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ESE 2023 : 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**
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	44
Q.2	34
Q.3	0
Q.4	8
Section-B	
Q.5	48
Q.6	38
Q.7	0
Q.8	0
Total Marks Obtained	172

Signature of Evaluator ....

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IMPORTANT INSTRUCTIONS

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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 :

1. Support your answers with logical conclusions
2 Use proper statements and avoid short forms
3 Improve handwriting and represe-ntation

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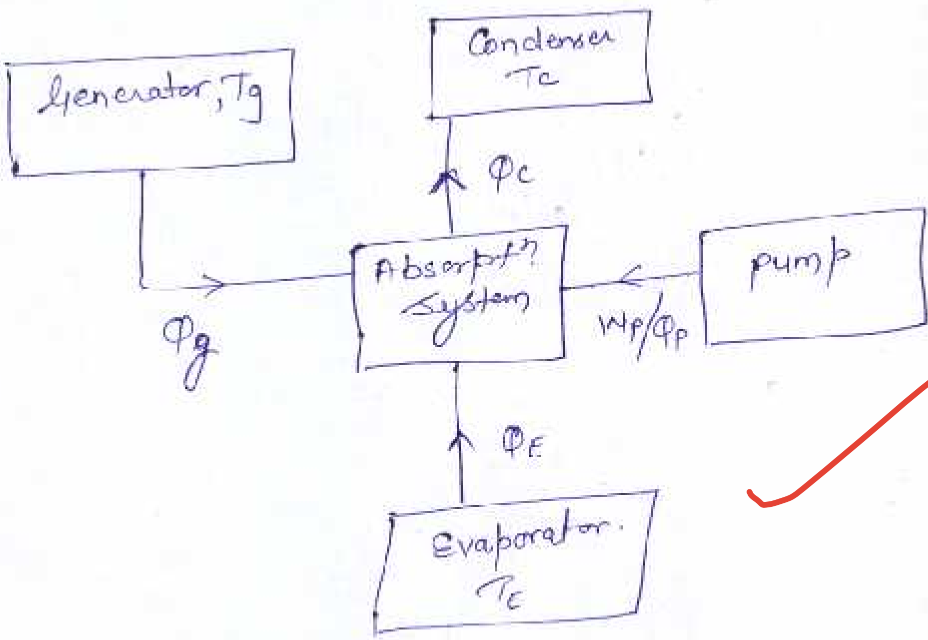
Section : A

Q.1 (a) **(i)** Derive the expression of COP of an ideal vapour absorption refrigeration system.

(ii) In an absorption type refrigerator, the heat is supplied to NH_3 generator by condensing 75% dry steam at 1.6 bar. The temperature in the refrigerator is to be maintained at -7°C. Find maximum COP possible. Take saturation temperature of steam at a pressure of 1.6 bar is 113.3°C and atmospheric temperature is 30°C.

[8 + 4 = 12 marks]

i).



$$Q_g + W_p + Q_E = Q_c$$

[∵ pump work $W_p \simeq 0$]

$$Q_g + Q_E = Q_c \quad \text{—— (I)}$$

$$\frac{Q_g}{T_g} + \frac{Q_E}{T_E} = \frac{Q_c}{T_c} \quad \text{—— (II)}$$

$$\frac{Q_g}{T_g} + \frac{Q_E}{T_E} = \frac{Q_g}{T_c} + \frac{Q_E}{T_c}$$

$$\phi_g\left[\frac{1}{T_g}-\frac{1}{T_c}\right] = \phi_E\left[\frac{1}{T_c}-\frac{1}{T_E}\right] \longrightarrow (11)$$

COP of Absorptⁿ System $= \dfrac{\phi_g}{\phi_E + \cancel{w_p}}$ →0

$$(COP)_{actual} = \frac{\phi_g}{\phi_E}$$

$$COP = \frac{\phi_g}{\phi_E} = \frac{\dfrac{(T_E - T_c)}{\cancel{T_c}\,T_E}}{\dfrac{(T_c - T_g)}{T_g\,\cancel{T_c}}}$$

$$\boxed{(COP)_{max} = \frac{T_g\,(T_E - T_c)}{T_E\,(T_c - T_g)}}$$

ii) Given data $T_E = -7^\circ C = 266\,K$

$T_0 = T_c = 30^\circ C = 303\,K$

$T_g = 386.3\,K$

10/12

$$(COP)_{max.} = \frac{T_g (T_E - T_c)}{T_E (T_c - T_g)}$$

$$= \frac{386.3 (266 - 303)}{266 (303 - 386.3)}$$

$$(COP)_{max.} = 0.64505$$

Q.1 (b) A 10 mm radius mild steel sphere is exposed to cooling airflow at 27°C. If the convective heat transfer coefficient is 114 W/m^2K then, calculate

(i) time required to cool the sphere from 520°C to 120°C.

(ii) instantaneous heat transfer rate 2 minutes after the start of cooling.

(iii) total energy transferred from the sphere during the first 2 minutes. The relevant properties of mild steel are: density ρ = 7850 kg/m^3; thermal conductivity, k = 42.5 W/mK; specific heat, c = 475 J/kgK, and thermal diffusivity, α = 0.043 m^2/hr

[12 marks]

Ans:

Given data :- Sphere mild steel ball

$R = 10\,mm$

$T_\infty = 27^\circ C$

$L_c = \frac{V}{A} = \frac{R}{3}$

$h = 114\ W/m^2K$; $\rho = 7850\ kg/m^3$

$k = 42.5\ W/mK$ & $C = 475\ J/kg\,K$

$$Bi = \frac{hL_c}{K} = \frac{114 \times R}{3 \times 42.5} = \frac{114 \times 0.01}{3 \times 42.5}$$

$$= 8.94 \times 10^{-3} < 0.1$$

∴ Lumped Analysis is applicable for this process.

i)

$$\frac{T - T_\infty}{T_i - T_\infty} = e^{-\frac{hA}{\rho V C_p} \times t}$$

$$\frac{120 - 27}{520 - 27} = e^{-\frac{114 \times 3}{7850 \times 0.01 \times 475} \times t}$$

$t = 181.8484$ seconds

ii)

$$-mc\frac{dT}{dt} = hA(T_0 - T_\infty)$$

$$-mc\frac{dT}{dt} = hA(T - T_\infty)$$

$t = 2\times60 = 120$ seconds

$$\dot{Q}_{stored} = mc\frac{dT}{dt}$$

$$= \rho \times \frac{4}{3}\pi(0.01)^3 \times 475 \times \frac{(400)}{120}$$

$$= 52.063 \text{ W}$$

iii)

$$\frac{T-27}{T_i-27} = e^{-\frac{114\times3}{7850\times0.01\times475}\times2\times60}$$

$$\frac{T-27}{T_i-27} = 0.33267$$

$$T - T_\infty = 164.006 \text{ K.}$$

$$Q_{conv.} = hA(T-T_\infty)$$

$$= 114\times4\pi\times(0.01)^2\times(T-T_\infty)$$

$$= 23.494 \text{ W.}$$

Total Energy transfered from sphere.

$$Q_{Total} \Rightarrow Q_{stored} + Q_{conv.}$$

$$Q_t \Rightarrow 75.557 \text{ W}$$

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Q.1 (c) Briefly discuss thermodynamic, physical and chemical properties of good refrigerant.

[12 marks]

Ans:- Thermodynamic & thermo-physical properties of a good refrigerant are given below:-

i) Critical temperature should have be High as possible.

ii) The Refrigerant of the critical pressure is also have as High as possible.

iii) The freezing point of a refrigerant as low.

iv) The latent heat of vaporization should have as high.

v) The specific heat of liquid as low bcz. the subcooled of refrigerant is High whereas the specific heat of Vapour as High bcz. the superheated of refrigerant is low possible.

vi) The Refrigerant are non-toxicity & Non-flammable.

vii) As economical purpose the refrigerants are cheap & easily available in market.

viii) As environment purpose

↳ a) ozone deflection :- In (Cl & Br) Components are Minimum.

b) Misibility

c) Global warming

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Q.1 (d) Calculate the shape factors 'F_{12}' and F_{21}' for the configurations shown in the figure given below:

(i) Sphere of diameter of d inside a cubical box of length $l = d$.

(ii) Hemispherical surface closed by a plane surface.

(iii) End and side of circular tube of equal length and diameter [Take $F_{13} = 0.17$]

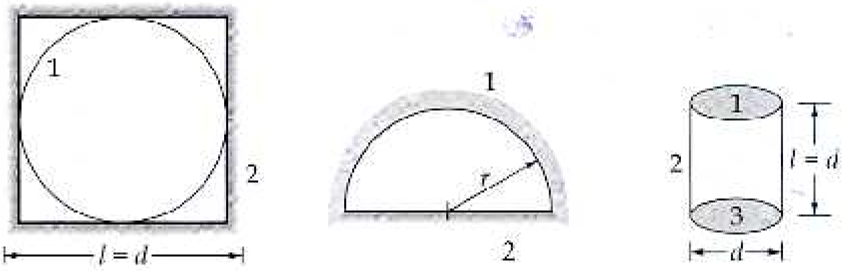
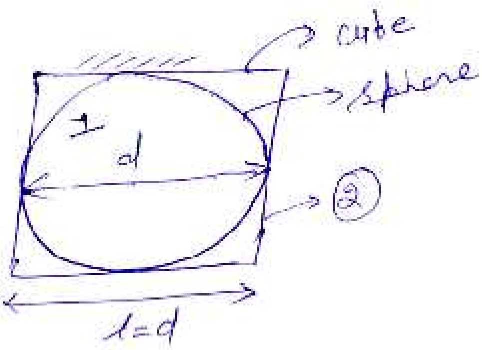


Fig (a) Fig (b) Fig (c)

[12 marks]

i)



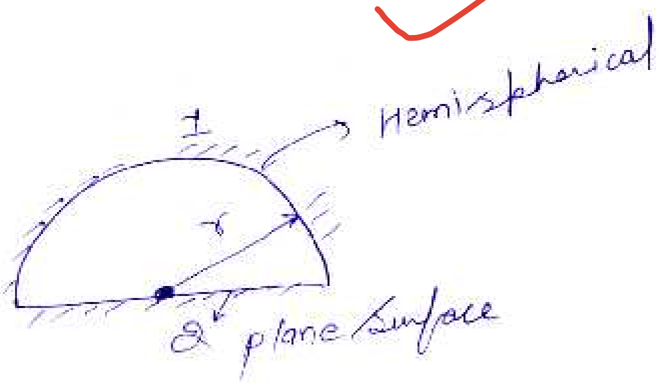
$F_{12} = 1$

By Reciprocal theorem :-

$F_{12} A_1 = F_{21} A_2$

$F_{21} = F_{12} \frac{A_1}{A_2} = 1 \times \frac{\pi d^2}{6(d^2)} = \pi/6$

ii)



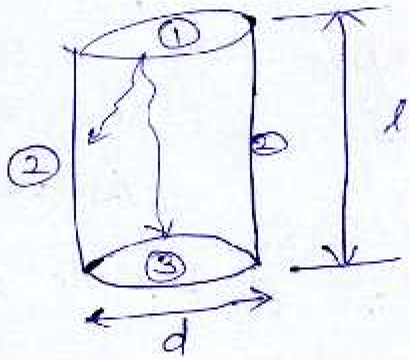
$F_{22} + F_{21} = 1$

$F_{22} = 0$

$F_{21} = 1$

$$F_{12} = \frac{F_{21} A_2}{A_1} = \frac{\pi (r)^2}{2\pi r^2} = 0.5$$

iii)



given that data.

$F_{13} = 0.17$

plane surface

$$F_{11} + F_{12} + F_{13} = 1 \quad [\because F_{11} = 0]$$

$$F_{12} + 0.17 = 1$$

$$F_{12} = 1 - 0.17 = 0.83$$

$$F_{21} = \frac{F_{12} A_1}{A_2} = \frac{0.83 \times \pi/4\, d^2}{\pi d (d)}$$

$$= \frac{0.83 \times 1}{4}$$

$$= \underline{0.2075}$$

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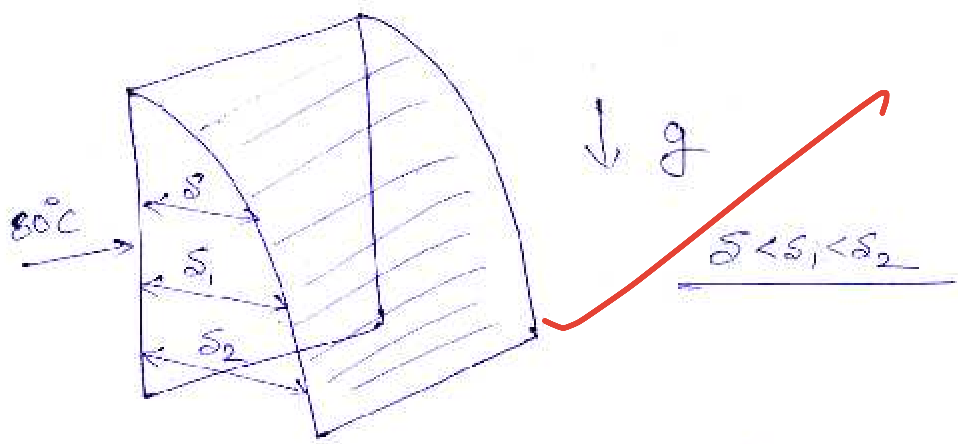
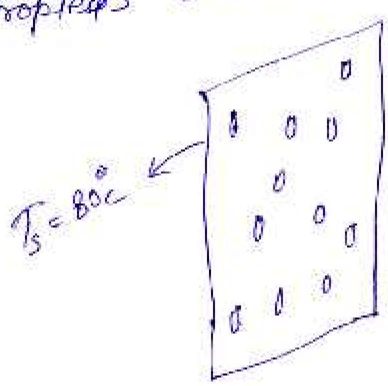
Q.1 (c) Explain briefly the mechanism of filmwise and dropwise condensation. Which type has a higher heat transfer film coefficient?

[12 marks]

Ans:- The mechanism of filmwise & dropwise Condensation in Heat transfer. In filmwise Condensation the flowing fluid in Continous in the form of film. The thickness of film will have to be increased in drop side by effect of gravity flow.



In Case of dropwise Condensation the flowing fluid instead of Continous flow the droplets are created on the surface.



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In surface of solid plate oil 4 Coated for ~~film~~ dropwise Condensation.

As per know Condensation for the sufrace temperature T_s is less than saturation temperature T_{sat}.

The Heat transfer is almost 10 times greater in dropwise Condensation as Compare to filmwise Condensation.

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Q.2 (a) A counter-flow, concentric tube heat exchanger is used to cool the lubricating oil for a large industrial gas turbine engine. The flow rate of cooling water through the inner tube (d_i = 25 mm) is 0.2 kg/s, while the flow rate of oil through the outer annulus (d_o = 50 mm) is 0.15 kg/s. The inlet and outlet temperatures of oil are 95°C and 65°C, respectively. The water enters at 30°C to the exchanger. Neglecting tube wall thermal resistance, fouling factors and heat loss to the surroundings, calculate the overall heat transfer coefficient and length of the tube. [Assume uniform temperature along the inner surface of annulus].

Take the following properties at the bulk mean temperature:

Engine oil at 80°C : c_p = 2131 J/kg°C; μ = 0.0325 N-s/m², k = 0.138 W/m°C

Water at 35°C : c_p = 4174 J/kg°C; μ = 725 × 10^{-6} N-s/m², k = 0.625 W/m°C, Pr = 4.85

[20 marks]

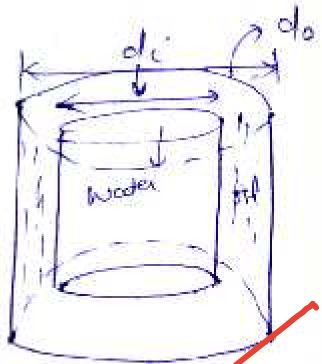
Given data :-

$\dot{m}_c = 0.2$ kg/s

$d_i = 25$ mm $T_{ci} = 30°C$

$d_o = 50$ mm $\dot{m}_h = 0.15$ kg/s

$T_{hi} = 95°C$ $T_{he} = 65°C$



$$\dot{m}_h \times C_h \times (T_{hi} - T_{he}) = \dot{m}_c \times C_c \times (T_{ce} - T_{ci})$$

$$0.15 \times 2131 \times (95 - 65) = 0.2 \times 4174 \times (T_{ce} - 30)$$

$$T_{ce} = 41.487°C$$

Assumptions.

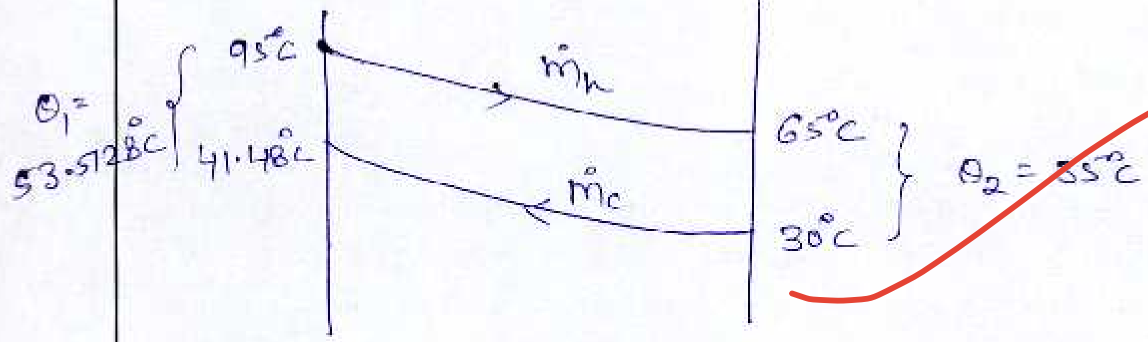
i) Neglecting tubewall thermal Resistance.

ii) fouling factor also Neglected

iii) $\phi_{surround} \simeq 0$

(iv) flow is Counter-flow Heat Exchanger.

Write in statements



$$\theta_m = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)} = \frac{18.5728}{0.4245}$$

$$= 43.603\,°C$$

$$\phi = UA\,\theta_m$$

$$0.2 \times 4174 \times (41.487 - 30) = U \times A \times \theta_m$$

$$9589.3476 = UA\theta_m$$

$$UA = 219.924$$

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Area of Annulus. $\frac{\pi}{4} \times (d_o^2 - d_i^2)$

$$A = \frac{\pi}{4} \times \left[0.05^2 - 0.025^2\right]$$

$$A = 1.4726 \times 10^{-3}\ m^2$$

Q.2 (b) An ammonia ice plant operates between a condensor temperature of 35°C and an evaporator temperature of –15°C. It produces 12 tons of ice per day from water at 35°C to ice at –7°C. Assuming simple saturation cycle. Using only tables of properties of ammonia, determine:

(a) the capacity of the refrigeration plant.

(b) the mass flow rate of refrigerant.

(c) the discharge temperature.

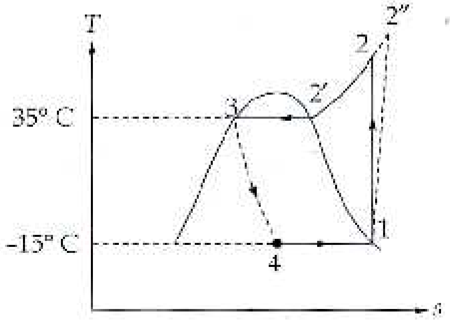
(d) the compressor cylinder diameter and stroke, if it's volumetric efficiency is $\eta_v = 0.7$, $N = 1500$ rpm and stroke/bore ratio $\frac{L}{D} = 1.3$.

(e) the horse power of the compressor motor, if the adiabatic efficiency of the compressor $\eta_a = 0.82$ and mechanical efficiency $\eta_m = 0.95$.

(f) the theoretical and actual COP.

Take $(c_p)_{water} = 4.1868$ kJ/kgK; $(c_p)_{ice} = 1.94$ kJ/kgK, $(LH)_{ice} = 335$ kJ/kg

[Use Ammonia Refrigerant Table, attached at the end]



[20 marks]

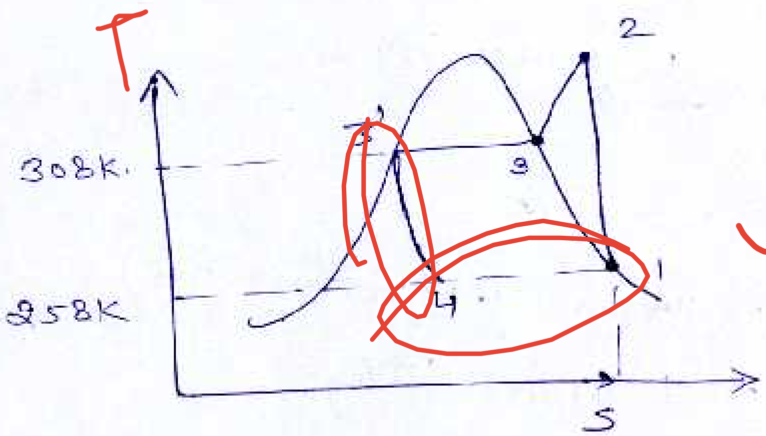
Ans:-

$T_C = 35°C = 308K$

$T_E = -15°C = 258K$

$$R.E = \frac{12 \times 10^3}{24 \times 3600}\left[4.1868 \times 35 + 335 + 7 \times 1.94\right]$$

$R.C = 68.7663$ kJ/s (kW)



$s_1 = s_2 = 5.8223$ kJ/kgK.

$s_3 = 5.2086$

$h_3' = h_4 = 366.1$ kJ/kg.

$h_1 = 1443.9$ kJ/kg.

$R.E = h_1 - h_4 = 1077.8$ kJ/kg.

$\dot{m}_R \times R.E = R.C$

$\dot{m}_R = 0.0638$ kg/s.

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$$s_2 = s_3 + C_{pv} \ln\left(\frac{T_2}{T_3}\right)$$

$$5.8223 = 5.2086 + C_{pv} \ln\left(\frac{T_2}{308}\right)$$

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Assume (NH_3) $C_{pv} = 1.9$

$$0.323 = \ln\left(\frac{T_2}{308}\right)$$

$$T_2 = 425.429 \text{ K}$$

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

$$h_2 = 1488.6 + 1.9(425.429 - 308)$$

$$h_2 = 1711.7151 \text{ kJ/kg}$$

$$v_1 = 0.508 \text{ m}^3/\text{kg}$$

$$\dot{V}_a = \frac{\pi}{4} D^2 L \times \frac{N}{60} \times \eta_v$$

$$v_1 \times \dot{m}_R = \frac{\pi}{4} \times D^2 \times 1.3D \times \frac{1500}{60} \times 0.7$$

$$0.0324 = \frac{\pi}{4} D^3 \times 1.3 \times \frac{1500}{60} \times 0.7$$

$$D = 0.1219 \text{ m}$$

$$L = 0.1585 \text{ m}$$

power = $h_2 - h_1$ = 1711.7157 − 1443.9
⇒ 267.8157 kJ/kg

R.E = $h_1 - h_4$ ⇒ 1077.8 kJ/kg

$(COP)_{actual} = \frac{R.E}{W_{in}}$ = 4.0244 ✗

The Horse power of Compressor ⇒ $\frac{(h_2 - h_1)}{\eta_c} \times \eta_m$

$\frac{0.0638 \times 310.273 \text{ kJ/kg}}{746}$

$(H.P)_{comp}$ = 26.535 H.P ✗

$(COP)_{theor} = \frac{T_L}{T_H - T_L} = \frac{258}{50} = 5.16$ ✗

Q.2 (c) An air-cooling system for a jet plane cockpit operates on the simple aircraft refrigeration cycle. The cockpit is to be maintained at 27°C. The ambient air pressure and temperature are 0.34 bar and −17°C respectively. The pressure ratio of the jet compressor is 4 and compressor efficiency is 0.85. The plane speed is 1200 kilometers per hour. The pressure drop through the cooler coil is 0.15 bar. The pressure of the air leaving the cooling turbine is 1.05 bar and that in the cockpit is 1.01325 bar. The cockpit cooling load is 62.05 kW. Calculate:

(a) Stagnation temperature and pressure of the air entering the compressor.

(b) Mass flow rate of the air circulated.

(c) Volume handled by the compressor and expander.

(d) Net power delivered by the engine to the refrigeration unit.

(e) COP of the system.

[20 marks]

Ans:-

Given data.

$P_1 = 0.34$ bar $\quad T_1 = -17°C = 256 K$

$r_p = 4 \quad \eta_c = 0.85$

$V = 1200 \ km/hr = 1200 \times 5/18 = 333.33 \ m/s$

$P_2 = 1.36$ bar

$P_3 = 1.36 - 0.15$

$P_3 = 1.21$ bar

$$\frac{T_{2s}}{T_1} = (4)^{2/7} = 1.4859$$

$T_{2s} = 380.414 K$

$$T_{01} = T_1 + \frac{V^2}{2C_p}$$

$$T_{01} = 256 + \frac{(333.33)^2}{2 \times 1005} = 311.278 K$$

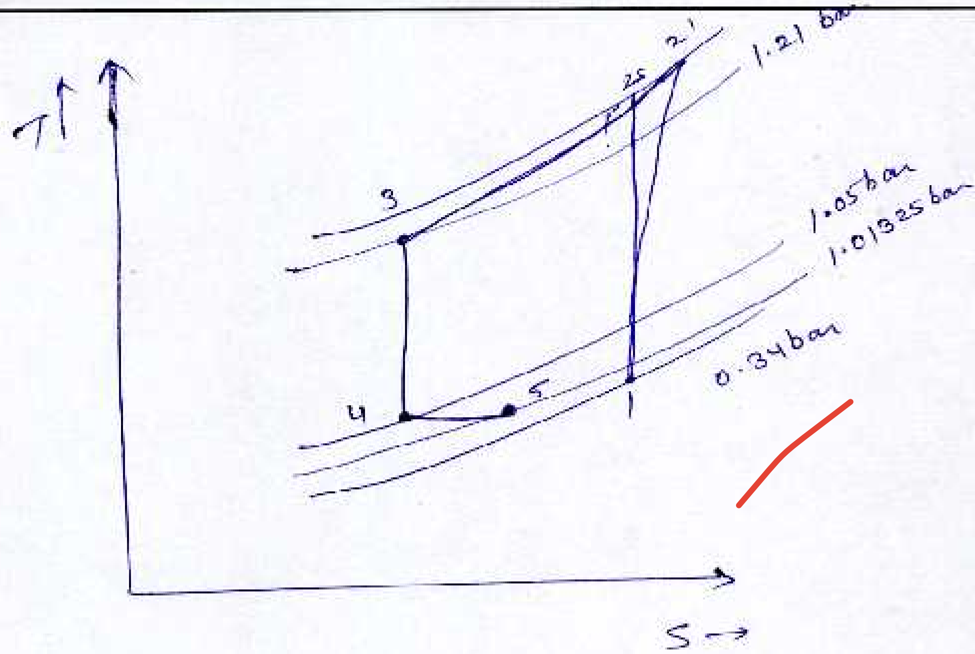
$$\frac{P_{01}}{P_1} = \left(\frac{T_{01}}{T_1}\right)^{\gamma/\gamma-1}$$

$P_{01} = 0.6739$ bar

$$T_2 - T_1 = \frac{T_{2s} - T_1}{\eta_c}$$

$T_2 = 402.369 K$

10/20



Cockpit Cooling load = 62.05 kW.

$62.05 = \dot{m}_a \times ($

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Q.3 (a) A sheet metal air duct carries air-conditioned air at an average temperature of 10°C. The duct size is 300 mm × 150 mm and length of duct exposed to the surrounding air at 30°C is 15 m long. Calculate the heat gain by the air in the duct. Assume 150 mm side is vertical and top surface of the duct is insulated. Use the following properties:

$Nu = 0.6\,(Gr \cdot Pr)^{0.25}$ for vertical surface

$Nu = 0.27(Gr \cdot Pr)^{0.25}$ for horizontal surface

Take the properties of the air at mean temperature of 20°C as given below:

$c_p = 1000$ J/kgK; $\rho = 1.204$ kg/m^3, $\mu = 18.2 \times 10^{-6}$ Pa.s ; $\nu = 15.1 \times 10^{-6}$ m^2/s;

$k = 0.256$ W/mK and $Pr = 0.71$

[20 marks]

Q.3 (b) A theatre of 1600 seating capacity is to be air-conditioned for winter conditions when the following data is known:

Outdoor conditions = 12°C and 60% RH

Required comfort condition = 20°C and 60% RH

Amount of free air supplied = 0.30 m^3/min/person

The required condition is achieved by the heating, adiabatic humidifying and the again heating. The air coming out of the humidifier has 80% RH then find following:

(a) Heating capacity of the first heater in kW and condition of the air coming out of the heating coil. Also find the surface temperature of the coil if the bypass factor is 0.35.

(b) The capacity of the humidifier.

(c) Heating capacity of second heater in kW and the bypass factor if the surface temperature of the coil is maintained at 26°C.

[Use Psychrometric Chart]

[20 marks]

Q.3 (c) An internally cooled copper conductor of 5 cm outer radius and 2 cm inner radius carries a current density of 5000 amp/cm². A constant temperature of 90°C is maintained at the inner surface and there is no heat transfer through insulation surrounding the copper. Derive an equation for temperature distribution through copper. Proceed to calculate the maximum temperature of copper and the radius at which occurs. Also find the internal heat transfer rate per unit length in the conductor.

For copper: Thermal conductivity k = 380 W/mK; resistivity, $\rho = 2 \times 10^{-8}$ Ωm.

[20 marks]

Ans:-

$$\dot{q}_g = \frac{P}{V} = \frac{I^2 R}{AL} = \frac{I^2 \times \rho \cancel{L}}{A^2 \times \cancel{L}}$$

$$\dot{q}_g = J^2 \rho = \left(\frac{5000}{10^{-4}}\right)^2 \times 2 \times 10^{-8} = 5 \times 10^{7} \text{ W/m}^3$$

Given data $J = 5000$ A/cm²

$\rho = 2 \times 10^{-8}$ Ωm

$R_i = 2$ cm

$R_o = 5$ cm.

$k = 380$ W/mK.

$T_{o,i} = 90°C$

$\dot{Q} = \dot{Q}_o + \dot{q}_g$

8/20

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right) + \frac{\dot{q}_g}{k} = 0$$

$$\frac{d}{dr}\left(r\frac{dT}{dr}\right) + \frac{\dot{q}_g r}{k} = 0$$

$$\frac{dT}{dr} + \frac{\dot{q}_g r}{2K} = \frac{C_1}{r}$$

$$T = -\frac{\dot{q}_g r^2}{4K} + C_1 \ln r + C_2$$

$r = 0$ $\frac{dT}{dr} = 0 \Rightarrow C_1 = 0$

$$T = -\frac{\dot{q}_g r^2}{4K} + C_2$$

$r = 2\,cm$ $T_i = 90°C$

$$90° = -\frac{5\times10^7 \times (0.02)^2}{4\times380} + C_2$$

$$C_2 = 103.157$$

$$T = \frac{-\dot{q}_g (0.05)^2}{4\times380} + 103.157$$

$$T_{r=0.05m} = 185.3938\ °C$$

Q.4 (a) The cylinder head of an engine is 1.5 m long and has an outside diameter of 40 mm. Under typical operating conditions, the outer surface of the head is at a temperature of 180°C and is exposed to ambient air at 40°C with a convective coefficient of 80 kJ/m^2hrdeg. The head has been provided with 12 longitudinal straight fins which are 0.75 mm thick and protrude 3.5 cm from the cylindrical surface. It may be presumed that the fins have insulated tips and that the thermal conductivity of the cylinder head and fin material is 260 kJ/m-hr-deg. Calculate the increase in heat dissipation per unit width due to addition of fins. Also calculate the temperature at the centre of the fin.

[20 marks]

Q.4 (b) **(i)** A heat pump system is designed to maintain the temperature of 30°C in an office when the surrounding air temperature is 7°C. The heat pump has to supply 6500 kJ/min. The heat pump is coupled to an engine. The heat supplied to the engine at 1000°C. The actual COP of the heat pump is 65% of ideal and the actual efficiency of the engine is 50% of the ideal. Determine

(a) Heat supplied to the engine

(b) Overall COP of the system

(c) Work produced by the engine

(ii) A dense air refrigeration machine operates on reversed Brayton cycle and is used for 12 tonnes refrigeration capacity. The cooler pressure is 3.9 bar and refrigerator pressure is 1.3 bar. The air is cooled in cooler to a temperature of 52°C and the temperature of air at inlet to the compressor is –22°C.

For ideal cycle, determine the following

(a) COP of the system

(b) Mass of air circulated per minute

(c) Theoretical piston displacement of the compressor

(d) Net power per ton of refrigeration.

Show the cycle on p-v and T-s diagram.

Take c_p = 1.05 kJ/kg-K [For dense air]

[10 + 10 marks]

Q.4 (c) A single cylinder single acting compressor of 40 × 50 cm is used in ammonia-vapour compression refrigeration system. It works between the pressure limit 11 bar and 3.036 bar. The vapour is dry and saturated when entered into compressor and it is saturated liquid before entering into the throttle valve.

Taking $n = 1.33$ for NH_3 and RPM = 500; Clearance = 15% of stroke, find the refrigeration capacity of plant and theoretical power required. Neglect the pressure and heat losses in the system and assume the compression is isentropic.

If the compression follows the law $pv^{1.4} = c$ and refrigerant behaves an ideal gas in superheated region, then find

(i) Power required

(ii) Heat rejected in condenser

(iii) Heat transfer between cylinder walls and gas during compression

Take specific heat for ammonia (c_{pv}) = 3.028 kJ/kgK

[Use Ammonia Refrigerant Table, attached at the end]

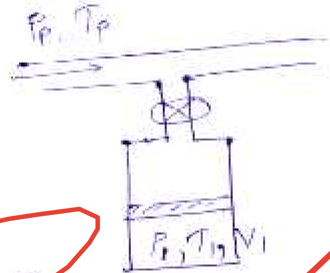
[20 marks]

Section : B

Q.5 (a) An insulated piston-cylinder assembly has an initial volume V_1 and contains air at pressure, P_1 and temperature, T_1. Air is supplied to the cylinder from a pipeline, maintained to the constant pressure P_p and constant temperature T_p, through a valve fitted into the cylinder. The piston is restrained in such a manner that the pressure of the air in the cylinder remains constant at P_1 during the process of filling. The filling process is terminated when the final volume V_2 is twice the initial volume V_1. Show that the final temperature of the air T_2 in the cylinder is given by

$$T_2 = \frac{2}{\frac{1}{T_1} + \frac{1}{T_P}}$$

[12 marks]



$\{V_2 = 2V_1,\ P_2 = P_1\}$

By Mass Conservat^n Eq^n :-

$$\dot{m}_i - \dot{m}_e^{\,0} = \dot{m}_2 - \dot{m}_1$$

$$\dot{m}_i = \dot{m}_2 - \dot{m}_1 \quad \text{---} \quad (1)$$

By Energy Conservat^n Eq^n :-

$$\dot{m}_2 u_2 - \dot{m}_1 u_1 = m_i h_i + \dot{Q}^{0} - \dot{m}_e h_e^{0} - \dot{W}$$

4/12

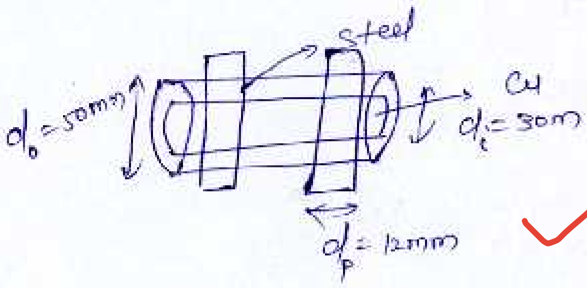
Avoid short forms

Do not write in this margin

Q.5 (b) A copper bar of 30 mm diameter is completely enclosed in a steel tube whose internal diameter is 30 mm and external diameter is 50 mm. A pin, 12 mm in diameter is fitted transversely to the axis of the bar near each end to secure the bar to the tube. Calculate the intensity of shear stress (N/mm^2) induced in the pin when the temperature of the whole assembly is raised by 50 Kelvin.

Take, $E_C = 1.2 \times 10^5\ N/mm^2$; $E_s = 2.2 \times 10^5\ N/mm^2$; $\alpha_c = 20 \times 10^{-6}$ per Kelvin, $\alpha_s = 14 \times 10^{-6}$ per Kelvin

[12 marks]



$A_{cu} = \pi/4 \times (30)^2 = 706.858\ mm^2$

$A_{s} = \pi/4 \left[(50)^2 - (30)^2\right] = 1256.637\ mm^2$

$A_p = \pi/4 \times (12)^2 = 113.097\ mm^2$

$$\frac{\sigma_s}{E_s} + \frac{\sigma_{cu}}{E_{cu}} = (\alpha_c - \alpha_s)\Delta T$$

$$\frac{\sigma_s}{E_s} + \frac{\sigma_{cu}}{E_{cu}} = (20 - 14) \times 10^{-6} \times 50$$

$$\frac{\sigma_s}{2.2} + \frac{\sigma_{cu}}{1.2} = 6 \times 10^{-6} \times 50 \times 10^{5}$$

$$\frac{\sigma_s}{2.2} + \frac{\sigma_{cu}}{1.2} = 30 \quad \text{---} (1)$$

$$\sigma_s A_s = \sigma_{cu} A_{cu}$$

$$\sigma_s \times (1600) \times \pi/4 = \sigma_{cu} \times 900 \times \pi/4$$

$$\sigma_s = 0.5625\, \sigma_{cu} \quad \text{---} (11)$$

$$\sigma_{cu} = 27.547 \text{ MPa}$$

$$\sigma_s = 15.4956 \text{ MPa}$$

$$P = \sigma_s \times \pi/4 \times (1600)$$

$$P = 19472.4108 \text{ N}$$

$$\tau_{pin} = \frac{P}{2 A_p} = \frac{19472.4108}{2 \times \pi/4 \times (12)^2}$$

$$\tau_{pin} \Rightarrow 86.087 \text{ MPa}$$

12/12

Do not write in this margin

Q.5 (c) An electric motor drives a machine at 1440 rpm delivering a torque of 14 Nm to its input shaft under steady state. The motor draws 15A current with a voltage of 220 V. The rate of heat loss from the motor surface to the surroundings is given by the relationship $\dot{Q}_{out} = 20(T_s - T_o)$ Watts, where T_s is the temperature of the surface of the motor and the ambient temperature is T_0 = 30°C.

Determine:

(i) The motor surface temperature T_s in Kelvin.

(ii) The entropy generation rate (W/K) for the enlarged system, if the system boundary is located to include all the surroundings where there exists a temperature gradient.

[12 marks]

Ans:- i)

$$P_{in} = T \times \omega = \frac{14 \times 2\pi \times 1440}{60}$$

$$= 2111.15 \text{ Watt}$$

$$P_{out/motor} = VI = 220 \times 15$$

$$= 3300 \text{ Watt}$$

$$\dot{Q}_{out} = 20(T_s - T_o) \qquad T_o = 30°C$$

$$\dot{Q}_{out} = 20(T_s - 30)$$

$$\dot{Q}_{out} = 3300 - 2111.15$$
$$= 1188.85 \text{ watt}$$

$$1188.85 = 20(T_s - 30)$$

$$T_s = 89.4425°C$$

ii)

$$\frac{ds}{dt}^{0} = \sum \frac{Q_e}{T} + S_{in} - S_{out} + S_{gen}$$

steady state.

$$S_{gen} = S_{out} - S_{in} - \frac{Q_{lost}}{T_{surr}}$$

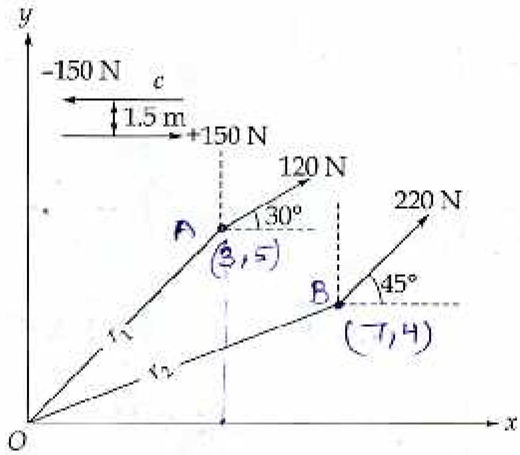
$$S_{gen} = -\frac{Q_{lost}}{T_{sur}} = -\frac{1188.85}{303}$$

$$S_{gen} = -3.9235 \text{ W/K}$$

Write conclusions

12/12

Q.5 (d) Force 120 N at (3, 5) m, 220 N at $B(7, 4)$ m and couple of forces ±150 N at an arm length of 1.5 m act in xy plane on a body as shown in figure. Replace these forces and couple by a single equivalent force and a single equivalent couple. Also show the direction of equivalent force with x-axis.



[12 marks]

$\vec{F_A} = 120[\cos 30\,\hat{i} + \sin 30\,\hat{j}]$

~~$r_A = \sqrt{3^2+5^2} = 5.83\,m$~~

$\vec{F_B} = 220[\cos 45°\,\hat{i} + \sin 45°\,\hat{j}]$

~~$r_B = 8.062\,m$~~

$M_c = 150 \times 1.5 = 225\ \hat{k}$

~~$\vec{F_A} = 120[5.83 \cos 30° \hat{i} + 5.83 \sin 30° \hat{j}]$~~

~~$\vec{F_B} = 220[8.062 \cos 45° \hat{i} + 8.062 \sin 45° \hat{j}]$~~

~~$\vec{F_A} = 605.87 \hat{i} + 349.2 \hat{j}$~~

~~$\vec{F_B} = 1254.15 \hat{i} + 1254.15 \hat{j}$~~

$\vec{F_A} = 103.923 \hat{i} + 60 \hat{j}$

$\vec{F_B} = 155.56 \hat{i} + 155.56 \hat{j}$

$\vec{r_A} = 3\hat{i} + 5\hat{j}$

$\vec{r_B} = 7\hat{i} + 4\hat{j}$

$M_A = \vec{r_A} \times \vec{F_A} = (3\hat{i} + 5\hat{j}) \times (103.923\hat{i} + 60\hat{j})$

$M_A = 180\hat{k} - 519.615\hat{k}$

$M_A = -339.615\hat{k}$

$M_B = \vec{r_B} \times \vec{F_B} = (7\hat{i} + 4\hat{j}) \times (155.56\hat{i} + 155.56\hat{j})$

$M_B = 466.68\ \hat{k}$

$\Sigma M = M_A + M_B + M_C$

$= -339.615\hat{k} + 466.68\hat{k} + 225\hat{k}$

$M_t = 352.065\hat{k}$

$\vec{F_x} = 259.483\hat{i}$

$\vec{F_y} = 215.56\hat{j}$

$\tan\theta = \frac{F_y}{F_x}$

$\theta = 39.717^\circ$

Write conclusions

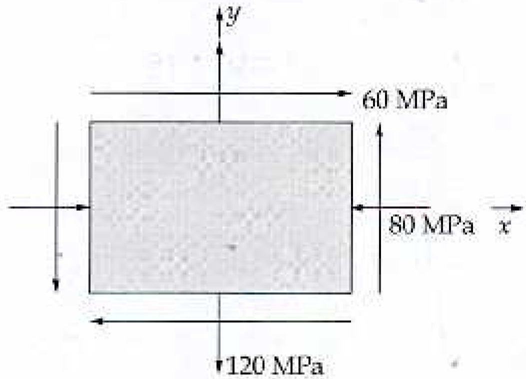
12/12

Q.5 (e) A plane element is subjected to the stresses as shown in the figure. Determine

(i) the principal stresses and their directions.

(ii) the maximum shearing stresses and the directions of the planes on which they occur.

(iii) the normal stress on the maximum shear stress plane.



[12 marks]

Ans:- i) Given data

$\sigma_x = -80$ MPa

$\sigma_y = 120$ MPa

$\tau_{xy} = 60$ MPa

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

$$= \frac{120 - 80}{2} \pm \sqrt{\left(\frac{-120 - 80}{2}\right)^2 + (60)^2}$$

$$= 20 \pm 116.619$$

$$\sigma_1 = 136.619 \text{ MPa}$$

$$\sigma_2 = -96.619 \text{ MPa}$$

$$\tan 2\theta_p = \frac{2 \times 60}{(-80 - 120)}$$

$$\theta_p = 164.518^\circ$$

$$\theta_2 = 254.518^\circ$$

ii)

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2} = \frac{\sigma_1 - \sigma_2}{2}$$

$$\tau_{max} = 116.619 \text{ MPa}$$

(iii)

$$\tan\beta = \sqrt{-\frac{\sigma_1}{\sigma_2}} \Rightarrow$$

$$\beta = 49.937$$

$$\theta_5 = \theta_1 + \beta = 214.455^\circ$$

$$\theta_6 = \theta_1 - \beta = 114.58^\circ$$

iii) $\sigma_n = \frac{\sigma_1 + \sigma_2}{2} = 80 \text{ MPa}$

8/12

Q.6 (a) 1 kg of steam at 12 bar pressure and a vapour fraction of 0.4 is heated at constant volume inside a cylinder till the pressure rises to 40 bar. It is then allowed to expand reversibly and isothermally back to the initial pressure of 12 bar. The cylinder is then cooled allowing the piston to move at constant pressure till the initial state is reached. Calculate the various energy transfers and entropy changes for each of these processes using steam tables and determine the thermal efficiency of the cycle.

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

p MPa	T_{sat} °C	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}
0.40	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	0.38956	632.95	2559.3	633.47	2746.3	2112.8	1.8448	6.8344	4.9895
0.50	151.831	0.00109255	0.37481	639.54	2560.7	640.09	2748.1	2108.0	1.8604	6.8207	4.9603
0.52	153.314	0.00109423	0.36120	645.93	2562.1	646.50	2749.9	2103.4	1.8754	6.8075	4.9321
0.54	154.753	0.00109587	0.34858	652.13	2563.3	652.72	2751.5	2098.8	1.8899	6.7948	4.9049
0.56	156.149	0.00109748	0.33682	658.16	2564.5	658.77	2753.1	2094.4	1.9040	6.7825	4.8786
0.58	157.506	0.00109905	0.32585	664.01	2565.7	664.65	2754.7	2090.0	1.9176	6.7707	4.8531
0.60	158.826	0.00110060	0.31558	669.72	2566.8	670.38	2756.1	2085.8	1.9308	6.7592	4.8284
0.62	160.112	0.00110212	0.30596	675.28	2567.9	675.96	2757.6	2081.6	1.9437	6.7482	4.8045
0.64	161.365	0.00110362	0.29691	680.70	2568.9	681.41	2758.9	2077.5	1.9562	6.7374	4.7813
0.66	162.587	0.00110509	0.28840	686.00	2570.0	686.73	2760.3	2073.5	1.9684	6.7270	4.7587
0.68	163.781	0.00110654	0.28036	691.17	2570.9	691.92	2761.5	2069.6	1.9802	6.7169	4.7367
0.70	164.946	0.00110796	0.27277	696.22	2571.9	697.00	2762.8	2065.8	1.9918	6.7071	4.7153
0.72	166.086	0.00110936	0.26559	701.17	2572.7	701.97	2763.9	2062.0	2.0031	6.6975	4.6944
0.74	167.200	0.00111075	0.25879	706.02	2573.6	706.84	2765.1	2058.2	2.0141	6.6882	4.6741
0.76	168.291	0.00111211	0.25233	710.76	2574.4	711.61	2766.2	2054.6	2.0248	6.6791	4.6543
0.78	169.360	0.00111346	0.24618	715.41	2575.3	716.28	2767.3	2051.0	2.0354	6.6703	4.6349
0.80	170.406	0.00111478	0.24034	719.97	2576.0	720.86	2768.3	2047.4	2.0457	6.6616	4.6160
0.82	171.433	0.00111609	0.23477	724.44	2576.8	725.36	2769.3	2043.9	2.0557	6.6532	4.5975
0.84	172.440	0.00111739	0.22946	728.84	2577.6	729.78	2770.3	2040.5	2.0656	6.6449	4.5793
0.86	173.428	0.00111867	0.22438	733.15	2578.2	734.11	2771.2	2037.1	2.0753	6.6369	4.5616
0.88	174.398	0.00111993	0.21953	737.38	2578.9	738.37	2772.1	2033.8	2.0847	6.6290	4.5443
0.90	175.350	0.00112118	0.21489	741.55	2579.6	742.56	2773.0	2030.5	2.0940	6.6213	4.5272
0.92	176.287	0.00112242	0.21044	745.65	2580.3	746.68	2773.9	2027.2	2.1032	6.6137	4.5106
0.94	177.207	0.00112364	0.20617	749.67	2580.9	750.73	2774.7	2024.0	2.1121	6.6063	4.4942
0.96	178.112	0.00112485	0.20208	753.64	2581.5	754.72	2775.5	2020.8	2.1209	6.5991	4.4782
0.98	179.002	0.00112605	0.19814	757.55	2582.1	758.65	2776.3	2017.7	2.1296	6.5920	4.4624
1.00	179.878	0.00112723	0.19436	761.39	2582.7	762.52	2777.1	2014.6	2.1381	6.5850	4.4470
1.05	182.009	0.00113014	0.18552	770.75	2584.1	771.94	2778.9	2007.0	2.1587	6.5681	4.4095
1.10	184.062	0.00113299	0.17745	779.78	2585.4	781.03	2780.6	1999.6	2.1785	6.5520	4.3735
1.15	186.043	0.00113577	0.17006	788.51	2586.6	789.82	2782.2	1992.4	2.1976	6.5365	4.3390
1.20	187.957	0.00113850	0.16326	796.96	2587.8	798.33	2783.7	1985.4	2.2159	6.5217	4.3058
1.25	189.809	0.00114116	0.15699	805.15	2588.9	806.58	2785.1	1978.6	2.2337	6.5074	4.2737
1.30	191.605	0.00114380	0.15119	813.11	2590.0	814.60	2786.5	1971.9	2.2508	6.4936	4.2428
1.35	193.347	0.00114638	0.14580	820.84	2590.9	822.39	2787.7	1965.3	2.2674	6.4803	4.2129
1.40	195.039	0.00114892	0.14078	828.36	2591.7	829.97	2788.8	1958.9	2.2835	6.4675	4.1839
1.45	196.685	0.00115141	0.13609	835.68	2592.6	837.35	2789.9	1952.6	2.2992	6.4550	4.1559
1.50	198.287	0.00115387	0.13171	842.83	2593.4	844.56	2791.0	1946.4	2.3143	6.4430	4.1286

Water/Steam at $p = 4.0$ MPa ($T_{sat} = 250.354$°C)

T	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00099819	0.03	4.02	0.00009
5	0.00099813	21.00	24.99	0.07617
10	0.00099844	41.92	45.91	0.15072
15	0.00099909	62.80	66.80	0.22385
20	0.00100001	83.67	87.67	0.29564
25	0.00100120	104.52	108.52	0.36619
30	0.00100263	125.36	129.37	0.43553
35	0.00100427	146.20	150.22	0.50374
40	0.00100612	167.05	171.07	0.57085
45	0.00100816	187.89	191.92	0.63691
50	0.00101038	208.74	212.78	0.70196
55	0.00101277	229.59	233.64	0.76604
60	0.00101534	250.46	254.52	0.82918
65	0.00101807	271.34	275.41	0.89141
70	0.00102095	292.23	296.31	0.95277
75	0.00102399	313.13	317.23	1.0133
80	0.00102719	334.05	338.16	1.0730
85	0.00103054	354.99	359.11	1.1319
90	0.00103403	375.94	380.08	1.1900
95	0.00103768	396.93	401.08	1.2475
100	0.00104148	417.93	422.10	1.3042
105	0.00104543	438.97	443.15	1.3602
110	0.00104953	460.02	464.22	1.4156
115	0.00105379	481.12	485.34	1.4703
120	0.00105820	502.26	506.49	1.5245
125	0.00106277	523.43	527.68	1.5780
130	0.00106751	544.64	548.91	1.6310
135	0.00107240	565.90	570.19	1.6835
140	0.00107747	587.22	591.53	1.7354
145	0.00108272	608.58	612.91	1.7869
150	0.00108814	630.01	634.36	1.8379
155	0.00109375	651.49	655.87	1.8884
160	0.00109956	673.05	677.45	1.9385
165	0.00110556	694.69	699.11	1.9882
170	0.00111178	716.39	720.84	2.0376
175	0.00111821	738.19	742.66	2.0865
180	0.00112487	760.07	764.57	2.1352
185	0.00113177	782.05	786.58	2.1835
190	0.00113893	804.13	808.69	2.2315
195	0.00114635	826.33	830.92	2.2792
200	0.00115405	848.65	853.27	2.3267
210	0.00117038	893.67	898.35	2.4210
220	0.00118807	939.29	944.04	2.5148
230	0.00120733	985.59	990.42	2.6077
240	0.00122842	1032.7	1037.6	2.7005
250	0.00125169	1080.8	1085.8	2.7935
250.354	0.00125256	1082.5	1087.5	2.7968
250.354	0.0497760	2601.7	2800.8	6.0696
260	0.0517770	2630.0	2837.1	6.1383
270	0.0536930	2656.4	2871.2	6.2016

T	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
270	0.0536930	2656.4	2871.2	6.2016
280	0.0554970	2680.9	2902.9	6.2595
290	0.0572170	2704.1	2933.0	6.3133
300	0.0588700	2726.2	2961.7	6.3639
310	0.0604680	2747.5	2989.4	6.4118
320	0.0620210	2768.2	3016.3	6.4576
330	0.0635360	2788.4	3042.5	6.5014
340	0.0650190	2808.0	3068.1	6.5435
350	0.0664730	2827.4	3093.3	6.5843
360	0.0679030	2846.5	3118.1	6.6238
370	0.0693110	2865.4	3142.6	6.6621
380	0.0707010	2884.0	3166.8	6.6994
390	0.0720730	2902.4	3190.7	6.7358
400	0.0734310	2920.8	3214.5	6.7714
410	0.0747760	2939.0	3238.1	6.8061
420	0.0761080	2957.1	3261.5	6.8402
430	0.0774290	2975.1	3284.8	6.8736
440	0.0787410	2993.0	3308.0	6.9064
450	0.0800430	3011.0	3331.2	6.9386
460	0.0813370	3028.9	3354.2	6.9703
470	0.0826230	3046.7	3377.2	7.0015
480	0.0839020	3064.6	3400.2	7.0321
490	0.0851750	3082.4	3423.1	7.0624
500	0.0864420	3100.2	3446.0	7.0922
520	0.0889590	3136.0	3491.8	7.1506
540	0.0914570	3171.7	3537.5	7.2075
560	0.0939380	3207.4	3583.2	7.2631
580	0.0964050	3243.4	3629.0	7.3174
600	0.0988590	3279.5	3674.9	7.3705
620	0.10130	3315.7	3720.9	7.4226
640	0.10373	3352.1	3767.0	7.4737
660	0.10616	3388.6	3813.2	7.5238
680	0.10857	3425.4	3859.7	7.5730
700	0.11098	3462.4	3906.3	7.6214
720	0.11338	3499.6	3953.1	7.6690
740	0.11577	3537.0	4000.1	7.7159
760	0.11816	3574.7	4047.3	7.7620
780	0.12054	3612.5	4094.7	7.8074
800	0.12292	3650.6	4142.3	7.8523
820	0.12530	3689.0	4190.2	7.8964
840	0.12767	3727.6	4238.3	7.9400
860	0.13003	3766.5	4286.6	7.9830
880	0.13240	3805.5	4335.1	8.0255
900	0.13476	3844.9	4383.9	8.0674
920	0.13712	3884.4	4432.9	8.1088
940	0.13947	3924.2	4482.1	8.1498
960	0.14183	3964.3	4531.6	8.1902
980	0.14418	4004.6	4581.3	8.2302
1000	0.14652	4045.1	4631.2	8.2697

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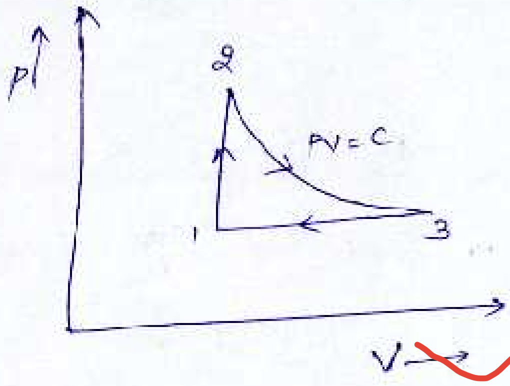
Water/Steam at p = 1.2 MPa (T_{sat} = 187.957°C)

T	v	u	h	s	T	v	u	h	s
°C	m³/kg	kJ/kg	kJ/kg	kJ/kg K	°C	m³/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00099960	-0.02	1.18	-0.00008	270	0.20111	2739.2	2980.5	6.9155
5	0.00099949	21.01	22.21	0.07623	280	0.20540	2756.1	3002.6	6.9558
10	0.00099977	41.99	43.19	0.15098	290	0.20964	2772.9	3024.5	6.9951
15	0.00100039	62.93	64.13	0.22428	300	0.21386	2789.7	3046.3	7.0335
20	0.00100129	83.84	85.04	0.29623	310	0.21804	2806.4	3068.0	7.0710
25	0.00100246	104.74	105.94	0.36692	320	0.22220	2823.0	3089.6	7.1078
30	0.00100388	125.62	126.82	0.43639	330	0.22634	2839.6	3111.2	7.1438
35	0.00100551	146.50	147.71	0.50471	340	0.23045	2856.2	3132.7	7.1792
40	0.00100736	167.38	168.59	0.57194	350	0.23455	2872.7	3154.2	7.2139
45	0.00100939	188.27	189.48	0.63811	360	0.23863	2889.2	3175.6	7.2480
50	0.00101162	209.16	210.37	0.70326	370	0.24270	2905.8	3197.0	7.2816
55	0.00101402	230.04	231.26	0.76743	380	0.24675	2922.3	3218.4	7.3147
60	0.00101660	250.95	252.17	0.83067	390	0.25079	2939.0	3239.9	7.3472
65	0.00101933	271.87	273.09	0.89299	400	0.25482	2955.5	3261.3	7.3793
70	0.00102223	292.79	294.02	0.95444	410	0.25883	2972.1	3282.7	7.4109
75	0.00102529	313.74	314.97	1.0150	420	0.26284	2988.8	3304.2	7.4421
80	0.00102851	334.70	335.93	1.0748	430	0.26684	3005.5	3325.7	7.4728
85	0.00103188	355.67	356.91	1.1338	440	0.27083	3022.2	3347.2	7.5032
90	0.00103540	376.67	377.91	1.1921	450	0.27482	3038.9	3368.7	7.5332
95	0.00103907	397.69	398.94	1.2496	460	0.27879	3055.8	3390.3	7.5628
100	0.00104290	418.74	419.99	1.3064	470	0.28276	3072.6	3411.9	7.5921
105	0.00104688	439.81	441.07	1.3625	480	0.28673	3089.4	3433.5	7.6210
110	0.00105102	460.92	462.18	1.4179	490	0.29069	3106.4	3455.2	7.6496
115	0.00105531	482.06	483.33	1.4728	500	0.29464	3123.3	3476.9	7.6779
120	0.00105976	503.25	504.52	1.5270	520	0.30253	3157.5	3520.5	7.7336
125	0.00106438	524.46	525.74	1.5806	540	0.31041	3191.8	3564.3	7.7881
130	0.00106916	545.73	547.01	1.6337	560	0.31826	3226.4	3608.3	7.8416
135	0.00107410	567.04	568.33	1.6863	580	0.32611	3261.3	3652.5	7.8940
140	0.00107923	588.41	589.71	1.7383	600	0.33394	3296.3	3697.0	7.9455
145	0.00108453	609.83	611.13	1.7899	620	0.34177	3331.6	3741.7	7.9961
150	0.00109001	631.32	632.63	1.8410	640	0.34958	3367.1	3786.6	8.0459
155	0.00109569	652.87	654.18	1.8916	660	0.35739	3402.9	3831.8	8.0948
160	0.00110157	674.49	675.81	1.9419	680	0.36518	3439.0	3877.2	8.1430
165	0.00110765	696.19	697.52	1.9917	700	0.37297	3475.3	3922.9	8.1904
170	0.00111395	717.97	719.31	2.0411	720	0.38076	3511.9	3968.8	8.2371
175	0.00112047	739.84	741.18	2.0902	740	0.38853	3548.8	4015.0	8.2832
180	0.00112723	761.80	763.15	2.1390	760	0.39631	3585.9	4061.5	8.3286
185	0.00113424	783.87	785.23	2.1874	780	0.40407	3623.3	4108.2	8.3734
187.957	0.00113850	796.96	798.33	2.2159	800	0.41184	3661.0	4155.2	8.4176
187.957	0.16326	2587.8	2783.7	6.5217	820	0.41959	3698.9	4202.4	8.4612
190	0.16432	2592.2	2789.4	6.5340	840	0.42735	3737.1	4249.9	8.5042
195	0.16686	2602.8	2803.0	6.5631	860	0.43510	3775.6	4297.7	8.5468
200	0.16934	2612.9	2816.1	6.5909	880	0.44285	3814.3	4345.7	8.5888
210	0.17417	2632.3	2841.3	6.6437	900	0.45059	3853.3	4394.0	8.6303
220	0.17887	2651.1	2865.7	6.6937	920	0.45834	3892.6	4442.6	8.6713
230	0.18346	2669.3	2889.5	6.7414	940	0.46608	3932.1	4491.4	8.7119
240	0.18797	2687.1	2912.7	6.7872	960	0.47381	3971.9	4540.5	8.7520
250	0.19241	2704.7	2935.6	6.8313	980	0.48155	4011.9	4589.8	8.7917
260	0.19679	2722.1	2958.2	6.8740	1000	0.48928	4052.3	4639.4	8.8310
270	0.20111	2739.2	2980.5	6.9155					

[20 marks]

Ans:-



at state 1 :-

$x = 0.4$

$m_s = 1\,kg$ $P_1 = 12\,bar$

$T_1 = 187.957\,°C$

$v_1 = v_f + x(v_g - v_f)$

$= 0.0011385 + 0.4(0.16326 - 0.0011385)$

$= 0.06598\ m^3/kg$

$h_1 = 798.33 + 0.4(1985.4)$

$= 1592.49\ kJ/kg$

at state 2.

$P_2 = 40\,bar$

$v_2 = v_1 = 0.06598\ m^3/kg.$

$$\frac{T_2 - 350}{340 - 350} = \frac{0.06598 - 0.066473}{0.065019 - 0.066473} = 0.34$$

$T_2 = 346.6093\,°C$

$h_2 = 3084.732\ kJ/kg.$

at state 3.

$346.6093°C = T_2 = T_3$ $P_3 = 12$ bar

$v_3 = 0.23255\ m^3/kg$

$h_3 = 3145.6\ kJ/kg$

process 1-2 $W_{1-2} = 0$

$Q_{1-2} = 1492.242$ kJ

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process 2-3. $U_{23} = 0$

$Q_{23} = W_{23}$

$W_{23} = P_2 v_2 \ln\left(\frac{P_2}{P_3}\right)$

$\Rightarrow 40 \times 100 \times 0.06598$

$\Rightarrow 317.7525$ kJ

process 3-1

$W_{31} = 1200 \times (v_1 - v_3) = -199.884$ kJ

$Q_{31} = (-)1553.11$ kJ

$W.d = 317.7525 - 199.884$

$\Rightarrow 117.8685$ kJ

$Q_s = 1492.242$ kJ

$$\eta = \frac{W_{net}}{Q_s} = 0.0789$$

$\eta = 7.89\%$

Q.6 (b) **(i)** State Carnot's theorem. Prove that the efficiency of a reversible heat engine is more than that of an irreversible heat engine.

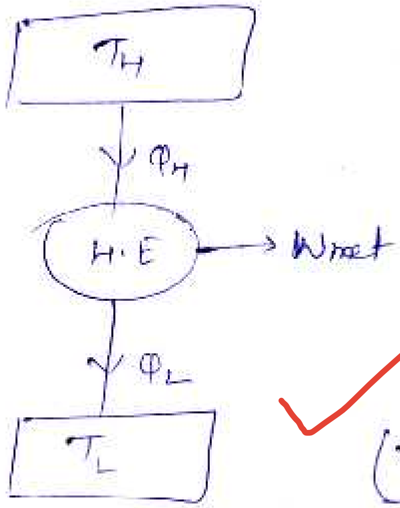
(ii) A heat engine operates between two thermal reservoirs at 350 K and 1000 K and produces 150 kW power. Find the rate of heat rejection and entropy generation when

(a) the engine is completely reversible.

(b) the engine is internally reversible but receives and rejects heat at 900 K and 450 K rather than 1000 K and 350 K.

[8 + 12 marks]

Ans:- i) Carnot's Theorem :-



$(W_{irrev} = Q_H - Q_L)$

$$\eta_{H.E} = 1 - \frac{Q_L}{Q_H} = \frac{W_{net}}{Q_H}$$

$$\eta_{Carnot} = 1 - \frac{T_L}{T_H}$$

The efficiency of Carnot is only depends on the limit of temperatures.

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

$$W_{rever} = \eta_{H\cdot E} \times dQ$$

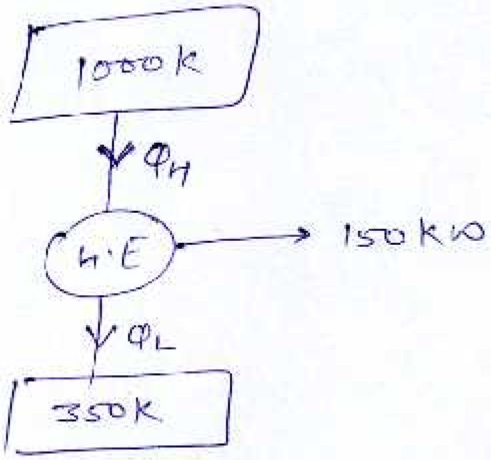
$$W_{rever.} = \left[1 - \frac{T_0}{T}\right] \times mc\,dT$$

$$W_{rever.} = \int_{T_L}^{T_H} \left(1 - \frac{T_0}{T}\right) mc\,dT$$

$$\boxed{W_{rever} = Q_{net} - T_0 \Delta S}$$

$$\boxed{W_{rever} > W_{irreversible}}$$

(ii)



a) Engine is Completely reversible.

$$Q_H - Q_L = 150 \quad \text{---} \quad (1)$$

$$\frac{Q_H}{1000} = \frac{Q_L}{350}$$

$$\boxed{Q_L = 0.35\, Q_H}$$

$0.65\, Q_H = 150$

$Q_H = 230.769\ kW$

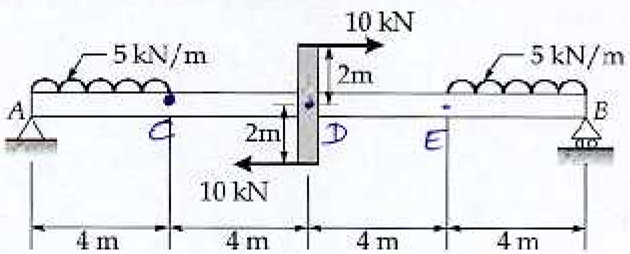
~~$Q_H = 659.3406\ kW$~~

$Q_L = 80.769\ kW.$

$$S_{gen} = \frac{80.769}{350} - \frac{230.769}{1000}$$

$$\boxed{S_{gen} = 0}$$

Q.6 (c) A beam *AB* is loaded by two segments of uniform load and two horizontal forces acting at the ends of a vertical arm as shown in figure. Draw the shear force and bending moment diagrams for this beam. Also find the point of contraflexure if any.



[20 marks]

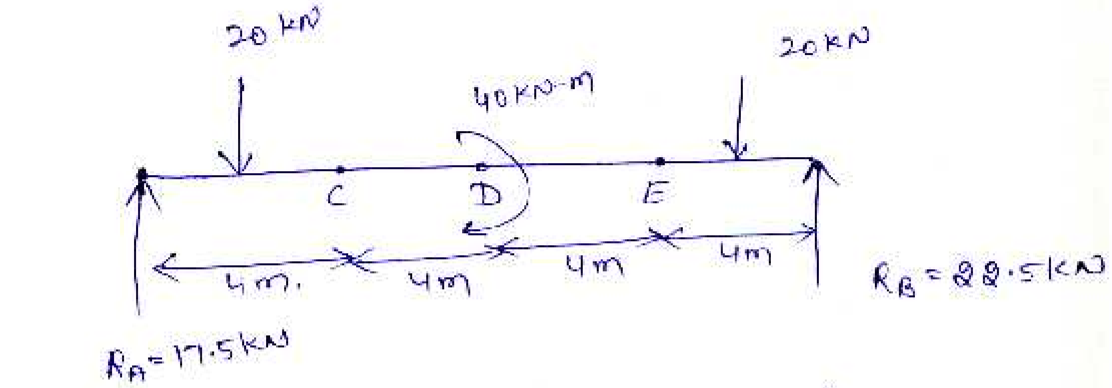
$R_A + R_B = 5 \times 4 + 5 \times 4 = 40\ kN$

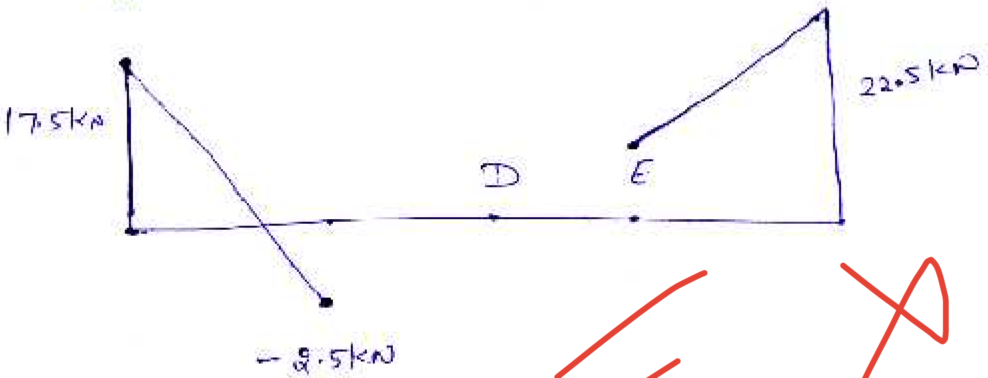
$\Sigma M_A = 0$

$40 + 40 + 280 = R_B \times 16$

$R_B = 22.5\ kN$

$R_A = 17.5\ kN.$





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'AC' Section

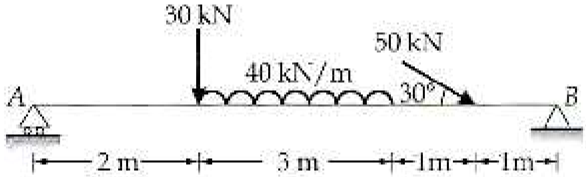
$$S_x = 17.5 - 5x$$

'CD' Section

$$S_x = 17.5$$

Q.7 (a) **(i)** Calculate the thickness in mm of shell required for a vessel of thick spherical shape, 600 mm inside diameter, to withstand an internal pressure of 30 N/mm^2, if the maximum permissible tensile stress in the shell is 80 N/mm^2.

(ii) Calculate the reactions at supports *A* and *B* of the beam as shown in figure.



[16 + 4 marks]

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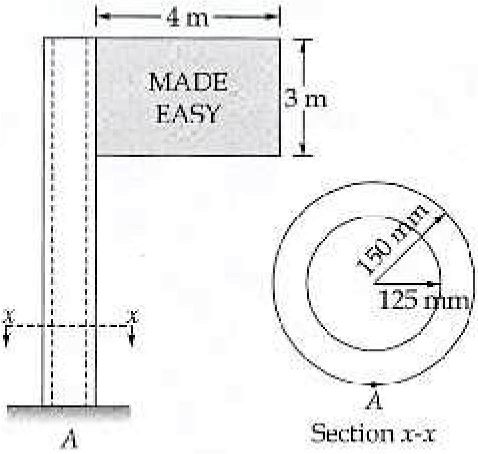
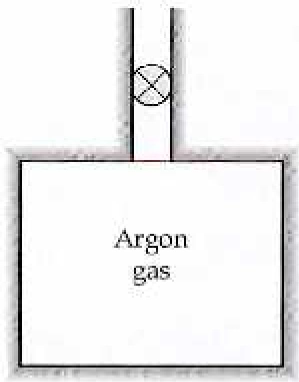
Q.7 (b) A sign board is supported by a pole of hollow circular cross-section as shown in figure. The outer and inner diameters of the pole are 300 and 250 mm, respectively. The pole is 15 m high and weighs 100 kN. The sign board has dimensions 4 m × 3 m and the weight of sign board can be neglected. The wind pressure against the sign board is 2 kPa.

Determine the maximum tensile, maximum compressive and maximum shear stress at point *A*.



[20 marks]

Q.7 (c) (i) An insulated rigid tank contains 4 kg of argon gas at 550 kPa and 30°C. A valve is now opened and argon is allowed to escape until the pressure inside drops to 230 kPa. Assuming the argon remaining inside the tank has undergone a reversible adiabatic process. Determine the mass of argon escaped out?



(ii) Raw food items with an average mass of 2.5 kg each and average specific heat of 3.75 kJ/kg°C are to be cooled by chilled water that enters a continuous-flow type immersion chiller at 0.6°C and leaves at 3°C. The raw food items are dropped into the chiller at a uniform temperature of 17°C and at a rate of 270 items per hour and are cooled to an average temperature of 4°C before they are taken out. The chiller gains heat from the surroundings at 27°C at the rate of 150 kJ/h. Determine the rate of entropy generation during this chilling process in W/K.
[Take C_{water} = 4.18 kJ/kg°C]

[6 + 14 marks]

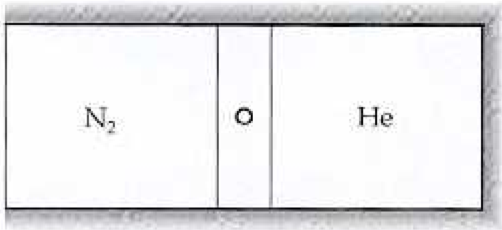
Q.8 (a) (i) A horizontal cylinder is separated into two compartments by adiabatic, frictionless piston. One side contains 0.3 m^3 of nitrogen and the other side contains 0.2 kg of helium, both initially at 25°C and 100 kPa. The sides of the cylinder and the helium end are insulated as shown in figure. Now heat is added to the nitrogen side from a reservoir at 600°C until the pressure of the helium rises to 130 kPa. Determine:

(a) the final temperature of the helium in Kelvin.

(b) the final volume of the nitrogen in m^3.

(c) the heat transferred to the nitrogen in kJ.

(d) the entropy generation during the process in kJ/K.



(ii) 12 kg of air stored in a metallic cylinder at 45 bar and 30°C is used to start an engine using an air turbine as shown in figure. This process can continue till the cylinder pressure drops to 4.5 bar. During the process, heat transfer with atmosphere at 30°C is permitted and the temperature of air in the cylinder remains constant. Neglecting kinetic and potential energy, determine the maximum possible work output of the turbine (kJ). Given atmospheric pressure is 1 bar and treat air as an ideal gas with $c_p = 1.005$ kJ/kg-K.

[10 + 10 marks]

Q.8 (b) **(i)** Show that the entropy change in any polytropic process of an ideal gas, with constant specific heats can be calculated as

$$s_2 - s_1 = \frac{(n-\gamma)R}{n(\gamma-1)} \ln \frac{P_2}{P_1}$$

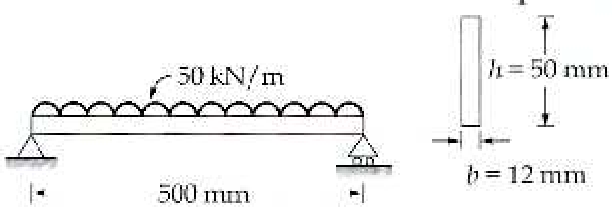
where, subscript 1 and 2 represent initial and final states.

(ii) Consider a 20 m diameter hot air balloon that together with its cage, has a mass of 150 kg when empty. The air in the balloon, which is now carrying two 80 kg persons, is heated by propane burners at a location where the atmospheric pressure and temperature are 95 kPa and 10°C respectively. Determine the average temperature (Kelvin) of the air in the balloon when the balloon first starts rising.

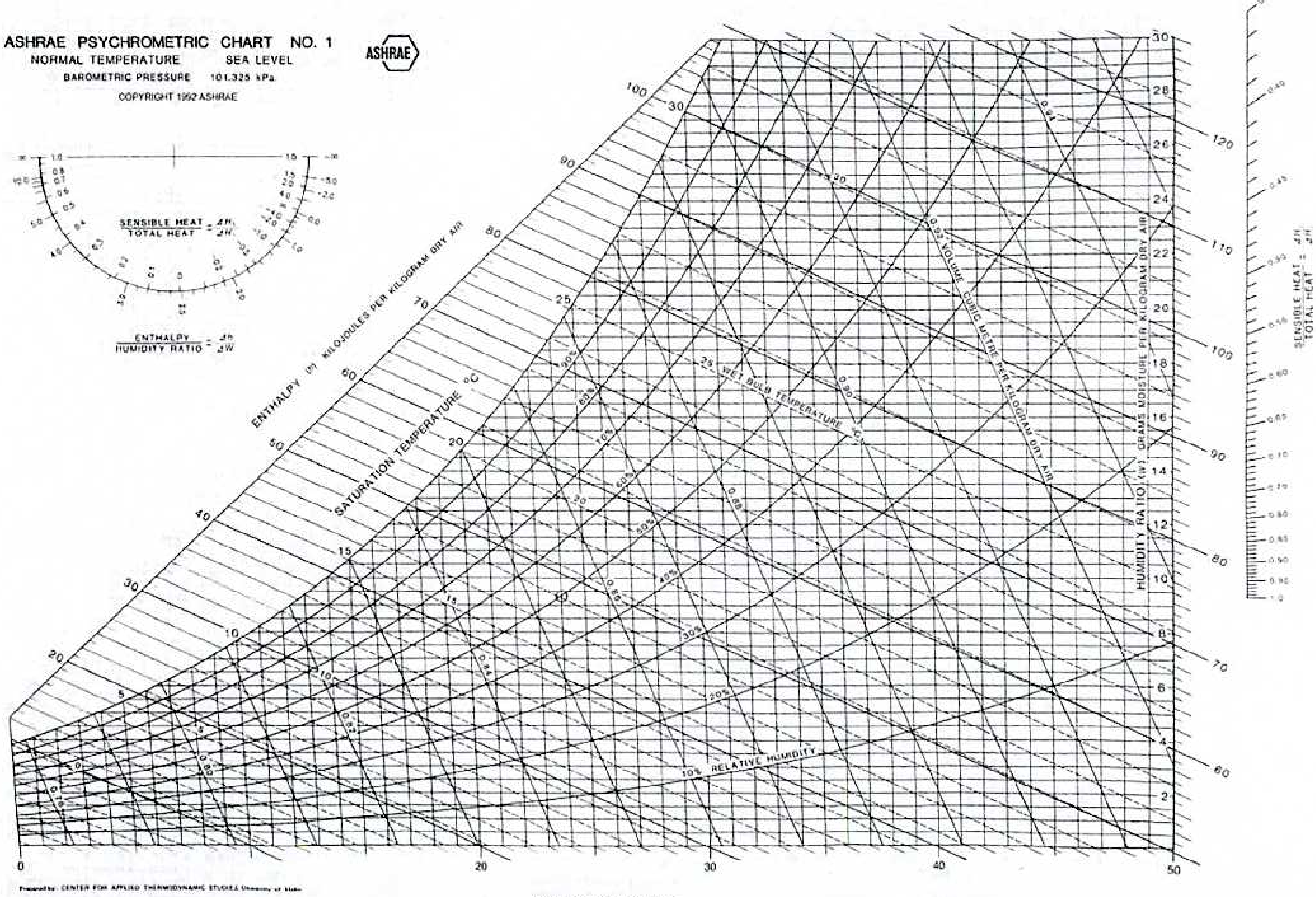
[12 + 8 marks]

Q.8 (c) **(i)** A compound bar is made by fastening one flat bar of steel between two similar bars of aluminium alloy. The dimensions of each bar are 50 mm wide and 10 mm thick, so that the cross-section of the composite bar measures 50 mm × 30 mm. If modulus of elasticity for steel is 210 GPa and for aluminium alloy is 65 GPa, find the apparent value of the modulus of elasticity for the composite bar loaded in tension. If the respective elastic limits are 240 MPa and 45 MPa, find the elastic limit of the compound bar.

(ii) A steel beam of length L = 500 mm and cross-sectional dimensions b = 12 mm and h = 50 mm (as shown in figure) supports a uniform load of intensity w = 50 kN/m, which includes the weight of the beam. Calculate the shear stresses in the beam (at the cross-section of maximum shear force) at points located 10 mm, 18.75 mm and 25 mm from the top surface of the beam. From these calculations, plot a graph showing the distribution of shear stresses from top to bottom of the beam.



[10 + 10 marks]


ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE SEA LEVEL
BAROMETRIC PRESSURE 101.325 kPa
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SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔHt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE °C
RELATIVE HUMIDITY
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
HUMIDITY RATIO (W) GRAMS MOISTURE PER KILOGRAM DRY AIR
DRY BULB TEMPERATURE °C
Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho

Thermodynamic Properites of R717 (Ammonia)

Table B.7.1 Saturation table of R717 (ammonia)

Temp. (°C)	*Pressure* (bar)	*Specific Volume* (m³/kg)		*Enthalpy* (kJ/kg)		*Entropy* kJ/kg.K)	
		$v_f \times 10^3$	v_g	h_f	h_g	s_f	s_g
–60	.2199	1.40	4.685	–69.5	1373.2	–0.1095	6.6592
–55	.3029	1.41	3.474	–47.5	1382.0	–0.0071	6.5454
–50	.4103	1.42	2.617	–25.4	1390.6	0.0926	6.4382
–45	.5474	1.43	2.000	–3.3	1399.0	0.1904	6.3369
–40	.7201	1.45	1.547	18.9	1407.2	0.2865	6.2410
–35	.9349	1.46	1.212	41.2	1415.2	0.3808	6.1501
–30	1.1990	1.48	.961	63.6	1422.8	0.4735	6.0636
–28	1.3202	1.48	.878	72.5	1425.8	0.5101	6.0302
–26	1.4511	1.48	.809	81.5	1428.7	0.5465	5.9974
–25	1.5216	1.49	.770	86.0	1430.2	0.5646	5.9813
–24	1.5922	1.49	.737	90.5	1431.6	0.5827	5.9652
–22	1.7441	1.49	.677	99.6	1434.4	0.6186	5.9336
–20	1.9074	1.50	.622	108.6	1437.2	0.6543	5.9025
–18	2.0826	1.50	.573	117.7	1439.9	0.6898	5.8720
–16	2.2704	1.51	.528	126.7	1442.6	0.7251	5.8420
–15	2.3709	1.52	.508	131.3	1443.9	0.7426	5.8223
–14	2.4714	1.52	.488	135.8	1445.2	0.7601	5.8125
–12	2.6863	1.53	.451	144.9	1447.7	0.7950	5.7835
–10	2.9157	1.53	.417	154.2	1450.2	0.8296	5.7550
–9	3.0360	1.53	.402	158.6	1451.4	0.8469	5.7409
–8	3.1602	1.54	.387	163.2	1452.6	0.8641	5.7269
–7	3.2884	1.54	.373	167.8	1453.8	0.8812	5.7131
–6	3.4207	1.54	.359	172.4	1455.0	0.8983	5.6993
–5	3.5571	1.55	.346	176.9	1456.1	0.9154	5.6856
–4	3.6977	1.55	.334	181.6	1457.2	0.9324	5.6721
–3	3.8426	1.55	.322	186.2	1458.4	0.9493	5.6586
–2	3.9920	1.56	.310	190.8	1459.5	0.9663	5.6453
–1	4.1458	1.56	.299	195.4	1460.6	0.9831	5.6320
0	4.3043	1.57	.289	200.0	1461.7	1.0000	5.6189
1	4.4674	1.57	.279	204.6	1462.7	1.0167	5.6058
2	4.6353	1.57	.269	209.3	1463.8	1.0335	5.5929
3	4.8081	1.57	.260	213.9	1464.8	1.0502	5.5800
4	4.9859	1.58	.251	218.5	1465.8	1.0669	5.5672
5	5.1687	1.58	.243	223.2	1466.8	1.0835	5.5545
6	5.3567	1.59	.235	227.8	1467.8	1.1001	5.5419
7	5.5500	1.59	.227	232.5	1468.8	1.1167	5.5294
8	5.7487	1.59	.219	237.1	1459.7	1.1332	5.5170
9	5.9528	1.60	.212	241.8	1470.7	1.1496	5.5046
10	6.1625	1.60	.205	246.5	1471.5	1.1661	5.4924

(Contd)

Temp. (°C)	Pressure (bar)	Specific Volume (m^3/kg)		Enthalpy (kJ/kg)		Entropy kJ/kg.K)	
		$v_f \times 10^3$	v_g	h_f	h_g	s_f	s_g
11	6.3778	1.60	.198	251.2	1472.5	1.1825	5.4802
12	6.5989	1.61	.192	255.9	1473.3	1.1988	5.4681
13	6.8259	1.61	.186	260.6	1474.2	1.2152	5.4561
14	7.0588	1.61	.180	265.3	1475.4	1.2314	5.4441
15	7.2979	1.62	.174	270.0	1475.9	1.2477	5.4322
16	7.5431	1.62	.169	274.8	1476.2	1.2639	5.4204
17	7.7946	1.62	.164	279.5	1477.5	1.2801	5.4087
18	8.0525	1.63	.158	284.8	1478.3	1.2963	5.3971
19	8.3169	1.63	.154	289.0	1479.0	1.3124	5.3855
20	8.5879	1.64	.149	293.8	1479.8	1.3285	5.3740
21	8.8657	1.64	.144	298.5	1480.5	1.3445	5.3626
22	9.1503	1.64	.140	303.3	1481.2	1.3606	5.3512
23	9.4418	1.65	.136	308.4	1481.9	1.3765	5.3399
24	9.7403	1.65	.132	312.9	1482.5	1.3925	5.3286
25	10.046	1.66	.128	317.7	1483.2	1.4084	5.3175
26	10.359	1.66	.124	322.5	1483.8	1.4243	5.3063
27	10.680	1.67	.128	327.3	1484.4	1.4402	5.2953
28	11.007	1.67	.117	332.1	1485.0	1.4560	5.2843
29	11.343	1.67	.114	336.9	1485.8	1.4718	5.2733
30	11.686	1.68	.110	341.8	1486.1	1.4876	5.2624
31	12.037	1.68	.107	346.6	1486.7	1.5033	5.2516
32	12.396	1.69	.104	351.5	1487.2	1.5191	5.2408
33	12.763	1.69	.101	356.3	1487.7	1.5348	5.2300
34	13.139	1.70	.098	361.2	1488.1	1.5504	5.2193
35	13.522	1.70	.096	366.1	1488.6	1.5660	5.2086
36	13.915	1.71	.092	370.9	1489.0	1.5816	5.1980
37	14.314	1.71	.090	375.9	1489.4	1.5972	5.1874
38	14.724	1.72	.088	380.8	1489.8	1.6128	5.1768
39	15.143	1.72	.085	385.7	1490.1	1.6283	5.1663
40	15.570	1.72	.083	390.6	1490.4	1.6437	5.1558
41	16.006	1.73	.080	395.5	1490.7	1.6592	5.1453
42	16.451	1.73	.078	400.4	1490.9	1.6747	5.1349
43	16.906	1.74	.076	405.4	1491.2	1.6901	5.1244
44	17.370	1.74	.074	410.4	1491.4	1.7055	5.1140
45	17.843	1.75	.072	415.4	1491.5	1.7209	5.1036
46	18.326	1.75	.070	420.4	1491.7	1.7363	5.0932
47	18.819	1.76	.068	425.4	1491.8	1.7517	5.0827
48	19.322	1.76	.066	430.4	1491.8	1.7671	5.0723
49	19.835	1.77	.065	435.4	1491.9	1.7825	5.0618
50	20.359	1.77	.063	440.5	1491.8	1.7979	5.0514
51	20.892	1.78	.061	445.6	1491.8	1.8134	5.0409
52	21.436	1.78	.060	450.7	1491.7	1.8289	5.0303
53	21.991	1.79	.058	455.9	1491.5	1.8444	5.0198
54	22.556	1.79	.056	461.1	1491.3	1.8600	5.0092
55	23.132	1.80	.055	466.3	1491.1	1.8757	4.9985

t_{sat}	p_{sat}	Degree of Superheat of Vapour 50°C			100°C		
		v	h	s	v	h	s
(°C)	(bar)	(m^3/kg)	(kJ/kg)	(kJ/kg.K)	(m^3/kg)	(kJ/kg)	(kJ/kg.K)
–40	0.718	1.82	1517	6.667	2.08	1624	7.016
–35	0.932	1.45	1526	6.572	1.76	1634	6.919
–30	1.196	1.24	1535	6.483	1.45	1644	6.827
–25	1.516	.96	1544	6.399	1.15	1654	6.741
–20	1.9	.78	1553	6.319	.90	1664	6.659
–15	2.36	.61	1561	6.243	.73	1674	6.581
–10	2.91	.53	1570	6.171	.59	1683	6.507
–5	3.55	.42	1578	6.102	.49	1693	6.437
0	4.29	.36	1586	6.036	.42	1702	6.370
5	5.16	.30	1594	5.974	.35	1711	6.307
10	6.15	.25	1601	5.914	.285	1720	6.247
15	7.28	.22	1608	5.856	.25	1729	6.189
20	8.57	.185	1615	5.801	.215	1737	6.133
25	10.01	.165	1622	5.748	.18	1746	6.080
30	11.67	.137	1628	5.697	.16	1754	6.030
35	13.5	.118	1634	5.648	.14	1762	5.982
40	15.54	.110	1640	6.601	.12	1770	5.935
45	17.82	.090	1646	5.555	.105	1778	5.890
50	20.33	.070	1651	5.510	.085	1785	5.847

Space for Rough Work

$m_2 u_2 - m_1 u_1 = m_i h_i - W_{cv}$

$(m_2 - m_1) h_i - W_{cv}$

$= -P_1 V_1$

$m_2 u_2 - m_1$

$m_2(u_2 - h_i) - m_1(h_i - u_1) = -P_1 V_1$

$\frac{2 P_1 \times 2 V_1}{R T_2}(C_v T_2 - C_p T_p) - \frac{P_1 V_1}{R T_1}(C_p T_p - C_v T_1) = -P_1 V_1 - 1$

$q_g = q_p + q_E + q_C$

$q_g = \frac{q_E + q_C}{}$

$\frac{q_g}{T_H}$

$\frac{2}{}$

$\frac{1}{R}\left[2C_v - 2C_p \frac{T_p}{T_2}\right] - \frac{1}{R}\left[C_p \frac{T_p}{T_1} - C_v\right] = -1$

$\frac{1}{R}\left[3 - \gamma\left[\frac{2T_p}{T_2} + \frac{T_p}{T_1}\right]\right] = -1$

$\frac{1}{R}\left[3 - \left[\frac{2T_p}{T_2} + \frac{T_p}{T_1}\right]\right] = -1$

$\frac{1}{R}\left[\frac{3}{\gamma-1} - \frac{\gamma}{\gamma-1}\left[\frac{2T_p}{T_2} + \frac{T_p}{T_1}\right]\right] = -1 - \frac{3}{\gamma-1}$

$-\frac{\gamma}{\gamma-1}\left[\quad\right] = \frac{-\gamma-1-3}{\gamma-1}$

$-\gamma\left[\quad\right] = -\gamma-4$

$\frac{1.33}{0.33} \quad \frac{8.314}{17}$