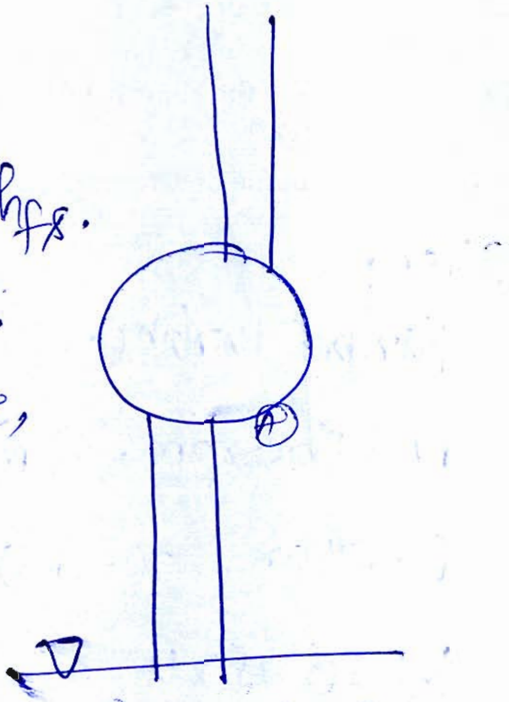
Applying bernoulli's, At (A) & (1)

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 + h_{fa} = \frac{P_A}{\rho g} + \frac{V_A^2}{2g} + z_A + h_{fs} + h_{fa}$$



⇒ Considering gauge pressure,
$[P_1 \to 0]$

$$0 = \frac{P_A}{\rho g} + \frac{V_A^2}{2g} + 2.5 + 5$$

$$\Rightarrow \frac{P_A}{\rho g} = -7.5 \text{ m.}$$

$$\Rightarrow \boxed{P_A = -73.75 \text{ KN/m}^2}$$

(Vacuum)

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, it's 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 m^3/kg

[20 marks]

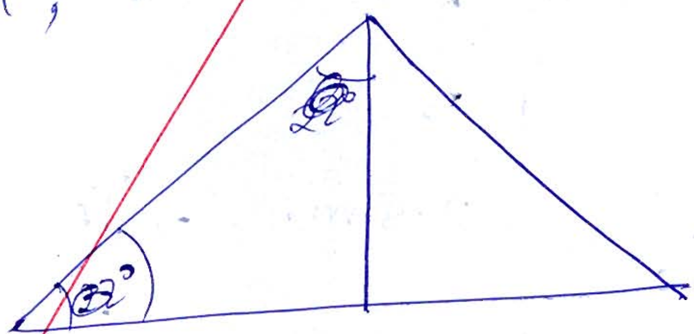
Given,

Parson Turbine, [DOR = 50%]

$N = 500$ rpm, $\dot{m}_{stem} = 7$ kg/sec,

$P = 2$ bar, $x = 0.97$, Pdeveloped → 5.4 kW

$V_f = 0.75 \times u$,



$$DOR = \frac{V_f}{2u}[\tan\beta_1 + \tan\beta_2]$$

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 degree 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

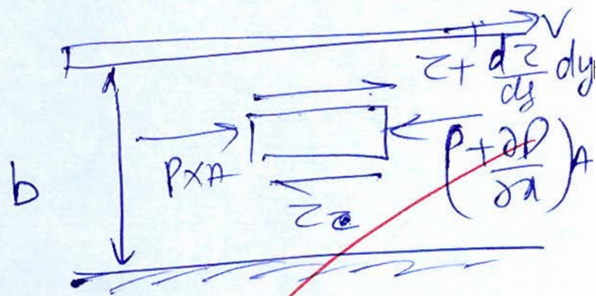
(a) the velocity and shear stress distribution between the plates.

(b) the maximum flow velocity, and

(c) the shear stress on the upper plate

[10 + 10 marks]

(i) Considering an element,



$+\frac{\partial P}{\partial x} = +\frac{d\tau}{dy}$

$\Rightarrow$ So, $\tau = \mu \left(\frac{du}{dy}\right)$ For newtonian fluid.

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

$\Rightarrow \frac{du}{dy} = -\frac{1}{\mu}\left(\frac{\partial p}{\partial x}\right) y + C_1$

$\Rightarrow u = -\frac{1}{\mu}\left(\frac{\partial p}{\partial x}\right)\frac{y^2}{2} + C_1 x + C_2$

by boundary condition, $y \to 0,\ u \to 0$
$y \to h,\ u \to V.$

$u = \frac{1}{2\mu}\left(-\frac{\partial p}{\partial x}\right)(hy - y^2) + \frac{Vy}{h},$

$\tau = \mu \frac{du}{dy} = \mu\left[\frac{1}{2\mu}\left(-\frac{\partial p}{\partial x}\right)(h - 2y) + \frac{V}{2h}\right]$

$\Rightarrow$ at $y \to 0$ $\tau = 0$ so,

$\boxed{\frac{1}{2\mu}\left(\frac{\partial p}{\partial x}\right) h^2 = V}$ — (i)

10

and $\frac{q}{b} = \int u \times dy$

$\Rightarrow \frac{1}{2\mu}\left(-\frac{\partial p}{\partial x}\right)\left[\frac{hy^2}{2} - \frac{y^3}{3}\right] + \frac{Vy^2}{2h}.$

$y \to 0$ to $y = h$

$\Rightarrow \frac{1}{2\mu}\left(\frac{\partial p}{\partial x}\right)\left[\frac{h^3}{6}\right] + \frac{Vh^2}{2}$

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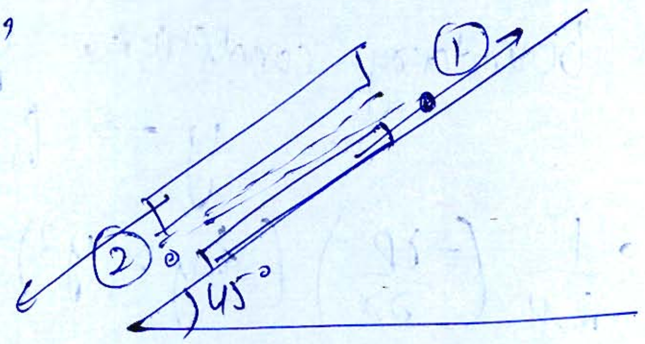
from (i) : $-\frac{Vh}{6} + \frac{Vh}{2} \Rightarrow \left(\frac{-1+3}{6}\right) Vh$

$\Rightarrow q = \frac{2Vh}{6} = \frac{Vh}{3}$

(ii) Given, $\mu = 0.85$ Kg/ms,

$\rho = 1150$ Kg/m³,

$P_1 =$



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 W/m²K and at 25°C temperature. The thermal conductivity of the rod is 40 W/mK. Calculate the

(i) fin efficiency

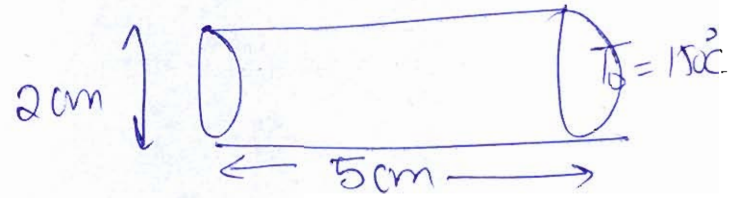
(ii) temperature at the tip of fin and

(iii) the rate of heat dissipation.

[12 marks]

Given

Insulated at Tip,



$h = 70\ W/m^2K$,

$T_\infty = 298K$, $K = 40\ W/mK$,

$\Rightarrow m = \sqrt{\dfrac{70 \times \pi \times 0.02 \times 4}{40 \times \pi \times 0.02 \times 0.02}} = 18.708$

and $q_{loss} = \sqrt{hp \times k \times A}\ \tanh mL \times \Delta T$.

$\Rightarrow q_{loss} = 0.235 \times \tanh(18.708 \times 0.05) \times \Delta T$

$\Rightarrow 0.722 \times 125 = \boxed{21.53\ \text{Watt}}$ (iii)

(12)

$q_{max} = h \times p \times l \times \Delta T$
when whole body will at T_0

$\Rightarrow 70 \times \pi \times 0.02 \times \dfrac{5}{100} \times 125$

$= 27.488$ watt.

$\eta_{fine} = \dfrac{q_{actual}}{q_{max}} = \dfrac{21.53}{27.488} = \boxed{78.32\%}$ (i)

$$\frac{T - T_\infty}{T_0 - T_\infty} = \frac{\cosh m(l - x)}{\cosh ml}$$

$$\Rightarrow \frac{T - 25}{125} = \frac{\cosh m(0)}{\cosh (18.708 \times 0.05)}$$

So, $\boxed{T_{\text{at end}} \rightarrow 110.014°C}$ — (ii)

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

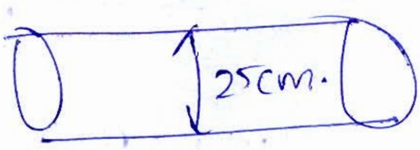
$$h = 1.52\left(\frac{\Delta t}{d}\right)^{0.25} \text{W/m}^2\text{K}$$

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]

Given:

$T_{gas} = 450°C$



$h_\infty = 1.5\left(\frac{\Delta t}{d}\right)^{0.25}$

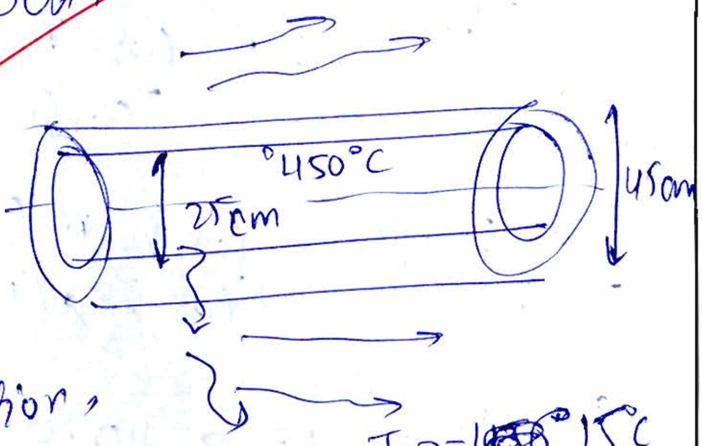
$T_\infty = 15°C$

$q_1 = h_\infty \times A \times \Delta T$

$\Rightarrow 1.5\left(\frac{435}{0.25}\right)^{0.25} \times \frac{\pi}{4} \times l \times 0.25 \times (435)$

$\frac{q_1}{l} = 3309.845$ watt

Condition 2 :-



so, $q_{pipe\ wall} = q_{convection}$,

$$\Rightarrow \frac{(450-T)}{\frac{\ln\left(\frac{45}{25}\right)}{2\pi \times 0.07 \times l}} = 1.5\left(\frac{\Delta t}{0.45}\right)^{0.25} \times \pi \times 0.45 \times l \times \Delta T$$

$$\Rightarrow \frac{450-T}{1.3364} = \frac{2.1205 \times (\Delta T)^{1.25}}{(0.45)^{0.25}}$$

$$\Rightarrow (450-T) = 3.46\,[T-15]^{1.25}$$

12

$\Rightarrow$ By solving putting values,

$T \approx 60°C$ (approx)

so, $$q_2 = \frac{(450-60) \times 2\pi \times 0.07 \times l}{\ln\left(\frac{45}{25}\right)}$$

$$q_2 = \frac{171.5309}{\ln\left(\frac{45}{25}\right)} = 291.825 \text{ watt}.$$

$$q_{reduce}\% = \frac{q_1 - q_2}{q_1} \times 100$$

$$\Rightarrow \left(\frac{3309.845 - 291.825}{3309.845}\right) \times 100$$

$\Rightarrow$ 91.18% (reduction in heat Transfer).

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]

(i) There are various types of Expansion devices in refrigeration system such as :-

3

(i) Thermostatic Expansion valve.

(ii) Automatic Expansion valve.

in pratical usuage const pressure valve is more preferred.

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~~Examples~~ → Generally, Capillary ~~Tube~~ pipe is used as Expansion device in domestic refrigeration devices.

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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]

Given: $Q_1 = 100$ KJ/Kg,

$P_1 = 1$ bar, $T_1 = 40°C = 313K$,

and $P_2 = 1$ bar and $T_\infty = 300K$,

So, $Q = C_p(T_2 - T_1) = 100 = 1.005(T_2 - 313)$

$T_2 = 412.502K$

12

Change in availability:

$\Rightarrow (U_1 - U_2) + p_0(V_1 - V_2) - T_0(s_1 - s_2)$

$\Rightarrow C_v(313 - 412.502) + p_0\left[\frac{RT_1}{P_1} - \frac{RT_2}{P_2}\right] - T_0(s_1 - s_2)$

$\Rightarrow (s_2 - s_1) = C_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}$

$\Rightarrow s_2 - s_1 = 1.005 \ln\left(\frac{412.502}{313}\right) = 0.2774$

$s_1 - s_2 = -0.2774$,

$\Rightarrow -71.4212 + 0.287[313 - 412.502] + 300(0.2774)$

$\Rightarrow -100 + 300(0.2774)$

$\Rightarrow -16.779$ KJ/Kg

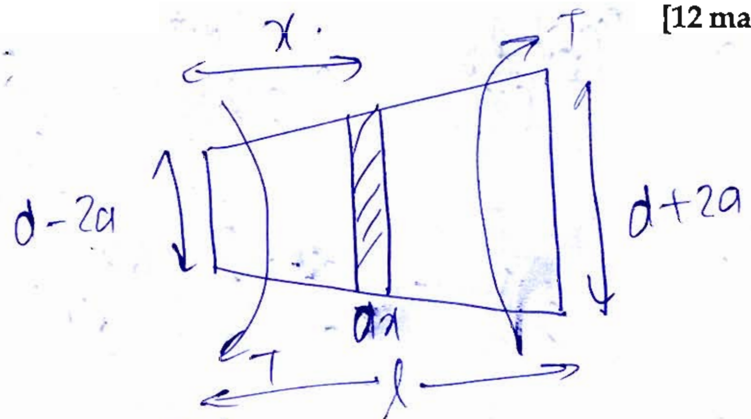
Negative sign represent loss of availability.

Q.5 (e) 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]

Given,

$a = 0.15d$,



So,

$d_1 = 0.7d$

and $d_2 = 1.3d$,

$$\frac{T}{J} = \frac{G\phi}{l} = \frac{\tau}{R}, \quad \{\text{for circular shaft}\}.$$

$$\frac{T}{\frac{\pi}{64} d_x^4} = \frac{G \times \phi}{(dx)} \quad \text{for length } \{dx\} \text{ element.}$$

12

$$\Rightarrow \int_0^\phi \phi = \int \frac{64T}{\pi G} \frac{dx}{d\left[0.7 + \frac{0.6d}{l}x\right]^4}$$

$$\Rightarrow \phi = \frac{64T}{\pi G} \times (-3) \left[0.7 + \frac{0.6d}{l}x\right]^{-3}_{0 \text{ to } l}.$$

$$\phi = -\frac{64}{3\pi G}\left[\frac{1}{(1.3d)^3} - \frac{1}{(0.7d)^3}\right] \times \frac{l}{0.6d}$$

$$\Rightarrow \frac{64}{3\pi G}\left[\frac{1.854d^3}{(0.7 \times 1.3d^2)^3}\right] = \phi.$$

$$\frac{64}{3\pi G} \times \frac{2.4602 \times Tl}{0.6 d^4} = Q_{actual}.$$

and $Q_{By\ (2)}$ = $Q_{actual} = \frac{64}{3\pi G} \times \frac{4.1\, l T}{d^4}$

$$Q_2 = \frac{Tl}{GJ} \Rightarrow \frac{T \times l \times 64}{G \times \pi \times d^4} = \frac{64Tl}{G\pi d^4}$$

$$Error = Q_1 - Q_2$$

$$= \frac{64Tl}{\pi G d^4}\left[\frac{4.1}{3} - 1\right] \Rightarrow 0.366 \times \frac{64Tl}{\pi G d^4}.$$

$$\%\ Error = \frac{\Delta Error}{Q_{actual}}$$

$$\Rightarrow \frac{0.366 \times \left(\frac{64Tl}{\pi G d^4}\right)}{\frac{4.1}{3}\left(\frac{64Tl}{\pi G d^4}\right)} \times 100$$

$$= 26.8\%$$

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 $pv^{1.25} = c$.

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]

Given, 15% CO_2, 17.5 O_2, 67.5% N_2.

$T_1 = 1200°C$, $\frac{V_2}{V_1} = 8$ {Reversible Expansion}

$pv^{1.25} = c$.

$\Rightarrow$ $C_{p\,equ} = \frac{m_1 C_{p1} + m_2 C_{p2} + m_3 C_{p3}}{m_1 + m_2 + m_3}$

$\Rightarrow$ no. of mole $= \frac{\text{mass given}}{\text{molar mass}}$

$\Rightarrow$ $0.15 = \frac{m}{44}$, $m_{CO_2} = 6.6$ g/unit volume.

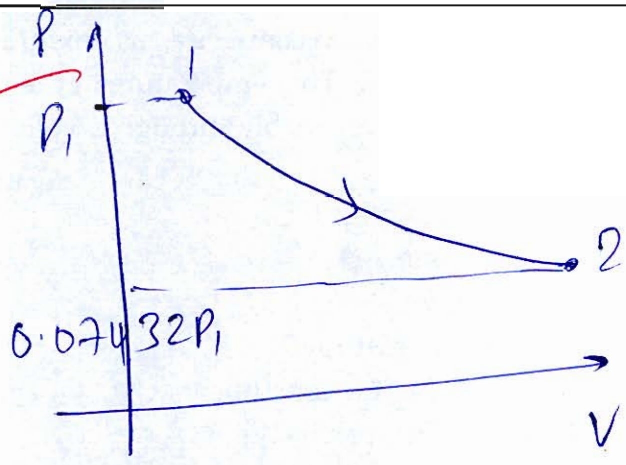
$m_{O_2} = 5.6$ g/unit vol, $m_{N_2} = 18.9$ g/unit volume

$\Rightarrow$ $C_{peq} = \frac{6.6 \times 1.235 + 5.6 \times 1.088 + 18.9 \times 1.172}{6.6 + 5.6 + 18.9}$

$= 1.1702$ kJ/kg-K,

$R_{eq} = \frac{\frac{6.6 \times 8.314}{44} + \frac{5.6 \times 8.314}{32} + \frac{18.9 \times 8.314}{28}}{6.6 + 5.6 + 18.9}$

$R_{eq} = 0.2673$ kJ/kgK.



$$C_p = \frac{\gamma R}{\gamma - 1}$$

$$\Rightarrow \frac{\gamma - 1}{\gamma} = \frac{R}{C_p} = 1 - \frac{1}{\gamma} \Rightarrow \frac{0.2673}{1.1702} = 1 - \frac{1}{\gamma}$$

$$\Rightarrow \gamma_{mix} = 1.296$$

(ii) ~~work done~~ $P_1 V_1^{1.25} = P_2 \times (8 \times V_1)^{1.25}$

$$P_2 = 0.07432\, P_1$$

(20)

$\Rightarrow$ (i) Work done $= \dfrac{P_1V_1 - P_2V_2}{(n-1)}$

$$\Rightarrow \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1} = 0.5946$$

$$\Rightarrow T_2 = 0.5946\,T_1$$

$$\Rightarrow \frac{mR(T_1 - T_2)}{(n-1)} \Rightarrow \frac{m \times R_{eq} \times (T_1 - 0.5946\,T_1)}{0.25}$$

$$\Rightarrow 0.4334 \times T_1 = 638.47 \text{ kJ/kg}.$$

(b) $Q_{flow} = \left(\dfrac{\gamma - n}{\gamma - 1}\right) W$

$Q_{flow} = \left(\frac{1.296 - 1.25}{0.296}\right) \times 638.47$

$= 99.22$ kJ/kg.

$T\,ds = du + p\,dv = dh - v\,dp$

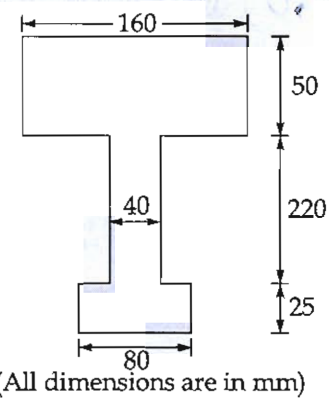
$ds = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$

$= 1.1702 \ln(0.5946) - 0.2673 \ln(0.07432)$

$\Rightarrow -0.6083 + 0.69481$

$\Rightarrow (\Delta s)_{system} = 0.08651$ kJ/kgK.

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)

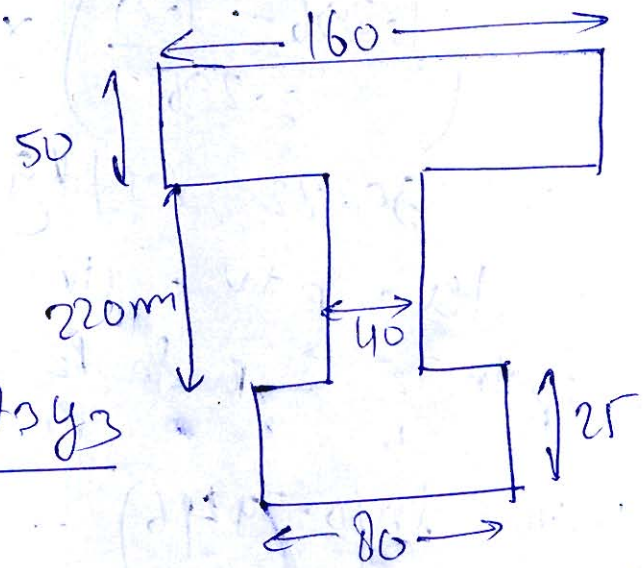
[20 marks]

Given

Top → Compress'

So,

$\bar{y}$



$$\bar{y} = \frac{A_1y_1 + A_2y_2 + A_3y_3}{A_1 + A_2 + A_3}$$

$$\Rightarrow \bar{y} = \frac{(80\times25\times12.5) + 40\times220\times135 + (50\times160\times270)}{(80\times25) + (40\times220) + (50\times160)}$$

$$\Rightarrow \bar{y} = \frac{3373000}{18800} = 179.414\text{mm from base.}$$

$$\Rightarrow I = \frac{(80)(25)^3}{12} + (80)(25)(154.414)^2 + \frac{(40)(220)^3}{12} + (40)(220)(44.414)^2 + \frac{(160)(50)^3}{12} + (160)(50)(90.586)^2$$

$$I = (67.313 + 52.85 + 47.791) \times 10^{-6}\ m^4$$

$$I = 167.95 \times 10^{-6}\ m^4,$$ calculation error

$$\sigma = \frac{My}{I}.\ \text{So,}\ M = \frac{\sigma \times I}{y}$$

For Top surface → compression.

$M = \frac{120 \times 10^6 \times 167.95 \times 10^{-6}}{(0.1155)} = 174.49$ KNm [compression]

For bottom surface,
→ Tension,

$M = \frac{160 \times 10^6 \times 167.95 \times 10^{-6}}{0.179414} = 149.788$ KNm [Tension].

Mmax should be → 149.788 KNm,

Compressive force in Top flange:- 14

$F \Rightarrow \int \frac{M \times}{I} y \times b \times dy.$

$\Rightarrow \frac{149.788 \times 10^3}{167.95 \times 10^{-6}} \times 0.16 \times \left[\frac{y^2}{2}\right]_{65.586m}^{115.586mm}$

$\Rightarrow \frac{149.788 \times 4.529 \times 0.16}{167.95} \times 10^{6}$

$\Rightarrow$ ~~846 KN~~. 646 KN.

Tensile force for bottom,

$f = \frac{149.788 \times 10^3 \times 0.08}{167.95 \times 10^{-6} \times 2} \left[y^2\right]_{0.1544}^{0.1794}$

$\Rightarrow \frac{149.788 \times 10^3}{167.95 \times 10^{-6}} \times 3.34 \times 10^{-4}$

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$F_{Tensil\,(Bottom)} = 297.88\ kN$ [Tension].

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 °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 W/m²K. The temperature at the interface between the two layers is estimated to be 70°C. Determine

(i) Rate of heat flux from the slab to the fluid.

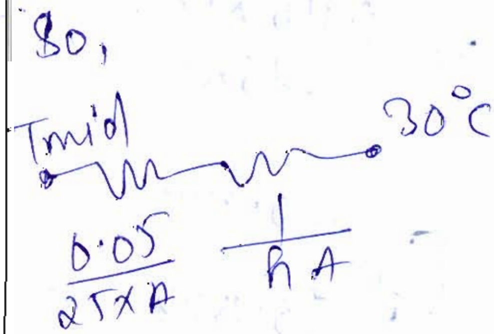
(ii) Maximum temperature in the system, and

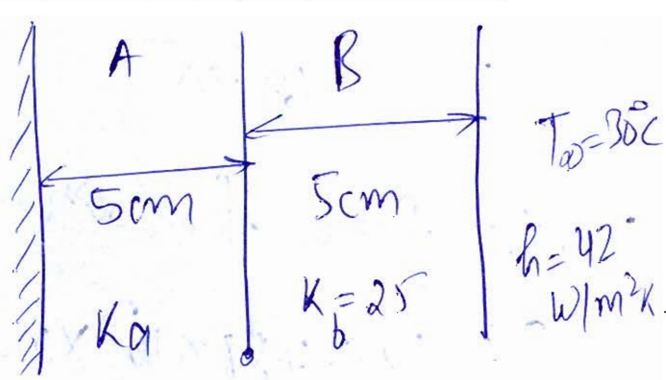
(iii) Location of the point from the insulated surface where the temperature is 80°C.

[20 marks]

Sol

So,





$T_{mid} = 70°C$.

(i) $q = \dfrac{(T_{mid} - 30^\circ)}{\frac{0.05}{25} + \frac{1}{42}} = \dfrac{40}{\frac{1}{500} + \frac{1}{42}}$

$Q = 1549.81\ W/m^2$,

(ii). for slab A,

$Q = -KA\dfrac{dT}{dx}$

$\Rightarrow -\int Q\,dx = K\int_{T_A}^{70} 0.2(1+0.05t)\,dt$ —— (i)

10

$\Rightarrow -1549.81 \times 0.05 = 0.2[t]_{T_A}^{70} + \dfrac{0.01}{2}[t^2]_{T_A}^{70}$

$\Rightarrow -77.4907 = 0.2[70 - T_A] + 0.005[70^2 - T_A^2]$

$\Rightarrow -77.4907 = 14 - 0.2T_A + 24.5 - 0.005T_A^2$

$\Rightarrow 0.005T_A^2 + 0.2T_A - 116 = 0$

check calculation

$\Rightarrow \boxed{T_A = 113.62\ ^\circ C} = T_{max}$.

(iii) from (i)

$-\int Q\,dx = 0.2\left[[t]_{113.62}^{t} + 0.005[t^2 - 113.62^2]\right]$

$\Rightarrow$ ~~-1754.~~

$-1549.81 \times x = -8.724 - 40.047$

$x = 3.1\,cm$ from Insulated surface having Temp $70°C$.

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

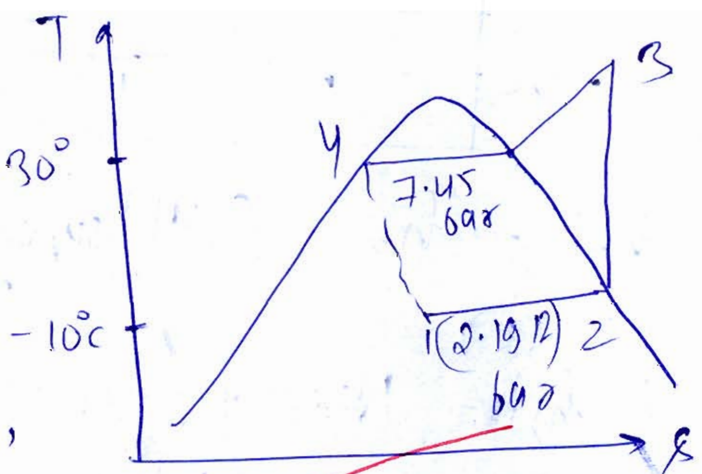
Saturation Temp.	Saturation Pressure	Saturated Liquid and Vapour						Vapour Superheated By 20		By 40°C	
t (°C)	p (bar)	v_f (kJ/kg)	v_g (m³/kg)	h_f (kJ/kg)	h_g (kJ/k)	s_f (kJ/kg.K)	s_g (kJ/kg.K)	h (kJ/kg)	s (kJ/kg.K)	h (kJ/kg)	s (kJ/kg.K)
–40	0.6417	0.66	0.2421	0	169.0	0	0.7274	180.8	0.7737	192.4	0.8178
–35	0.8069	0.67	0.1950	4.4	171.9	0.0187	0.7220	183.3	0.7681	195.1	0.8120
–30	1.0038	0.67	0.1595	8.9	174.2	0.0371	0.7171	185.8	0.7631	197.8	0.8068
–25	1.2368	0.68	0.1313	13.3	176.5	0.0552	0.7127	188.3	0.7586	200.4	0.8021
–20	1.5089	0.69	0.1089	17.8	178.7	0.0731	0.7088	190.8	0.7546	203.1	0.7979
–15	1.8256	0.69	0.0911	22.3	181.0	0.0906	0.7052	193.2	0.7510	205.7	0.7942
–10	2.1912	0.70	0.0767	26.9	183.2	0.1080	0.7020	195.7	0.7477	208.3	0.7909
–5	2.610	0.71	0.0650	31.4	185.4	0.1251	0.6991	198.1	0.7449	210.9	0.7879
0	3.086	0.72	0.0554	36.1	187.5	0.1420	0.6966	200.5	0.7423	213.5	0.7853
5	3.626	0.72	0.0475	40.7	189.7	0.1587	0.6942	202.9	0.7401	216.1	0.7830
10	4.233	0.73	0.0409	45.4	191.7	0.1752	0.6921	205.2	0.7381	218.6	0.7810
15	4.914	0.74	0.0354	50.1	193.8	0.1915	0.6902	207.5	0.7363	221.2	0.7792
20	5.673	0.75	0.0308	54.9	195.8	0.2078	0.6885	209.8	0.7348	223.7	0.7777
25	6.516	0.76	0.0269	59.7	197.7	0.2239	0.6869	212.1	0.7334	226.1	0.7763
30	7.450	0.77	0.0235	64.6	199.6	0.2399	0.6854	214.3	0.7321	228.6	0.7751
35	8.477	0.79	0.0206	69.5	201.5	0.2559	0.6839	216.4	0.7310	231.0	0.7741
40	9.607	0.80	0.0182	74.6	203.2	0.2718	0.6825	218.5	0.7300	233.4	0.7732
45	10.843	0.81	0.0160	79.7	204.9	0.2877	0.6812	220.6	0.7291	235.7	0.7724
50	12.193	0.83	0.0142	84.9	206.5	0.3037	0.6797	222.6	0.7282	238.0	0.7718
60	15.259	0.86	0.0111	95.7	209.3	0.3358	0.6777	226.4	0.7265	242.4	0.7706
70	18.859	0.90	0.0087	107.1	211.5	0.3686	0.6738	230.2	0.7240	246.2	0.7650

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

[20 marks]

Given:

Case I :-



$h_4 = h_1 = 64.6$ kJ/kg

$h_2 = 183.2$ kJ/kg,

$s_2 = s_3 = 0.702$

by interpolation, {for T_3} superheated.

$(0.702 - 0.7321) = \frac{(0.7757 - 0.7321)}{20}(x - 20)$

Superheated by 6.046°C,

$h_3 =$ ~~201~~ 204 kJ/kg,

so, $R.E = (h_2 - h_1) = 118.6$ kJ/kg,

for 1 kg/s of mass flow rate

RC = 33.78 TR

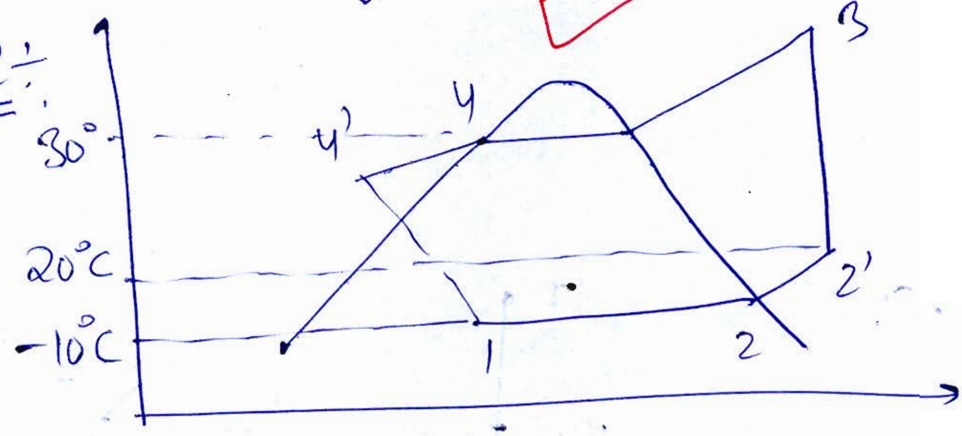
16

and $w_{input} = \dot{m}(h_3 - h_2)$

$= (204 - 183.2) = 20.8$ kJ/kg,

for 1 kg/sec = 20.8 kW,

Case 2:-



$\Rightarrow$

$h_2' = h_2 + (\Delta h)$ superheat by 30°C

$\Rightarrow h_2' =$ ~~183.2~~ + 202 kJ/kg,

$h_2' - h_2 = 18.8$ kJ/kg.

So, $h_4 - h_4' = h_2' - h_2$

$\Rightarrow h_4' = 64.6 - 18.8 = 45.8$ kJ/kg.

$= h_1$

So, $R \cdot E = \dot{m}(h_2 - h_1')$

$\Rightarrow (183.2 - 45.8) = 137.4 \, kJ/kg$

For 1kg/se mass flow rate $= 39.14 \, TR$

and $W_{input} = \dot{m}[h_3 - h_2']$

$s_2' = s_3$

$\Rightarrow$ $0.7693 = s_3$

$h_3 \approx 223 \, kJ/kg$,

So,

$W_{input} = [223 - 202] = 21 \, kJ/kg$

$= 21 \, kW$,

Chang in winput $= 21 - 20.8 = 0.2 \, kW$

Chang in Refrigeration Capacity $= 39.14 - 33.78$

$= 5.36 \, TR$

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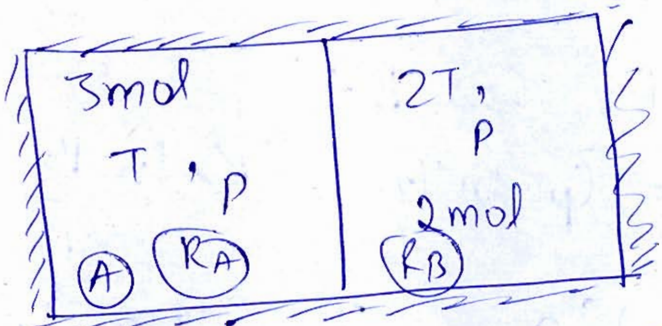
Q.7 (b) Three moles of an ideal gas at temperature T and pressure P are contained in a compartment. In an adjacent compartment is two moles of an another ideal gas at temperature $2T$ and pressure P. The gases mix adiabatically but do not react chemically when a partition separating the compartments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

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

where $\bar{R}$ 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]

Given:



Assuming:

(i) Both gases behaves as ideal gas.

(ii) No Heat interaction from external side.

(iii) C_p, C_v & γ are not fn (T).

So, consider both as system,

$\Delta U_i = U_f$ {WD → 0, Q → 0 interaction}

$\Rightarrow n_1 \bar{C_v} T + n_2 \bar{C_v} 2T = n \bar{C_v} \times T_{final}$

$\Rightarrow (3 \times T + 2T \times 2) \bar{C_v} = n \bar{C_v} \times T_{final}$

$\Rightarrow T_{final} = \frac{(3+4)}{5} T = \frac{7}{5} T$

pressure final = P, but,

$P_A = \frac{x_A}{P} \cdot P = \frac{3}{5} P$ & $P_B = \frac{2}{5} P$,

so, for gas A,

$T ds = dh - v dp \Rightarrow ds = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$

$\Rightarrow 3 \left[\bar{C_p} \ln \frac{7}{5} - \bar{R} \ln \frac{3}{5} \right]$

$\Rightarrow$ for Gas B :-

$ds = \bar{C_p} \ln \frac{T_2}{T_1} - \bar{R} \ln \frac{P_2}{P_1}$

(20)

$\Rightarrow 2 \left[\bar{C_p} \ln \frac{7}{10} - \bar{R} \ln \frac{2}{5} \right]$

so, $(\Delta S)_{Total} = \bar{C_p} \ln \left(\frac{7}{5}\right)^3 - \bar{R} \ln \left(\frac{3}{5}\right)^3$

$+ \bar{C_p} \ln \left(\frac{7}{10}\right)^2 - \bar{R} \ln \left(\frac{2}{5}\right)^2$

$\Rightarrow \bar{C_p} \ln \left[\frac{16807}{12500}\right] - \bar{R} \ln \left[\frac{108}{3125}\right]$

$\Rightarrow \frac{\gamma - 1}{\gamma} \bar{R} \cdot \ln \left(\frac{16807}{12500}\right) + \bar{R} \ln \left(\frac{3125}{108}\right)$

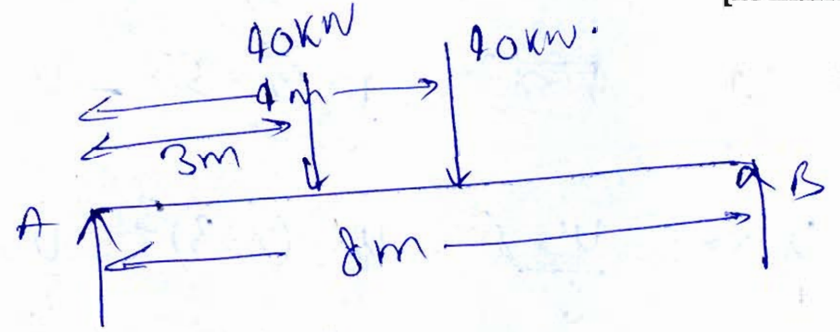
$\Rightarrow \bar{R} \left[\ln \left(\frac{3125}{108}\right) + \frac{\gamma - 1}{\gamma} \ln \left[\frac{16807}{12500}\right] \right]$

Hence proved

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 $E = 2.5 \times 10^5$ N/mm^2 and $I = 15000$ cm^4.

[20 marks]

Sol.



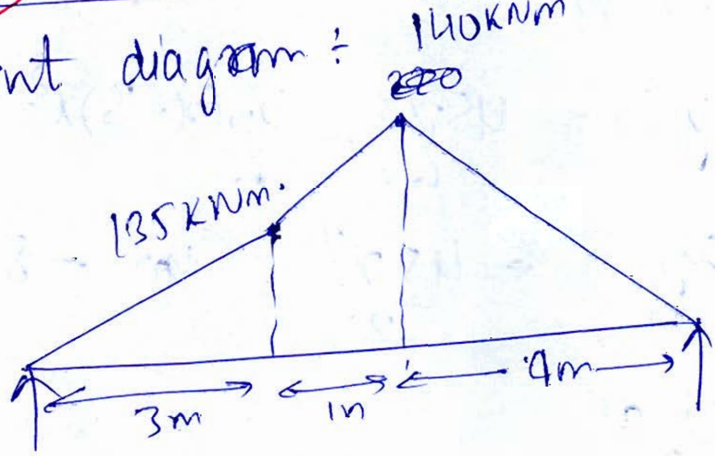
$R_A + R_B = 80$,

$\Sigma M_A = 0$, $40 \times 3 + 40 \times 4 = R_B \times 8$

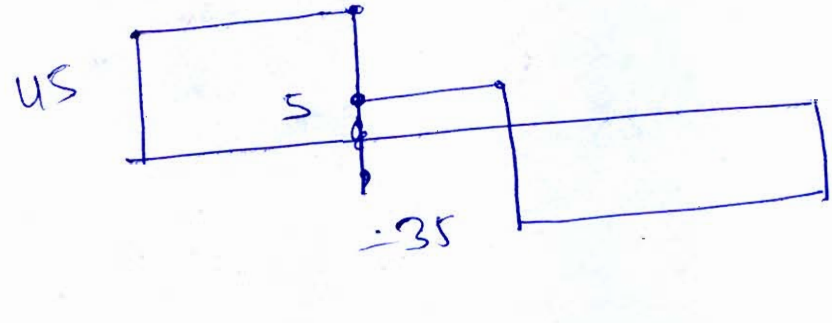
$\Rightarrow R_B = 35$ KN

and $R_A = 45$ KN

Bending moment diagram:



SFD:



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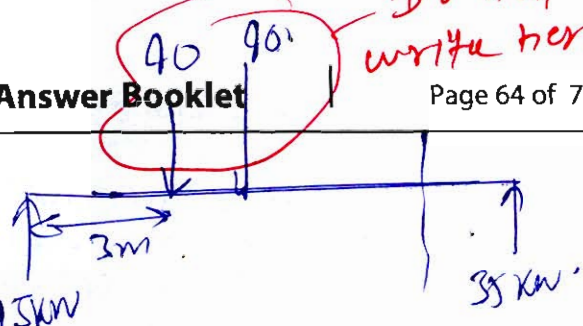
By Maclauy's



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

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

$$\Rightarrow y \times EI = \frac{45}{6}x^3 - \frac{40}{6}(x-3)^3 - \frac{40}{6}(x-4)^3 + C_1x + C_2$$

at $x \to 0$, $y \to 0$ $C_2 \to 0$

6

at $x = 8$, $y \to 0$

$$0 = \frac{45}{6}(512) - \frac{40}{6}(125) - \frac{40}{6}(64) + C_1 \times 4$$

$$\Rightarrow C_1 = -833.3,$$

Applying Eqn b/w loads, $[3 < x < 4]$

$$\Rightarrow yEI = \frac{45x^3}{6} - \frac{40}{6}(x-3)x^3 - 833.33x.$$

$$\Rightarrow \frac{dy}{dx} = \frac{45x^2}{2} - 40 - 833.3 - \frac{40}{2}(x-3)^2$$

$\Rightarrow$

$0 =$

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

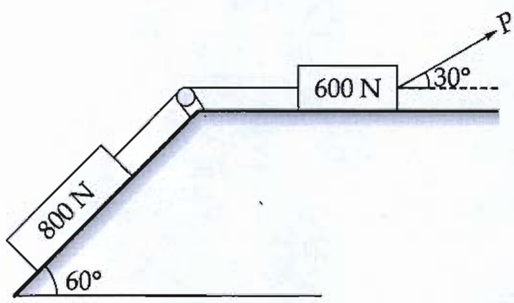
[Assume unit width for the plate and air flow over both sides of the plate]

[20 marks]

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

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

(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]

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

(a) kW-capacity required to take the load in the cooling cabin.

(b) 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]

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Space for Rough Work

Space for Rough Work