Good accuracy

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India's Best Institute for IES, GATE & PSUs

ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-1 : Thermodynamics [All Topics]

Strength of Materials & Mechanics [All Topics]

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. Answer must be written in English only.
3. Use only black/blue pen.
4. 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.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	56
Q.2	0
Q.3	45
Q.4	45
Section-B	
Q.5	18
Q.6	0
Q.7	0
Q.8	21
Total Marks Obtained	185

Signature of Evaluator: Sonelal yadav

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.

- Improve presentation skill.
- Need to increase Attempt little bit.
- write assumptions and given data.
- Try to attempt all mandatory Questions.

Section : A

Q.1 (a) (i) A vertical frictionless piston-cylinder device contains a gas at pressure of 150 kPa. The piston is having a mass of 10 kg and diameter of 10 cm. If the pressure of gas is to be increased by 200 percent by placing some bricks each having a mass of 16 kg over the piston then determine the number of bricks rounding off to nearest integer that would be required. Also calculate the local atmospheric pressure in kPa.
[Take $g = 9.81\ m/s^2$]

(ii) A power transmitting machine uses a gear box which operates under steady state. The input shaft receives 30 kW from a prime mover and transmits 26 kW to the output shaft, the rest being lost due to friction, etc. The average surface temperature of gear box is 55°C and heat is lost to surroundings at 27°C. Estimate the rate of entropy production inside the gear box in W/K.

[8 + 4 marks]

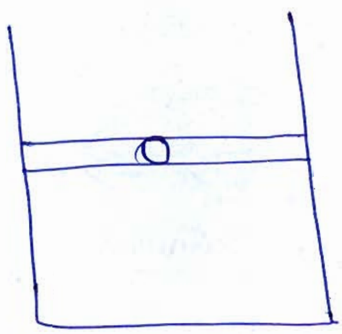
(I)

$P_1 = 150\ kPa$

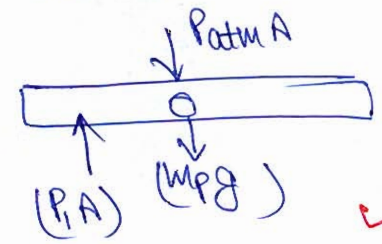
$m_p = 10\ kg$

$D = 10\ cm \therefore A = \frac{\pi}{4}D^2$

$P_2 = 3P_1 = 450\ kPa$



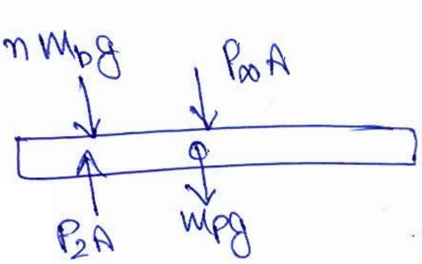
Cond^n (1) $P_{atm} = P_\infty$



$(P_\infty A + m_p g) = (P_1 A)$ — (1)

8

Cond^n (2) when bricks (m_b) placed Let ~~total~~ n bricks



$(P_2 A) = (m_p g) + P_\infty A + n m_b g$ — (II)

From (1) & (II)

$(P_2 A) = (P_1 A) + n m_b g$

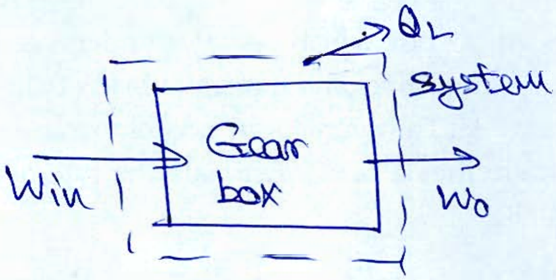
$n \simeq 15$ bricks

From eqn (1)

$P_\infty A + m_p g = P_1 A$

$\boxed{P_\infty = 1.375 \text{ bar}}$

(II)



$W_{in} = 30 \text{ kW}$

$W_o = 26 \text{ kW}$

$T_G = 55°C$

$T_\infty = 27°C$

Energy balance

$\Sigma E_{in} - \Sigma E_o = \Delta E_{CV}$

$W_{in} = W_o + Q_L$

$Q_L = 4 \text{ kW}$

Exergy balance

$(X_i - X_o) - X_{Des} = \Delta X_{CV}$

Steady state ∴ $\Delta X_{CV} = 0$

$(X_i - X_o) = X_{Des}$

$X_i = W_{in}$

$X_o = W_o + Q_L\left(1 - \frac{T_\infty}{T_G}\right)$

$X_{Dest} = 3.658 \text{ kW}$

$\Delta S_{gen} = \left(\frac{X_{Dest}}{T_o}\right)$

$\boxed{\Delta S_{gen} = 12.195 \text{ W/K}}$

4

Q.1 (b) A set of stoppers is fixed somewhere above the piston in a frictionless piston-cylinder device in which air is contained at 500 kPa, 727°C and occupies a volume of 1 m^3. The air undergoes an isothermal process until the pressure is reduced to 300 kPa. As the pressure reaches 300 kPa, the piston hits the stopper and now heat is removed until the air reaches 27°C without piston movement.

(i) Sketch the processes undergone by the system on the *P-V* diagram.

(ii) Determine the net amount of heat transfer for the combined process in kJ.

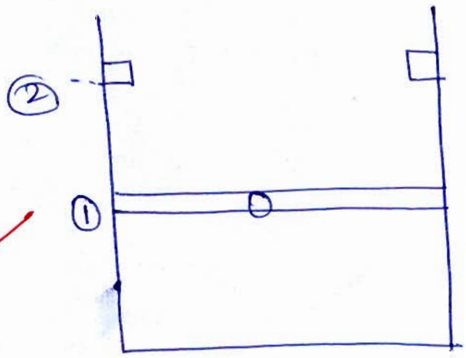
[12 marks]

$P_1 = 500\,kPa$

$T_1 = 1000\,K$

$V_1 = 1\,m^3$

$m = \frac{P_1 V_1}{R T_1} = 1.742\,kg$



1–2

$T = C$

$P_2 = 300\,kPa$ $\qquad \frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1}$ $\qquad T_2 = 1000\,K$

$V_2 = \left(\frac{P_1 V_1}{P_2}\right) = 1.667\,m^3$

2–3

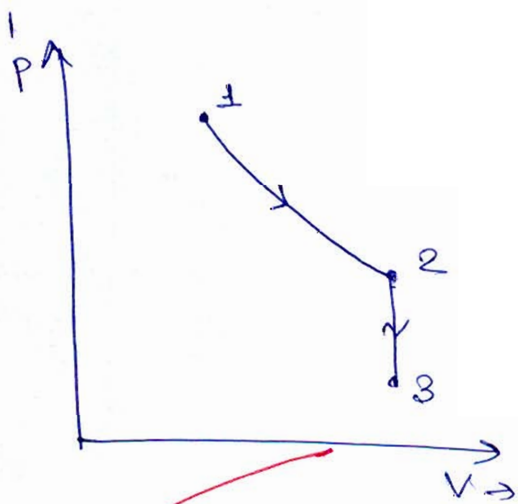
$V = C \Rightarrow V_3 = V_2 = 1.667\,m^3$

$T_3 = 300\,K$

$\frac{P_2 V_2}{T_2} = \frac{P_3 V_3}{T_3}$

$P_3 = \left(\frac{T_3}{T_2}\right)\left(\frac{V_2}{V_3}\right) \cdot P_2$

$P_3 = 90\,kPa$



Do not write in this margin

$Q_{net} = Q_{1-2} + Q_{23}$

$Q_{1-2} = W_{1-2} = mRT_1 \ln\left(\frac{V_2}{V_1}\right) \quad (\because T = C)$

$Q_{1-2} = 255.512$ kJ

$Q_{2-3} = \Delta U + \Delta W \quad (\Delta V = 0 \Rightarrow W_{23} = 0)$

$Q_{2-3} = mC_v(T_3 - T_2)$

12

$Q_{2-3} = -875.529$ kJ

$\boxed{Q_{net} = -620.012 \text{ kJ}}$

↳ -ve sign indicates heat loss from system.

Write conclusion in proper statements.

Q.1 (c) Water contained in a piston-cylinder assembly undergoes two processes in series from an initial state where the pressure is 10 bar and temperature is 500°C, as given below:

Process 1 - 2 : The water is cooled as it is compressed at a constant pressure of 10 bar to the saturated vapour state.

Process 2 - 3 : The water is cooled at constant volume to 130°C.

(i) Sketch both processes on P-v and T-v diagrams.

(ii) Determine the work transfer for the overall process in kJ/kg.

(iii) Determine the heat transfer for the overall process in kJ/kg.

Use the data provided in the steam table.

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}
120	0.19867	0.00106033	0.89121	503.60	2528.8	503.81	2705.9	2202.1	1.5279	7.1291	5.6012
121	0.20505	0.00106123	0.86525	507.84	2530.0	508.06	2707.4	2199.3	1.5387	7.1186	5.5799
122	0.21159	0.00106215	0.84019	512.09	2531.0	512.31	2708.8	2196.5	1.5494	7.1081	5.5587
123	0.21830	0.00106307	0.81598	516.33	2532.2	516.56	2710.3	2193.7	1.5602	7.0977	5.5375
124	0.22518	0.00106400	0.79261	520.58	2533.2	520.82	2711.7	2190.9	1.5709	7.0873	5.5165
125	0.23224	0.00106494	0.77003	524.82	2534.3	525.07	2713.1	2188.0	1.5816	7.0770	5.4955
126	0.23947	0.00106588	0.74821	529.07	2535.3	529.33	2714.5	2185.2	1.5922	7.0668	5.4746
127	0.24689	0.00106683	0.72713	533.33	2536.4	533.59	2715.9	2182.3	1.6029	7.0566	5.4538
128	0.25450	0.00106778	0.70675	537.58	2537.4	537.85	2717.3	2179.5	1.6135	7.0465	5.4330
129	0.26229	0.00106874	0.68705	541.84	2538.5	542.12	2718.7	2176.6	1.6241	7.0364	5.4124
130	0.27028	0.00106971	0.66800	546.09	2539.6	546.38	2720.1	2173.7	1.6346	7.0264	5.3918
131	0.27846	0.00107068	0.64959	550.35	2540.6	550.65	2721.5	2170.8	1.6452	7.0165	5.3713
132	0.28685	0.00107166	0.63177	554.61	2541.6	554.92	2722.8	2167.9	1.6557	7.0066	5.3509
133	0.29543	0.00107265	0.61454	558.87	2542.6	559.19	2724.2	2165.0	1.6662	6.9967	5.3305
134	0.30423	0.00107365	0.59786	563.14	2543.6	563.47	2725.5	2162.1	1.6767	6.9869	5.3102
135	0.31323	0.00107465	0.58173	567.40	2544.7	567.74	2726.9	2159.1	1.6872	6.9772	5.2900
136	0.32245	0.00107566	0.56611	571.67	2545.7	572.02	2728.2	2156.2	1.6976	6.9675	5.2699
137	0.33188	0.00107667	0.55099	575.94	2546.6	576.30	2729.5	2153.2	1.7081	6.9579	5.2498
138	0.34154	0.00107769	0.53636	580.22	2547.6	580.59	2730.8	2150.3	1.7185	6.9483	5.2298
139	0.35143	0.00107872	0.52218	584.49	2548.6	584.87	2732.1	2147.3	1.7289	6.9388	5.2099
140	0.36154	0.00107976	0.50845	588.77	2549.6	589.16	2733.4	2144.3	1.7392	6.9293	5.1901
141	0.37189	0.00108080	0.49516	593.05	2550.6	593.45	2734.7	2141.3	1.7496	6.9199	5.1703
142	0.38247	0.00108185	0.48227	597.33	2551.5	597.74	2736.0	2138.3	1.7599	6.9105	5.1506
143	0.39329	0.00108291	0.46979	601.61	2552.5	602.04	2737.3	2135.2	1.7702	6.9011	5.1309
144	0.40437	0.00108397	0.45769	605.90	2553.4	606.34	2738.5	2132.2	1.7805	6.8919	5.1114
145	0.41568	0.00108504	0.44596	610.19	2554.4	610.64	2739.8	2129.2	1.7907	6.8826	5.0919
146	0.42726	0.00108612	0.43459	614.48	2555.3	614.94	2741.0	2126.1	1.8010	6.8734	5.0724
147	0.43909	0.00108720	0.42357	618.77	2556.3	619.25	2742.3	2123.0	1.8112	6.8643	5.0530
148	0.45118	0.00108830	0.41288	623.07	2557.2	623.56	2743.5	2119.9	1.8214	6.8552	5.0337
149	0.46354	0.00108940	0.40251	627.37	2558.1	627.87	2744.7	2116.9	1.8316	6.8461	5.0145
150	0.47616	0.00109050	0.39245	631.66	2559.0	632.18	2745.9	2113.7	1.8418	6.8371	4.9953
151	0.48907	0.00109162	0.38269	635.97	2559.9	636.50	2747.1	2110.6	1.8520	6.8281	4.9761
152	0.50225	0.00109274	0.37323	640.26	2560.8	640.81	2748.3	2107.5	1.8621	6.8192	4.9571
153	0.51571	0.00109387	0.36404	644.58	2561.8	645.14	2749.5	2104.3	1.8722	6.8103	4.9380
154	0.52946	0.00109501	0.35512	648.88	2562.7	649.46	2750.7	2101.2	1.8823	6.8014	4.9191
155	0.54350	0.00109615	0.34646	653.19	2563.5	653.79	2751.8	2098.0	1.8924	6.7926	4.9002
156	0.55784	0.00109730	0.33805	657.51	2564.4	658.12	2753.0	2094.8	1.9025	6.7838	4.8814
157	0.57247	0.00109846	0.32989	661.82	2565.2	662.45	2754.1	2091.6	1.9125	6.7751	4.8626
158	0.58742	0.00109963	0.32196	666.14	2566.1	666.79	2755.2	2088.4	1.9225	6.7664	4.8439
159	0.60267	0.00110081	0.31426	670.47	2566.9	671.13	2756.3	2085.2	1.9326	6.7578	4.8252
160	0.61823	0.00110199	0.30678	674.79	2567.7	675.47	2757.4	2082.0	1.9426	6.7491	4.8066

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

p	T_{sat}	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
MPa	°C	v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
0.40	143.608	0.00108355	0.46238	604.22	2553.1	604.65	2738.1	2133.4	1.7765	6.8955	5.1190
0.42	145.375	0.00108544	0.44165	611.79	2554.8	612.25	2740.3	2128.0	1.7946	6.8791	5.0846
0.44	147.076	0.00108729	0.42274	619.10	2556.4	619.58	2742.4	2122.8	1.8120	6.8636	5.0516
0.46	148.716	0.00108908	0.40542	626.14	2557.9	626.64	2744.4	2117.7	1.8287	6.8487	5.0199
0.48	150.300	0.00109084	0.38950	632.95	2559.3	633.47	2746.3	2112.8	1.8448	6.8344	4.9895
0.50	151.831	0.00109255	0.37481	639.54	2560.7	640.09	2748.1	2108.0	1.8604	6.8207	4.9603
0.52	153.314	0.00109423	0.36120	645.93	2562.1	646.50	2749.9	2103.4	1.8754	6.8075	4.9321
0.54	154.753	0.00109587	0.34858	652.13	2563.3	652.72	2751.5	2098.8	1.8899	6.7948	4.9049
0.56	156.149	0.00109748	0.33682	658.16	2564.5	658.77	2753.1	2094.4	1.9040	6.7825	4.8786
0.58	157.506	0.00109905	0.32585	664.01	2565.7	664.65	2754.7	2090.0	1.9176	6.7707	4.8531
0.60	158.826	0.00110060	0.31558	669.72	2566.8	670.38	2756.1	2085.8	1.9308	6.7592	4.8284
0.62	160.112	0.00110212	0.30596	675.28	2567.9	675.96	2757.6	2081.6	1.9437	6.7482	4.8045
0.64	161.365	0.00110362	0.29691	680.70	2568.9	681.41	2758.9	2077.5	1.9562	6.7374	4.7813
0.66	162.587	0.00110509	0.28840	686.00	2570.0	686.73	2760.3	2073.5	1.9684	6.7270	4.7587
0.68	163.781	0.00110654	0.28036	691.17	2570.9	691.92	2761.5	2069.6	1.9802	6.7169	4.7367
0.70	164.946	0.00110796	0.27277	696.22	2571.9	697.00	2762.8	2065.8	1.9918	6.7071	4.7153
0.72	166.086	0.00110936	0.26559	701.17	2572.7	701.97	2763.9	2062.0	2.0031	6.6975	4.6944
0.74	167.200	0.00111075	0.25879	706.02	2573.6	706.84	2765.1	2058.2	2.0141	6.6882	4.6741
0.76	168.291	0.00111211	0.25233	710.76	2574.4	711.61	2766.2	2054.6	2.0248	6.6791	4.6543
0.78	169.360	0.00111346	0.24618	715.41	2575.3	716.28	2767.3	2051.0	2.0354	6.6703	4.6349
0.80	170.406	0.00111478	0.24034	719.97	2576.0	720.86	2768.3	2047.4	2.0457	6.6616	4.6160
0.82	171.433	0.00111609	0.23477	724.44	2576.8	725.36	2769.3	2043.9	2.0557	6.6532	4.5975
0.84	172.440	0.00111739	0.22946	728.84	2577.6	729.78	2770.3	2040.5	2.0656	6.6449	4.5793
0.86	173.428	0.00111867	0.22438	733.15	2578.2	734.11	2771.2	2037.1	2.0753	6.6369	4.5616
0.88	174.398	0.00111993	0.21953	737.38	2578.9	738.37	2772.1	2033.8	2.0847	6.6290	4.5443
0.90	175.350	0.00112118	0.21489	741.55	2579.6	742.56	2773.0	2030.5	2.0940	6.6213	4.5272
0.92	176.287	0.00112242	0.21044	745.65	2580.3	746.68	2773.9	2027.2	2.1032	6.6137	4.5106
0.94	177.207	0.00112364	0.20617	749.67	2580.9	750.73	2774.7	2024.0	2.1121	6.6063	4.4942
0.96	178.112	0.00112485	0.20208	753.64	2581.5	754.72	2775.5	2020.8	2.1209	6.5991	4.4782
0.98	179.002	0.00112605	0.19814	757.55	2582.1	758.65	2776.3	2017.7	2.1296	6.5920	4.4624
1.00	179.878	0.00112723	0.19436	761.39	2582.7	762.52	2777.1	2014.6	2.1381	6.5850	4.4470
1.05	182.009	0.00113014	0.18552	770.75	2584.1	771.94	2778.9	2007.0	2.1587	6.5681	4.4095
1.10	184.062	0.00113299	0.17745	779.78	2585.4	781.03	2780.6	1999.6	2.1785	6.5520	4.3735
1.15	186.043	0.00113577	0.17006	788.51	2586.6	789.82	2782.2	1992.4	2.1976	6.5365	4.3390
1.20	187.957	0.00113850	0.16326	796.96	2587.8	798.33	2783.7	1985.4	2.2159	6.5217	4.3058
1.25	189.809	0.00114118	0.15699	805.15	2588.9	806.58	2785.1	1978.6	2.2337	6.5074	4.2737
1.30	191.605	0.00114380	0.15119	813.11	2590.0	814.60	2786.5	1971.9	2.2508	6.4936	4.2428
1.35	193.347	0.00114638	0.14580	820.84	2590.9	822.39	2787.7	1965.3	2.2674	6.4803	4.2129
1.40	195.039	0.00114892	0.14078	828.36	2591.7	829.97	2788.8	1958.9	2.2835	6.4675	4.1839
1.45	196.685	0.00115141	0.13609	835.68	2592.6	837.35	2789.9	1952.6	2.2992	6.4550	4.1559
1.50	198.287	0.00115387	0.13171	842.83	2593.4	844.56	2791.0	1946.4	2.3143	6.4430	4.1286

Water/Steam at $p = 1.0$ MPa ($T_{sat} = 179.878$°C)

T	v	u	h	s	T	v	u	h	s
°C	m³/kg	kJ/kg	kJ/kg	kJ/kg K	°C	m³/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00099970	-0.02	0.98	-0.00009	270	0.24296	2743.9	2986.9	7.0087
5	0.00099959	21.01	22.01	0.07624	280	0.24801	2760.6	3008.6	7.0482
10	0.00099987	41.99	42.99	0.15100	290	0.25301	2777.2	3030.2	7.0868
15	0.00100048	62.94	63.94	0.22431	300	0.25799	2793.6	3051.6	7.1246
20	0.00100138	83.85	84.85	0.29628	310	0.26294	2810.1	3073.0	7.1616
25	0.00100255	104.75	105.75	0.36697	320	0.26786	2826.5	3094.4	7.1979
30	0.00100397	125.64	126.64	0.43645	330	0.27276	2842.9	3115.7	7.2335
35	0.00100560	146.52	147.53	0.50478	340	0.27764	2859.3	3136.9	7.2685
40	0.00100744	167.40	168.41	0.57202	350	0.28250	2875.7	3158.2	7.3029
45	0.00100948	188.29	189.30	0.63819	360	0.28735	2892.0	3179.4	7.3367
50	0.00101171	209.18	210.19	0.70335	370	0.29218	2908.5	3200.7	7.3700
55	0.00101411	230.08	231.09	0.76753	380	0.29700	2924.9	3221.9	7.4028
60	0.00101669	250.98	252.00	0.83077	390	0.30181	2941.4	3243.2	7.4351
65	0.00101943	271.90	272.92	0.89310	400	0.30661	2957.9	3264.5	7.4669
70	0.00102233	292.84	293.86	0.95455	410	0.31139	2974.4	3285.8	7.4984
75	0.00102539	313.78	314.81	1.0152	420	0.31617	2990.9	3307.1	7.5294
80	0.00102860	334.74	335.77	1.0750	430	0.32094	3007.6	3328.5	7.5600
85	0.00103197	355.72	356.75	1.1340	440	0.32569	3024.2	3349.9	7.5902
90	0.00103550	376.72	377.76	1.1922	450	0.33045	3040.9	3371.3	7.6200
95	0.00103917	397.75	398.79	1.2497	460	0.33519	3057.6	3392.8	7.6495
100	0.00104300	418.80	419.84	1.3065	470	0.33993	3074.4	3414.3	7.6786
105	0.00104699	439.87	440.92	1.3626	480	0.34466	3091.1	3435.8	7.7075
110	0.00105112	460.99	462.04	1.4181	490	0.34939	3108.0	3457.4	7.7360
115	0.00105542	482.13	483.19	1.4729	500	0.35411	3125.0	3479.1	7.7641
120	0.00105987	503.32	504.38	1.5272	520	0.36354	3159.1	3522.6	7.8196
125	0.00106449	524.54	525.60	1.5808	540	0.37295	3193.3	3566.2	7.8740
130	0.00106927	545.81	546.88	1.6339	560	0.38235	3227.8	3610.1	7.9273
135	0.00107423	567.13	568.20	1.6865	580	0.39174	3262.5	3654.2	7.9796
140	0.00107935	588.50	589.58	1.7386	600	0.40111	3297.5	3698.6	8.0310
145	0.00108466	609.93	611.01	1.7901	620	0.41047	3332.7	3743.2	8.0815
150	0.00109015	631.41	632.50	1.8412	640	0.41982	3368.2	3788.0	8.1312
155	0.00109583	652.96	654.06	1.8919	660	0.42916	3403.9	3833.1	8.1800
160	0.00110171	674.60	675.70	1.9421	680	0.43850	3440.0	3878.5	8.2281
165	0.00110780	696.30	697.41	1.9919	700	0.44783	3476.3	3924.1	8.2755
170	0.00111410	718.09	719.20	2.0414	720	0.45715	3512.9	3970.0	8.3221
175	0.00112063	739.96	741.08	2.0905	740	0.46647	3549.6	4016.1	8.3681
179.878	0.00112723	761.39	762.52	2.1381	760	0.47578	3586.7	4062.5	8.4135
179.878	0.19436	2582.7	2777.1	6.5850	780	0.48508	3624.1	4109.2	8.4582
180	0.19444	2583.0	2777.4	6.5857	800	0.49438	3661.7	4156.1	8.5024
185	0.19742	2593.3	2790.7	6.6148	820	0.50368	3699.6	4203.3	8.5460
190	0.20034	2603.2	2803.5	6.6427	840	0.51297	3737.8	4250.8	8.5890
195	0.20320	2612.8	2816.0	6.6695	860	0.52226	3776.2	4298.5	8.6315
200	0.20602	2622.3	2828.3	6.6955	880	0.53155	3814.9	4346.5	8.6735
210	0.21156	2640.6	2852.2	6.7456	900	0.54083	3854.0	4394.8	8.7150
220	0.21698	2658.5	2875.5	6.7934	920	0.55011	3893.2	4443.3	8.7560
230	0.22231	2676.1	2898.4	6.8393	940	0.55939	3932.7	4492.1	8.7965
240	0.22756	2693.3	2920.9	6.8836	960	0.56867	3972.4	4541.1	8.8366
250	0.23275	2710.4	2943.1	6.9265	980	0.57794	4012.5	4590.4	8.8763
260	0.23788	2727.2	2965.1	6.9681	1000	0.58721	4052.7	4639.9	8.9155
270	0.24296	2743.9	2986.9	7.0087					

[12 marks]

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1.C

$P_1 = 10$ bar $\xrightarrow[\text{Cooling}]{P=C}$ $x_2 = 1$ $\xrightarrow[\text{Cooling}]{V=C}$ $T_3 = 130°C$

$T_1 = 500°C$

$T_{sat} = 179.878°C$

$v_1 = 0.35411$

$u_1 = 3125$

$h_1 = 3479.1$

$s_1 = 7.7641$

~~$v_2 = 0.00$~~

$v_2 = 0.19436$

$u_2 = 2582.7$

$h_2 = 2777.1$

$s_2 = 6.5850$

$v_2 = v_3 = 0.19436$

$v_{g@130°C} > v_3$.

So it in water - vapour mix.

$v_3 = (v_f + x v_{fg})_{@130°C}$

$x_3 = 0.2898$

$h_3 = (h_f + x_3 h_{fg})$

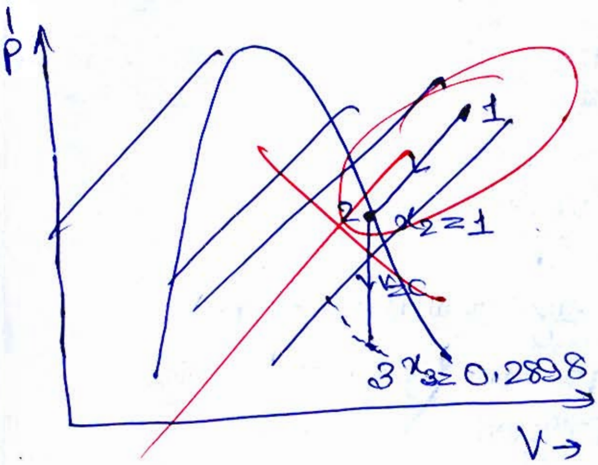
$h_3 = 1176.36$

$u_3 = (u_f + x u_{fg})$

$u_3 = 1123.809$

$s_3 = (s_f + x s_{fg})$

$s_3 = 3.197$ kJ/kgK



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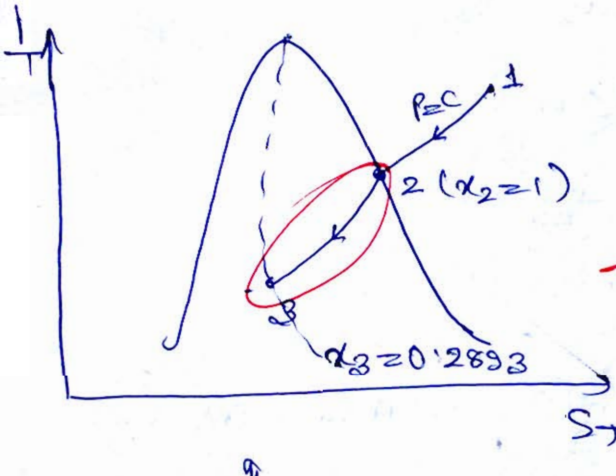
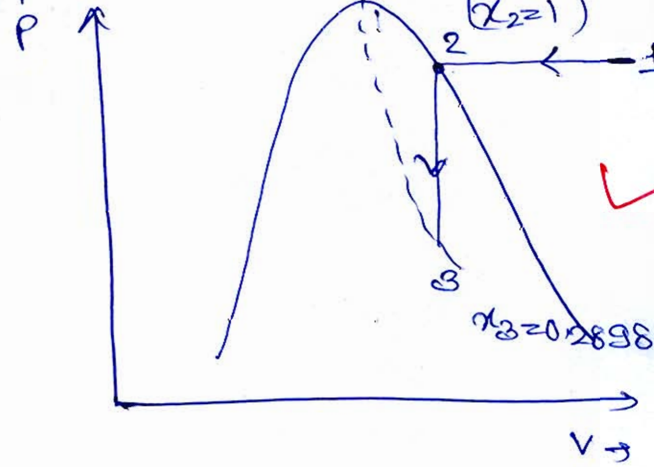


~~we have~~ Draw T-V diagram



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Heat transfer $(Q) = Q_{1-2} + Q_{2-3}$

$Q = Q_{1-2} + Q_{2-3}$

$Q_{1-2} = (h_2 - h_1) = -702$

$Q_{2-3} = \Delta U + \Delta W$ $\because W_{2-3} = 0$

$\Delta U = (U_3 - U_1)$

$\Delta U = Q_{2-3}$

$Q_{2-3} = -1458.891 \frac{kJ}{kg}$

$Q_{net} = -2160.891 \, kJ/kg$

↳ -ve sign indicates that heat loss from the these process

Work transfer $(W) = W_{1-2} + W_{2-3}$

$W_{1-2} = (Q_{1-2}) - (\Delta U)$

$W_{1-2} = -159.7 \frac{kJ}{kg}$

$W_{2-3} = 0$ $(\because V = C)$

$W_{net} = -159.7 \frac{kJ}{kg}$ → WD on system by these 2 processes

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Q.1 (d) 2500 cm^3 of gaseous combustion products at a pressure of 6 bar and a temperature of 1200 K is contained in a cylinder of an internal combustion engine just before the exhaust valve opens. Ignoring the effects of gravity and motion and assuming the combustion products as air only, determine the specific exergy of the gas in kJ/kg. The atmospheric pressure and temperature are 1.013 bar and 27°C.

[12 marks]

$$m = \left(\frac{P_1 V_1}{RT_1}\right) = 0.004355 \text{ kg}$$

Exergy of Gas $(\phi) = (u - u_0) - T_0(s - s_0) + P_0(v - v_0)$

$$Pv = RT$$

$$v_0 = \left(\frac{RT_0}{P_0}\right) = 0.8499 \text{ m}^3/\text{kg}$$

$$v = \left(\frac{V}{m}\right) = 0.574 \text{ m}^3/\text{kg}$$

10

$$\phi = C_v(T - T_0) - T_0(s - s_0) + P_0(v - v_0)$$

$$T = 1200 \text{ K}$$

$$(s - s_0) = C_p \ln\left(\frac{T}{T_0}\right) - R \ln\left(\frac{P}{P_0}\right) = 0.88269$$

$\phi = 353.436$ kJ/kg — Ans.

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write assumptions any given data

any utilize space given to make more presentable

Q.1 (e) (i) A Carnot engine is working between two temperature limits T_1 (Source temperature) and T_2 (Sink temperature). The efficiency of this engine can be increased by the following two ways:

1. By increasing T_1 and keeping T_2 as constant.
2. By decreasing T_2 and keeping T_1 as constant.

Which of the above two ways is the more effective way to increase the efficiency?

(ii) A reversible heat engine operates between two reservoirs at temperature 500°C and 30°C. A reversible refrigerator which operates between 30°C and –10°C is driven the given engine. 2200 kJ of heat is required to drive the engine and there is a net work output of 400 kJ from the combined engine-refrigerator plant. Evaluate the net heat transfer to the reservoir at 30°C in kJ.

[6 + 6 marks]

(I) Increasing $T_1 \rightarrow T_2$ Const (by T amount)

$$\eta_1 = 1 - \frac{T_2}{T_1+T}$$

Decreasing $T_2 \rightarrow T_1$ Const

$$\eta_2 = 1 - \frac{(T_2-T)}{T_1}$$

6

$$(\eta_2 - \eta_1) = \frac{-T_2+T}{T_1} + \frac{T_2}{T_1+T}$$

$$= \frac{-T_1T_2 + T_1T - T_2T + T^2 + T_1T_2}{T_1(T_1+T)}$$

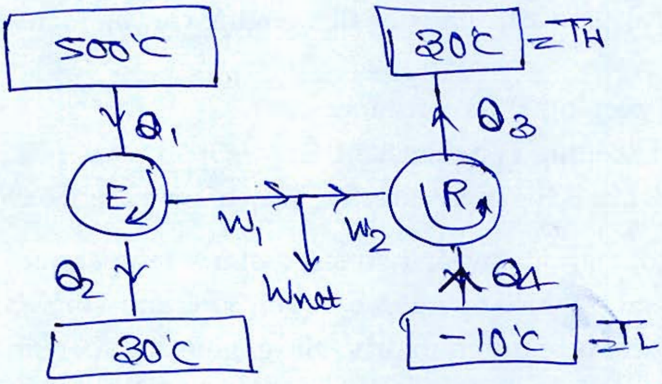
$$= \frac{(T_1-T_2)T + T^2}{T_1(T_1+T)}$$

as $T_1 > T_2$ $\quad T \rightarrow +ve$

$$\eta_2 > \eta_1$$

so Decreasing T_2 · more beneficial

(II)



$Q_1 = 2200$ kJ

6

$W_{net} = (W_1 - W_2) = 400$ kJ

Net Heat transferred to 30°C $= Q = Q_2 + Q_3$

$$\eta_E = \left(1 - \frac{(30+273)}{(500+273)}\right) = \frac{W_1}{Q_1}$$

$W_1 = 1337.64$ kJ

$Q_2 = (Q_1 - W_1) = 862.354$ kJ

$W_2 = -W_{net} + W_1 = 937.645$ kJ

$$(COP)_R = \left(\frac{Q_4}{W_2}\right) = \frac{T_L}{T_H - T_L}$$

$Q_4 = 6165.01$ kJ

$Q_3 = Q_4 + W_2 = 7102.66$

$Q = Q_2 + Q_3$

$Q = 7965.02$ kJ — (1)

Q.2 (a) (i) Define PMM1 and PMM2 and explain why these machines are not possible to exist.

(ii) There is a finite mass system whose heat capacity at constant volume is given as $C_V = BT^3$, where T is the temperature in Kelvin and B is a constant having a value of 6×10^{-5} J/K^4. The system is initially at 300 K and a thermal reservoir at 100 K is also available. What is maximum amount of work (in kJ) that can be obtained as the system is cooled to the reservoir temperature?

[6 + 14 marks]

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Q.2 (b) **(i)** Show that the enthalpy of a fluid before throttling is equal to that after throttling.

(ii) A pump steadily draws water from a pond at volumetric flow rate of 1 m^3/min through a pipe having a 10 cm diameter inlet. The water is delivered through a hose terminated by a converging nozzle. The nozzle exit has a diameter of 3 cm and is located at 12 m above the pipe inlet. The water enters at 25°C, 1 atm and exits with no significant change in temperature and pressure. The magnitude of the rate of heat transfer from the pump to the surroundings is 8% of the power input. Determine the power required by the pump in kW. [Take $g = 9.81\ m/s^2$]

[4 + 16 marks]

Q.2 (c) (i) For the Berthelot equation of state:

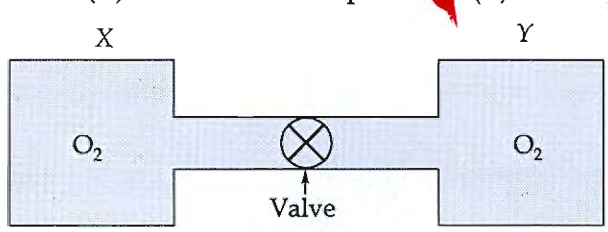
$$P = \frac{RT}{v-b} - \frac{a}{Tv^2}$$

Show that $\lim_{\substack{P \to 0 \\ T \to \infty}} (RT - Pv) = 0$

(ii) Oxygen gas is present in two vessels X and Y which are connected by a valve which is opened to allow the contents to mix and achieve an equilibrium temperature of 30°C as shown in figure below. The properties of oxygen in vessels X and Y before mixing are :

Vessel X : Pressure (P) = 2 MPa; Temperature (T) = 60°C; Contents = 0.6 kg mol.

Vessel Y : Pressure (P) = 0.8 MPa; Temperature (T) = 15°C; Contents = 3 kg



Calculate the final equilibrium pressure in MPa and the amount of heat transferred to the surroundings in kJ. [Take $\gamma = 1.4$]

[4 + 16 marks]

Q.3 (a) (i) An ideal gas is compressed reversibly and adiabatically from state a to state b. It is then heated reversibly at constant volume to state c. After expanding reversibly and adiabatically to state d such that $T_b = T_d$, the gas is again reversibly heated at constant pressure to state e such that $T_c = T_e$. Heat is then rejected reversibly from the gas at constant volume till it returns to state a (i.e., initial state). Draw all the processes on T-s diagram and if $T_b = 600$ K, $T_c = 800$ K and $\gamma = 1.4$ then what is the temperature in Kelvin at the initial state (T_a)?

(ii) Show that if two bodies of thermal capacities c_1 and c_2 at temperatures T_1 and T_2 are brought to the same temperature T by means of a reversible heat engine, then

$$\ln T = \frac{c_1 \ln T_1 + c_2 \ln T_2}{c_1 + c_2}$$

[10 + 10 marks]

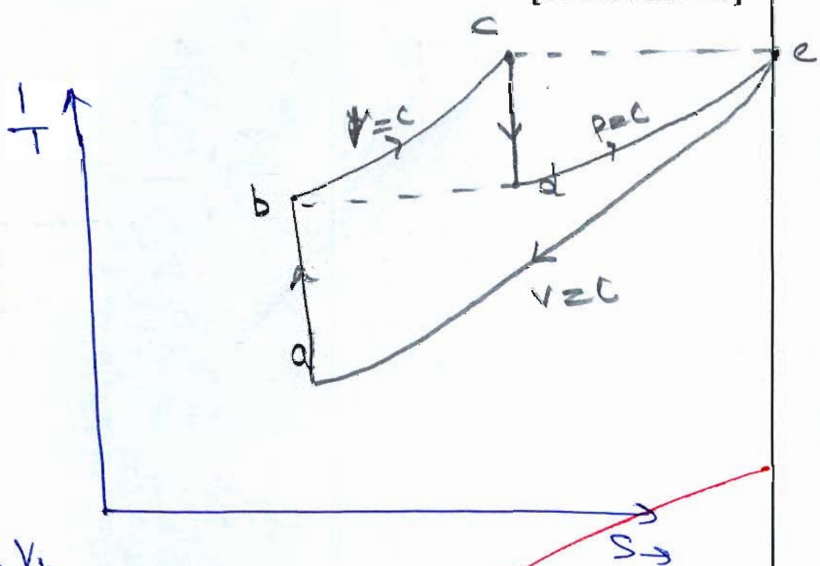
3.A (I)

$T_b = 600K = T_d$

$T_c = 800K = T_e$

$\gamma = 1.4$

$T_a = ?$



$$\frac{P_a V_a}{T_a} = \frac{P_b V_b}{T_b}$$

$$T_a = \left(\frac{P_a}{P_b}\right)\left(\frac{V_b}{V_a}\right) \cdot T_b$$

10

$$\frac{P_b V_b}{T_b} = \frac{P_c V_c}{T_c}$$

$$\left(\frac{P_b}{P_c}\right) = \left(\frac{T_b}{T_c}\right) = \left(\frac{3}{4}\right) \Rightarrow P_c = \frac{4}{3} P_b$$

$$\frac{P_a V_a}{T_a} = \frac{P_e V_e}{T_e}$$

$$T_a = \left(\frac{P_a}{P_e}\right) \cdot T_e$$

$$P_d = P_c \left(\frac{T_d}{T_c}\right)^{\left(\frac{\gamma}{\gamma-1}\right)} = 0.365\, P_c$$

$$P_d = P_e = (0.365)\, P_c$$

$$P_d = P_e = (0.365) \times \left(\frac{4}{3}\right) P_b = 0.487\, P_b$$

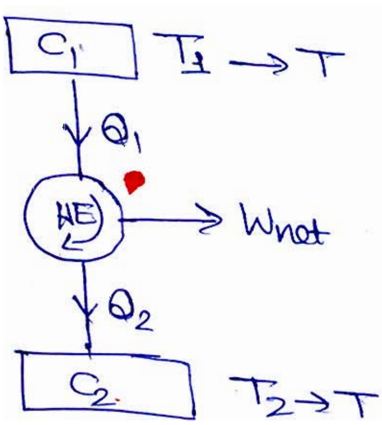
$$P_a = \left(\frac{T_a}{T_e}\right) \times P_e$$

$$T_b = T_a \left(\frac{P_b}{P_a}\right)^{\frac{\gamma-1}{\gamma}} = T_a \left(\frac{P_b}{\left(\frac{T_a}{T_e}\right) \cdot P_e}\right)^{\left(\frac{\gamma-1}{\gamma}\right)}$$

$$T_b = T_a \left(\frac{2.053\, T_e}{T_a}\right)^{\left(\frac{\gamma-1}{\gamma}\right)}$$

$$\boxed{T_a = 401.08\,K}$$ — Ans

(II)



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For reversible cycle.

$$\oint \frac{dQ}{T} = 0$$

Now

$$\Delta S = (\Delta S)_{sys} + (\Delta S)_{surr}^{\to 0} + (\Delta S)_{cycle}^{\to 0}$$

$$\Delta S_{sys} = (\Delta S)_{C_1} + (\Delta S)_{C_2}.$$

For W_{max} (Reversible engine)

$$T\,ds = dQ$$

$$ds = \left(\frac{dQ}{T}\right)$$

$$(\Delta S)_{C_1} = C_1\int_{T_1}^{T}\frac{dT}{T} = C_1\left(\ln T\right]_{T_1}^{T} = C_1\ln\left(\frac{T}{T_1}\right)$$

$$(\Delta S)_{C_2} = C_2\int_{T_2}^{T}\frac{dT}{T} = C_2\left(\ln T\right]_{T_2}^{T} = C_2\ln\left(\frac{T}{T_2}\right)$$

$$\Delta S_{C_1} + \Delta S_{C_2} = 0$$

$$C_1\ln\left(\frac{T}{T_1}\right) + C_2\ln\left(\frac{T}{T_2}\right) = 0$$

$$(C_2 + C_1)\ln T = C_1\ln T_1 + C_2\ln T_2$$

$$\boxed{\ln T = \left(\frac{C_1\ln T_1 + C_2\ln T_2}{C_1 + C_2}\right)}$$

Q.3 (b) (i) A large vessel contains steam at a pressure of 20 bar and a temperature of 400°C. The vessel is connected through a valve to the turbine followed by a small initially evacuated tank with a volume of 0.5 m^3. Under emergency situation, when power is required, the valve is opened and the tank fills with steam until the pressure is 20 bar. After filling of the tank, the temperature of tank becomes 500°C. The filling process takes place adiabatically and kinetic and potential energy effects are neglected. Determine the amount of work developed by the turbine in kJ. [Use steam table provided for the required data]

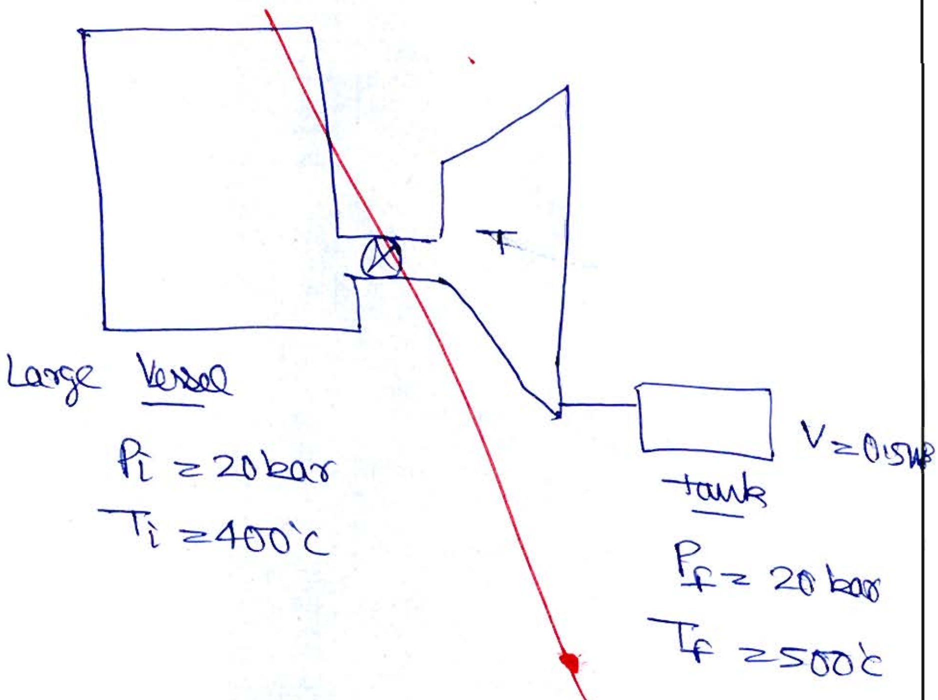
Water/Steam at p = 2.0 MPa (T_{sat} = 212.377°C)

T	v	u	h	s	T	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K	°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00099919	-0.01	1.99	-0.00003	270	0.11726	2718.6	2953.1	6.6409
5	0.00099910	21.01	23.01	0.07622	280	0.12005	2737.0	2977.1	6.6849
10	0.00099939	41.97	43.97	0.15091	290	0.12280	2755.2	3000.8	6.7273
15	0.00100001	62.89	64.89	0.22416	300	0.12551	2773.2	3024.2	6.7684
20	0.00100093	83.79	85.79	0.29607	310	0.12818	2790.9	3047.3	6.8083
25	0.00100210	104.68	106.68	0.36671	320	0.13082	2808.5	3070.1	6.8472
30	0.00100352	125.54	127.55	0.43615	330	0.13344	2825.9	3092.8	6.8851
35	0.00100516	146.42	148.43	0.50444	340	0.13603	2843.2	3115.3	6.9221
40	0.00100700	167.29	169.30	0.57163	350	0.13860	2860.5	3137.7	6.9583
45	0.00100904	188.15	190.17	0.63776	360	0.14115	2877.6	3159.9	6.9937
50	0.00101126	209.04	211.06	0.70289	370	0.14369	2894.7	3182.1	7.0285
55	0.00101366	229.91	231.94	0.76704	380	0.14621	2911.8	3204.2	7.0627
60	0.00101623	250.81	252.84	0.83024	390	0.14872	2928.9	3226.3	7.0962
65	0.00101897	271.71	273.75	0.89254	400	0.15121	2945.9	3248.3	7.1292
70	0.00102187	292.64	294.68	0.95396	410	0.15370	2962.9	3270.3	7.1616
75	0.00102492	313.56	315.61	1.0145	420	0.15617	2980.0	3292.3	7.1935
80	0.00102813	334.51	336.57	1.0743	430	0.15864	2997.0	3314.3	7.2250
85	0.00103149	355.48	357.54	1.1333	440	0.16109	3014.1	3336.3	7.2560
90	0.00103501	376.46	378.53	1.1915	450	0.16354	3031.1	3358.2	7.2866
95	0.00103867	397.47	399.55	1.2490	460	0.16598	3048.2	3380.2	7.3168
100	0.00104249	418.51	420.59	1.3057	470	0.16842	3065.4	3402.2	7.3466
105	0.00104647	439.57	441.66	1.3618	480	0.17085	3082.5	3424.2	7.3760
110	0.00105059	460.67	462.77	1.4173	490	0.17327	3099.7	3446.2	7.4050
115	0.00105487	481.79	483.90	1.4721	500	0.17568	3116.8	3468.2	7.4337
120	0.00105931	502.96	505.08	1.5263	520	0.18050	3151.4	3512.4	7.4901
125	0.00106392	524.16	526.29	1.5799	540	0.18530	3186.1	3556.7	7.5453
130	0.00106868	545.41	547.55	1.6330	560	0.19009	3221.0	3601.2	7.5994
135	0.00107362	566.71	568.86	1.6855	580	0.19486	3256.2	3645.9	7.6523
140	0.00107872	588.06	590.22	1.7375	600	0.19961	3291.5	3690.7	7.7043
145	0.00108401	609.47	611.64	1.7890	620	0.20436	3327.1	3735.8	7.7553
150	0.00108948	630.94	633.12	1.8401	640	0.20910	3362.8	3781.0	7.8054
155	0.00109513	652.48	654.67	1.8907	660	0.21383	3398.8	3826.5	7.8547
160	0.00110099	674.08	676.28	1.9409	680	0.21855	3435.1	3872.2	7.9032
165	0.00110705	695.76	697.97	1.9907	700	0.22326	3471.7	3918.2	7.9509
170	0.00111332	717.51	719.74	2.0401	720	0.22797	3508.4	3964.3	7.9978
175	0.00111982	739.36	741.60	2.0892	740	0.23267	3545.5	4010.8	8.0441
180	0.00112655	761.31	763.56	2.1379	760	0.23737	3582.7	4057.4	8.0897
185	0.00113353	783.34	785.61	2.1863	780	0.24206	3620.2	4104.3	8.1347
190	0.00114076	805.49	807.77	2.2344	800	0.24674	3658.0	4151.5	8.1790
195	0.00114827	827.75	830.05	2.2822	820	0.25142	3696.1	4198.9	8.2228
200	0.00115607	850.14	852.45	2.3298	840	0.25610	3734.4	4246.6	8.2660
210	0.00117262	895.31	897.66	2.4244	860	0.26078	3772.9	4294.5	8.3087
212.377	0.00117675	906.15	908.50	2.4468	880	0.26545	3811.8	4342.7	8.3509
212.377	0.0995850	2599.1	2798.3	6.3390	900	0.27012	3850.9	4391.1	8.3925
220	0.10218	2617.2	2821.6	6.3867	920	0.27478	3890.2	4439.8	8.4336
230	0.10541	2639.4	2850.2	6.4440	940	0.27944	3929.8	4488.7	8.4743
240	0.10850	2660.2	2877.2	6.4973	960	0.28411	3969.7	4537.9	8.5145
250	0.11150	2680.2	2903.2	6.5475	980	0.28876	4009.9	4587.4	8.5543
260	0.11441	2699.7	2928.5	6.5952	1000	0.29342	4050.2	4637.0	8.5936
270	0.11726	2718.6	2953.1	6.6409					

(ii) An insulated 10 m^3 rigid tank contains air at 500 kPa and 400 K. A valve connected to the tank is now opened and air is allowed to escape until the pressure inside drops to 150 kPa. The air temperature is maintained constant by an electric resistance heater placed in the tank. Determine the electrical energy supplied to air during this process in kWh. [Take R = 0.287 kJ/kg-K]

[12 + 8 marks]

(I)



Do not write in this margin

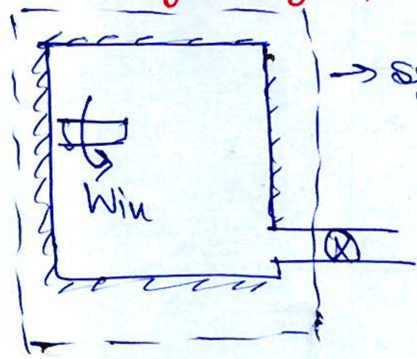
(3 i) Do not write anything in margin.

$V = 10\ m^3$

$P_1 = 500\ kPa$

$T_1 = 400\ K$

$P_2 = 150\ kPa$



Mass balance

$T_2 = 400\ K$

$\dot{m}_i^{\,0} - \dot{m}_o = \dot{m}_{cv}$

$-m_o = (m_2 - m_1)$

$m_2 = \left(\frac{P_2 V_2}{R T_2}\right) = 1310.66\ kg$

$m_1 = 43.55\ kg$

$m_o = 30.489\ kg$

(7)

Energy balance

$E_i - E_o = \Delta E_{cv}$

$(W_{in}) - m_o h_o = m_2 u_2 - m_1 u_1$

$W_{in} = (m_2 u_2 - m_1 u_1) + m_o h_o$

$W_{in} = 3501.17\ \frac{kJ}{s} \times s.$

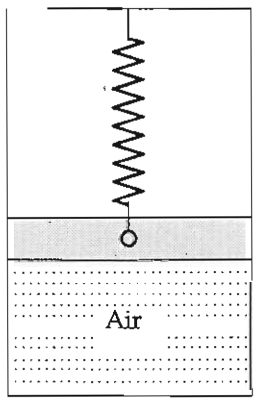
$\boxed{W_{in} = 0.9725\ kWh}$

write assumption also

Do not write in this margin

Q.3 (c) (i) Write the Carnot principles.

(ii) 0.06 m^3 of air is contained in the spring-loaded piston cylinder device as shown in figure below. The diameter of piston and the spring constant are 22 cm and 900 N/m. The state of air is 2300 kPa and 220°C when there is no force exerted by the spring on the piston. The device is now cooled until the volume is one-half its original or initial volume. Estimate the change in internal energy and enthalpy of air in kJ.



[4 + 16 marks]

Carnot Principles

① The efficiency of any two reversible devices working between same reservoir must be same.

(II) The efficiency of an irreversible device can not be more than reversible device working between same temperature limit reservoirs.

3

(II)

$V_1 = 0.06 m^3$

$D = 22 cm$

$k = 900 N/m$

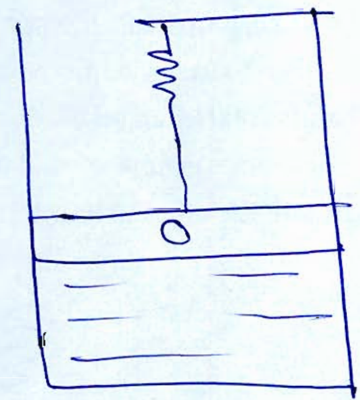
$P_1 = 2300 kPa$

$T_1 = 220 ^\circ C$

F_1 = Spring force @ 1

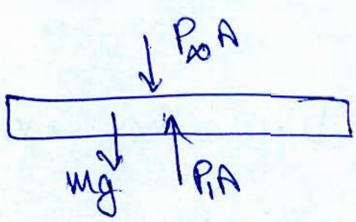
$F_1 = 0$

$V_2 = \left(\frac{V_1}{2}\right)$



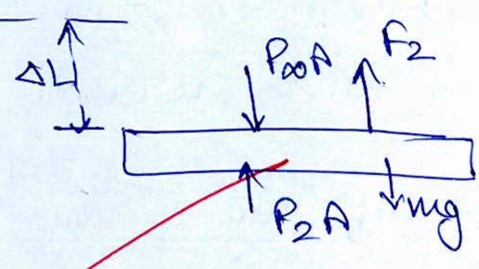
At Cond^n (1)

Avoid short forms



$P_1 A = P_\infty A + mg$ — (1)

At Cond^n (2)



$P_2 A + F_2 = P_\infty A + mg$

$P_2 A + F_2 = P_1 A$ — (2)

$(V_1 - V_2) = .03 = A \Delta L$

$A = \frac{\pi}{4} D^2$

$\Delta L = 0.789$

$F_2 = k \Delta L = 710.1278$

$P_2 A = (P_1 A - F_2)$

$P_2 = 2281.315 kPa$

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

$$T_2 = \left(\frac{P_2 V_2}{P_1 V_1}\right) T_1$$

$$T_2 = 244.497 \text{ K}$$

$$\Delta U = m C_v (T_2 - T_1)$$

15

$$m = \left(\frac{P_1 V_1}{R T_1}\right) = 0.9753 \text{ kg}$$

$$\boxed{\Delta U = -174.0228 \text{ kJ}}$$

↳ –ve sign indicates there is dec in internal energy.

$$\boxed{\Delta H = m C_p (\Delta T) = -243.576 \text{ kJ}}$$

–ve sign indicates there is ↓se in ΔH

Q.4 (a) A reversible polytropic process having exponent value 1.2 begins with a fluid at pressure 15 bar and temperature 300°C and ends at pressure 1.3 bar. Determine the final specific volume, final temperature in Kelvin and the heat transferred in kJ per kg of fluid by considering

1. The fluid is air
2. The fluid is steam

Also draw the process on the *P*-*v* and *T*-*s* diagrams.

[Use steam table provided for the required data]

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

p	T_{sat}	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
MPa	°C	v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
0.050	81.317	0.00102993	3.2400	340.49	2483.2	340.54	2645.2	2304.7	1.0912	7.5930	6.5018
0.055	83.709	0.00103154	2.9635	350.53	2486.2	350.59	2649.2	2298.6	1.1194	7.5606	6.4412
0.060	85.926	0.00103307	2.7317	359.85	2489.0	359.91	2652.9	2292.9	1.1454	7.5311	6.3857
0.065	87.993	0.00103452	2.5346	368.53	2491.6	368.60	2656.3	2287.7	1.1696	7.5040	6.3345
0.070	89.932	0.00103590	2.3648	376.68	2493.9	376.75	2659.4	2282.7	1.1921	7.4790	6.2869
0.075	91.758	0.00103723	2.2170	384.36	2496.1	384.44	2662.4	2277.9	1.2132	7.4557	6.2425
0.080	93.486	0.00103850	2.0871	391.63	2498.2	391.71	2665.2	2273.5	1.2330	7.4339	6.2009
0.085	95.125	0.00103972	1.9720	398.53	2500.2	398.62	2667.8	2269.2	1.2518	7.4135	6.1617
0.090	96.687	0.00104091	1.8694	405.11	2502.1	405.20	2670.3	2265.1	1.2696	7.3943	6.1246
0.095	98.178	0.00104205	1.7772	411.38	2503.9	411.48	2672.7	2261.2	1.2866	7.3761	6.0895
0.10	99.606	0.00104315	1.6939	417.40	2505.5	417.50	2674.9	2257.4	1.3028	7.3588	6.0561
0.11	102.292	0.00104527	1.5495	428.73	2508.8	428.84	2679.2	2250.3	1.3330	7.3269	5.9938
0.12	104.784	0.00104727	1.4284	439.23	2511.7	439.36	2683.1	2243.7	1.3609	7.2977	5.9367
0.13	107.109	0.00104917	1.3253	449.05	2514.3	449.19	2686.6	2237.5	1.3868	7.2709	5.8840
0.14	109.292	0.00105099	1.2366	458.27	2516.9	458.42	2690.0	2231.6	1.4110	7.2461	5.8351
0.15	111.349	0.00105273	1.1593	466.97	2519.2	467.13	2693.1	2226.0	1.4337	7.2230	5.7893
0.16	113.297	0.00105440	1.0914	475.21	2521.4	475.38	2696.0	2220.7	1.4551	7.2014	5.7463
0.17	115.148	0.00105600	1.0312	483.04	2523.5	483.22	2698.8	2215.6	1.4753	7.1812	5.7059
0.18	116.911	0.00105756	0.97747	490.51	2525.5	490.70	2701.4	2210.7	1.4945	7.1621	5.6676
0.19	118.596	0.00105906	0.92924	497.65	2527.3	497.85	2703.9	2206.0	1.5127	7.1440	5.6313
0.20	120.210	0.00106052	0.88568	504.49	2529.1	504.70	2706.2	2201.5	1.5302	7.1269	5.5967
0.21	121.759	0.00106193	0.84614	511.07	2530.8	511.29	2708.5	2197.2	1.5469	7.1106	5.5638
0.22	123.250	0.00106330	0.81007	517.40	2532.4	517.63	2710.6	2193.0	1.5628	7.0951	5.5323
0.23	124.686	0.00106464	0.77704	523.50	2534.0	523.74	2712.7	2188.9	1.5782	7.0803	5.5021
0.24	126.072	0.00106594	0.74668	529.38	2535.4	529.64	2714.6	2185.0	1.5930	7.0661	5.4731
0.25	127.411	0.00106722	0.71866	535.07	2536.8	535.34	2716.5	2181.1	1.6072	7.0524	5.4452
0.26	128.708	0.00106846	0.69273	540.59	2538.2	540.87	2718.3	2177.4	1.6210	7.0394	5.4184
0.27	129.965	0.00106968	0.66865	545.95	2539.5	546.24	2720.0	2173.8	1.6343	7.0268	5.3925
0.28	131.185	0.00107086	0.64624	551.14	2540.8	551.44	2721.7	2170.3	1.6471	7.0146	5.3675
0.29	132.370	0.00107203	0.62533	556.19	2542.0	556.50	2723.3	2166.8	1.6596	7.0029	5.3433
0.30	133.522	0.00107317	0.60576	561.11	2543.2	561.43	2724.9	2163.5	1.6717	6.9916	5.3199
0.31	134.644	0.00107429	0.58741	565.89	2544.3	566.22	2726.4	2160.2	1.6835	6.9807	5.2972
0.32	135.737	0.00107539	0.57017	570.56	2545.3	570.90	2727.8	2157.0	1.6949	6.9701	5.2752
0.33	136.802	0.00107647	0.55395	575.10	2546.5	575.46	2729.3	2153.8	1.7060	6.9598	5.2538
0.34	137.842	0.00107753	0.53864	579.54	2547.5	579.91	2730.6	2150.7	1.7168	6.9498	5.2330
0.35	138.857	0.00107857	0.52418	583.88	2548.5	584.26	2732.0	2147.7	1.7274	6.9401	5.2128
0.36	139.849	0.00107960	0.51050	588.13	2549.4	588.52	2733.2	2144.7	1.7377	6.9307	5.1931
0.37	140.819	0.00108061	0.49753	592.28	2550.4	592.68	2734.5	2141.8	1.7477	6.9216	5.1739
0.38	141.769	0.00108161	0.48522	596.34	2551.3	596.75	2735.7	2139.0	1.7575	6.9126	5.1551
0.39	142.698	0.00108259	0.47352	600.32	2552.2	600.74	2736.9	2136.2	1.7671	6.9040	5.1369
0.40	143.608	0.00108355	0.46238	604.22	2553.1	604.65	2738.1	2133.4	1.7765	6.8955	5.1190

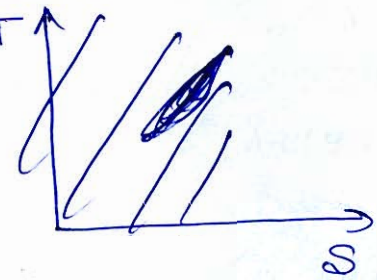
$n = 1.2$ (Reversible Polytropic process)

$P_1 = 15$ bar $\longrightarrow$ $P_2 = 1.3$ bar

$T_1 = 300°C = 573 K$

(i) v_2 (ii) T_2 (iii) Q

Case - 1 :- Air fluid

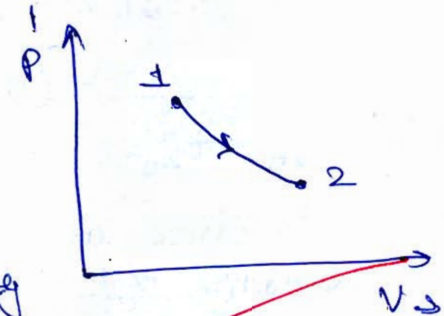


$P V^n = C$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = 381.18 K$$

$t_2 = 108.18°C$ — (1)



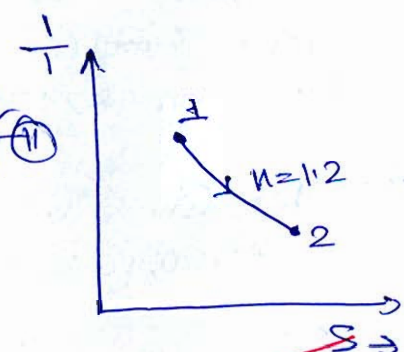
$P_1 V_1 = m R T_1$

$$v_1 = \left(\frac{RT_1}{P_1}\right) = 0.1096 \; m^3/kg$$

$P_1 v_1^n = P_2 v_2^n$

~~$P_1 \times \left(\frac{RT_1}{P_1}\right)$ $v_2 = 5.13 \; m^3/kg$ — (ii)~~

$v_2 = 0.8413 \; m^3/kg$ — (2)



$$Q_{poly} = W_{poly}\left(\frac{\gamma - n}{\gamma - 1}\right)$$

$$W_{poly} = \left(\frac{P_1 v_1 - P_2 v_2}{n-1}\right) = 275.155 \; \frac{kJ}{kg}$$

$Q_{poly} = 137.57 \; \frac{kJ}{kg}$ (Heat gain to system)

Steam

$P_1 = 15$ bar

$t_1 = 300°C$

$v_1 = 0.16971$ m³/kg

$u_1 = 2783.6$

$h_1 = 3038.2$

$s_1 = 6.9198$

From table

$P_2 = 1.3$ bar

$P_2 v_2^{1.2} = P_1 v_1^{1.2}$

$v_2 = 1.3026$ m³/kg

Now at 1.3 bar

$T_{sat} = 107.109$

$v_f = 0.00104917$

$v_g = 1.3253$

$u_f = 449.05$, $u_g = 2514.8$

$h_f = 449.19$

$h_{fg} = 2237.5$

$v_2 = (v_f + x_2 v_{fg})$ @ 1.3 bar

$x_2 = 0.98285$

$u_2 = (u_f + x_2 u_{fg})$ @ 1.3 bar

$u_2 = 2478.897$

$h_2 = (h_f + x_2 h_{fg})$ @ 1.3 bar

$h_2 = 2648.31$ kJ/kg

$s_2 = (s_f + x_2 s_{fg})$ @ 1.3 bar

$s_2 = 7.1699$ kJ/kgK

(1) $v_2 = 1.3026$ m³/kg — (1)

(2) $t_{sat} = t_2 = 107.109°C$

since at condition 2 the system is in steam mixture condⁿ ($x_2 = 0.98285$)

(3) 1st law of thermodynamics

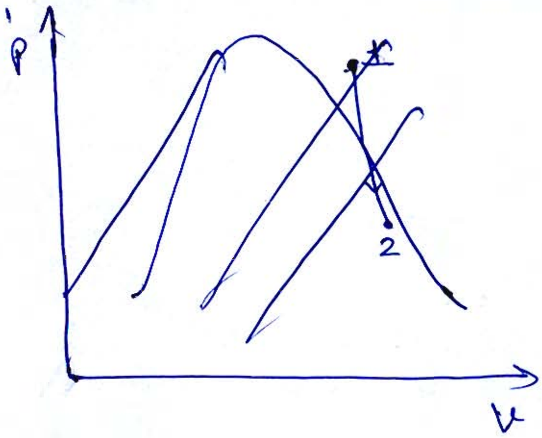
$\Delta Q = \Delta U + \Delta W$

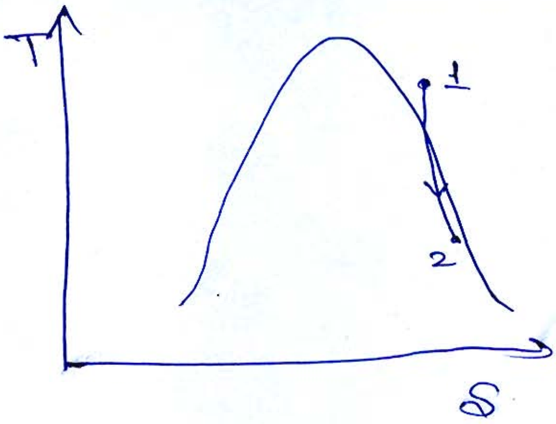
$\Delta Q = (h_2 - h_1)$

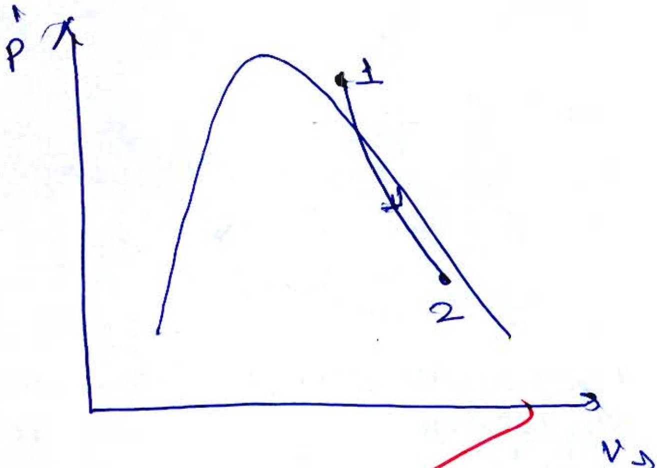
$\Delta Q = -389.89$ kJ/kg

$Q = 389.89$ kJ/kg

(−ve sign indicates heat loss from system)







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Q.4 (b) (i) Prove that the slope of the constant volume or isochoric curve is greater than constant pressure or isobaric curve for ideal gas on the *T*-*s* diagram.

(ii) A certain mass of air undergoes three reversible processes. First, the air with initial state of 600 kPa, 230°C and 0.04 m³ is expanded at constant pressure to 0.12 m³. Second, a polytropic process having a polytropic index 1.5 is carried out and third a constant temperature process is carried to complete a cycle. Sketch the cycle on the *P*-*v* and *T*-*s* and determine the efficiency of the cycle.

[6 + 14 marks]

For Ideal Gas

$$Tds = du + Pdv \quad \text{— (I)}$$

$$Tds = dh - vdP \quad \text{— (II)}$$

Process (1)

$$Tds = du + Pdv$$

$$Tds = C_v dT + Pdv$$

when $v = C \Rightarrow dv = 0$

$$Tds = C_v dT$$

$$\left(\frac{dT}{ds}\right)_v = \frac{T}{C_v} \quad \text{— (1)}$$

Part - ii

$T ds = dh - v dP$

$dh = C_p dT$

$T ds = C_p dT - v dP$

$P = C \Rightarrow dP = 0$

$T ds = C_p dT$

$\left.\frac{dT}{ds}\right|_P = \frac{T}{C_p}$ — (ii)

6

$\because C_p > C_v$

$$\boxed{\left.\frac{dT}{ds}\right|_v > \left.\frac{dT}{ds}\right|_P}$$

(II) 3 Reversible process. (Air)

$P_1 = 600 kPa$, $T_1 = 280°C$, $V_1 = 0.04 m^3$ $\xrightarrow[\text{exp}^n]{P=C}$ $P_2 = 600 kPa$, $T_2 = 1509 K$, $V_2 = 0.12 m^3$

$\downarrow n = 1.5$

$P_1 =$, $T_1 = 280°C$, $V_1 =$ $\xleftarrow{T=C}$ $P_3 = 22.22 kPa$, $V_3 =$, $T_3 = 280°C$

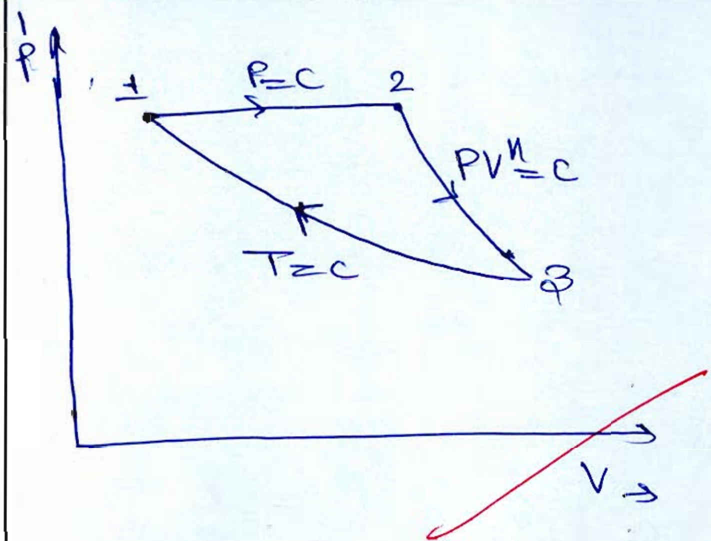
$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \Rightarrow T_2 = 1509 K$

$P_3 = P_2 \left(\frac{T_3}{T_2}\right)^{\left(\frac{n}{n-1}\right)}$

$P_3 = 22.22 kPa$

$V_3 = V_2 \left(\frac{P_2}{P_3}\right)^{\frac{1}{n}}$

$V_3 = 1.08 m^3$



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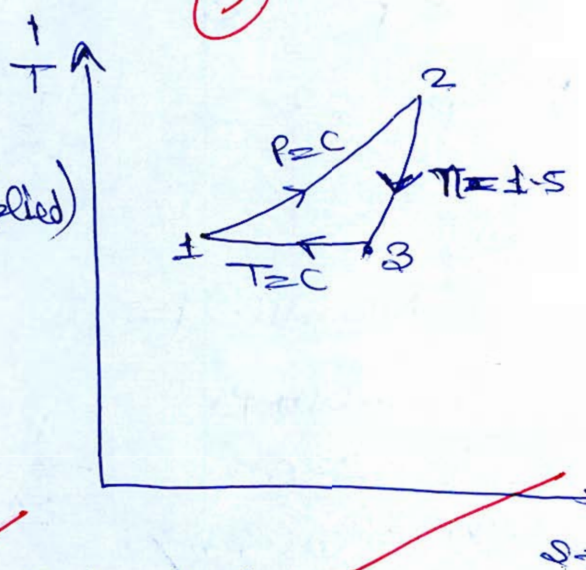


$Q_{1-2} = C_p(T_2 - T_1)$

$Q_{1-2} = 1011.03 \frac{kJ}{kg}$ (Heat supplied)

$Q_{2-3} = (W_{2-3})\left(\frac{\gamma - n}{\gamma - 1}\right)$

$W_{2-3} = \left(\frac{P_2V_2 - P_3V_3}{n-1}\right)$

$Q_{2-3} = -24 \frac{kJ}{kg}$ (Heat reject) −ve sign

$Q_{3-1} = \Delta U + \Delta W = \Delta W = RT_1 \ln\left(\frac{V_1}{V_2}\right)$ ($\Delta U \to 0$, ∵ T=C)

$Q_{3-1} = -475.79 \frac{kJ}{kg}$ (−ve sign Heat reject)

$\eta = \left(1 - \frac{Q_R}{Q_S}\right) \times 100$

$\eta = 50.56\%$

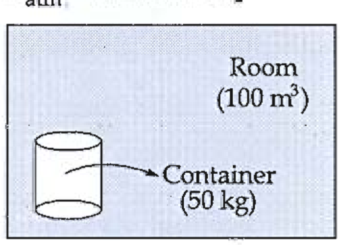
Q.4 (c) (i) A 40 kg iron block and a 15 kg copper block both at 100°C are dropped into a large lake at 10°C. Thermal equilibrium is established after a while as a result of heat transfer between the blocks and the lake water. Determine the total entropy change for the process.

[Take, specific heat of iron as 0.5 kJ/kg-K, specific heat of copper as 0.4 kJ/kg-K]

(ii) A container filled with 50 kg of liquid water at 90°C is placed in a 100 m^3 room that is well sealed and insulated and initially at 15°C and pressure is atmospheric. Thermal equilibrium is established after a while as a result of heat transfer between the water and the air in the room. Using constant specific heats, determine

1. The final equilibrium temperature in Kelvin.
2. The amount of heat transfer between the water and the air in the room in kJ.
3. The entropy generation in kJ/K.

[Take R_{air} = 0.287 kJ/kg-K, $(C_p)_{air}$ = 1.005 kJ/kg-K,
C_{water} = 4.18 kJ/kg-K, P_{atm} = 1.0132 bar]



[6 + 14 marks]

(I) Heat transferred from iron $Q_{iron} = m_i c_i \Delta T$

$$Q_{iron} = 40 \times 0.5 \times (100 - 10) = 1800\ kJ$$

Heat transferred from copper

$$Q_{cu} = m_c c_c (\Delta T) = 540\ kJ$$

total heat gained by lake (Q_L)

$$Q_L = Q_{iron} + Q_{cu} = 2340\ kJ$$

Now

$$\Delta S_{gen} = \Delta S_{sys} + \Delta S_{Lake}$$

take system as (iron + Cu)

$$\Delta S_{lake} = \left(\frac{Q_L}{T_{lake}}\right) = 8.268\ \frac{kJ}{K}$$

$$\Delta S_{sys} = \Delta S_{iron} + \Delta S_{cu}$$

$$= m_i c_i \ln\left(\frac{T_f}{T_i}\right) + m_c c_c \ln\left(\frac{T_f}{T_i}\right)$$

$T_f \rightarrow$ final equilibrium temp

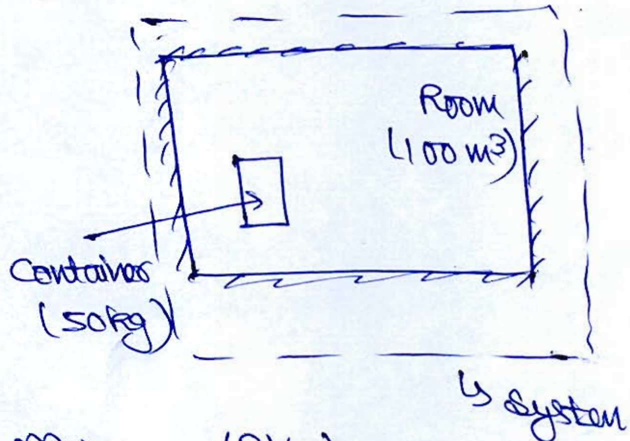
$T_i \rightarrow$ Initial temp

$$\Delta S_{sys} = -7.179\ kJ/K$$

6

$$\boxed{\Delta S_{gen} = 1.0885\ \frac{kJ}{K}}$$

(II) Container (C)
$m_a = 50\,kg$
$T_i = 90^\circ C$



Room (R)
$V = 100\,m^3$
$P = 1.0132\,bar$
$T_R = 15^\circ C$

$m_{air} = \left(\frac{PV}{RT_R}\right) = 122.58\,kg$

For system
1st law of TD
$\Delta Q^{\nearrow 0} = \Delta U + \Delta W^{\nearrow 0}$

$\Delta U = \Delta U_{container} + \Delta U_{ROOM} = 0$

$m C_w (T_f - T_i) + m_{air} C_v (T_f - T_R) = 0$

$T_f = 67.775^\circ C$ — (i)

Heat transferred from water to room (Q)
$Q = m_w C_{pw} (T_i - T_f)$

$Q = 4644.915\,kJ$ — (ii)

13

Entropy generation (ΔS_{gen})
$\Delta S_{gen} = (\Delta S)_{room} + (\Delta S_{container})$

$\Delta S_C = m_w C_w \ln\left(\frac{T_f}{T_i}\right)$

$\Delta S_{room} = m_{air} C_v \ln\left(\frac{T_f}{T_R}\right)$

$\Delta S_{gen} = 1.604\,\frac{kJ}{K}$ — (iii)

write assumption also

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Section : B

Q.5 (a) A lift is operated by four ropes each having 30 wires of 1.6 mm diameter. The cage weighs 1.5 kN and the weight of the rope is 4.6 N/m. Determine the maximum load carried by the lift if each wire is of 40 m length and the lift operates

(i) without any drop

(ii) with a drop of 100 mm during operation.

[Take E_{rope} = 70 GPa and allowable stress = 120 MPa]

[12 marks]

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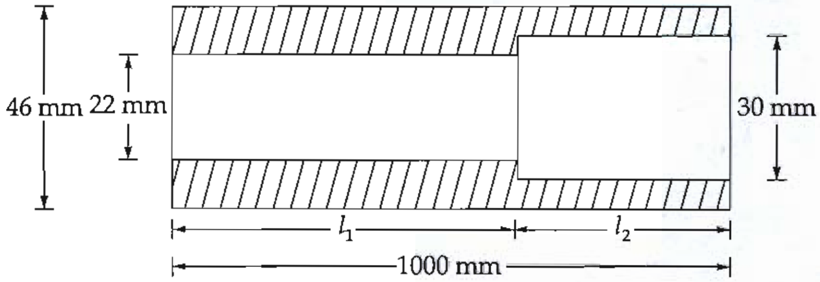
Q.5 (b) (i) A hollow shaft as shown in the figure is transmitting power at 250 rpm. If the shear stress in the shaft is not to exceed 80 MPa then determine the maximum power in kW transmitted by the shaft. Also find the lengths in mm of the two portions if the twist produced in the two portions of the shaft are equal.



(ii) The modulus of rigidity for a material is 0.7×10^5 N/mm². A 10 mm diameter rod of the same material is subjected to an axial pull of 15 kN and the change in diameter was observed to be 4×10^{-3} mm. Calculate Poisson's ratio and modulus of elasticity of the material in GPa.

[6 + 6 = 12 marks]

B.1

$N = 250$ rpm

$\tau_{max} = 80$ MPa

$\theta_1 = \theta_2$

$\theta = \frac{T_1 L_1}{G_1 J_1}$

$X_1 \neq X_2$

Power $= T \cdot \omega$

$\omega = \left(\frac{2\pi N}{60}\right) = 26.18$ rad/s

$\frac{T}{I_p} = \frac{\tau}{r}$

$T = \tau\left(\frac{I_p}{r}\right)$

$T = (T_1 + T_2)$

$T_1 = \tau_{max}\left(\frac{I_{p_1}}{r_1}\right)$

$I_{p_1} = \frac{\pi}{32}(D_o^4 - D_{1i}^4)$

$T_1 = 1448.957$ Nm

$T_2 = \tau_{max} \frac{I_{p_2}}{r_2}$

$I_{p_2} = \frac{\pi}{32}(D_o^4 - D_{2i}^4)$

$T_2 = 1252.32$ Nm

(2)

$T = T_1 + T_2 = 2701.81 \text{ Nm}$

$P_{max} = (T_{max})\,\omega$

$\boxed{P_{max} = 70.72 \text{ kW}}$

$\theta_1 = \theta_2$

$$\frac{T_1 L_1}{G_1 I_{P_1}} = \frac{T_2 L_2}{G_1 I_{P_2}}$$

$$\left(\frac{L_1}{L_2}\right) = \left(\frac{T_2}{T_1}\right) \times \left(\frac{I_{P_1}}{I_{P_2}}\right)$$

$L_1 = L_2$

$L_1 + L_2 = 1000$

$\boxed{L_1 = L_2 = 500 \text{ mm}}$

(II) $G = 700\ GPa$ $E = 2G(1+\mu)$

$D = 10\ mm$ $\varepsilon_D = 4\times10^{-4}$

$P = 15\ kN$

$\Delta D = 4\times10^{-3}\ mm$

$$\mu = \frac{\left(\frac{\Delta D}{D}\right)}{(\varepsilon_l)}$$

5

$$\varepsilon_l = \left(\frac{P}{AE}\right) = \left(\frac{190.985}{E}\right)$$

$$\varepsilon_D = -\left(\frac{190.985}{E}\right)\mu = 4\times10^{-4}$$

$$+\frac{190.985\mu}{2G(1+\mu)} = 4\times10^{-4}$$

$\mu = 0.414$

$E = 1980.805\ GPa$

Avoid silly mistake

Q.5 (c) A copper cylinder 1000 mm long, 500 mm internal diameter and 5 mm thick with flat ends, is initially full of oil at atmospheric pressure. Calculate the volume of oil which must be pumped into the cylinder in order to raise the pressure to 10 MPa above atmospheric pressure. For copper take $E_C = 1\times10^5$ MPa and Poisson's ratio = 0.3. Take Bulk modulus of oil as 2500 MPa. Neglect the deformation of the end plates.

[12 marks]

Initial cond^n

$L = 1000\ mm$

$d = 500\ mm$

$t = 5\ mm$

$p = 10\ MPa$

$$V = \left(\frac{\pi}{4}d^2\right)L$$

~~$V = 1.9635\times10^{-4}$~~

$V = 0.1968\ m^3$

$(\delta V) = (\delta V_1) + (\delta V_2)$

$\delta V_1 \rightarrow$ exp^n of cylinder

$\delta V_2 \rightarrow$ contraction of fluid

$$\delta V_2 = \left(\frac{pV}{K}\right)$$

$$\delta V_1 = \frac{pd}{4tE}(5-4\mu)V$$

δV = vol of extra water needed

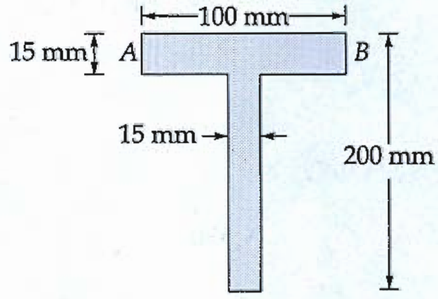
$\delta V_1 = 1.18653 \times 10^{-3}\ m^3$

$\delta V_2 = \left(\frac{pV}{K}\right) = 7.1852 \times 10^{-4}\ m^3$

$\boxed{\delta V = 2.6505 \times 10^{-3}\ m^3}$ → Ans.

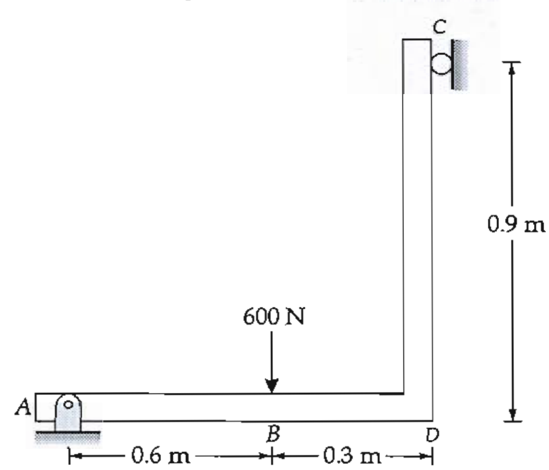
11

Q.5 (d) The cross-section of a joist is a *T*-section, as shown in figure, 100 mm × 200 mm × 15 mm, with 100 mm side horizontal. Calculate the maximum shear stress, if it has to resist a shear force of 250 kN. Also draw the shear stress distribution.

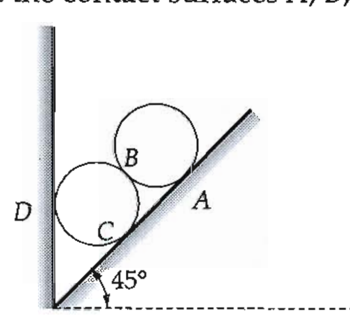


[12 marks]

Q.5 (e) (i) A corner plate *ABCD* is hinged at end *A*, and roller supported at *C*. A force of 600 N acts at point *B* as shown in figure. Find the reactions at supports in Newton.

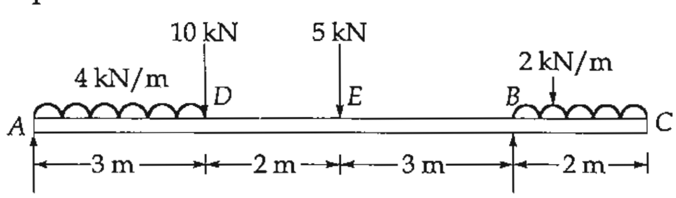


(ii) Two identical rollers each weighing 150 N are supported by an inclined plane and a vertical wall as shown in figure. Assuming all contact surfaces are smooth, find the reactions developed at the contact surfaces *A*, *B*, *C* and *D* in newtons.



[4 + 8 marks]

Q.6 (a) Draw the shear force and bending moment diagrams for the beam shown in figure indicating principal values.



[20 marks]

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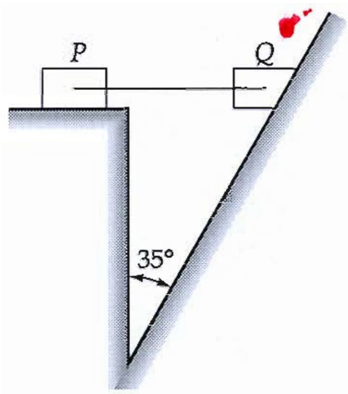
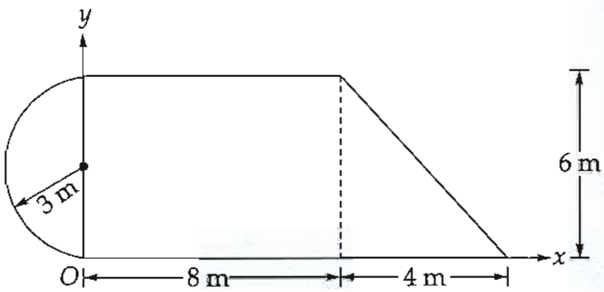
Q.6 (b) (i) Two blocks connected by a horizontal link PQ are supported on two rough planes as shown in figure. The coefficient of friction for the block on the horizontal plane is 0.3. The limiting angle of friction for block Q on the inclined plane is 22°. What is the smallest weight W of block P for which equilibrium of the system can exist, if weight of the block Q is 7 kN?



(ii) Determine the centroid of the area as shown in figure with respect to the axis shown.



[10 + 10 marks]

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Q.6 (c) (i) Write the assumptions made in the Lame's theory for the analysis of thick cylinders.

(ii) The external diameter of a steel collar is 300 mm. When shrunk on a solid shaft of 150 mm diameter, the internal diameter of the collar decreases by 0.2 mm. Calculate:

(a) the radial pressure between the collar and the shaft.

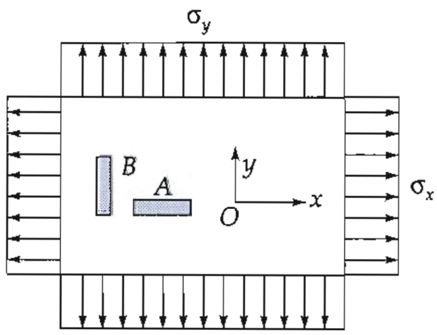
(b) Hoop stress at the inner surface of the tube.

(c) the reduction in the diameter of the shaft.

Take $E = 2 \times 10^5$ N/mm^2 and $\mu = 0.3$.

[5 + 15 marks]

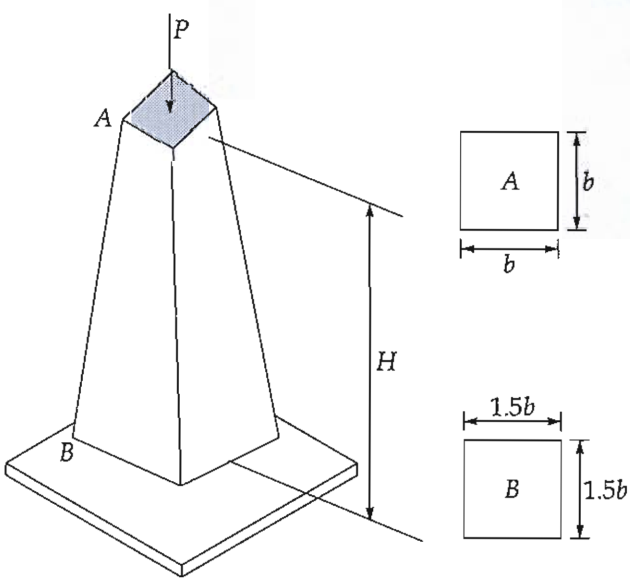
Q.7 (a) (i) Strain gauges A and B (Oriented in the x and y directions respectively) are attached to a rectangular aluminium plate with a thickness of $t = 5$ mm. The plate is subjected to uniform normal stresses σ_x and σ_y, as shown in figure. The gauge readings for normal strains are $\varepsilon_x = -0.00060$ (shortening, gauge A) and $\varepsilon_y = 0.00130$ (elongation, gauge B). The modulus of elasticity is $E = 75$ GPa and Poisson's ratio, $\mu = 0.33$. Find the stresses σ_x and σ_y and the change Δt in the thickness of the plate. Also, find the unit volume change (or dilatation) e and the strain-energy density u for the plate.



(ii) A post AB supporting equipment in a laboratory having modulus of elasticity E, is tapered uniformly throughout its height H (as shown in figure). The cross-sections of the post are square with dimensions $b \times b$ at the top and $1.5b \times 1.5b$ at the base. Show that the shortening δ of the post due to the compressive load P acting at the top is

$$\delta = \frac{2PH}{3Eb^2}$$

[Assume that the angle of taper is small and disregard the weight of the post itself]



[10 + 10 marks]

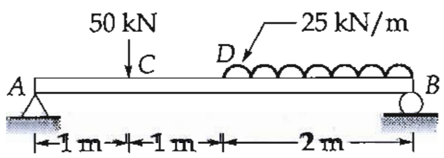
Q.7 (b) A beam AB of 4 m span and simply supported at the ends is loaded as shown in figure. Calculate

(i) deflection at midspan

(ii) maximum deflection, and

(iii) slope at the end *A*.

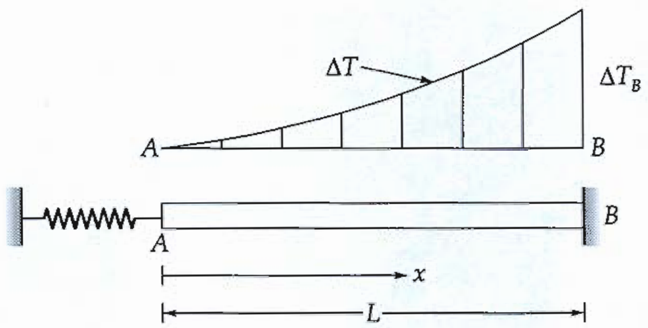
Take $I = 25 \times 10^{-6}$ m^4, $E = 210$ GPa



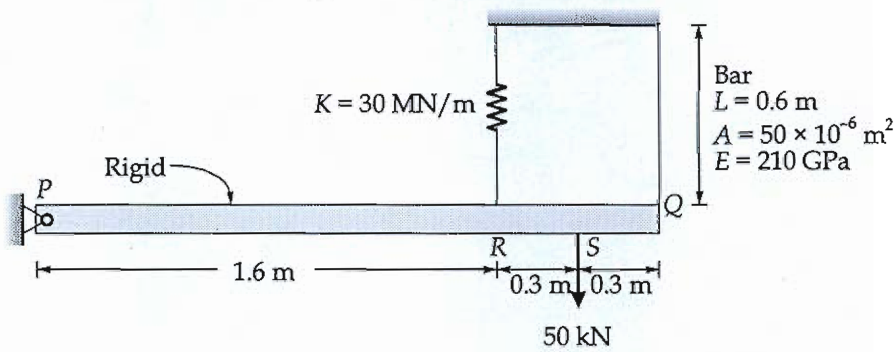
[20 marks]

Q.7 (c) (i) A bar AB of length L and area A held between rigid supports along with a linear spring having spring constant K is heated non-uniformly in such a manner that the temperature increases ΔT at a distance x from end A is given by the expression $\Delta T = \Delta T_B \frac{x^3}{L^3}$, where ΔT_B is the increase in temperature at end B of the bar as shown in figure. If the material has modulus of elasticity E and coefficient of thermal expansion α then show that the compressive stress (σ_c) in the bar would be

$$\sigma_c = \frac{E\alpha(\Delta T_B)}{4\left(\frac{EA}{KL}+1\right)}$$



(ii) A rigid bar PQ as shown in figure is pinned at P and supported by a steel rod at Q, together with a linear spring at R. The bar carries a vertical load of 50 kN applied at S. Determine the vertical displacement of point Q in mm.



[12 + 8 marks]

Q.8 (a) A solid circular shaft transmits 300 kW at 100 rpm is to be replaced by a hollow shaft of equal weight and of the same material, having the bore equal to half the external diameter. If the power transmitted is to remain unaltered, find the percentage change in the speed of the shaft. The maximum shear stress in the shaft is not to exceed 70 N/mm^2.

[20 marks]

Solid shaft (S) → Dia (D)

$P = 300\ kW$

$N = 100\ rpm$

$\omega = \frac{2\pi N}{60} = 10.472\ rad/s$

$P = T\omega$

$T = 28647.89\ Nm$

Hollow (H) → $D_o = 2D_i$

$W_H = W_S$

$\rho_H \times V_H g = \rho_S V_S g$

$V_H = V_S$

$(D_o^2 - D_i^2) = D^2$

$$D^2 = D_o^2 - \frac{D_o^2}{4}$$

$$D^2 = \frac{3D_o^2}{4} \Rightarrow D = 0.866\, D_o$$

$$P_S = P_H$$

$$T_S \times \omega_S = T_H\, \omega_H$$

19

$$\frac{T_S}{I_{P_S}} = \frac{\tau_{max}}{r}$$

$$T_S = \tau_{max} \frac{\pi}{16} D^3$$

write given data

$$\frac{T_H}{I_{P_H}} = \frac{\tau_{max}}{r_o}$$

$$T_H = \tau_{max} \frac{\pi}{16} D_o^3 \left(1 - \left(\frac{D_i}{D_o}\right)^4\right)$$

$$T_H = \tau_{max}\left(\frac{\pi}{16}\right) D_o^3 \left(\frac{15}{16}\right)$$

$$\left(\frac{\omega_H}{\omega_S}\right) = \left(\frac{T_S}{T_H}\right) = \frac{\tau_{max} \frac{\pi}{16} D^3}{\tau_{max}\left(\frac{\pi}{16}\right) D_o^3 \left(\frac{15}{16}\right)}$$

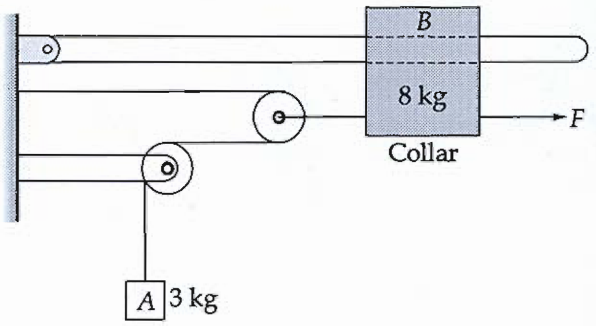
$$\frac{\omega_H}{\omega_S} = 0.6928$$

$$\text{Fractional change} = \left(\frac{\omega_H - \omega_S}{\omega_S}\right) \times 100$$

$$= -30.718\ \%$$

There is decrease in max operational speed in Hollow shaft.

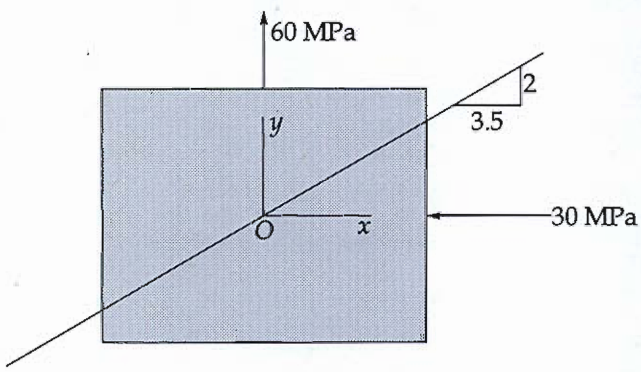
Q.8 (b) (i) System shown in the figure is initially at rest. Neglecting friction determine the force F required if velocity of collar B becomes 8 m/s in 3 seconds after the start.



(ii) An element in biaxial stress is subjected to stresses σ_x = –30 MPa and σ_y = 60 MPa as shown in figure. Using Mohr's circle, determine the following.

(a) The stresses acting on an element oriented at a slope of 2 on 3.5.

(b) The maximum shear stresses and associated normal stresses.



[10 + 10 marks]

(II) $\tan\theta = \left(\frac{2}{3.5}\right)$

$\theta = 29.744$

2

$\sigma_n = \frac{1}{2}(\sigma_x + \sigma_y) + \frac{1}{2}(\sigma_x - \sigma_y)\cos 2\theta + \tau_{xy}\sin 2\theta$

$\tau_n = \frac{1}{2}(\sigma_x - \sigma_y)\sin 2\theta - \tau_{xy}\sin 2\theta$

$\sigma_x = -30$

$\sigma_y = 60$

$\tau_{xy} = 0$

$\sigma_n = \frac{1}{2}(\sigma_x + \sigma_y) + \frac{1}{2}(\sigma_x - \sigma_y)\cos 2\theta$

$\boxed{\sigma_n = -7.847 \text{ MPa}}$

Q.8 (c) (i) The principal stresses in a material are 70 MPa, 50 MPa and –30 MPa. For unit volume, calculate:

(a) total strain energy

(b) volumetric strain energy

(c) shear strain energy

Also, if the material yields at 150 MPa, then calculate the factor of safety on the total strain energy criterion.

Take E = 200 GPa, ν = 0.3

(ii) A vertical flat staff standing 7.5 m above the ground is of square section throughout, the dimensions being 75 mm × 75 mm at the top, tapering uniformly to 150 mm × 150 mm at the ground. A horizontal pull of 5000 N is applied at the top along a diagonal of the section. Calculate the maximum stress due to bending and the position where it acts.

[10 + 10 marks]

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Space for Rough Work

Space for Rough Work