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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 : RAJESH KASANIYA

Roll No : ME24MBL10044

Test Centres

Delhi ☐ Bhopal ☐ Jaipur ☐

Pune ☐ Kolkata ☐ Hyderabad ☐

Student's Signature

Rajesh

Instructions for Candidates

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

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	
Q.2	
Q.3	
Q.4	
Section-B	
Q.5	
Q.6	
Q.7	
Q.8	
Total Marks Obtained	

Signature of Evaluator ....

Cross Checked by ....

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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]

Ans

$RC = 25 \times 3.5 = 87.5\ kW$

(i) max possible cop

T_1 133.5°C, T_2 40°C — HE

T_2 40°C, T_3 −15°C — RE

$$(COP)_{max} = \left(1 - \frac{T_2}{T_1}\right)\left(\frac{T_3}{T_2 - T_3}\right)$$

$$= \frac{93.5}{406.5} \times \frac{256}{65}$$

$$(COP)_{max} = 0.9058$$ Ans

(ii) $(COP)_{act} = 0.317 = \frac{Q_E}{Q_G} = \frac{87.5}{Q_G}$

$\Rightarrow Q_G = 276.025\ kW$

$Q_G = x \dot{m}_s h_{fg}$

$\Rightarrow 276.025 = 0.9 \times \dot{m}_s (2163.2)$

$\Rightarrow \dot{m}_s = 0.1417\ kg/s$

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:

$\rho = 1.09$ 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:

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

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

[12 marks]

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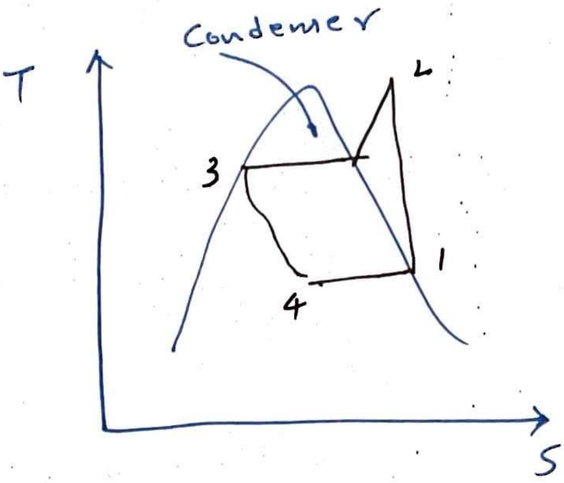
Q.1 (c) What are the functions of condenser in a refrigerating machine? Name different types of condensers. Describe with neat sketch the evaporative condenser.

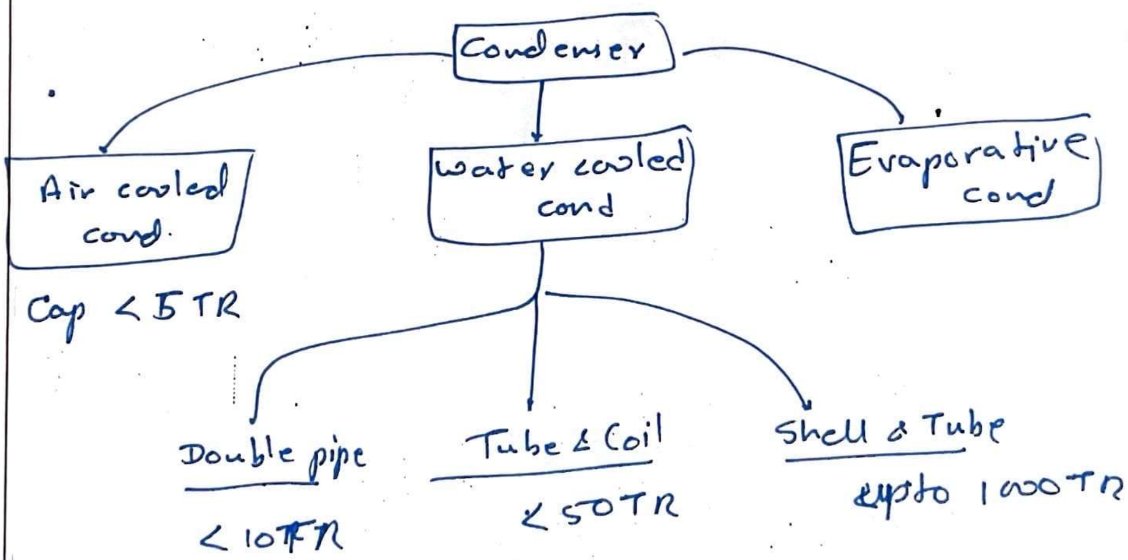
[12 marks]



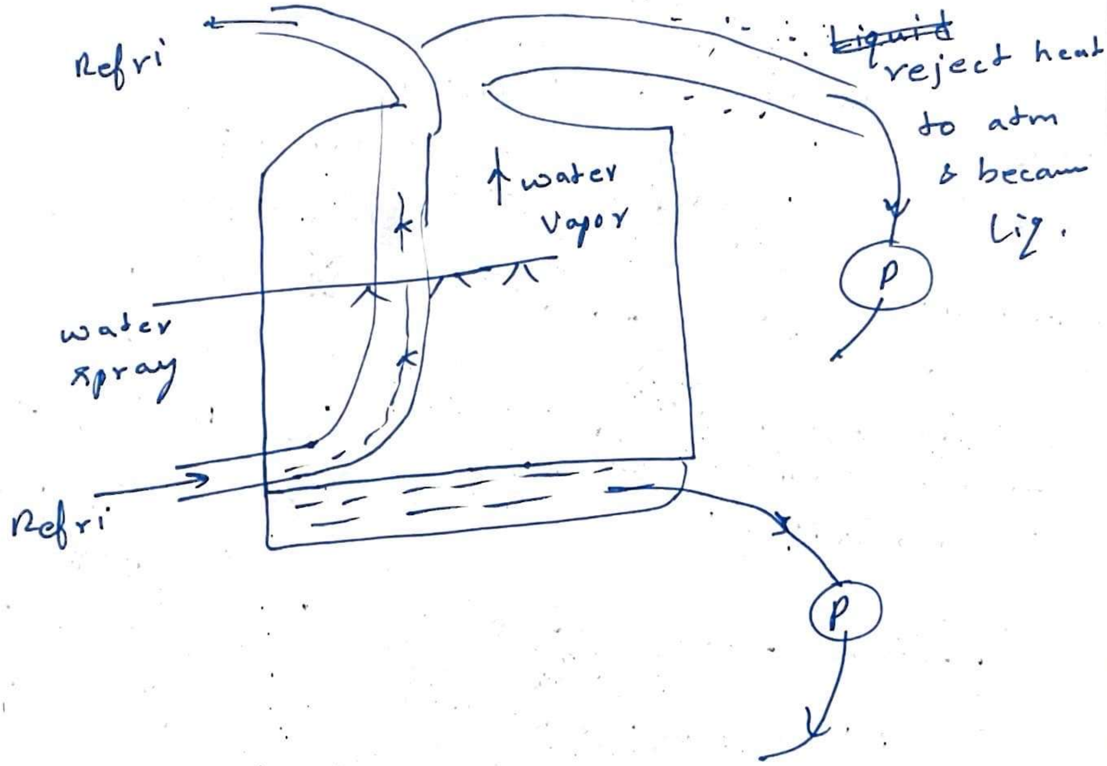
VCRS

Functions

① Liquidify the refrigerent by rejecting heat (at const P)



Evaporative cond - Refrigerant cooled by water & then water rejects heat heat. to air & liquidify.



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]

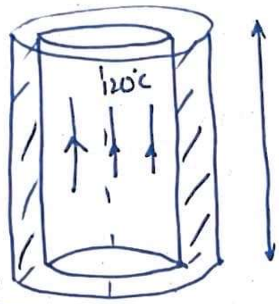
Ans

Find

Q_{loss} = ?

Air

30°C



Given

$T_{steam} = 120°C$

$K_{cu} = 450$ W/mK

$r_i = 6$ cm

$r_o = 7$ cm

$h_i = 11500$ W/m²K

$h_o = 20$ W/m²K

$A_i = 2\pi r_i L = 0.3769$ m²

$A_o = 0.4398$ m²

Assumptions

① L = 1m

② neglecting convective heat transfer w/o insulation

r_i → r_o

120°C → 30°C

q: $\frac{1}{h_i A}$ — $\frac{\ln(r_o/r_i)}{2\pi L K}$ — $\frac{1}{h_o A}$

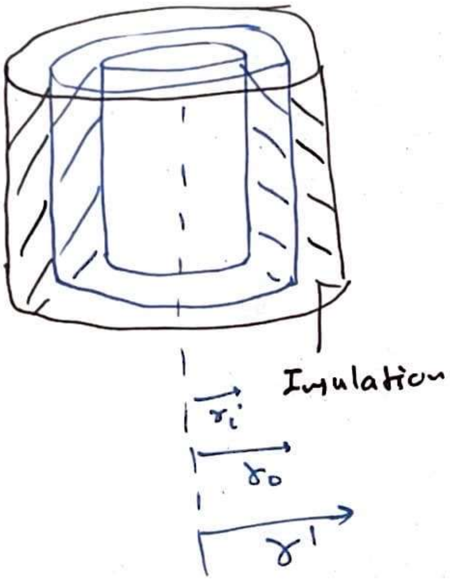
$$\Rightarrow q = \frac{\Delta T}{R_{total}} = \frac{90}{\frac{1}{11500 A_i} + \frac{\ln(7/6)}{2\pi L \times 450} + \frac{1}{20 A_o}}$$

$$\Rightarrow q = \frac{90}{0.11397}$$

$$\Rightarrow \boxed{q_{w/o\ insulation} = 789.658\ W}$$

$$\boxed{Q_{loss} = q = 789.658\ W}$$

↳ Heat loss from pipe w/o insulation.



$t = 3cm$

$r' = r_0 + 3 = 10 cm$

$K_{in} = 0.2 \ W/mK$

<u>with</u> <u>insulation</u>

$R_1 = \frac{1}{h_i A_i}$, $R_2 = \frac{\ln(r_o/r_i)}{2\pi L K_{al}}$, $R_3 = \frac{1}{h_o A_o}$, $R_4 = \frac{\ln\left(\frac{r'}{r_o}\right)}{2\pi L K_{in}}$

$$\Rightarrow q' = \frac{\Delta T}{R_{total}} = \frac{90}{\frac{1}{11500 \times 0.3769} + \frac{\ln(7/6)}{2\pi L \times 410} + \frac{1}{20 \times 0.4398} + \frac{\ln(10/7)}{2\pi L \times 0.2}}$$

$$\Rightarrow q' = \frac{90}{0.3978}$$

$$\Rightarrow \boxed{q' = 226.2427 W}$$

→ Heat loss with insulation

$$\boxed{q - q' = 563.4153 W}$$

→ So by adding insulation if we neglect convection HT then 563.4153 W heat loss will be less.

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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]

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]

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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]

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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]

(i) Assumptions

(1) Thermal conductivity (k) is const for fin over entire length

(2) h (Heat transfer coff) is const.

(3) No resistance at junction of fin and base material

(4) No radiative heat transfer from fin

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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]

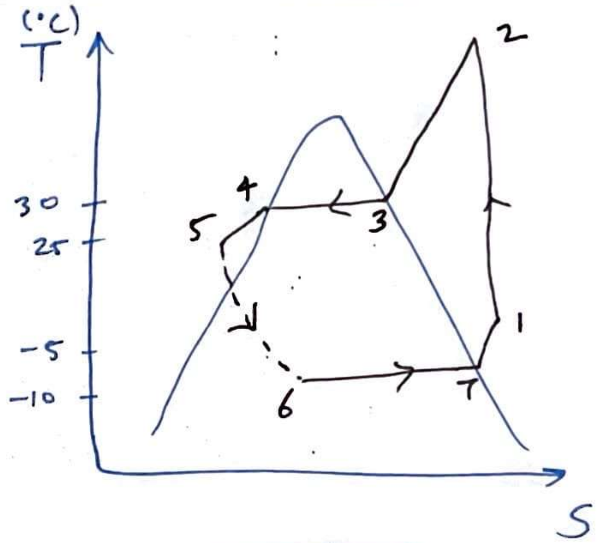
Ans

$RC = 20 \times 3.5 = 70\,kW$

$K = 2$

$L = 1.5D$

$N = 1200\,rpm$



(i) $RE = \frac{RC}{\dot{m}}$

$\eta_{vol} = \frac{\dot{m} v_1}{\frac{\pi}{4} D^2 L \frac{N K}{60}} = 1$

Assumptions

(1) $\eta_{vol} = 1$

(2) Bore $D = 0.1\,m$

$\Rightarrow \frac{v_1}{v_7} = \frac{T_1}{T_7}$ ($\because$ const P)

$\Rightarrow$ $v_1 = 0.07840\,m^3/kg$

$\Rightarrow \dot{m}(0.07840) = \frac{\pi}{4} 1.5 D^3 \times \frac{1200}{60} \times 2$

$\Rightarrow \dot{m} =$

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

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

[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]

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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 : ρ = 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]

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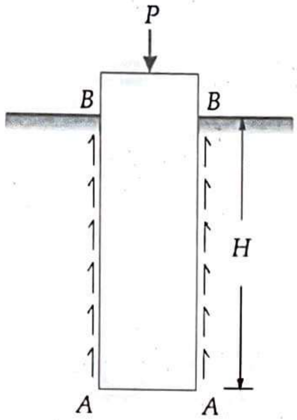
Section : B

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]

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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.

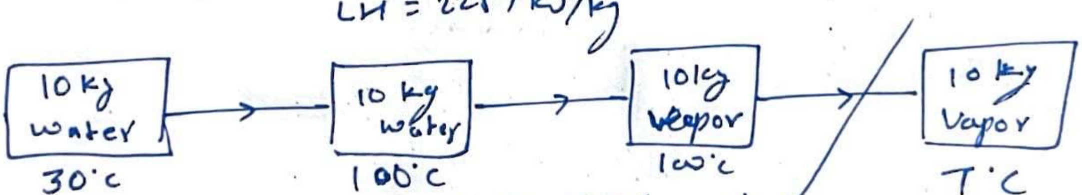
[12 marks]

$M_s = 15\,kg$ $\quad M_w = 10\,kg$

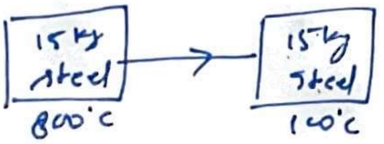
$T_{s_1} = 800^\circ C$ $\quad T_{w_1} = 30^\circ C$

$C_s = 0.5\,kJ/kgK$ $\quad C_w = 4.27\,kJ/kgK$

$LH = 2257\,kJ/kg$



$Q_1 = 10 \times 4.27 \times 70 + 10 \times 2257 + \ldots$
$= 2989 + 22570 > Q_2$



$Q_2 = 15 \times 0.5 \times 700$
$= 5250\,kJ$

∵ $Q_1 > Q_2$

So only a fraction of water will be evaporated.

• Heat rejected by steem = Heat gained by H_2O

$\Rightarrow 5250 = 2989 + m' \times 2257$

$\Rightarrow$ $m' = 1.0017$ kg → water converted into vapor.

• $(\Delta S)_{steel} = m_s c_s \ln \frac{T_f}{T_{s1}}$

$= 15 \times 0.5 \ln \left(\frac{373}{1073}\right)$

$(\Delta S)_{steel} = -7.9247$ kJ/K Ans

• $(\Delta S)_{water} = m_w c_w \ln \left(\frac{T_f}{T_{w1}}\right) + \frac{m'L}{373}$

$= 10 \times 4.27 \ln \left(\frac{373}{303}\right) + \frac{2261}{373}$

$\Rightarrow$ $(\Delta S)_{water} = 14.9366$ kJ/K Ans

Assumptions

① There is no heat transfer to the atmosphere

• $\Delta S_{univ} = (\Delta S)_s + (\Delta S)_w + (\Delta S)_{su}$ ($(\Delta S)_{su} \to 0$)

$\Rightarrow$ $(\Delta S)_{univ} = 7.0119$ kJ/K Ans

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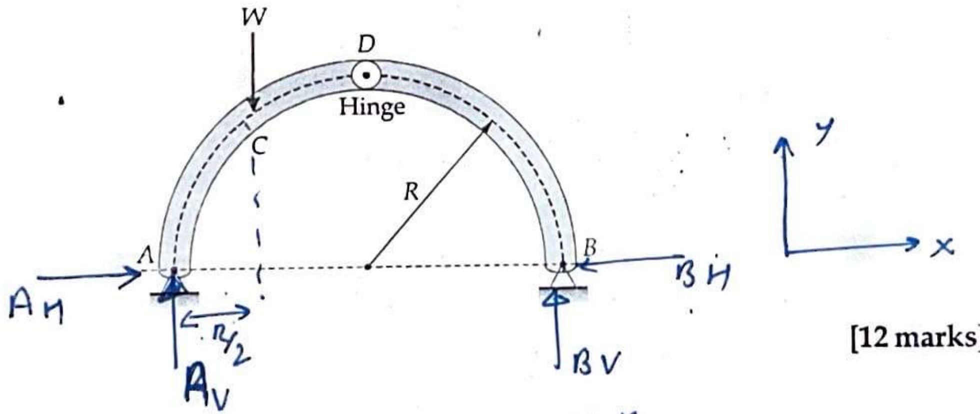
Q.5 (c) A 3-hinged arch loaded at C, at a distance $\frac{R}{2}$ from A. Find the resultant forces at A and B as shown in figure below.



[12 marks]

A -

Force equil of arch in y dir^n

$\Sigma F_y = 0$

$\Rightarrow \boxed{A_v + B_v = W}$ —— (1)

in x - dir^n

$\Sigma F_x = 0$

$\Rightarrow \boxed{A_H = B_H}$ —— (2)

· Now by

$\Sigma M_A = 0$

$\Rightarrow -W\frac{R}{2} + B_v \times 2R = 0$

$\Rightarrow \boxed{B_v = \frac{W}{4}}$

from equ^n (1)

$\boxed{A_v = \frac{3W}{4}}$

. Now taking momen in right side of hige D

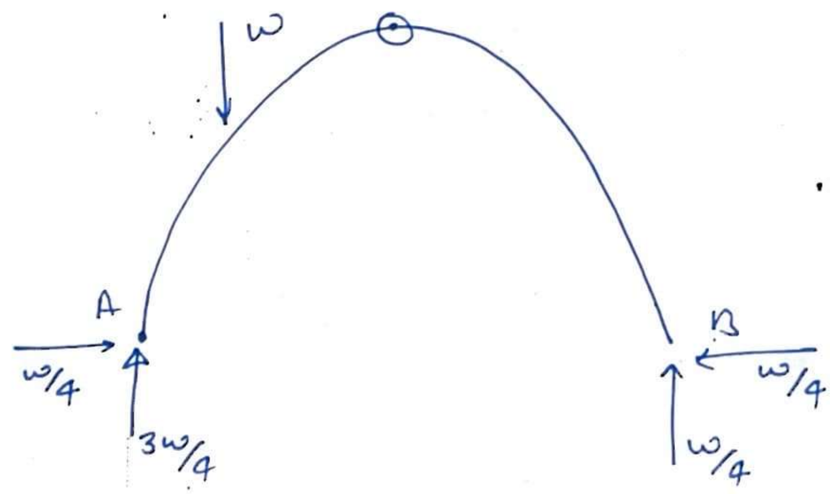
$\Sigma M_{DR} = 0$

$\Rightarrow +B_v R - B_H R = 0$

$\Rightarrow \boxed{B_H = B_v = W/4}$

from equ^n (2)

$\boxed{A_H = W/4}$



So Resultant at A

$$F_A = \sqrt{\left(\frac{w}{4}\right)^2 + \left(\frac{3w}{4}\right)^2} = 0.7905\ w$$

$$\Rightarrow \boxed{F_A = 0.7905 W}$$ Ans

Resultant at B

$$F_B = \sqrt{\left(\frac{w}{4}\right)^2 + \left(\frac{w}{4}\right)^2}$$

$$\Rightarrow \boxed{F_B = 0.3535\ W}$$ Ans

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

[12 marks]

Clausius Inequality :-

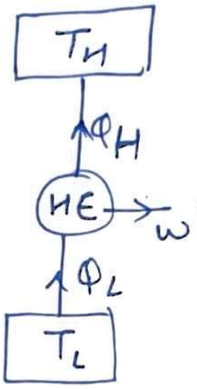
$$\boxed{\oint \frac{\delta Q}{T} \le 0}$$

According to clausius in a ~~thermo~~ cyclic heat transfer process ratio of differential heat transfer to temp at which this is taking place, over entire cycle will be less than or equal to zero

$\rightarrow$ $\oint \frac{\delta Q}{T} = 0 \rightarrow$ for reversible

$\oint \frac{\delta Q}{T} < 0$ — for irreversible.

Proof (a) for reversible



Assume a carnot reversible HE working b/w two thermal reserviors T_H & T_L

- we know that,

$$\eta = 1 - \frac{T_L}{T_H} = \frac{w}{Q_L} \quad \text{—(1)}$$

- from 1st law

$$W = Q_H - Q_L$$

from eqn (1)

$$1 - \frac{T_H}{T_L} = \frac{Q_H - Q_L}{Q_L}$$

$$\Rightarrow \frac{T_H}{T_L} = \frac{-Q_H}{Q_L} \Rightarrow \frac{-Q_H}{T_H} = \frac{Q_L}{T_L} \quad \text{—(2)}$$

$$\Rightarrow \frac{Q_H}{T_H} + \frac{Q_L}{T_L} = 0$$

$$\Rightarrow \boxed{\oint \frac{\delta Q}{T} = 0} \rightarrow \text{for reversible HE}$$

(HP)

(b) for irreversible

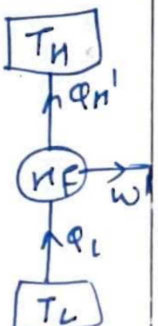
Assume Q_L same as last case

If engine is irreversible then it will do less work

↳ Q_H' will be higher then last case ($Q_H' > Q_H$)

$$\boxed{Q_H' - Q_H = Q_{diff}} \quad \text{—(3)} \quad \text{(Assume)}$$

$\boxed{Q_{diff} > 0}$



from 1st law

$$Q_H' = Q_L + w'$$

from eqn (2) & (3)

$$\frac{-(Q_H' - Q_{diff})}{T_H} = \frac{Q_L}{T_L}$$

$$\Rightarrow \frac{Q_H'}{T_H} + \frac{Q_L}{T_L} = \frac{Q_{diff}}{T_L} > 0 \quad (\because Q_{diff} > 0)$$

$$\Rightarrow \boxed{\oint \frac{\delta Q}{T} > 0}$$ → for irreversible HE / HP

So;

$$\Rightarrow \boxed{\oint \frac{\delta Q}{T} \geq 0}$$

→ clausius inequality

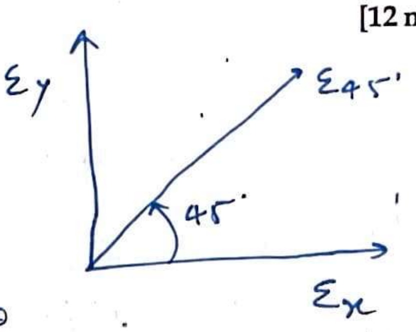
Q.5 (e) A rectangular strain rosette strain gauge records the following values for linear strain at a point in two dimensional stress system : $e_x = 520 \times 10^{-6}$, $e_y = -140 \times 10^{-6}$, and $e_{45°} = 270 \times 10^{-6}$, the later being at 45° to the x and y axes. Calculate the principal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

[12 marks]

Find

$\sigma_{1,2} = ?$

$\varepsilon_{1,2} = ?$



We know that

$$\varepsilon_x' = \left(\frac{\varepsilon_x + \varepsilon_y}{2}\right) + \left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)\cos 2\theta + \frac{\phi_{xy}}{2}\sin 2\theta$$

by putting values

$$270 \times 10^{-6} = \left(\frac{520 \times 10^{-6} - 140 \times 10^{-6}}{2}\right) + \left(\frac{520 \times 10^{-6} + 140 \times 10^{-6}}{2}\right)\cos 90 + \frac{\phi_{xy}}{2}\sin 90$$

$$\Rightarrow 270 \times 10^{-6} = 190 \times 10^{-6} + \frac{\phi_{xy}}{2}$$

$$\Rightarrow \boxed{\phi_{xy} = 160 \times 10^{-6}}$$

Now,

$$\varepsilon_{1,2} = \frac{\varepsilon_x + \varepsilon_y}{2} \pm \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\phi_{xy}}{2}\right)^2}$$

$$\Rightarrow \varepsilon_{1,2} = \left\{\frac{520-140}{2} \pm \sqrt{\left(\frac{520+140}{2}\right)^2 + \left(\frac{160}{2}\right)^2}\right\} \times 10^{-6}$$

$$\Rightarrow \varepsilon_{1,2} = (190 \pm 339.5585) \times 10^{-6}$$

$$\Rightarrow \boxed{\varepsilon_1 = 529.5585 \times 10^{-6}}$$

$$\& \boxed{\varepsilon_2 = -149.5585 \times 10^{-6}}$$

Ans

Now

$$\varepsilon_1 = \frac{\sigma_1}{E} - \mu\frac{\sigma_2}{E} \;\&\; \varepsilon_2 = \frac{\sigma_2}{E} - \mu\frac{\sigma_1}{E} \quad -(2)$$

$$\Rightarrow \mu\varepsilon_1 = \frac{\mu\sigma_1}{E} - \mu^2\frac{\sigma_2}{E} \quad -(1)$$

equ^n (1) + (2)

$$\Rightarrow \mu\varepsilon_1 + \varepsilon_2 = \frac{\sigma_2}{E} - \mu^2\frac{\sigma_2}{E}$$

$$\Rightarrow \sigma_2 = \frac{E}{1-\mu^2}(\varepsilon_2 + \mu\varepsilon_1)$$

$$\Rightarrow \sigma_2 = \frac{205\times10^9}{1-(0.32)^2}\left(-149.558 + 0.32\times529.5585\right)\times10^{-6}$$

$$\Rightarrow \sigma_2 = 4544.9477\times10^3\ Pa$$

$$\Rightarrow \boxed{\sigma_2 = 4.545\ MPa}$$ Ans

& similarily

$$\sigma_1 = \frac{E}{1-\mu^2}\left(\varepsilon_1 + \mu\varepsilon_2\right)$$

$$\Rightarrow \sigma_1 = \frac{205\times10^9}{1-(0.32)^2}\left(529.5585 + 0.32(-149.5585)\right)\times10^{-6}$$

$$\Rightarrow \sigma_1 = 110013.8758\times10^3\ Pa$$

$$\Rightarrow \boxed{\sigma_1 = 110.014\ MPa}$$ Ans

Sol

$\varepsilon_1 = 529.5585\times10^{-6}$

$\varepsilon_2 = -149.5585\times10^{-6}$

$\sigma_1 = 110.014\ MPa$

$\sigma_2 = 4.545\ MPa$

Ans

Do not write in this margin

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]

Ans

Given

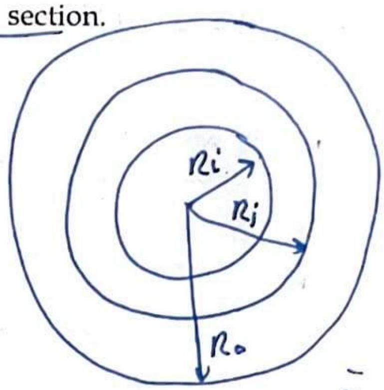
$P_i = 60\,MPa$

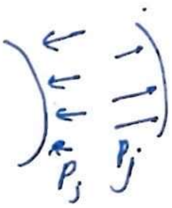
$R_i = 60\,mm$

$R_o = 110\,mm$

$R_j = 90\,mm$

$P_j = 10\,MPa$





Case 1 | w/o affect of fluid P_i

for inner cyl

Radial Pressure intensity

$P_r = \frac{B}{r^2} - A$

at $r = R_i$; $P_r = 0$

$r = R_j$; $P_r = P_j = 10$

$\Rightarrow$ $0 = \frac{B}{60^2} - A$ —(1)

$10 = \frac{B}{90^2} - A$ —(2)

from eqn (1) & (2)

$\Rightarrow$ $B = -64800$

& $A = -18$

So, hoop stress

$\sigma_h = \frac{B}{r^2} + A$

$\sigma_{hj} = \frac{-64800}{90^2} - 18 \Rightarrow \sigma_{hj} = -26\,MPa$

$\sigma_{hi} = \frac{-64800}{60^2} - 18 \Rightarrow \sigma_{hi} = -36\,MPa$

for outer cyl

$P_r = \frac{B}{r^2} - A$

at $r = R_j$; $P_r = 10$ ⇒ $10 = \frac{B}{90^2} - A$ — (3)

$r = R_o$; $P_r = 0$ ⇒ $0 = \frac{B}{110^2} - A$ — (4)

from (3) & (4)

⇒ $B = 245025$

& $A = 20.25$

So, hoop stress

$\sigma_h = \frac{B}{r^2} + A$

$\sigma_{hj} = \frac{245025}{90^2} + 20.25$ ⇒ $\sigma_{hj} = 50.5$ MPa

$\sigma_{ho} = \frac{245025}{110^2} + 20.25$ ⇒ $\sigma_{ho} = 40.5$ MPa

Case 2 for internal pressure P_i

$P_r = \frac{B}{r^2} - A$

at $r = R_i$; $P_r = P_i$ ⇒ $60 = \frac{B}{60^2} - A$ — (5)

$r = R_o$; $P_r = 0$ ⇒ $0 = \frac{B}{110^2} - A$ — (6)

from eqn (5) & (6)

~~$B = 51247.0588$~~
~~$A = 4.2353$~~

$B = 307482.3529$

$A = 25.4117$

So, hoop stress

$\sigma_h = \frac{B}{r^2} + A$

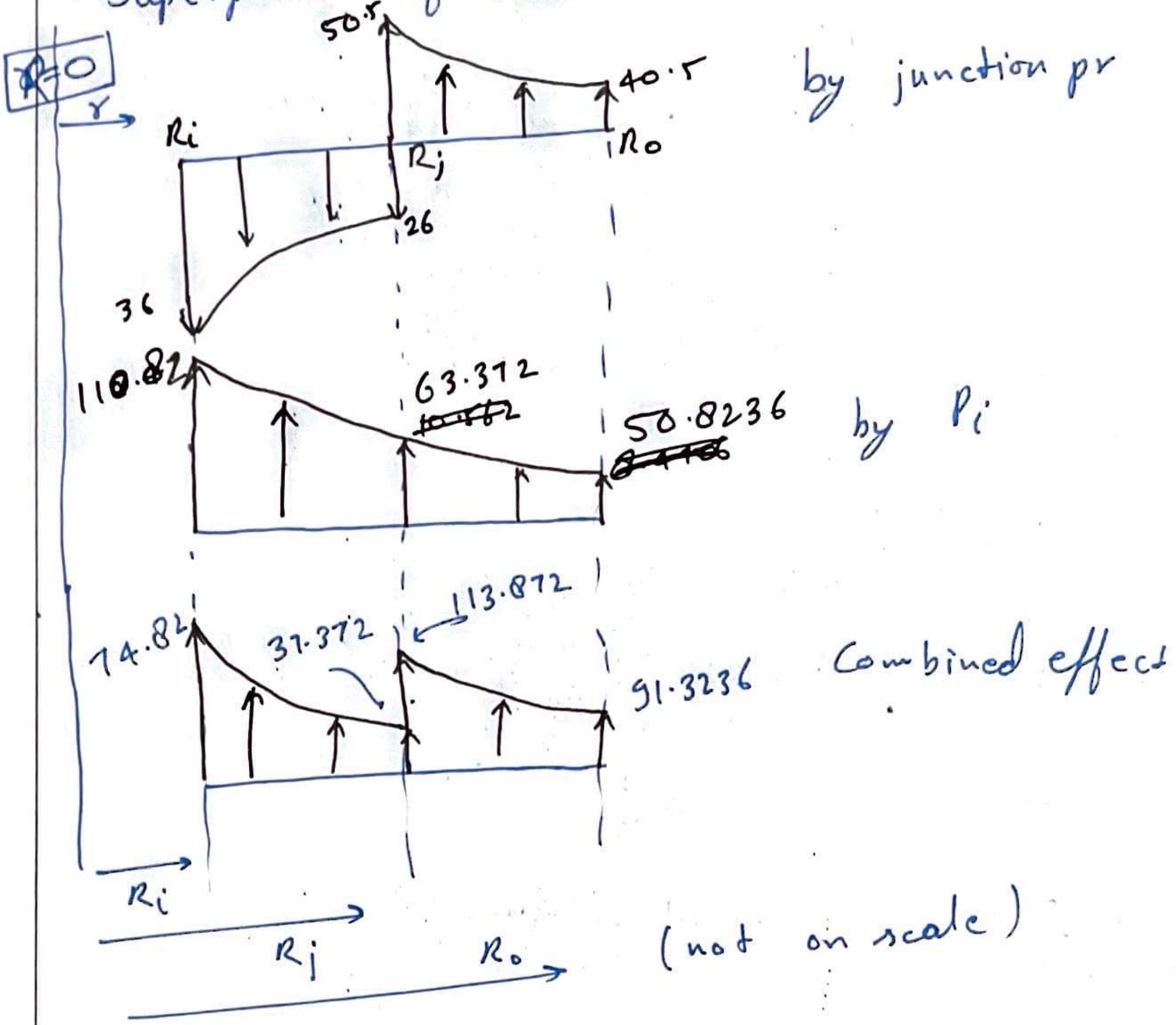
$\sigma_{hi} = \frac{51247.0588}{60^2} + 4.2353$ ⇒ $\sigma_{hi} = 110.823$ MPa

$\sigma_{hj} = \frac{B}{90^2} + A$ ⇒ $\sigma_{hj} = 63.372$ MPa

$\sigma_{ho} = \frac{B}{110^2} + A$ ⇒ $\sigma_{ho} = 50.8235$ MPa

Do not write in this margin

· Superposition of results



So, final stresses

$\sigma_{hi} = 74.823$ MPa

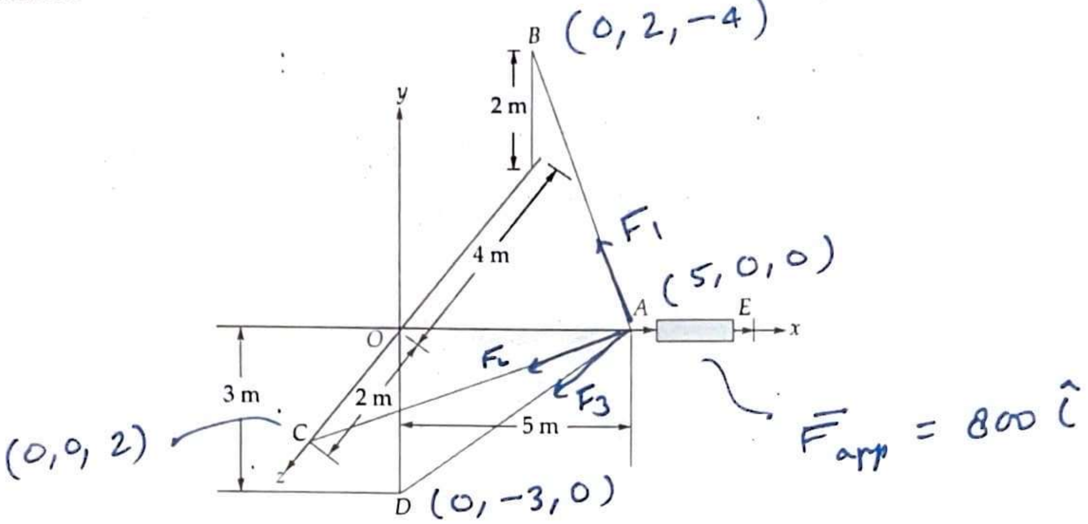
$(\sigma_{hj})_I = 37.372$ MPa

$(\sigma_{hj})_o = 113.872$ MPa

$\sigma_{ho} = 91.3236$ MPa

Ans

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]

- unit vector in AB dirⁿ

$$\hat{AB} = \frac{(0\hat{i} + 2\hat{j} - 4\hat{k}) - (5\hat{i} + 0\hat{j} + 0\hat{k})}{|\vec{AB}|}$$

$$\Rightarrow \hat{AB} = \frac{-5\hat{i} + 2\hat{j} - 4\hat{k}}{\sqrt{5^2 + 2^2 + 4^2}} \rightarrow 6.7082$$

$$\Rightarrow \boxed{\hat{AB} = -0.7454\,\hat{i} + 0.2981\,\hat{j} - 0.5962\,\hat{k}}$$

- $$\hat{AC} = \frac{(0,0,2) - (5,0,0)}{|\vec{AC}|} = \frac{(-5,\ 0,\ 2)}{\sqrt{25+4}}$$

$$\boxed{\hat{AC} = -0.9285\,\hat{i} + 0\,\hat{j} + 0.3714\,\hat{k}}$$

- $$\hat{AD} = \frac{(0,-3,0) - (5,0,0)}{|\vec{AD}|} = \frac{(-5,\ -3,\ 0)}{\sqrt{25+9}}$$

$$\Rightarrow \boxed{\hat{AD} = -0.8575\,\hat{i} - 0.5145\,\hat{j} + 0\,\hat{k}}$$

So, $\vec{F_1} = F_1 (\hat{AB})$

$\Rightarrow \vec{F_1} = [-0.7454\hat{i} + 0.2981\hat{j} - 0.5962\hat{k}] F_1$ — (1)

Similarily

$\vec{F_2} = [-0.9285\hat{i} + 0.3714\hat{k}] F_2$ — (2)

& $\vec{F_3} = [-0.8575\hat{i} - 0.5145\hat{j}] F_3$ — (3)

In equilibrium

$(\Sigma F)_{ext} = 0$

$\Rightarrow \vec{F_1} + \vec{F_2} + \vec{F_3} + \vec{F}_{app} = 0$

from above equ^n (1), (2) & (3)

In x dir^n →

$-0.7454 F_1 - 0.9285 F_2 - 0.8575 F_3 + 8\omega = 0$

$\Rightarrow 0.7454 F_1 + 0.9285 F_2 + 0.8575 F_3 = 8\omega$ — (4)

similarily in y-dir^n

$0.2981 F_1 - 0.5145 F_3 = 0$ — (5)

~~$\Rightarrow F_3 = 0.5794 F_1$~~

& z-dir^n — (6)

$-0.5962 F_1 + 0.3714 F_2 = 0$

from equ^n (4), (5) & (6)

$$\begin{bmatrix} 0.7154 & 0.9285 & 0.8575 \\ 0.2981 & 0 & -0.5145 \\ -0.5962 & 0.3714 & 0 \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} = \begin{bmatrix} 8\omega \\ 0 \\ 0 \end{bmatrix}$$

by solving →

Do not write in this margin

$$\begin{bmatrix} F_1 = 295.9966 \text{ kN} \\ F_2 = 475.1567 \text{ kN} \\ F_3 = 171.4997 \text{ kN} \end{bmatrix} \quad \underline{\underline{Am}}$$

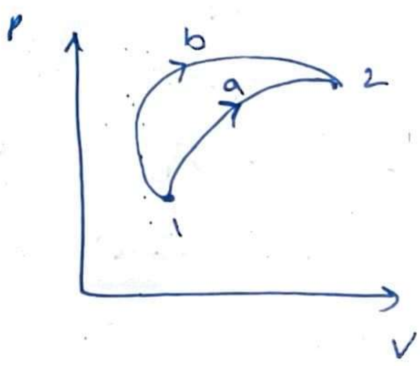
Q.6 (c) (i) Show that the first law of thermodynamics leads to the fact that heat interaction is a path function.

(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]

(i) Ist law of thermo

$$\boxed{\delta Q = dE + \delta W}$$



$\Rightarrow \quad \delta W = \delta Q - dE$

We know that for closed system $\delta W = \int p\, dV$

↳ i.e W = area under curve projected on volume axis for 1a2 & 1b2 Path work is not same ∵ area under curve is diff.

$\Rightarrow \quad W_{1a2} \neq W_{1b2}$

$\Rightarrow (\delta Q - dE)_{1a2} \neq (\delta Q - dE)_{1b2}$

but we know that internal energy is point fxn (path independent)

so $dE_{1a2} = dE_{1b2}$

$\Rightarrow \quad \delta Q_{1a2} - dE_{1a2} \neq \delta Q_{1b2} - dE_{1b2}$ ($dE_{1b2} = dE_{1a2}$)

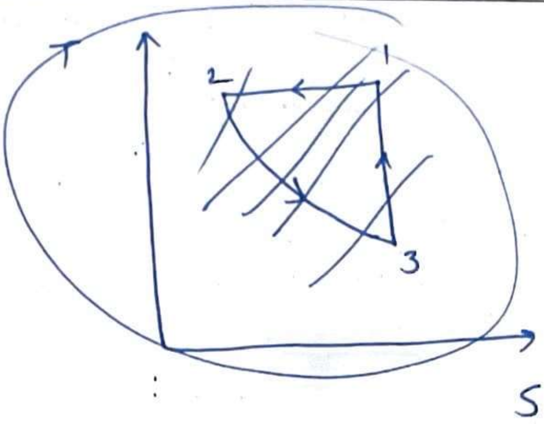
$\Rightarrow \quad \boxed{\delta Q_{1a2} \neq \delta Q_{1b2}}$ HP

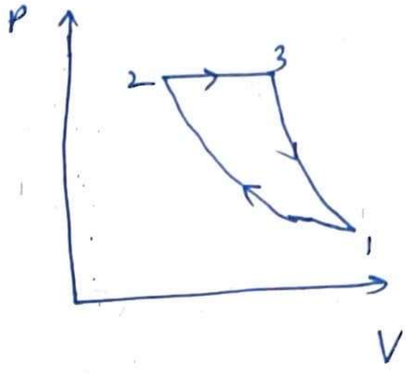
So the heat interaction is different for both the paths so Heat interaction will be a path fxn.

(ii)

PTO

(ii)





Given

$P_1 = 1$ bar $\quad T_1 = 300$ K $\quad v_2 = \frac{v_1}{5}$

$P_2 = 5$ bar $\quad T_2 = 300$ K

$P_3 = 5$ bar $\quad T_3 = 571.2065$ K

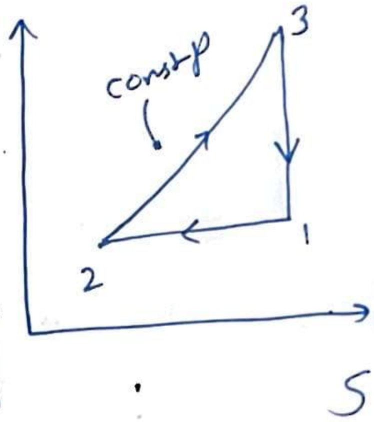
$C_p = 1.25$ kJ/kg K

$R = 0.5$ kJ/kg K

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

$\Rightarrow 1.25\gamma - 1.25 = 0.5\gamma$

$\Rightarrow \boxed{\gamma = 1.667}$



from,

$P_1 v_1 = R T_1$

$\Rightarrow v_1 = \frac{0.5 \times 300}{100} = \boxed{1.5 \text{ m}^3/\text{kg}}$

$\Rightarrow \boxed{v_2 = 0.3 \text{ m}^3/\text{kg}}$

Assumptions
① Gas is ideal
② 3-1 Reversible Adiabatic
③ closed system

Now for 1-2 const. T

$\frac{P_2}{P_1} = \frac{v_1}{v_2}$ (Boyle's law)

$\Rightarrow \boxed{P_2 = 5 \text{ bar}}$

for 2-3. const P so $P_3 = P_2 = 5$ bar

for 3-1 → isentropic (Assuming Reversible Adiabatic)

$$\frac{T_1}{T_3} = \left(\frac{P_1}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{300}{T_3} = \left(\frac{1}{5}\right)^{\frac{1.667-1}{1.667}}$$

$$\Rightarrow \boxed{T_3 = 571.2065\ K}$$ Ans

- So max cycle Temp $= T_3 = 571.2065\ K$
- & max cycle Pressure $= P_2 = P_3 = 5\ bar$ — Ans

Now Net work transfer = ?

$$W_{net} = W_{12} + W_{23} + W_{31}$$

$$= RT_1 \ln\left(\frac{P_1}{P_2}\right) + P(v_3 - v_2) + \frac{R(T_3 - T_1)}{\gamma - 1}$$

($P(v_3 - v_2) = R(T_3 - T_2)$)

$$= 0.5 \times 300 \ln\left(\frac{1}{5}\right) + 0.5(571.2065 - 300) + \frac{0.5(571.2065 - 300)}{1.667 - 1}$$

$$W_{net} = -241.4156 + 135.60325 + 203.40385$$

$$\boxed{W_{net} = 97.5915\ kJ/kg}$$ Ans

↳ net work transfer in cycle.

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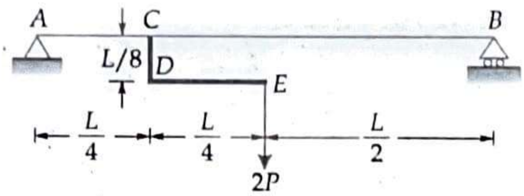
Q.7 (a) A rigid and insulated tank of volume 2.5 m^3 contains an ideal gas at 1 bar and 320 K. The tank is connected to a line carrying the same gas at 25 bar and 550 K. The valve in between the tank and the line is opened allowing the gas to enter the tank till the gas pressure in the tank rises to 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.

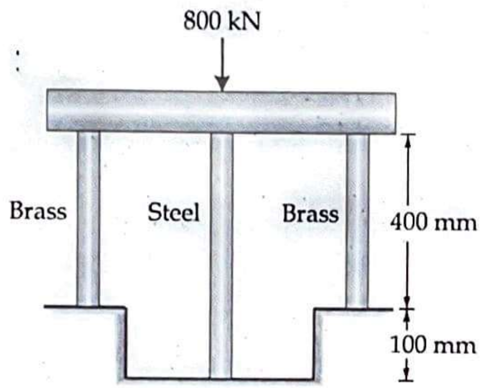
[Assume R = 0.287 kJ/kgK; c_p = 1.005 kJ/kgK and γ = 1.4 for ideal gas]

[20 marks]

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]

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]

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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.

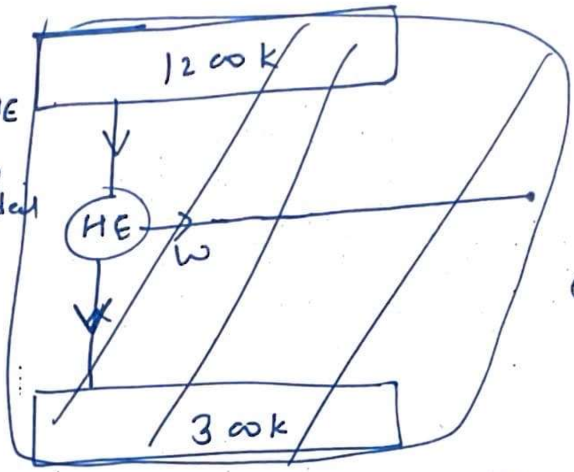
(ii) the rate of heat rejection from the heat pump if the rate of heat supply to the engine is 100 kW.

[20 marks]

Given

$\eta_{HE} = 0.4\,\eta_{CHE}$

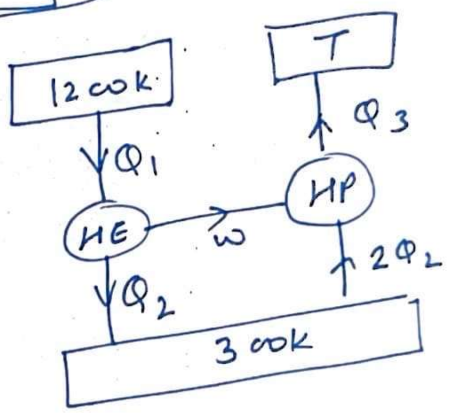
$COP_{HP} = 0.6\,COP_{ideal}$



from 1st law

$Q_1 = W + Q_2$ &

$Q_3 = W + 2Q_2$



(i) $\eta_{CHE} = 1 - \dfrac{300}{1200} = 0.74$

$\Rightarrow \boxed{\eta_{HE} = 0.3}$

$\eta_{HE} = \dfrac{W}{Q_1} = 0.3$

$\Rightarrow W = 0.3(W + Q_2)$

$\Rightarrow \boxed{W = \dfrac{3}{7} Q_2}$ —(1)

$(COP)_{HP} = 0.6 \times \dfrac{T}{T-300} = \dfrac{Q_3}{W}$

$\Rightarrow \dfrac{0.6T}{T-300} = 1 + \dfrac{2Q_2}{W} = 1 + 2 \times \dfrac{7}{3}$ (from equ^n (1))

$\Rightarrow \dfrac{0.6T}{T-300} = 1 + \dfrac{14}{3} = \dfrac{17}{3}$

$\Rightarrow \frac{180}{T-300} = \frac{17}{3}$

$\Rightarrow 17T - 5100 = 540$

$\Rightarrow \boxed{T = 331.76K}$

$1.8T = 17T - 5100$

$\Rightarrow 15.2T = 5100$

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

So the Temp. of resservior will be 335.526K to which the HP is rejecting heat.

(ii)

$Q_3 = ?$

Given

$Q_1 = 100\,kW$

Now, $\eta_{HE} = \frac{W}{Q_1} = 0.3$

$\Rightarrow \boxed{W = 30\,kW}$

for HP

$(COP)_{HP} = 0.6 \times \frac{335.526}{335.526 - 300} = \frac{Q_3}{W}$

$\Rightarrow \frac{Q_3}{W} = 5.6667$

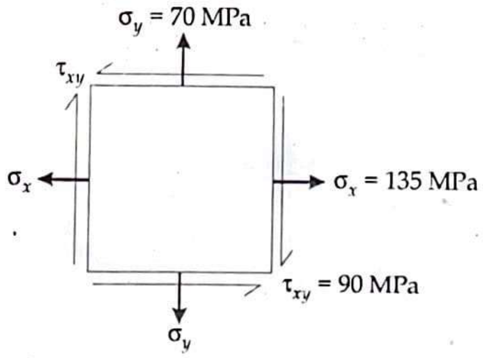
$\Rightarrow Q_3 = 5.6667 \times 30$

$\Rightarrow \boxed{Q_3 = 170.0013\,kW}$ Ans

So rate of Heat rejection from heat pump will be 170.0013 kW.

Do not write in this margin

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]

A-

Given

$\sigma_x = 135$ MPa

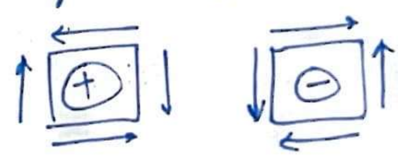
$\sigma_y = 70$ MPa

$\tau_{xy} = +90$ MPa

Sign conv

σ — Tensile = +ve; Comp = −ve

τ —



(i) We know that

$$\sigma_{1,2} = \frac{\sigma_x+\sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\Rightarrow \sigma_{1,2} = \frac{135+70}{2} \pm \sqrt{\left(\frac{135-70}{2}\right)^2 + 90^2}$$

$$\Rightarrow \sigma_{1,2} = 102.5 \pm 95.6883$$

$$\Rightarrow \boxed{\sigma_1 = 198.1883 \text{ MPa}}$$

& $\boxed{\sigma_2 = 6.8117 \text{ MPa}}$ Ans

- $\tan 2\theta_p = \frac{2\tau_{xy}}{\sigma_x - \sigma_y} = \frac{2\times 90}{135-70}$

$$\Rightarrow \tan 2\theta_p = 2.7692$$

$$\Rightarrow \boxed{\theta_{p_1} = 35.072^\circ} \ \& \ \boxed{\theta_{p_2} = 90+\theta_{p_1} = 125.072^\circ}$$

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

$$\Rightarrow \sigma_n = 102.5 + 32.5\times\cos(2\times 35.072) + 90\sin(2\times 35.072)$$

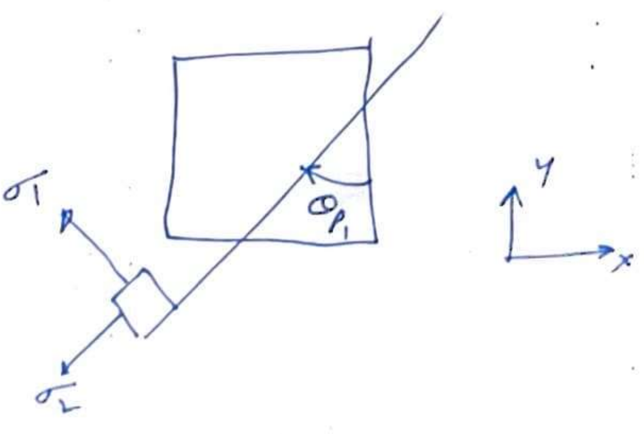
$$\Rightarrow \sigma_n = 198.188 \text{ MPa}$$

$\Rightarrow$ Major principal stress

$\sigma_1 = 198.1883$ MPa at $\theta_{p_1} = 35.072^\circ$

& Minor $\sigma_2 = 6.8117$ MPa at $\theta_{p_2} = 125.072^\circ$

} from vertical face ($x\rightarrow$) in cw dir^n



(ii) $\tau_{max} = \frac{\sigma_1 - \sigma_2}{2} \Rightarrow \boxed{\tau_{max} = 95.6083\ MPa}$

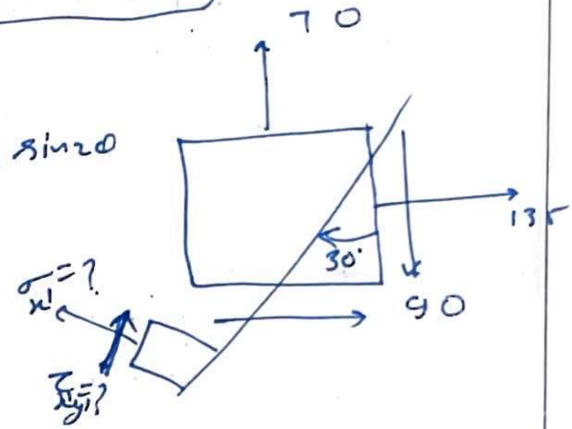
In plane

& $\theta_s = \theta_p + 45°$

$\Rightarrow \boxed{\theta_s = 80.072°}$ Ans

$(\tau_{max})_{abs} = \frac{\sigma_1 - 0}{2} = \boxed{99.0941\ MPa}$

(iii) $\sigma_{x'} = \frac{\sigma_x + \sigma_y}{2} + \left(\frac{\sigma_x - \sigma_y}{2}\right)\cos 2\theta + \tau_{xy} \sin 2\theta$



$\Rightarrow \sigma_{x'} = 102.5 + 32.5 \cos 60° + 90 \sin 60°$

$\Rightarrow \boxed{\sigma_{x'} = 196.6922\ MPa}$ Ans (Tensile)

$\tau_{x'y'} = -\left(\frac{\sigma_x - \sigma_y}{2}\right)\sin 2\theta + \tau_{xy} \cos 2\theta$

$\Rightarrow \tau_{x'y'} = -32.5 \sin 60° + 90 \cos 60°$

$\Rightarrow \boxed{\tau_{x'y'} = 16.8542\ MPa}$ Ans (cw)

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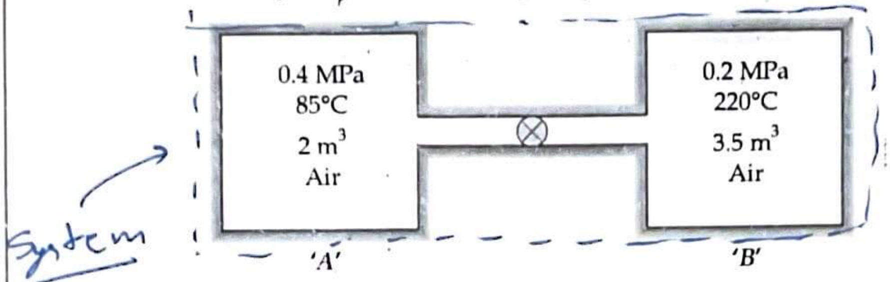
Q.8 (c) Two vessels, *A* and *B* of volume 2 m^3 and 3.5 m^3 respectively, are connected by a tube of negligible volume through a valve as shown below. Vessel *A* contains air at 0.4 MPa, 85°C while vessel *B* contains air at 0.2 MPa, 220°C. Determine the total change of entropy, when the valve is opened 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]

Find $\Delta S = ?$

Before mixing

for vessel A

$$m_A = \frac{P_A V_A}{R\, T_A}$$

$$\Rightarrow m_A = \frac{400 \times 2}{0.287 \times 358}$$

$$\Rightarrow \boxed{m_A = 7.7862\,kg}$$

for vessel B

$$m_B = \frac{200 \times 3.5}{0.287 \times 493}$$

$$\Rightarrow \boxed{m_B = 4.9473\,kg}$$

Assumptions

① Air ~~is~~ work as an ideal Gas.

② final volume of air will be V_T for each ~~vess~~ vesells air

After mixing

$$m_{final} = m_A + m_B$$

$$\Rightarrow \boxed{m_T = 12.7335\,kg}$$

$$V_T = V_A + V_B$$

$$\Rightarrow \boxed{V_T = 5.5\,m^3}$$

$$P_f V_f = m_f R T_f$$

$$\Rightarrow P_f = \frac{12.7335 \times 0.287 \times T_f}{5.5}$$

$$\Rightarrow \boxed{P_f = 0.6645\,T_f} \quad \text{— ①}$$

from 1st law for entire system

$\cancel{Q}^{0} = \Delta U + \cancel{W}^{0}$ ($W = 0$ ∵ no work done, $Q = 0$ ∵ adiabatic)

$\Rightarrow \Delta U_A + \Delta U_B = 0$

$m_A c_v (T_f - T_A) + m_B c_v (T_f - T_B) = 0$

$\Rightarrow 7.7862(T_f - 358) + 4.9473(T_f - 493) = 0$

$\Rightarrow 12.7335\, T_f = 5226.4785$

$\Rightarrow \boxed{T_f = 410.45\,K}$

from eqn (1) $\boxed{P_f = 272.7447\,kPa}$

• $(\Delta S)_A = m_A\left[C_V \ln \frac{T_F}{T_A} + R \ln\left(\frac{V_T}{V_A}\right)\right]$

$= 7.7862\left[0.717 \ln \frac{410.45}{358} + 0.287 \ln \frac{5.5}{2}\right]$

$\Rightarrow \boxed{(\Delta S)_A = 3.0238\ kJ/K}$

• $\Delta S_B = 4.9473\left[0.719 \ln\left(\frac{410.45}{493}\right) + 0.287 \ln \frac{5.5}{3.5}\right]$

$\Rightarrow \boxed{\Delta S_B = -0.0101\ kJ/K}$

So total change of entropy

$(\Delta S)_{Total} = (\Delta S)_A + (\Delta S)_B + \cancel{(\Delta S)_{surr}}^{0}$

$\Rightarrow \boxed{(\Delta S)_T = 3.0137\ kJ/K}$ Ans

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	0.00110316	0.29951	679.12	2568.5	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	0.00111554	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	2791.4	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	6.2341	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	0.068943	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	6.1845	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	6.1564	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