I4200 Grdge

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ESE 2024 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-2 : Heat Transfer + Refrigeration and Air-Conditioning [All Topics]
Thermodynamics-1 + Strength of Materials & Mechanics-1 [Part Syllabus]

Name :

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
Pune ☐	Kolkata ☐	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	28
Q.2	—
Q.3	20
Q.4	—
Section-B	
Q.5	24
Q.6	—
Q.7	57
Q.8	54
Total Marks Obtained	183

Signature of Evaluator: Naveen ✓.

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.

Comments:

- Accuracy is good.
- Representation is good
- Try to attempt all question in Compulsory part.
- Practice more such question and improve speed.

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Section : A

Q.1 (a) In a 25 tonnes absorption refrigeration system the heating in generator is carried out by using steam at 3 bar and 90% dry. The refrigeration temperature is –15°C. The condensation of the refrigerant is carried out at 40°C using cooling water. Determine:

(i) Maximum possible C.O.P. of the system and

(ii) Quantity of steam required per hour to run the plant if the steam leaves the generator as saturated water at same pressure. Assume relative C.O.P. = 0.35.

From steam tables we have

At 3 bar, T_{sat} = 133.5°C, h_{fg} = 2163.2 kJ/kg

[12 marks]

$T_E = -15°C = 258\ K$

$T_g = 133.5 + 273 = 406\ K$

$T_o = 40°C = 313\ K$.

$$(COP)_{VAR} = \left(\frac{T_E}{T_o - T_E}\right)\left(1 - \frac{T_o}{T_g}\right)$$

$$(COP)_{max} = \left(\frac{258}{313 - 258}\right)\left[1 - \frac{313}{406.5}\right]$$

$$\boxed{(COP)_{max} = 1.0789}$$ ✓

(8)

(ii) $(COP)_{actual} = .35 \times (COP)_{max} = .377615$.

$$(COP)_{actual} = \frac{25 \times 3.5}{Q_{input}}$$

$$\boxed{Q_{input} = 231.717\ kW}$$ ✓

at 3 bar, $x = .9$

$h =$

Incomplete solution

Q.1 (b) Air at 12°C flows past a flat plate 1.2 m wide and 1.6 m long. The plate is maintained at 88°C temperature and dissipates 3.95 kW of energy. Determine the convective heat transfer coefficient and the velocity at which air flows along the length of the plate. At the mean temperature of 50°C, the thermo-physical properties of air are:

ρ = 1.09 kg/m^3; k = 0.028 W/m°C; Pr = 0.73; c_p = 1007.5 J/kgK

and $\mu = 2.029 \times 10^{-5}$ kg/m-s

Use the following correlations if required:

$$Nu = \frac{hl}{k} = 0.664(\text{Re})^{0.5}(\text{Pr})^{0.33} \quad \text{for laminar flow}$$

$$= \frac{hl}{k} = \left[0.036(\text{Re})^{0.8} - 836\right](\text{Pr})^{0.33} \quad \text{for turbulent flow}$$

[12 marks]

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Q.1 (c) What are the functions of condenser in a refrigerating machine? Name different types of condensers. Describe with neat sketch the evaporative condenser.

[12 marks]

Function of Condenser :-

(i) Condenser is a device which is used to convert to vapour Refrigerant into Saturated Liquid.

(ii) It also helps to Subcool the Refrigerant to increase the Refrigerating Effect.

2

Types of Condenser

* Evaporative Condenser

* Surface Condenser.

Refer Solution

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Do not write in this margin

Q.1 (d) Saturated steam at 120°C flows inside a copper pipe of thermal conductivity 450 W/mK, having an internal diameter of 12 cm and external diameter of 14 cm. The surface resistance on the steam side is 11500 W/m²K and that on the outside surface of pipe is 20 W/m²K. Determine the heat loss from the pipe if it is located in space at 30°C. How this heat loss would be affected if the pipe is lagged with 3 cm thick insulation of thermal conductivity 0.20 W/mK?

[12 marks]

Let H be the length of pipe.

$A_i = 2\pi a H$

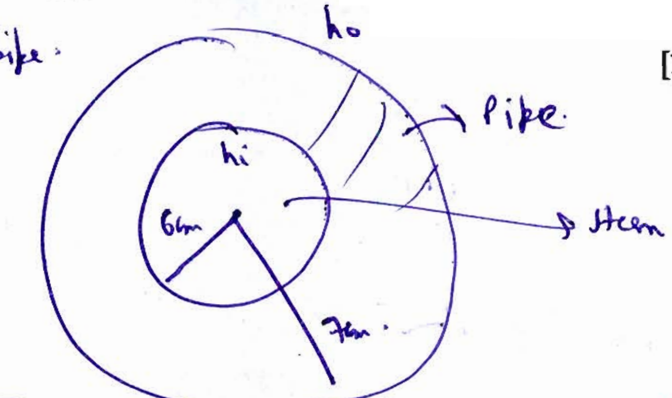
$= 2 \times \pi \times (.06) H$

$A_i = .377 H \ m^2$

$A_o = 2\pi b H$

~~= 2 × π × 0.07 × H~~

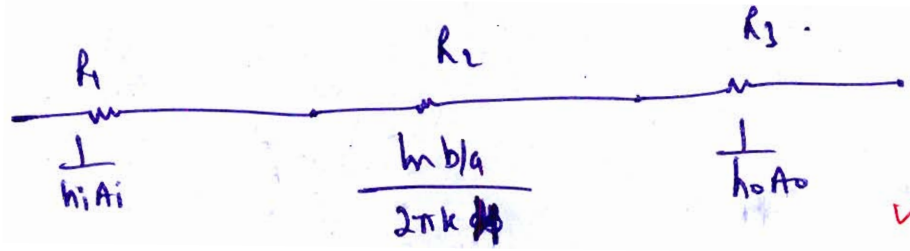
$A_o = .439 H \ m^2$



$h_i = 11500 \ W/m^2K$

$h_o = 20 \ W/m^2K$

~~Drawing Resistors~~ Total Resistance to the flow :-



$R_1 = \frac{1}{h_i A_i} = \frac{1}{11500 \times .377 H} = \frac{2.306 \times 10^{-4}}{H} \frac{K}{W}$

$R_2 = \frac{\ln b/a}{2\pi k H} = \frac{\ln \frac{7}{6}}{2 \times \pi \times 450 \times H} = \frac{.5452 \times 10^{-4}}{H} \frac{K}{W}$

$R_3 = \frac{1}{h_o A_o} = \frac{1}{20 (.439 H)} = .113 \ K/W$

Total Resistance $= .11328 \ K/W$

So, amount of heat transfer = $\frac{\Delta T}{R}$

$= \frac{120 - 30}{.1132}$

0.11328

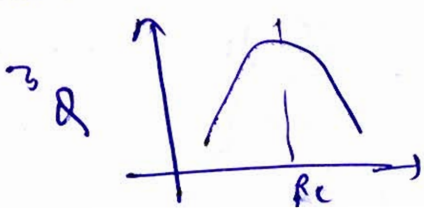
$Q = 795.05 \text{ W/m}$

6

for the insulation, Critical Radius = $\frac{k}{h_o}$

$R_c = \frac{.2 \times 1000}{20 \times 10} = 10\text{mm}$
$= 1\text{cm}$

as the insulation thickness is given to be ~~30mm~~, 3cm ~~which is greater than~~ Rc its critical Radius will be 10cm, and hence heat loss transfer will occur.



Incomplete Solution

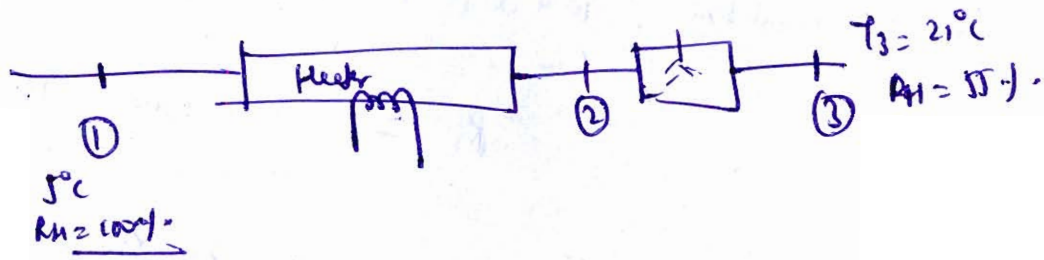
Q.1 (e) Saturated air at 5°C is required to be supplied to a room where the temperature must be held at 21°C with a relative humidity of 55%. The air is heated and then water is sprayed to give the required humidity. Determine the mass of spray water required per m^3 of air at room conditions. Assume that the total pressure is constant at 1.0132 bar. (Refer steam table for the properties of water vapour in moist air)

[12 marks]

At 5°C, P_{sat} = .0008726 MPa = .008726 bar.

as air is saturated at 5°C, so, RH = 100%.

so, $P_{v_1} = P_{vsat}$ = .008726 bar.



So, specific humidity at ①,

$w_1 = \frac{.622 P_{v_1}}{P - P_{v_1}} = .622 \times \frac{.008726}{1.0132 - .008726}$

w_1 = .0054 $\frac{\text{kg of w.v}}{\text{kg of da}}$

12 ✓

as for 1-2, there is ~~sensit~~ sensible heating,

so, $w_1 = w_2$.

~~as for 2-3, there is humidification~~,

at 3, T_3 = 21°C, RH = 55%.

at 21°C, P_{sat} = .0024882 MPa

$(P_v)_{sat}$ = .024882 bar.

so, RH = .55 = $\frac{P_{v_3}}{.024882}$; P_{v_3} = .01368 bar

So, $w_3 = \frac{.622 P_{v_3}}{P - P_{v_3}} = \frac{.622 (.01368)}{1.0132 - .01368}$

$w_3 = .0085 \frac{kg\ of\ w.v}{kg\ of\ da}$

So, Mass of water sprayed = $(w_3 - w_1)$ (mass of dry air)

$= (.0085 - .0054)\ m_a$

$= .0031\ m_a$ kg of wv.

for Room Condition, P = 1atm, T = 20°C (NTP).

~~1.01325 × V~~ $1.01325 \times 10^5 \times V = (m_a)(287)(293)$

$m_a = 1.205\ V$

So, Mass of water Sprayed $= (.0031) \times (1.205 V)$

$= .0037\ kg/m^3$

Q.2 (a) The following data refer to a steam jet refrigeration system:

Condition of the motive steam = 10 bar, dry saturated

Temperature of water in the flash chamber = 6°

Temperature at which the make up water is supplied = 22°

The pressure at which condenser is operated = 0.06 bar

Nozzle efficiency = 0.85

Entrainment efficiency = 0.65

Compression efficiency = 0.8

The quality of steam and flash vapour at beginning of compression = 0.9

Determine the following:

(i) Mass of motive steam required per kg of flash vapour.

(ii) Refrigerating effect per kg of flash vapour.

(iii) The coefficient of performance of the system.

[Refer steam table for properties of steam]

[20 marks]

Q.2 (b) A hemispherical cavity of radius 0.8 m is covered with a plate having a hole of 0.3 m diameter. The inner surface of the plate is maintained at 560 K by a heater embedded in the surface. Assuming the surfaces to be black and the hemisphere to be well insulated. Calculate:

(1) the temperature of the surface of the hemisphere

(2) the power input to the heater.

[20 marks]

Q.2 (c) Ambient conditions for an aircraft cruising at 1200 km/h are 0.35 bar and –15°C. The cabin temperature is 25°C and turbine exit pressure is 1.06 bar. The pressure ratio of compressor is 5.0. Assuming 100 percent efficiency of ram effect, compressor and turbine and ideal heat exchanger, determine for simple gas refrigeration cycle of 30 tonnes capacity.

(i) Temperatures and pressures at all points of cycle.

(ii) Mass flow rate and volume flow rate at compressor inlet and turbine outlet.

(ii) Work requirement

(iv) Coefficient of performance of cycle.

Assume : $c_p = 1.005$ kJ/kgK, $R_{air} = 0.286$ kJ/kgK, $\gamma = 1.4$

[20 marks]

Q.3 (a) (i) List the assumptions made while analysing the heat flow from a finned surface.

(ii) A turbine blade 6 cm long, 4.8 cm^2 cross-sectional area and 12 cm perimeter is made of stainless steel of thermal conductivity 110 kJ/m-hr-deg. The temperature at the root of the blade is 520°C and it is exposed to products of combustion passing through the turbine at 880°C. The film coefficient between the blade and the combustion gases is 1200 kJ/m^2-hr-deg. Determine the temperature at the middle of blade and the rate of heat flow from it. The blade may be treated as a fin losing heat at the tip.

[6 + 14 marks]

Q.3 (b) A Freon-12 VCRS installation has the following data:

Refrigeration capacity = 20 tons

Evaporator temperature = –10°C

Condenser temperature = 30°C

Temperature of refrigerant superheated as gas in evaporator = –5°C

Temperature of refrigerant subcooled as liquid in condenser = 25°C

Compressor particulars:

Number of cylinders = 2

Stroke = 1.5 times the bore

r.p.m. = 1200

Determine the following:

(i) refrigerating effect per kg

(ii) theoretical power

(ii) coefficient of performance

(iv) bore and stroke and compressor

Saturation temperature t_s °C	Absolute pressure p bar	Specific volume v_g m³/kg	Enthalpy of liquid h_f kJ/kg	Enthalpy of vapour h_g kJ/kg	Entropy of liquid s_f kJ/kg°K	Entropy of vapour s_g kJ/kg°K
–10	2.1928	0.07702	190.72	347.96	0.96561	1.5632
+30	7.4457	0.02372	229.11	364.96	1.0999	1.5481

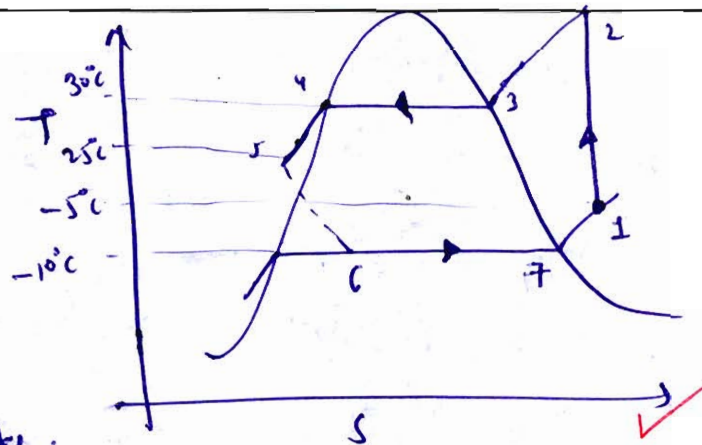
Take: Liquid specific heat, c_{pl} = 0.963 kJ/kgK

Vapour specific heat c_{pv} = 0.615 kJ/kgK

[20 marks]

$C_{pL} = .963$ kJ/kgK

$C_{pv} = .615$ kJ/kgK.



(i) Refrigerating Effect/kg (RE)

$h_4 = h_f|_{30°C} = 229.11$ kJ/kg.

Now, $h_4 - h_5 = (C_{pL})\,\Delta T$

$h_5 = h_4 - (C_{pL})\,\Delta T = 229.11 - (.963)(30-25)$

$h_5 = 224.295$ kJ/kg

for throttling process, 5-6 ⇒ $h_5 = h_6 = 224.295$ kJ/kg

for 7→1, $h_1 - h_7 = (C_{pv})\,\Delta T$.

here $h_7 = h_g|_{T=-10°C} = 347.96$ kJ/kg.

So, $h_1 = 347.96 + .615(-5+10)$

$h_1 = 351.035$ kJ/kg

So, Refrigerating effect $= h_1 - h_6$

$RE = 351.035 - 224.295$

$RE = 126.74$ kJ/kg

20

(ii) Power, let $\dot{m}$ be the mass flow rate of refrigerant.

as Refrigerating Capacity = 20 TR = 20 × 3.5 = 70 kW.

So, $(\dot{m})(RE) = 70$

$(\dot{m})(126.74) = 70$ ⇒ $\dot{m} = .552$ kg/s

Now, $S_1 - S_7 = C_{pv} \ln \frac{T_1}{T_7}$

here $S_7 = S_g|_{-10°C} = 1.5632$ kJ/kgK.

$S_1 = 1.5632 + .615 \ln \frac{268}{263}$ ⇒ $S_1 = 1.5747$ kJ/kgK for isentropic Compression, $S_2 = S_1 = 1.5747$ KJ/kgK.

for process 2→3, $S_2 = S_3 + C_{pv} \ln \frac{T_2}{T_3}$.

$S_3 = S_g|_{30°C} = 1.5481$.

$1.5747 = 1.5481 + .615 \ln \frac{T_2}{303}$

$T_2 = 316.39$ K

So, $h_2 - h_3 = (C_{pv})(T_2 - T_3)$

$h_3 = h_g|_{30°C} = 364.96$ KJ/kg.

So, $h_2 = 364.96 + (.615)[316.39 - 303]$

$h_2 = 373.194$ KJ/kg

So, ~~loss~~ theoretical Power $= \dot{m}(h_2 - h_1)$

$= .552[373.194 - 351.035]$

$P = 12.23$ kW

(iii) COP is $\text{COP} = \frac{\text{Refrigerating Capacity}}{\text{Power input}}$

$= \frac{70}{12.23}$

$\text{COP} = 5.723$

(iv) L, D,

Assuming $\eta_v = 100\%$

for ... , $\frac{v_7}{T_7} = \frac{v_1}{T_1}$ (assuming ideal gas behaviour)

$v_1 = \left(\frac{T_1}{T_7}\right) v_g$, here, $v_g = v_g|_{-10^\circ C} = .07702\ m^3/kg$

$v_1 = \left(\frac{268}{263}\right)(.07702) \Rightarrow v_1 = .07848\ m^3/kg$

So, $\eta_v = 1 = \frac{\dot{m} v_1}{\frac{\pi}{4} D^2 \times L \times \frac{2N}{60}}$, as $L = 1.5D$.

$1 = \frac{.552 \times .07848 \times 4 \times 60}{\pi \times D^3 \times 1.5 \times 2 \times 1200}$ $\Rightarrow$ $D = 97.23\ mm$

$L = 145.85\ mm$

Q.3 (c) An existing heat exchanger of 24 m^2 surface area is to be used to condense low pressure steam. The cooling medium will be feed water available at 42°C, its flow rate being 0.94 kg/s. The overall heat transfer coefficient is estimated at 130 W/m^2K.

Calculate the quantity of steam condensed and the exit temperature of the feed water. At the condensing pressure steam has saturation temperature of 100°C and latent heat of vapourisation is 2257 kJ/kgK. Assume that the steam is initially just saturated and that the condensate leaves the exchanger without sub-cooling. How would the performance of the exchanger be affected if the overall heat transfer coefficient can be doubled by a modification of feed water flow through the exchanger? Take C_p of water 4.187 kJ/kgK.

[20 marks]

Q.4 (a) 900 kg/hr of cream cheese at 16°C is pumped through 1.6 m length of 9 cm inner diameter tube which is maintained at 98°C. Determine the temperature of cheese leaving the heated section and the rates of heat transfer from the tube to the cheese. The relevant thermo-physical properties of cheese are : ρ = 1150 kg/m^3; μ = 22.5 kg/m-s; c_p = 2750 J/kgK; k = 0.42 W/mK.

Use the following correlation for laminar flow inside a tube

$$Nu = \frac{hd}{k} = 3.65 + \frac{0.067\frac{d}{l}\text{Re}\,\text{Pr}}{1 + 0.04\left(\frac{d}{l}\text{Re}\,\text{Pr}\right)^{0.67}}$$

[20 marks]

Q.4 (b) Air flowing at the rate of 120 m^3/min at 40°C DBT and 50% RH is mixed with another stream flowing at the rate of 60 m^3/min at 26°C DBT and 50% RH. The mixture flows over a cooling coil, whose ADP temperature is 10°C and by-pass factor is 0.2. Determine DBT and RH of air leaving the coil. If this air is supplied to an air-conditioned room where DBT of 26°C and RH of 50% are maintained estimate room sensible heat factor and cooling load capacity of the coil in tonnes of refrigeration.

[Refer Pschrometric chart attached]

[20 marks]

Q.4 (c) (i) During heat treatment, cylindrical pieces of 26 mm diameter, 32 mm height and at 30°C are placed in a furnace at 760°C with convection coefficient 84 W/m^2-K. Calculate the time required to heat the pieces to 620°C. What will be the shortfall in temperature if the pieces are taken out from the furnace after 270 seconds? Assume the following property values : $\rho = 7850\ kg/m^3$; $C_p = 480$ J/kgK; $K = 42$ W/m-K.

(ii) Draw a typical boiling curve for pool boiling of water at saturation temperature and atmospheric pressure. Mark each boiling regime and explain briefly its various regimes.

[10 + 10 marks]

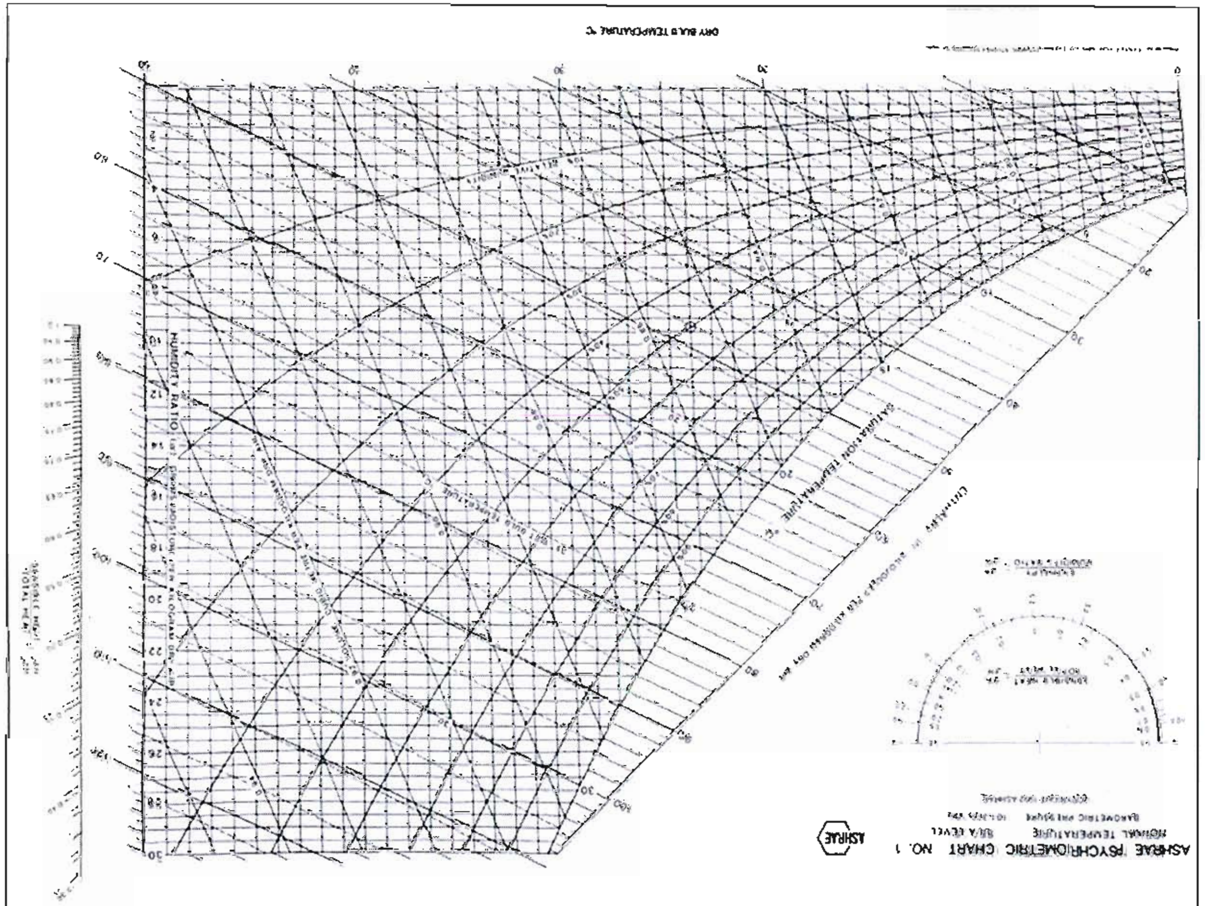
Saturated Water and Steam (Pressure-based)

$p_{tp} = 611.657$ Pa $= 0.000611657$ MPa

p MPa	T_{sat} ℃	Volume, m³/kg v_f	v_g	Energy, kJ/kg u_f	u_g	Enthalpy, kJ/kg h_f	h_g	h_{fg}	Entropy, kJ/(kg K) s_f	s_g	s_{fg}
p_{tp}	0.01	0.00100021	205.991	0	2374.9	0.00	2500.9	2500.9	0	9.1555	9.1555
0.0007	1.881	0.00100011	181.217	7.89	2377.4	7.89	2504.3	2496.5	0.02878	9.1058	9.0770
0.0008	3.761	0.00100008	159.640	15.81	2380.1	15.81	2507.8	2492.0	0.05748	9.0567	8.9992
0.0009	5.444	0.00100009	142.757	22.89	2382.4	22.89	2510.9	2488.0	0.08297	9.0135	8.9305
0.0010	6.970	0.00100014	129.178	29.30	2384.5	29.30	2513.7	2484.4	0.10591	8.9749	8.8690
0.0012	9.654	0.00100032	108.670	40.57	2388.2	40.57	2518.6	2478.0	0.14595	8.9082	8.7623
0.0014	11.969	0.00100054	93.899	50.28	2391.3	50.28	2522.8	2472.5	0.18015	8.8521	8.6719
0.0016	14.010	0.00100080	82.743	58.83	2394.1	58.83	2526.5	2467.7	0.21004	8.8035	8.5935
0.0018	15.837	0.00100108	74.011	66.49	2396.7	66.49	2529.9	2463.4	0.23662	8.7608	8.5241
0.0020	17.495	0.00100136	66.987	73.43	2398.9	73.43	2532.9	2459.4	0.26056	8.7226	8.4620
0.0024	20.114	0.00100193	56.375	85.65	2402.9	85.65	2538.2	2452.5	0.30239	8.6567	8.3541
0.0028	22.935	0.00100249	48.729	96.19	2406.4	96.19	2542.8	2446.6	0.33816	8.6012	8.2631
0.0032	25.158	0.00100305	42.952	105.49	2409.4	105.49	2546.8	2441.3	0.36945	8.5533	8.1838
0.0036	27.152	0.00100358	38.430	113.83	2412.1	113.83	2550.4	2436.6	0.39729	8.5110	8.1138
0.0040	28.960	0.00100410	34.791	121.39	2414.5	121.39	2553.7	2432.3	0.42239	8.4734	8.0510
0.0045	31.012	0.00100473	31.131	129.96	2417.3	129.96	2557.4	2427.4	0.45069	8.4313	7.9806
0.0050	32.874	0.00100533	28.185	137.74	2419.8	137.75	2560.7	2423.0	0.47620	8.3938	7.9176
0.0055	34.581	0.00100590	25.762	144.87	2422.1	144.88	2563.8	2418.9	0.49945	8.3599	7.8605
0.0060	36.159	0.00100645	23.733	151.47	2424.2	151.48	2566.6	2415.2	0.52082	8.3290	7.8082
0.0065	37.627	0.00100699	22.009	157.60	2426.2	157.61	2569.3	2411.6	0.54060	8.3007	7.7601
0.0070	39.000	0.00100750	20.524	163.34	2428.0	163.35	2571.7	2408.4	0.55903	8.2745	7.7154
0.0075	40.290	0.00100800	19.233	168.74	2429.8	168.75	2574.0	2405.3	0.57627	8.2501	7.6738
0.0080	41.509	0.00100848	18.099	173.83	2431.4	173.84	2576.2	2402.4	0.59249	8.2273	7.6348
0.0085	42.663	0.00100895	17.095	178.66	2433.0	178.67	2578.3	2399.6	0.60780	8.2060	7.5982
0.0090	43.761	0.00100940	16.199	183.24	2434.4	183.25	2580.2	2397.0	0.62230	8.1858	7.5635
0.0095	44.807	0.00100984	15.396	187.62	2435.8	187.63	2582.1	2394.5	0.63607	8.1668	7.5308
0.010	45.806	0.00101027	14.670	191.80	2437.2	191.81	2583.9	2392.1	0.64920	8.1488	7.4996
0.011	47.683	0.00101110	13.412	199.64	2439.7	199.65	2587.2	2387.5	0.67372	8.1154	7.4417
0.012	49.419	0.00101188	12.358	206.90	2442.0	206.91	2590.3	2383.4	0.69628	8.0849	7.3887
0.013	51.034	0.00101263	11.462	213.66	2444.1	213.67	2593.1	2379.4	0.71717	8.0570	7.3398
0.014	52.547	0.00101335	10.691	219.98	2446.1	219.99	2595.8	2375.8	0.73661	8.0311	7.2945
0.016	55.313	0.00101471	9.4306	231.55	2449.7	231.57	2600.6	2369.1	0.77201	7.9846	7.2126
0.018	57.798	0.00101597	8.4431	241.94	2453.0	241.96	2605.0	2363.0	0.80355	7.9437	7.1402
0.020	60.058	0.00101716	7.6480	251.40	2455.9	251.42	2608.9	2357.5	0.83202	7.9072	7.0752
0.024	64.053	0.00101934	6.4453	268.13	2461.2	268.15	2615.9	2347.7	0.88191	7.8442	6.9623
0.028	67.518	0.00102131	5.5778	282.63	2465.6	282.66	2621.8	2339.2	0.92472	7.7912	6.8664
0.032	70.586	0.00102312	4.9215	295.49	2469.6	295.52	2627.1	2331.6	0.96228	7.7453	6.7830
0.036	73.345	0.00102480	4.4072	307.05	2473.1	307.09	2631.8	2324.7	0.99579	7.7050	6.7092
0.040	75.857	0.00102638	3.9930	317.58	2476.4	317.62	2636.1	2318.4	1.0261	7.6690	6.6429
0.045	78.715	0.00102821	3.5759	329.57	2480.0	329.62	2640.9	2311.2	1.0603	7.6288	6.5686
0.050	81.317	0.00102993	3.2400	340.49	2483.2	340.54	2645.2	2304.7	1.0912	7.5930	6.5018

Saturated Water and Steam (Temperature-based)

T ℃	p_{sat} MPa	Volume, m³/kg v_f	v_g	Energy, kJ/kg u_f	u_g	Enthalpy, kJ/kg h_f	h_g	h_{fg}	Entropy, kJ/(kg K) s_f	s_g	s_{fg}
0.01	0.0006117	0.00100021	205.991	0	2374.9	0.00	2500.9	2500.9	0	9.1555	9.1555
1	0.0006571	0.00100015	192.439	4.18	2376.2	4.18	2502.7	2498.6	0.01526	9.1291	9.1138
2	0.0007060	0.00100011	179.758	8.39	2377.7	8.39	2504.6	2496.2	0.03061	9.1027	9.0720
3	0.0007581	0.00100008	168.008	12.60	2379.0	12.60	2506.4	2493.8	0.04589	9.0765	9.0306
4	0.0008135	0.00100007	157.116	16.81	2380.4	16.81	2508.2	2491.4	0.06110	9.0505	8.9894
5	0.0008726	0.00100008	147.011	21.02	2381.8	21.02	2510.1	2489.0	0.07625	9.0248	8.9486
6	0.0009354	0.00100011	137.633	25.22	2383.2	25.22	2511.9	2486.7	0.09134	8.9993	8.9080
7	0.0010021	0.00100014	128.923	29.43	2384.5	29.43	2513.7	2484.3	0.10637	8.9741	8.8677
8	0.0010730	0.00100020	120.829	33.63	2386.0	33.63	2515.6	2481.9	0.12133	8.9491	8.8278
9	0.0011483	0.00100026	113.301	37.82	2387.3	37.82	2517.4	2479.6	0.13624	8.9243	8.7881
10	0.0012282	0.00100035	106.303	42.02	2388.6	42.02	2519.2	2477.2	0.15109	8.8998	8.7487
11	0.0013130	0.00100044	99.787	46.22	2390.0	46.22	2521.0	2474.8	0.16587	8.8754	8.7096
12	0.0014028	0.00100055	93.719	50.41	2391.4	50.41	2522.9	2472.5	0.18061	8.8513	8.6707
13	0.0014981	0.00100067	88.064	54.60	2392.8	54.60	2524.7	2470.1	0.19528	8.8274	8.6321
14	0.0015990	0.00100080	82.793	58.79	2394.1	58.79	2526.5	2467.7	0.20990	8.8037	8.5938
15	0.0017058	0.00100094	77.875	62.98	2395.5	62.98	2528.3	2465.4	0.22446	8.7803	8.5558
16	0.0018188	0.00100110	73.286	67.17	2396.9	67.17	2530.2	2463.0	0.23897	8.7570	8.5180
17	0.0019384	0.00100127	69.001	71.36	2398.2	71.36	2532.0	2460.6	0.25343	8.7339	8.4805
18	0.0020647	0.00100145	64.998	75.54	2399.6	75.54	2533.8	2458.3	0.26783	8.7111	8.4433
19	0.0021983	0.00100164	61.256	79.73	2400.9	79.73	2535.6	2455.9	0.28218	8.6884	8.4063
20	0.0023393	0.00100184	57.757	83.91	2402.3	83.91	2537.4	2453.5	0.29648	8.6660	8.3695
21	0.0024882	0.00100205	54.483	88.10	2403.7	88.10	2539.3	2451.2	0.31073	8.6437	8.3330
22	0.0026453	0.00100228	51.418	92.28	2405.1	92.28	2541.1	2448.8	0.32493	8.6217	8.2967
23	0.0028111	0.00100251	48.548	96.46	2406.4	96.46	2542.9	2446.4	0.33908	8.5998	8.2607
24	0.0029858	0.00100275	45.858	100.65	2407.8	100.65	2544.7	2444.0	0.35318	8.5781	8.2250
25	0.0031699	0.00100301	43.337	104.83	2409.1	104.83	2546.5	2441.7	0.36722	8.5566	8.1894
26	0.0033639	0.00100327	40.973	109.01	2410.5	109.01	2548.3	2439.3	0.38123	8.5353	8.1541
27	0.0035681	0.00100354	38.754	113.19	2411.8	113.19	2550.1	2436.9	0.39518	8.5142	8.1191
28	0.0037831	0.00100382	36.672	117.37	2413.2	117.37	2551.9	2434.6	0.40908	8.4933	8.0842
29	0.0040092	0.00100411	34.716	121.55	2414.5	121.55	2553.7	2432.2	0.42294	8.4725	8.0496
30	0.0042470	0.00100441	32.878	125.73	2415.9	125.73	2555.5	2429.8	0.43675	8.4520	8.0152
31	0.0044969	0.00100472	31.151	129.91	2417.2	129.91	2557.3	2427.4	0.45052	8.4316	7.9810
32	0.0047596	0.00100504	29.526	134.09	2418.7	134.09	2559.2	2425.1	0.46424	8.4113	7.9471
33	0.0050354	0.00100537	27.998	138.26	2420.0	138.27	2561.0	2422.7	0.47792	8.3913	7.9134
34	0.0053251	0.00100570	26.560	142.44	2421.4	142.45	2562.8	2420.3	0.49155	8.3714	7.8799
35	0.0056290	0.00100605	25.205	146.62	2422.6	146.63	2564.5	2417.9	0.50513	8.3517	7.8466
36	0.0059479	0.00100640	23.929	150.80	2424.0	150.81	2566.3	2415.5	0.51867	8.3321	7.8135
37	0.0062823	0.00100676	22.727	154.98	2425.3	154.99	2568.1	2413.1	0.53217	8.3127	7.7806
38	0.0066328	0.00100713	21.593	159.16	2426.7	159.17	2569.9	2410.8	0.54562	8.2935	7.7479
39	0.0070002	0.00100750	20.524	163.34	2428.0	163.35	2571.7	2408.4	0.55903	8.2745	7.7154
40	0.0073849	0.00100789	19.515	167.52	2429.4	167.53	2573.5	2406.0	0.57240	8.2555	7.6831



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

p MPa	T_{sat} °C	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
		v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
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
0.61	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	0.00110651	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

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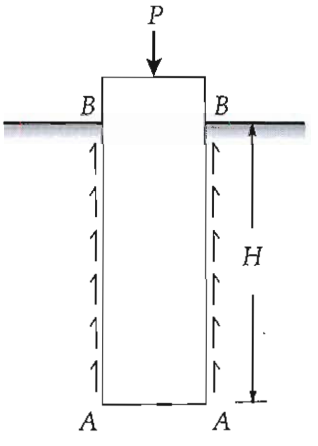
Section : B

Q.5 (a) A pile of uniform section is embedded in soil by a depth H. The pile supports a structural load P at its top which is transferred to the soil entirely by friction as shown in figure below. The variation of friction (f) along the depth of the pile is given by $f = ky^2$, where y is the elevation above the bottom of the pile. Determine the shortening of the pile.



[12 marks]

Q.5 (b) A lump of steel of mass 15 kg at 800°C is dropped in 10 kg of water at 30°C contained in an insulated container which is open to the atmosphere. If the specific heat of steel and water are 0.5 kJ/kgK and 4.27 kJ/kgK respectively and latent heat of vaporization of water at 100°C is 2257 kJ/kg, then calculate the change in entropy of steel, water and the universe.

[12 marks]

for steel

Mass of steel, $M_1 = 15 kg$

$T_1 = 800°C = 1073 K$.

final temp $= T_f$.

for water

$M_2 = 10 kg$

$T_2 = 303 K$

final temp $= T_f$.

for water to reach 100°C, the amount of heat required

$= M C \Delta T$

$= (10)(4.27)[70] = 2989 kJ$.

Amount of heat required by water to vaporize $= m L_{vp}$

$= (10)(2257)$

$= 22570 kJ$.

12

Amount of heat Rejected by Steel to Come to 100°C is

$(M_1) C_s (\Delta T)$ is $(15)(1.5)(800-100)$

$= 5250\ kJ$

as $5250\ kJ > 2989\ kJ$ and $5250 < 22530\ kJ$,
Some amount of water will vaporize only.

So, amount of water that vaporizes is

$(M)'(2253) = 5250 - 2989$

$\boxed{M' = 1\ kg}$

So, final temp, T_f for steel and water system $= 100°C$

$(\Delta S)_{steel} = M_1 C_s \ln \frac{T_f}{T_1} = (15)(1.5) \ln \frac{373}{1073}$

$(\Delta S)_{steel} = -7.925\ kJ/K.$

For water

$(\Delta S)_{water} = M_2 C_w \ln \frac{T_f}{T_1} + \frac{M' L}{T_f}$

↓ This Entropy is for the Mass that vaporizes.

$(\Delta S)_{water} = (10)(4.22) \ln \frac{373}{303} + \frac{(1)(2257)}{373}$

$= 8.875 + 6.051$

$\boxed{(\Delta S)_{water} = 14.926\ kJ/K.}$

As no heat is transferred to the atmosphere as tank is insulated,

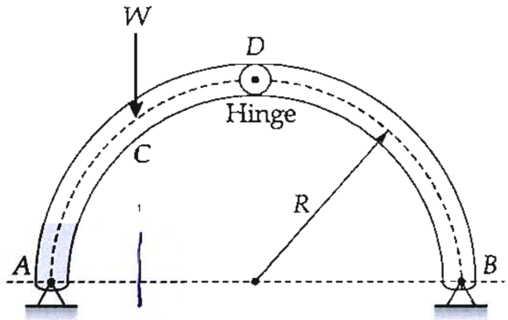
$(\Delta S)_{surrounding} = 0.$

$(\Delta S)_{universe} = (\Delta S)_{steel} + (\Delta S)_{water}$.

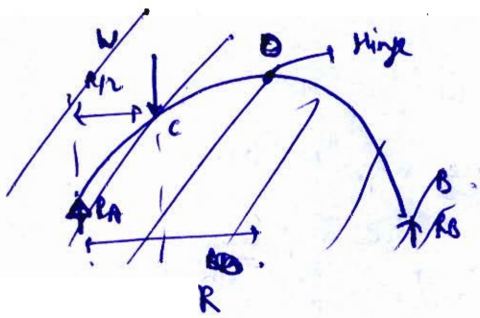
$= -7.925 + 14.926$

$(\Delta S)_{universe} = 7\ kJ/k$

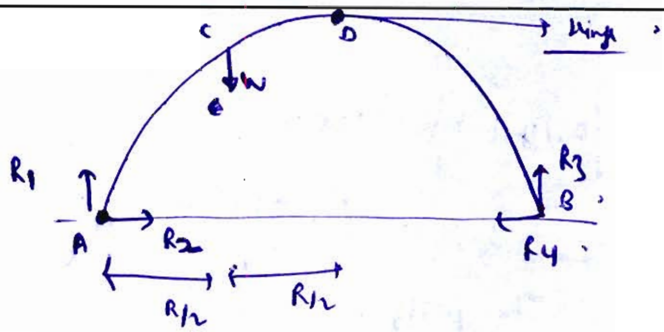
Q.5 (c) A 3-hinged arch loaded at *C*, at a distance $\frac{R}{2}$ from *A*. Find the resultant forces at *A* and *B* as shown in figure below.



[12 marks]



12



for section AD

$\Sigma M_D = 0 \Rightarrow R_1(R) - R_2(R) - W(R/2) = 0$

$$R_1 - R_2 = \frac{W}{2} \quad \text{— (I)}$$

for section BD :-

$\Sigma M_D = 0$

$R_3 \times R = R_4 \times R \Rightarrow$ $R_3 = R_4$

for horizontal Equilibrium, $\Sigma F_x = 0$

$R_2 = R_4$

So, $R_2 = R_4 = R_3$

So, Vertical Equilibrium,

$\Sigma F_y = 0$

$R_1 + R_3 = W$

as $R_3 = R_2$

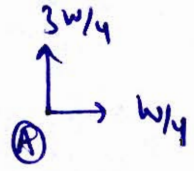
$\Rightarrow$ $R_1 + R_2 = W$ — (II)

from (I) and (II)

$2R_1 = \frac{3W}{2}$

$R_1 = \frac{3W}{4}$ and $R_2 = \frac{W}{4}$

So, At A



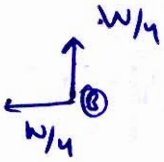
So, Resultant at A $= \frac{W}{4}\sqrt{9^2+1}$

$= \frac{\sqrt{10}}{4} W$

$= .7905 W$

at B

as $R_3 = R_2 = R_4 = \frac{W}{4}$



, Resultant at B $= \sqrt{\left(\frac{W}{4}\right)^2 + \left(\frac{W}{4}\right)^2}$

$= \frac{W}{4}\sqrt{2} = .3535 W$

Q.5 (d) State and prove Clausius inequality.

[12 marks]

Q.5 (e) A rectangular strain rosette strain gauge records the following values for linear strain at a point in two dimensional stress system : $e_x = 520 \times 10^{-6}$, $e_y = -140 \times 10^{-6}$, and $e_{45°} = 270 \times 10^{-6}$, the later being at 45° to the x and y axes. Calculate the principal strain and stresses. Take E = 205 GPa and μ = 0.32.

[12 marks]

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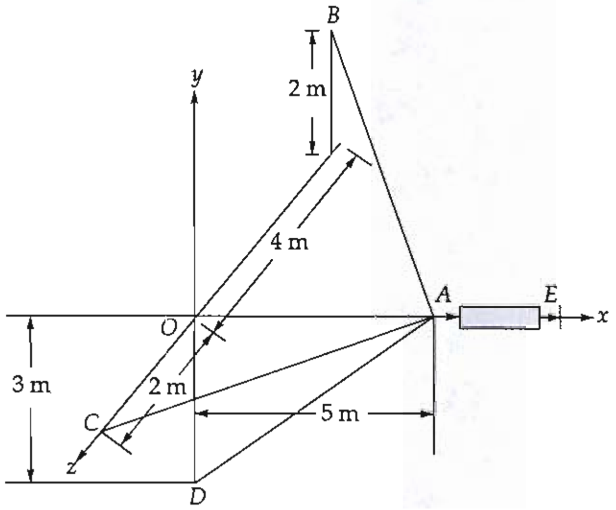
Q.6 (a) A compound cylinder, formed by shrinking one tube on to another, is subjected to an internal pressure of 60 MPa. Before the fluid is admitted, the internal and external diameters of the compound cylinder are 120 mm and 220 mm, and the diameter at the junction is 180 mm. If after shrinkage, the radial pressure at the common surface is 10 MPa, calculate the final stresses set-up by the section.

[20 marks]

Q.6 (b) A system of 3 cables AB, AC and AD shown in figure below is subjected to a force of 800 kN along the x-direction by turn buckle AE. Calculate the forces developed in the cables.



[20 marks]

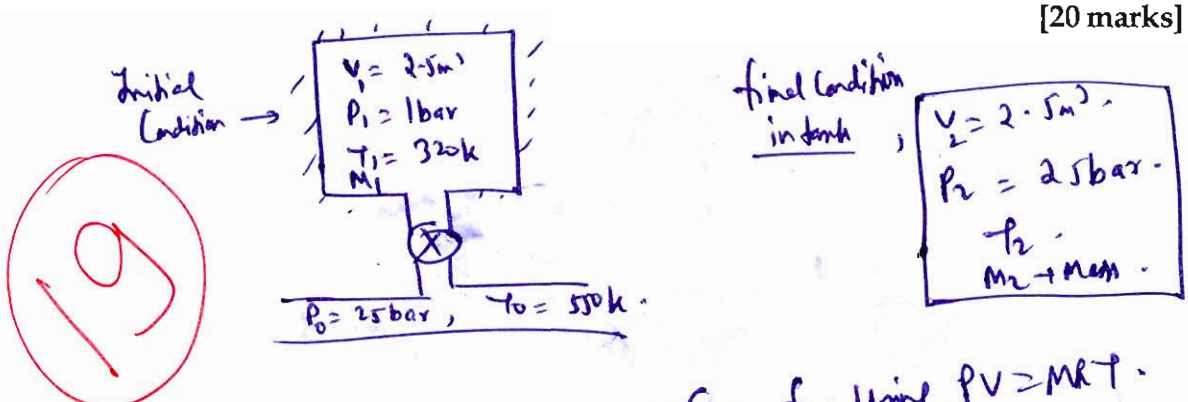
Q.6 (c) (i) Show that the first law of thermodynamics leads to the fact that heat interaction is a path function.

(ii) A perfect gas undergoes a cycle comprises of three processes. It is first compressed isothermally from 1 bar and 27°C to one-fifth of its initial volume. The energy is than added at constant pressure, increasing the temperature of gas and the cycle is completed by isentropic expansion to original conditions. Take c_p = 1.25 kJ/kgK and R = 0.5 kJ/kgK. Calculate the maximum cycle temperature and pressure. Also find the net work transfer.

[10 + 10 marks]

Q.7 (a) A rigid and insulated tank of volume 2.5 m^3 contains an ideal gas at 1 bar and 320 K. The tank is connected to a line carrying the same gas at 25 bar and 550 K. The valve in between the tank and the line is opened allowing the gas to enter the tank till the gas pressure in the tank rises to 25 bar and then closed. Determine the final temperature of the gas in the tank and the amount of gas that entered the tank. Neglect the effects of kinetic energy and potential energy.
[Assume R = 0.287 kJ/kgK; c_p = 1.005 kJ/kgK and γ = 1.4 for ideal gas]

[20 marks]



As tank contains an Ideal Gas, so, using $PV = MRT$.

So, $P_1 V_1 = M_1 R T_1$

$(100)(2.5) = M_1(.287)(320)$

$M_1 = 2.722$ kg

By Energy Conservation :-

$U_1 + m_0 h_0 = U_2$ — ①

where U_1 = internal Energy of air in tank initially.

h_0 = specific Enthalpy of air Entering the tank.

U_2 = final internal Energy of air in the tank.

by mass Conservation, $m_0 = M_2 - M_1$

So, from ①,

$M_1 C_v T_1 + (M_2 - M_1) C_p T_0 = M_2 C_v T_2$.

$2.722 \times .718 \times 320 + (-2.722 + M_2)(1.005)(550) = M_2 (.718)(T_2)$

$625.407 + (-2.722 + M_2)\, 552.75 = .718\, M_2 T_2$ — (II) also from $PV = MRT$

$P_2 V_2 = M_2 R T_2$.

$(2500)(2.5) = M_2 (.287)(T_2)$.

So, $M_2 T_2 = 21777$ — (iii)

Putting (iii) in (ii)

$625.407 + (-2.722 + M_2) 552.75 = (21777)(.718)$

ie upon solving, $M_2 = 29.878$ kg

Using M_2 in (iii),

$T_2 = \frac{21777}{29.878}$ ⇒ $T_2 = 728.86$ K.

So, final temp = 728.86 K

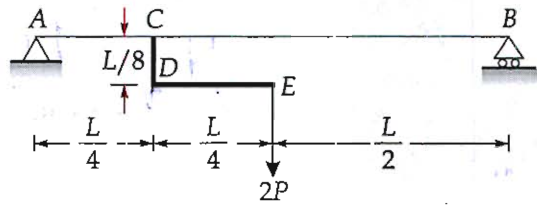
and Mass Entered in the tank = $M_2 - M_1$

$= 29.878 - 2.722$

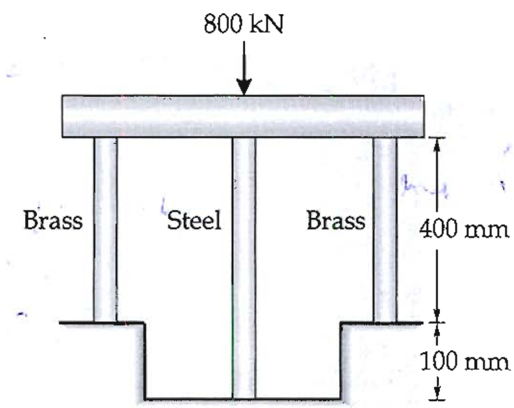
$M_0 = 27.156$ kg

 Do not write in this margin

Q.7 (b) (i) A simply supported beam ACB supports a vertical load 2P by means of a bracket CDE, as shown in figure below. Draw SFD and BMD for the beam.

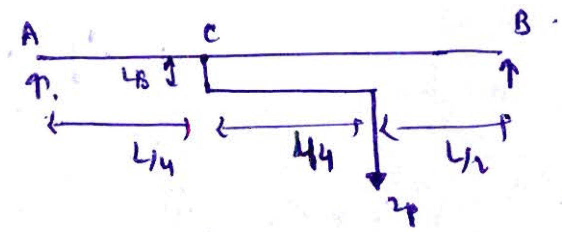


(ii) A steel rod and two brass rods, together support a load of 800 kN as shown in figure below. Young's modulus of steel and brass are 200 GPa and 100 GPa, respectively. Cross-sectional area of steel and brass rod are 2500 mm^2 and 1500 mm^2, respectively. Calculate the stresses in the rods.



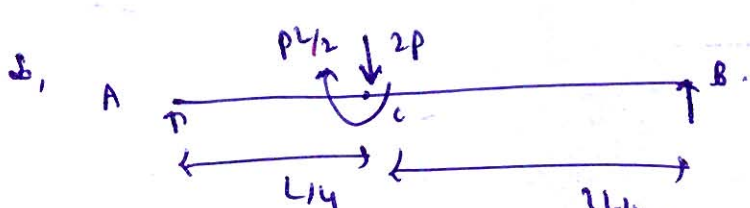
[10 + 10 marks]

(i)



Shifting the force '2P' at C ⇒ it will also produce a Moment $= (2P)\left(\frac{L}{4}\right) = \frac{PL}{2}$ (Clockwise).

So,

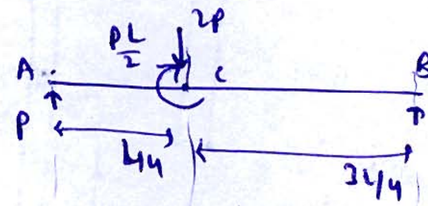


<u>Calculating the Reactions</u>

$\sum M_B = 0 \Rightarrow (R_A)(L) + \frac{PL}{2} - 2P\left(\frac{3L}{4}\right) = 0$

$(R_A)(L) = \frac{3PL}{2} - \frac{PL}{2} \Rightarrow \boxed{R_A = P}$

By $\sum f_y = 0$, $R_A + R_B = 2P \Rightarrow$ $\boxed{R_B = P}$.



Calculation for SFD :-

for Section AC [X from A]

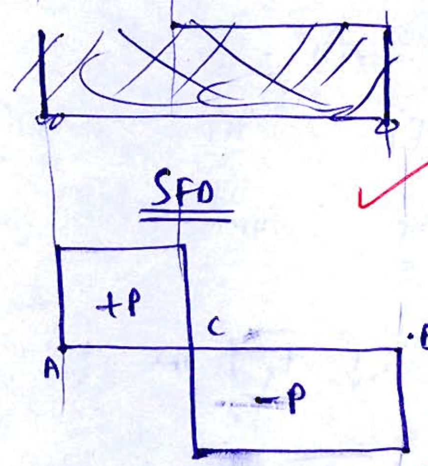
$SF_x = P$.

So, Shear force is Constant for section AC

for section BC [X from B]

$SF_x = P$ {Constant throughout BC}

at C, there is a 2P force downward, So, from left, there will be a rise in shear force from $-P + 2P = P$



SFD

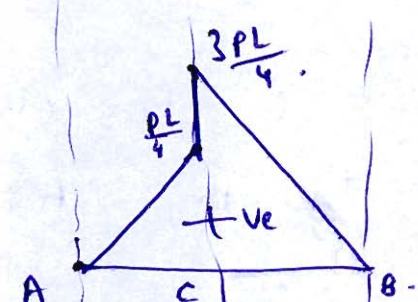
Calculation for the BMD :-

for Section AC [X from A]

$M_x = Px$ (linear)

$M_A|_{x=0} = 0$

$M_C|_{x=L/4} = PL/4$.



for Section BC [X from B]

$M_x = Px$

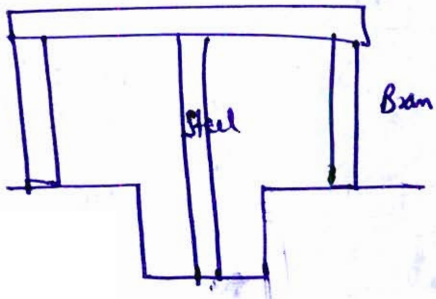
$M_B|_{x=0} = 0$

$M_C|_{x=\frac{3L}{4}} = \frac{P3L}{4} = \frac{3PL}{4}$.

at C, there is an external Moment of $\frac{PL}{2}$ acting CW

So, when Coming from end B, at C, Net Moment will be $\frac{3PL}{4} - \frac{PL}{2} = \frac{PL}{4}$

(ii)



for Steel

$E_s = 200$ GPa

$A_s = 2500 mm^2$

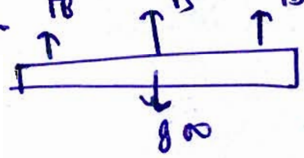
for Brass

$E_B = 100$ GPa

$A_B = 1500 mm^2$.

Let F_s be the force in steel and F_B the force in Brass.

Equilibrium Equation :-



so, $F_s + 2F_B = 800 \times 1000$

also, $F_s = \sigma_s A_s$ and $F_B = \sigma_s A_B$.

so, $\sigma_s A_s + 2\sigma_B A_B = 800 \times 1000$

$(\sigma_s)(2500) + 2(\sigma_B)(1500) = 800 \times 1000$

$\boxed{\sigma_s + 1.2\sigma_B = 320}$ — ①

Compatibility Equation :-

$\Delta L_s = \Delta L_B$.

$\frac{\sigma_s}{E_s} L_s = \frac{\sigma_B}{E_B} L_B$

here $L_s = 500$ mm, $L_B = 400$ mm.

$$\text{So, } \frac{\sigma_s \times 500}{200} = \frac{\sigma_B \times 400}{100}$$

$$\sigma_s = \frac{8}{5}\sigma_B \Rightarrow \boxed{\sigma_s = 1.6\,\sigma_B} \quad \text{—(ii)}$$

Putting (ii) in (i),

$$1.6\,\sigma_B + 1.2\,\sigma_B = 320$$

$$2.8\,\sigma_B = 320$$

$$\boxed{\sigma_B = 114.286 \text{ MPa}}$$

and $\sigma_s = 1.6 \times \sigma_B$

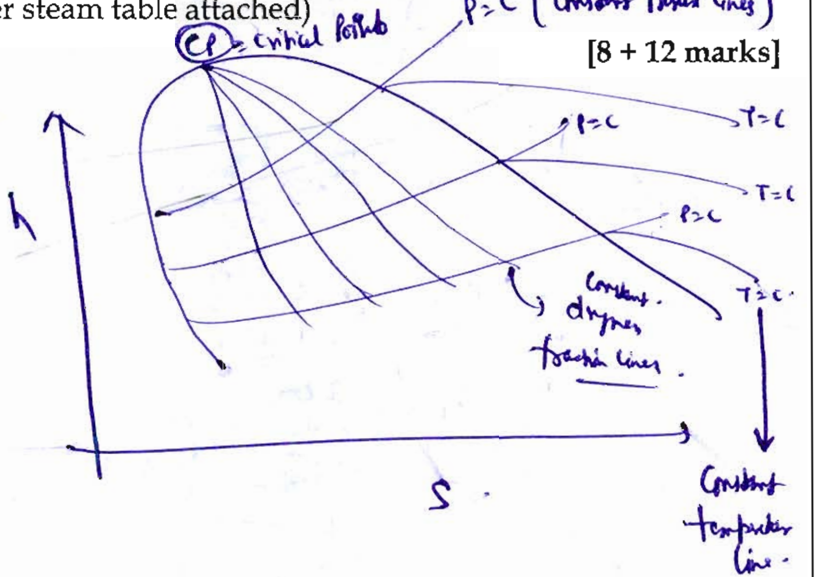
$$\Rightarrow \boxed{\sigma_s = 182.858 \text{ MPa}}$$

Q.7 (c) (i) Sketch the Mollier diagram and briefly explain its essential features.

(ii) A rigid and sealed tank of volume 1 m^3 is initial filled with dry saturated steam at 230°C and left in the room. After a while the temperature of the steam is reduced to 190°C. Determine the final conditions of steam in the tank and the amount of energy transferred as heat. (Refer steam table attached)

[8 + 12 marks]

Mollier diagram :-



6+12

features :-

- Mollier diagram is a plot between enthalpy and Entropy.
- In Mollier diagram, Constant Pressure lines are diverging to each other.
- for the Region between Saturated Liquid and Saturated vapour line or Vapour dome region, Constant Pressure and Constant temperature Lines are identical, which seperate from each other in Superheated Region.
- Constant dryness fraction lines meets up at the Critical Point.

(ii) Volume of tank = 1 m^3.

initial temp of dry saturated steam = 230°C.

from steam table, at $T = 230°C$, $v_1 = v_g = .071503$ m^3/kg, $u_1 = u_g = 2602.3$ kJ/kg

So, let M be the Mass of Steam Present.

So, $(M)\, v_g = V$

$(M)(.071503) = 1$

$M = 13.985$ kg

final temperature of steam = 150°C.
as the volume and Mass of steam Remain same,
the final specific volume also remain same, $v_2 = v_1$

$v_2 = .071503 = v_f|_{150°C} + x\, v_{fg}|_{150°C}$

at 150°C, $v_f = .00114145\ m^3/kg$, $v_g = .15636\ m^3/kg$.

So, $.071503 = .00114145 + (x)[.15636 - .00114145]$

dryness fraction, $x = .453$

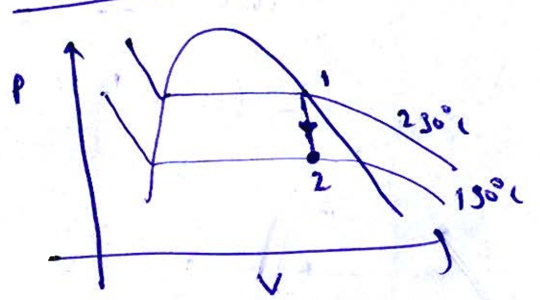
and $u_2 = u_f + x\, u_{fg}$

at 150°C, $u_f = 806\ kJ/kg$
$u_g = 2589\ kJ/kg$.

So, $u_2 = 806 + .453[2589 - 806]$

$u_2 = 1613.699\ kJ/kg$

So, final Condition of steam in tank ⇒
$P = 1.2552$ MPa,
$T = 150°C$
$x = .453$
$v = .071503\ m^3/kg$
$u = 1613.699\ kJ/kg$



Amount of heat transfer.

By energy balance

$U_1 - Q = U_2$.

$Q = U_1 - U_2$
$= (2602.9 - 1613.699)(13.985)$

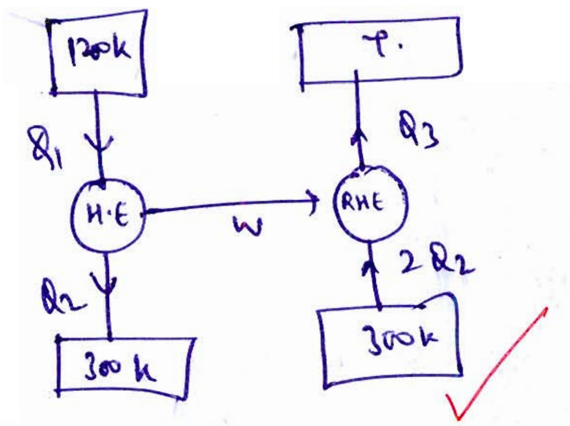
$Q = 13833.97\ kJ$ ⇒ (Rejection)

Q.8 (a) A heat engine operating between two reservoirs at 1200 K and 300 K is used to drive a heat pump which extracts heat from the rerservoir at 300 K at a rate twice that at which the engine rejects heat to it. If the efficiency of the engine is 40% of the maximum possible and the COP of the heat pump is 60% of the maximum possible, then determine:

(i) the temperature of the reservoir to which the heat pump rejects heat.

(ii) the rate of heat rejection from the heat pump if the rate of heat supply to the engine is 100 kW.

[20 marks]



20

Given

$\eta_{HE} = .4\,\eta_{carnot} = .4\left\{1 - \frac{300}{1200}\right)$

$\eta_{HE} = .4\left\{1 - \frac{1}{4}\right) = .3$

So, $.3 = \frac{W}{Q_1}$

also, $Q_1 = W + Q_2$ & $.3 = \frac{W}{W + Q_2}$

$.3W + .3Q_2 = W$

$.3Q_2 = .7W$ — (1)

for Heat Pump

$COP = (.6)\,(COP_{max}$

$COP = (.6)\left[\frac{T_H}{T_H - T_L}\right]$

here, $T_H = T$, $T_L = 300\,k$.

$COP = (.6)\left[\frac{T}{T - 300}\right)$

also, $COP = \frac{Q_3}{W} = \frac{W + 2Q_2}{W}$

So, $\frac{W + 2Q_2}{W} = .6\left(\frac{T}{T-300}\right)$.

Putting $Q_2 = \frac{7}{3}W$ from ①

So, $\frac{W + 2\left(\frac{7W}{3}\right)}{W} = (.6)\frac{T}{T-300}$

$9.44 = \frac{T}{T-300}$ or $T - 300 = .1058\,T$.

$$\boxed{T = 335.526\,K}$$

So, Heat Pump reject heat to Reservoir at $\boxed{T = 335.526\,K}$

(ii) $\boxed{Q_3 = ?}$

$Q_1 = 100\,kW$ (given).

So, as $\eta_{HE} = .3 = \frac{W}{Q_1}$

$$\boxed{W = (.3)(100) = 30\,kW.}$$

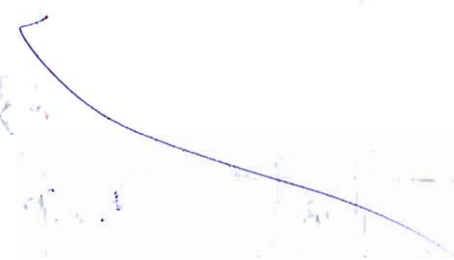
and as $Q_2 = \frac{7}{3}W$.

$$\boxed{Q_2 = 70\,kW}$$

So, $Q_3 = W + 2Q_2$

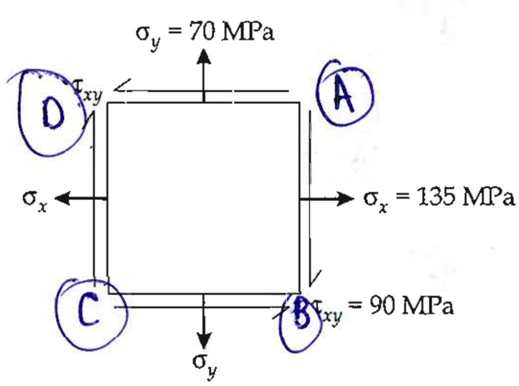
$Q_3 = 30 + 2(70)$

$$\boxed{Q_3 = 170\,kW}$$



Q.8 (b) At a certain point in a piece of elastic material, there are normal tensile stresses of magnitude 135 MPa (in x-direction), 70 MPa acting orthogonally to each other. In addition, there is a shearing stress of 90 MPa acting normal to the normal stresses.

Calculate : (i) the magnitude and direction of the principal stresses, (ii) the magnitude and direction of the maximum shearing stress. (iii) the normal and shearing stress on a plane inclined at 30° to the direction of 135 MPa stress.



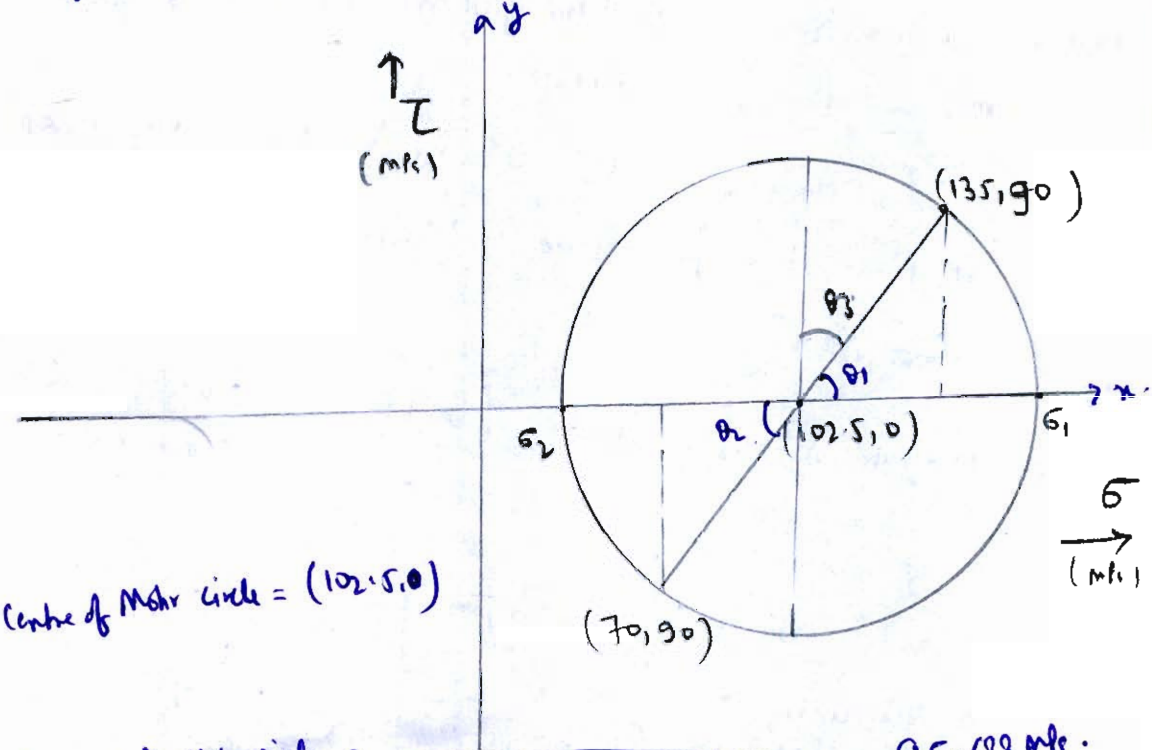
[20 marks]

$\sigma_x = 135$ MPa.

$\sigma_y = 70$ MPa.

$\tau = 90$ MPa.

Using Mohr circle



Centre of Mohr circle = (102.5, 0)

R, Radius of Mohr circle = $\sqrt{(135-102.5)^2 + 90^2}$ = 95.688 MPa.

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(i) Magnitude and direction of Principal Stresses :-

σ_1, σ_2 = 102.5 ± R

= 102.5 ± 95.688

σ_1 = 198.188 MPa σ_2 = 6.812 MPa

direction of σ_1 from AB face (vertical)

~~tan~~ $\sin\theta_1 = \frac{90}{95.688}$ $\theta_1 = 70.145°$

So, σ_1 plane is at $\frac{\theta_1}{2}$ i.e 35.072° (CW) from face AB.

direction of σ_2 from AB face (vertical)

~~$\sin\theta_2 = 90$~~ ~~$\theta_2 = \theta_1$~~

the σ_2 plane is at $\frac{180-\theta_1}{2}$ i.e, 54.927° (CCW) from AB or 125.0725 (CW) from AB.

(ii) ~~magnitude and direction of Maximum shearing stress~~ :-

Max shear stress = Radius of Mohr circle = 95.688 MPa.

Maximum shear plane direction

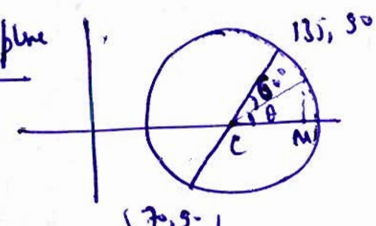
$\theta_3 = 90 - \theta_1 = 90 - 70.145 = 19.855°$

So, Max shear plane is at $\frac{19.855}{2} = 9.9275°$ (CCW) from AB.

other Maximum shear plane is at $\frac{(90+\theta_1)}{2} = 80.0725°$ (CW) from AB.

(iii) σ and τ at 30° from 135 MPa plane

on Mohr circle, θ = 30° will be shown as 60°.



$\theta = \theta_1 - 60$
$= 70.145 - 60 = 10.145°$.

$\sin\theta = \frac{\tau}{R}$ ⇒ $\tau = \sin 10.145 \times 95.688$

τ = 16.854 MPa

σ. also, $\cos\theta = \frac{CM}{R}$

$CM = 95.188 \cos(10.145)$

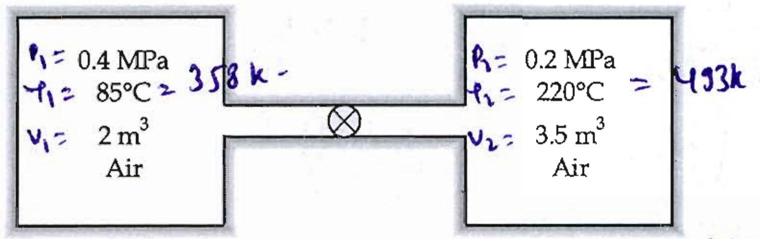
CM = 94.192 MPa

So, σ = Radius + CM
= 102.5 + 94.192

σ = 196.69 MPa

Refer Solution

Q.8 (c) Two vessels, *A* and *B* of volume 2 m^3 and 3.5 m^3 respectively, are connected by a tube of negligible volume through a valve as shown below. Vessel *A* contains air at 0.4 MPa, 85°C while vessel *B* contains air at 0.2 MPa, 220°C. Determine the total change of entropy, when the valve is opened and assuming the mixing to be complete and adiabatic. For air take R = 0.287 kJ/kgK; c_p = 1.005 kJ/kgK; c_v = 0.717 kJ/kgK.



[20 marks]

Taking Air to be Ideal Gas and using PV = MRT for ideal Gas.

for tank A:

let M_1 be the Mass present in tank A.

so, $P_1V_1 = M_1RT_1$

$(.4)(1000)[2] = (.287)(M_1)(85+273)$

$M_1 = 7.786$ kg

20

for tank B

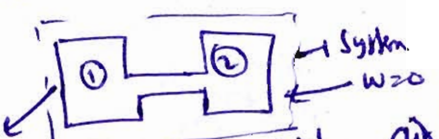
let M_2 be the Mass present in tank B.

so, $P_2V_2 = M_2RT_2$

$.2 \times 1000 \times 3.5 = (M_2)(.287)(220+273)$

$M_2 = 4.947$ kg

As the Mixing is adiabatic



By energy balance,

~~Heat lost by air in tank 2 = Heat gain by air in tank 1~~

~~Tf be the final common temperature.~~

As no work and heat interaction is happening, $\Delta U_{system} = 0$

$M_2 C_v (T_2 - T_f) = M_1 C_v (T_f - T_1)$.

$4.947[493 - T_f] = 7.786[T_f - 358]$

$493 - T_f = 1.574[T_f - 358]$

$T_f = 410.447$ K

also let P_f be the final Pressure.

so, $(P_f)(V_1+V_2) = (M_1+M_2)RT_f \Rightarrow P_f = \frac{12.733 \times .287 \times 410.447}{5.5} = .2727$ MPa

Change in Entropy

change in Entropy of air in tank 1 + Change in Entropy of air in tank 2.

↓ $(\Delta S)_1$ ↓ $(\Delta S)_2$

for air, $\Delta S = M\left[C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}\right]$

$\Delta S_1 = M_1\left[C_p \ln \frac{T_f}{T_1} - R \ln \frac{P_f}{P_1}\right]$.

$\Delta S_1 = 7.786\left[1.005 \ln \frac{410.448}{358} - .288 \ln \frac{.2728}{.4}\right]$.

$\Delta S_1 = 7.786\,(.1373 + .1099)$

$\boxed{\Delta S_1 = 1.924 \text{ kJ/K}}$

for tank 2

$\Delta S_2 = M_2\left(C_p \ln \frac{T_f}{T_2} - R \ln \frac{P_f}{P_2}\right)$.

$= 4.948\left[1.005 \ln \frac{410.448}{493} - .288 \ln \frac{.2728}{.2}\right]$

$4.948\,(-.184 - .0889]$

$\boxed{\Delta S_2 = -1.35 \text{ kJ/K}}$

So, total Entropy change $= \Delta S_1 + \Delta S_2$

$\boxed{\Delta S_{total} = .574 \text{ kJ/K}}$

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

T °C	p_{sat} MPa	Volume, m³/kg v_f	v_g	Energy, kJ/kg u_f	u_g	Enthalpy, kJ/kg h_f	h_g	h_{fg}	Entropy, kJ/(kg K) s_f	s_g	s_{fg}
160	0.61823	0.00110199	0.30678	674.79	2567.7	675.47	2757.4	2082.0	1.9426	6.7491	4.8066
161	0.63412	0.00110318	0.29951	679.12	2568.6	679.82	2758.5	2078.7	1.9525	6.7406	4.7880
162	0.65033	0.00110438	0.29245	683.45	2569.4	684.17	2759.6	2075.5	1.9625	6.7320	4.7695
163	0.66686	0.00110559	0.28559	687.78	2570.3	688.52	2760.7	2072.2	1.9725	6.7235	4.7511
164	0.68373	0.00110680	0.27892	692.12	2571.1	692.88	2761.8	2068.9	1.9824	6.7150	4.7327
165	0.70093	0.00110803	0.27243	696.46	2571.8	697.24	2762.8	2065.6	1.9923	6.7066	4.7143
166	0.71848	0.00110926	0.26612	700.80	2572.7	701.60	2763.9	2062.3	2.0022	6.6982	4.6960
167	0.73638	0.00111050	0.25999	705.14	2573.4	705.96	2764.9	2058.9	2.0121	6.6898	4.6778
168	0.75462	0.00111175	0.25403	709.49	2574.2	710.33	2765.9	2055.6	2.0220	6.6815	4.6596
169	0.77322	0.00111300	0.24823	713.85	2575.0	714.71	2766.9	2052.2	2.0318	6.6732	4.6414
170	0.79219	0.00111427	0.24259	718.20	2575.7	719.08	2767.9	2048.8	2.0417	6.6650	4.6233
171	0.81152	0.00111551	0.23710	722.55	2576.5	723.46	2768.9	2045.4	2.0515	6.6567	4.6053
172	0.83122	0.00111682	0.23176	726.92	2577.3	727.85	2769.9	2042.0	2.0613	6.6485	4.5872
173	0.85130	0.00111811	0.22656	731.28	2577.9	732.23	2770.8	2038.6	2.0711	6.6404	4.5693
174	0.87176	0.00111941	0.22150	735.65	2578.7	736.63	2771.8	2035.1	2.0809	6.6322	4.5514
175	0.89260	0.00112072	0.21658	740.02	2579.4	741.02	2772.7	2031.7	2.0906	6.6241	4.5335
176	0.91384	0.00112204	0.21179	744.39	2580.1	745.42	2773.6	2028.2	2.1004	6.6161	4.5157
177	0.93547	0.00112336	0.20712	748.77	2580.7	749.82	2774.5	2024.7	2.1101	6.6080	4.4979
178	0.95751	0.00112470	0.20258	753.15	2581.4	754.23	2775.4	2021.2	2.1198	6.6000	4.4802
179	0.97995	0.00112604	0.19815	757.54	2582.1	758.64	2776.3	2017.7	2.1296	6.5920	4.4625
180	1.0028	0.00112740	0.19384	761.92	2582.8	763.05	2777.2	2014.2	2.1392	6.5840	4.4448
181	1.0261	0.00112876	0.18964	766.31	2583.5	767.47	2778.1	2010.6	2.1489	6.5761	4.4272
182	1.0498	0.00113013	0.18555	770.71	2584.1	771.90	2778.9	2007.0	2.1586	6.5682	4.4096
183	1.0739	0.00113151	0.18157	775.10	2584.8	776.32	2779.8	2003.4	2.1683	6.5603	4.3921
184	1.0985	0.00113290	0.17769	779.51	2585.4	780.75	2780.6	1999.8	2.1779	6.5525	4.3746
185	1.1235	0.00113430	0.17390	783.92	2586.0	785.19	2781.4	1996.2	2.1875	6.5447	4.3571
186	1.1489	0.00113571	0.17021	788.33	2586.6	789.63	2782.2	1992.6	2.1971	6.5369	4.3397
187	1.1748	0.00113713	0.16662	792.73	2587.3	794.07	2783.0	1988.9	2.2067	6.5291	4.3223
188	1.2011	0.00113856	0.16311	797.15	2587.9	798.52	2783.8	1985.3	2.2163	6.5213	4.3050
189	1.2280	0.00114000	0.15969	801.57	2588.4	802.97	2784.5	1981.6	2.2259	6.5136	4.2877
190	1.2552	0.00114145	0.15636	806.00	2589.0	807.43	2785.3	1977.9	2.2355	6.5059	4.2704
191	1.2830	0.00114291	0.15311	810.42	2589.6	811.89	2786.0	1974.1	2.2450	6.4982	4.2532
192	1.3112	0.00114438	0.14994	814.86	2590.1	816.36	2786.7	1970.4	2.2546	6.4906	4.2360
193	1.3399	0.00114586	0.14685	819.29	2590.6	820.83	2787.4	1966.6	2.2641	6.4830	4.2188
194	1.3691	0.00114736	0.14383	823.74	2591.2	825.31	2788.1	1962.8	2.2736	6.4754	4.2017
195	1.3988	0.00114886	0.14089	828.18	2591.7	829.79	2788.8	1959.0	2.2832	6.4678	4.1846
196	1.4290	0.00115037	0.13802	832.64	2592.3	834.28	2789.5	1955.2	2.2926	6.4602	4.1676
197	1.4597	0.00115189	0.13522	837.09	2592.7	838.77	2790.1	1951.4	2.3021	6.4527	4.1505
198	1.4909	0.00115343	0.13248	841.54	2593.3	843.26	2790.8	1947.5	2.3116	6.4451	4.1335
199	1.5227	0.00115497	0.12982	846.00	2593.7	847.76	2791.1	1943.6	2.3211	6.4376	4.1166
200	1.5549	0.00115653	0.12721	850.47	2594.2	852.27	2792.0	1939.7	2.3305	6.4302	4.0996

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

T °C	p_{sat} MPa	Volume, m³/kg v_f	v_g	Energy, kJ/kg u_f	u_g	Enthalpy, kJ/kg h_f	h_g	h_{fg}	Entropy, kJ/(kg K) s_f	s_g	s_{fg}
200	1.5549	0.00115653	0.12721	850.47	2594.2	852.27	2792.0	1939.7	2.3305	6.4302	4.0996
201	1.5877	0.00115809	0.12467	854.94	2594.7	856.78	2792.6	1935.8	2.3400	6.4227	4.0827
202	1.6210	0.00115967	0.12218	859.42	2595.1	861.30	2793.2	1931.9	2.3494	6.4152	4.0658
203	1.6549	0.00116126	0.11976	863.90	2595.5	865.82	2793.7	1927.9	2.3588	6.4078	4.0490
204	1.6893	0.00116286	0.11739	868.39	2596.0	870.35	2794.3	1923.9	2.3683	6.4004	4.0322
205	1.7243	0.00116448	0.11508	872.87	2596.4	874.88	2794.8	1919.9	2.3777	6.3930	4.0154
206	1.7598	0.00116610	0.11282	877.37	2596.8	879.42	2795.3	1915.9	2.3871	6.3856	3.9986
207	1.7959	0.00116774	0.11061	881.86	2597.3	883.96	2795.9	1911.9	2.3964	6.3783	3.9819
208	1.8326	0.00116939	0.10846	886.37	2597.5	888.51	2796.3	1907.8	2.4058	6.3710	3.9651
209	1.8698	0.00117105	0.10635	890.88	2597.9	893.07	2796.8	1903.7	2.4152	6.3636	3.9484
210	1.9077	0.00117272	0.10429	895.39	2598.3	897.63	2797.3	1899.6	2.4245	6.3563	3.9318
211	1.9461	0.00117441	0.10228	899.91	2598.7	902.20	2797.7	1895.5	2.4339	6.3490	3.9151
212	1.9851	0.00117611	0.10031	904.44	2599.0	906.77	2798.1	1891.4	2.4432	6.3417	3.8985
213	2.0247	0.00117782	0.098394	908.97	2599.3	911.35	2798.5	1887.2	2.4526	6.3345	3.8819
214	2.0650	0.00117954	0.096516	913.50	2599.6	915.94	2798.9	1883.0	2.4619	6.3272	3.8653
215	2.1058	0.00118128	0.094679	918.04	2599.9	920.53	2799.3	1878.8	2.4712	6.3200	3.8488
216	2.1473	0.00118303	0.092881	922.58	2600.3	925.12	2799.7	1874.6	2.4805	6.3128	3.8323
217	2.1894	0.00118479	0.091129	927.14	2600.5	929.73	2800.0	1870.3	2.4898	6.3056	3.8158
218	2.2322	0.00118657	0.089413	931.69	2600.7	934.34	2800.3	1866.0	2.4991	6.2984	3.7993
219	2.2756	0.00118836	0.087734	936.26	2601.1	938.96	2800.7	1861.7	2.5084	6.2912	3.7828
220	2.3196	0.00119017	0.086092	940.82	2601.2	943.58	2800.9	1857.4	2.5177	6.2840	3.7663
221	2.3643	0.00119198	0.084486	945.39	2601.4	948.21	2801.2	1853.0	2.5269	6.2768	3.7499
222	2.4096	0.00119382	0.082916	949.97	2601.7	952.85	2801.5	1848.6	2.5362	6.2697	3.7335
223	2.4556	0.00119567	0.081379	954.55	2601.9	957.49	2801.7	1844.2	2.5455	6.2625	3.7171
224	2.5023	0.00119753	0.079875	959.14	2602.0	962.14	2801.9	1839.8	2.5547	6.2554	3.7007
225	2.5497	0.00119940	0.078403	963.74	2602.2	966.80	2802.1	1835.4	2.5640	6.2483	3.6843
226	2.5978	0.00120130	0.076964	968.34	2602.4	971.46	2802.3	1830.9	2.5732	6.2412	3.6680
227	2.6466	0.00120320	0.075551	972.95	2602.5	976.13	2802.5	1826.4	2.5824	6.2311	3.6516
228	2.6960	0.00120512	0.074175	977.56	2602.7	980.81	2802.7	1821.8	2.5917	6.2270	3.6353
229	2.7462	0.00120706	0.072825	982.19	2602.8	985.50	2802.8	1817.3	2.6009	6.2199	3.6190
230	2.7971	0.00120902	0.071503	986.81	2602.9	990.19	2802.9	1812.7	2.6101	6.2128	3.6027
231	2.8487	0.00121098	0.070210	991.44	2603.0	994.89	2803.0	1808.1	2.6193	6.2057	3.5864
232	2.9010	0.00121297	0.068913	996.08	2603.1	999.60	2803.1	1803.5	2.6285	6.1987	3.5702
233	2.9541	0.00121497	0.067702	1000.7	2603.1	1004.3	2803.1	1798.8	2.6377	6.1916	3.5539
234	3.0080	0.00121699	0.066488	1005.3	2603.2	1009.0	2803.2	1794.1	2.6469	6.1846	3.5376
235	3.0625	0.00121902	0.065298	1010.1	2603.2	1013.8	2803.2	1789.4	2.6561	6.1775	3.5214
236	3.1179	0.00122108	0.064133	1014.7	2603.2	1018.5	2803.2	1784.7	2.6653	6.1704	3.5052
237	3.1740	0.00122315	0.062991	1019.4	2603.2	1023.3	2803.1	1779.9	2.6745	6.1634	3.4890
238	3.2308	0.00122523	0.061873	1024.0	2603.2	1028.0	2803.1	1775.1	2.6836	6.1561	3.4727
239	3.2885	0.00122731	0.060778	1028.8	2603.1	1032.8	2803.0	1770.3	2.6928	6.1493	3.4565
240	3.3469	0.00122946	0.059705	1033.5	2603.2	1037.6	2803.0	1765.4	2.7020	6.1423	3.4403

Space for Rough Work

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