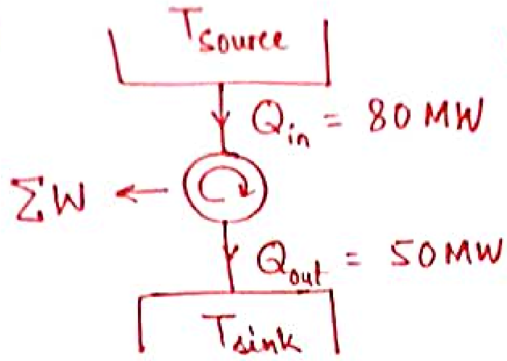
Solve (1)



a) Using the 1st law for cyclic process

$$\Sigma Q = \Sigma W$$

$$+80 - 50 = \Sigma W = 30\,MW$$

Net power output

b) Thermal efficiency of engine

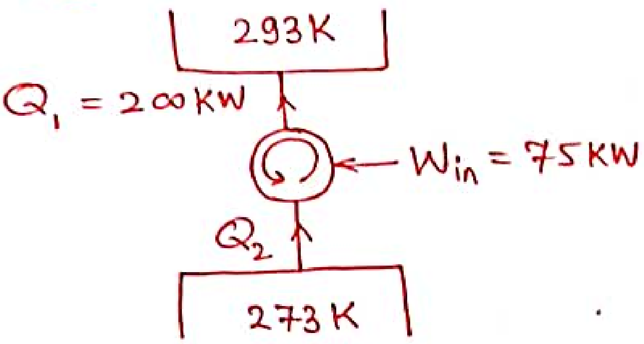
$$\eta = \frac{\Sigma W}{Q_{in}} \times 100$$

$$= \frac{30}{80} \times 100$$

$$= 37.5\,\%$$

Solve (2)

As per the inventor's claim



As per the 1st law

$$Q_2 + W_{in} = Q_1$$

$$Q_2 = Q_1 - W_{in} = 200 - 75$$

$$Q_2 = 125\,KW$$

$$(COP)_{HP} = \frac{HE}{W_{in}}$$

$$(COP)_{HP} = \frac{200}{75} = 2.67$$

a) As per the Carnot's theory $(COP)_{carnot} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}$

$$= \frac{293}{20}$$

$$= 14.65$$

$\therefore (COP)_{HP} < (COP)_{carnot}$

b) Using calculation of ΔS_{uni}

$$\Delta S_{uni} = \cancel{\Delta S_{sys}}^{\,0} + \Delta S_{surr} = \frac{+200}{293} - \frac{125}{273}$$

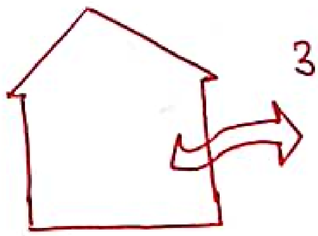
(cyclic process).

$$= +0.682 - 0.457$$

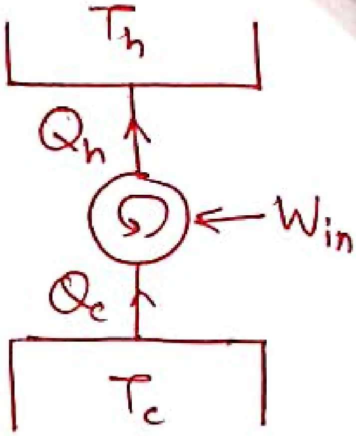
$$= +ve$$

$\Delta S_{uni} > 0$ Inventor's claim is right.

Solve (3)



3800 KJ/h°C



$T_h = 24 + 273 = 297\ K$

$W_{in} = 4\ KW$

$$(COP)_{HP} = \frac{Q_h}{W_{in}}$$

lowest outdoor temperature will be possible for max. performance of HP, i.e. Carnot theory

$$\Rightarrow (COP)_{HP} = \frac{T_h}{T_h - T_c} = \frac{Q_h}{W_{in}}$$

$$\left\{ \because Q_h = \frac{3800\,(T_h - T_c)}{3600} \right.$$

$$= 1.0556(297-T$$

$$\cancel{\Rightarrow Q_h = \frac{W_{in}\,T_h}{T_h - T_c}}$$

$$\cancel{\Rightarrow \frac{3800\ KW/°C}{3600}(297-T_c) = \frac{4 \times 297}{297 - T_c}}$$

$$\cancel{297 - T_c = \frac{4 \times 297}{1.055} = \frac{1188}{1.055}}$$

$$\Rightarrow \left(3800/3600(297-T_c)\right)/4 = 297/(297-T_c)$$

$$\frac{1.055(297-T_c)}{4} = \frac{297}{(297-T_c)}$$

$$(297-T_c)^2 = \frac{4 \times 297}{1.055} = \frac{1188}{1.0556} = 1125.42$$

$$297 - T_c = \sqrt{1125.42} = 33.55$$

$$T_c = 297 - 33.55\ K$$

$$T_c = 263.45\ K$$

$$\boxed{T_c = -9.55°C}$$

(4) Air is expanded from 2000 KPa, 500°C to 100 KPa, 50°C

$P_1 = 2000$ KPa
$T_1 = 500$°C

$\longrightarrow$

$P_2 = 100$ KPa
$T_2 = 50$°C

a. Assuming constant sp. heats (approx.)

$$\Delta S = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

for air $c_p = 1.005$ KJ/Kg K

$R = 0.287$ KJ/KgK

$$\Delta S = 1.005 \ln\left(\frac{273+50}{273+500}\right) - 0.287 \ln\left(\frac{100}{2000}\right)$$

$$= -0.8769 + 0.8597 = -0.0172 \text{ KJ/KgK}$$

b. Assuming variable sp. heats (exact)

× quad. $c_p = 0.99 - 5\times10^{-5}\,T + 2.2\times10^{-7}\,T^2$

✓ cubic. $c_p = 1.048 - 3.7\times10^{-4}\,T + 8.7\times10^{-7}\,T^2 - 4.15\times10^{-10}\,T^3$

c_p	T(K)
1.003	250
1.099	800

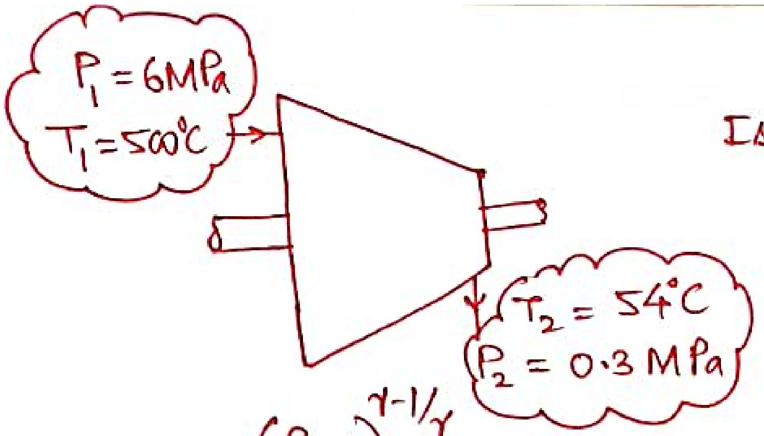
$$\int ds = \int \frac{c_p}{T}\,dT - \int R\,\frac{dP}{P}$$

$$= \int\left(\frac{1.048}{T} - 3.7\times10^{-4} + 8.7\times10^{-7}\,T - 4.15\times10^{-10}\,T^2\right) dT - R\ln\left(\frac{P_2}{P_1}\right)$$

$$= 1.048 \ln\left(\frac{T_2}{T_1}\right) - 3.7\times10^{-4}(T_2 - T_1) + \frac{8.7\times10^{-7}}{2}(T_2^2 - T_1^2) - \frac{4.15\times10^{-10}}{3}(T_2^3 - T_1^3)$$
$$- R\ln\left(\frac{P_2}{P_1}\right)$$

$=$

(5)



Isentropic process

$$P^{1-\gamma} T^{\gamma} = C$$

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

(a)

$$\therefore \; T_2 = T_1 \left(P_2/P_1\right)^{\gamma-1/\gamma}$$

$$= 773\left(\frac{0.3}{6}\right)^{0.4/1.4} = 773\,(0.05)^{0.286} = 327\ K$$

$$= 54°C$$

Max. amount of work by turbine

$$\dot{m}\left(h_1 + \frac{C_1^2}{2} + gz_1\right) + \cancel{Q_{1-2}}^{\,0} = \dot{m}\left(h_2 + \frac{C_2^2}{2} + gz_2\right) + W_{1-2}$$

$$W_{1-2} = \dot{m}\,(h_1 - h_2)$$

Not true for steam

$$\cancel{= 2 \times 1.005 \times (500-54)\ KJ/s}$$

$$\cancel{W_{1-2} = 896.46\ KJ/s}$$

from steam table

@ 6MPa, 500°c $h_1 = 3422.95$ KJ/Kg

@ 0.3MPa, 54°C $h_2 = 226.30$ KJ/Kg

$$W_{1-2} = m\,(h_1 - h_2)$$

$$= 2 \times (3422.95 - 226.30)\ KJ/s$$

$$\boxed{W_{isen} = 6393.3\ KJ/s}$$

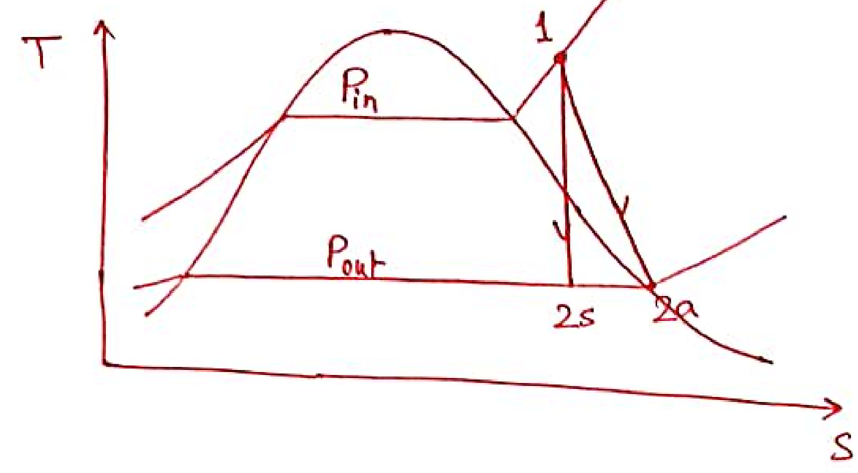
(b) If exit is saturated vapour

@ $x_2 = 1$, $P_2 = 0.3MPa$ $\quad h_2 = 2724.9$ KJ/Kg

$$W_{1-2} = 2 \times (3422.95 - 2724.9)\ KJ/s$$

$$\boxed{W_{act} = 1396.1\ KJ/s}$$

$$\eta_{isen} = \frac{W_{real}}{W_s} = \frac{1396.1}{6393.3} \times 100 = 21.83\%$$



Solve (6) Adiabatic nozzle (steady flow)

$C_1 \sim 0$
$P_1 = 6\,MPa$
(Saturated)

$\eta_{isen} = 0.88$

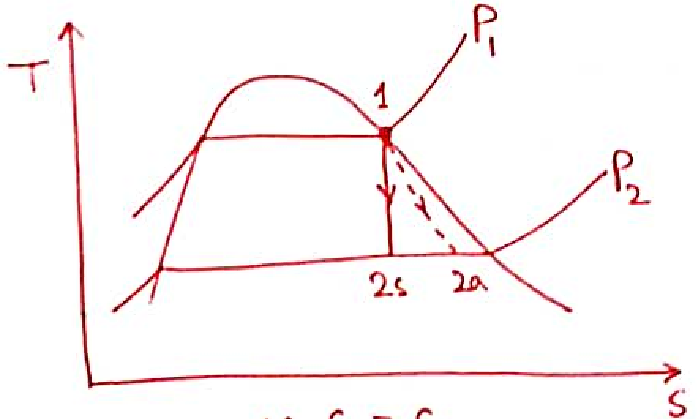
$C_2 = ?$
$P_2 = 1.2\,MPa$

Considering isoentropic process $Q_{1-2} = 0$

no work $W_{1-2} = 0$

$$h_1 = h_2 + \frac{C_2^2}{2}$$

$h_1 = 2784.6\ KJ/Kg$
$S_1 = 5.89\ KJ/KgK$
$h_2 = ?$
$S_2 = 5.89\ KJ/KgK$



$\because S_1 = S_2$

At 1.2 MPa $S_g = 6.52$; $h_g = 2783.7$
$S_f = 2.21$; $h_f = 798.33$

$$5.89 = x S_g + (1-x) S_f$$

$$5.89 = x\, 6.52 + (1-x)\, 2.21$$

$$5.89 - 2.21 = x(6.52 - 2.21)$$

$$x = \frac{5.89 - 2.21}{6.52 - 2.21} = \frac{3.68}{4.31}$$

$$\boxed{x_2 = 0.85}$$

$$h_2 = 0.85(2783.7) + 0.15(798.33)$$

$$= 2366.14 + 119.74$$

$$\boxed{h_2 = 2485.88\ KJ/Kg}$$

$$C_2 = \sqrt{2(h_1 - h_2)}$$

$$= \sqrt{2(2784.6 - 2485.98)}$$

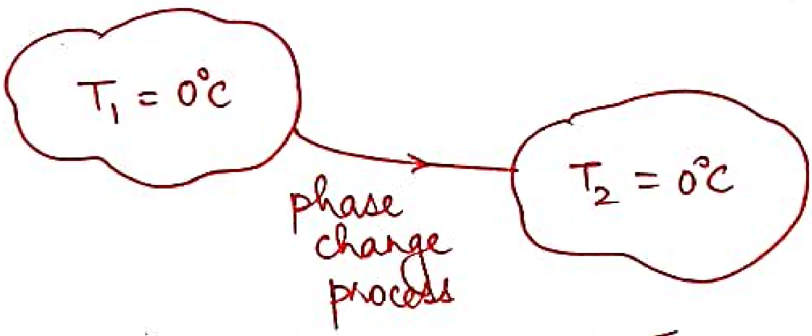
ideal $\quad C_{2s} = \sqrt{597.44} = 24.44 \text{ m/s}$

real $\quad \eta_{\text{isen, nozzle}} = \dfrac{C_{2a}^2}{C_{2s}^2}$

$$C_{2a} = \sqrt{0.88 \times (24.44)^2} = 22.93 \text{ m/s}$$

Solve (7) $\quad m = 10$ Kg of liq. water

$$\left.\begin{aligned} T_1 &= 0^\circ C \\ T_2 &= 0^\circ C \end{aligned}\right\} \text{ freezing process.}$$

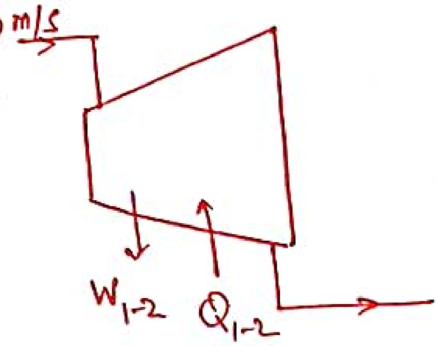


$$\Delta S_{sys} = -\frac{mL}{T_{sat}} = -\frac{10 \times 3.4 \times 10^5}{273} = -12454.21 \text{ J/K}$$

$$\Delta S_{surr} = +\frac{mL}{T_{surr}} = \frac{10 \times 3.4 \times 10^5}{298} = +11409.39 \text{ J/K}$$

$$\Delta S_{uni} = \Delta S_{sys} + \Delta S_{surr} =$$

Solve (8) $P_1 = 30\,bar$
$T_1 = 400°C$
$V_1 = 160\,m/s$



$T_2 = 100°C$
$V_2 = 100\,m/s$
$x_2 = 1$

Using steam properties

$h_1 = 3231.57\ KJ/Kg$ $\qquad h_2 = 2675.6\ KJ/Kg$

$s_1 = 6.92\ KJ/KgK$ $\qquad s_2 = 7.35\ KJ/KgK$

SFEE

$$\left(h_1 + \frac{V_1^2}{2} + gz_1\right) + Q_{1-2} = \left(h_2 + \frac{V_2^2}{2} + gz_2\right) + W_{1-2}$$

$$3231.57 + \frac{(160)^2}{2000} + Q_{1-2} = 2675.6 + \frac{(100)^2}{2000} + 540$$

$$Q_{1-2} = (2675.6 - 3231.57) + \frac{(100)^2 - (160)^2}{2000} + 540$$

$$Q_{1-2} = -555.97 - 7.8 + 540 = -23.77\ KJ/Kg$$

Entropy generated (per unit mass)

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

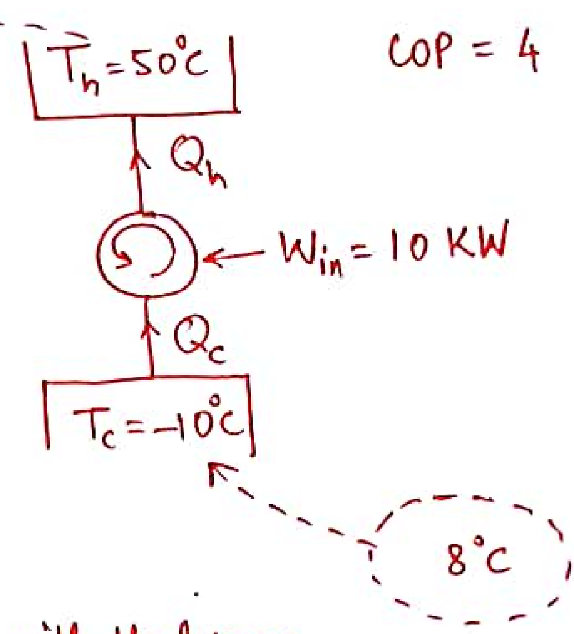
$$= (S_2 - S_1) + \frac{Q_{1-2}}{T_{surr}}$$

$$= (7.35 - 6.92) + \frac{23.77}{500}$$

$$= 0.43 + 0.0475$$

$$\boxed{S_{gen} = 0.4775\ KJ/KgK}$$

Solve (9) 21°C



COP = 4

$$COP = \frac{HE}{W_{in}}$$

$$4 = \frac{Q_h}{10}$$

$$Q_h = 40 \text{ KW}$$

$$Q_c = 30 \text{ KW}$$

Entropy generation associated with Heat pump

$$S_{gen} = \Delta S_{uni} = \underbrace{\cancel{\Delta S_{sys}}}_{\substack{0 \\ \text{(cyclic process)}}} + \Delta S_{surr}$$

$$S_{gen} = -\frac{Q_c}{273-10} + \frac{Q_h}{273+50}$$

$$= \frac{-30}{263} + \frac{40}{323} = -0.114 + 0.124$$

$$S_{gen} = 0.01 \text{ KW/K}$$

Entropy change associated with CV_1

$$\Delta S_{cv_1} = c_p \ln\left(T_c/T_1\right)$$

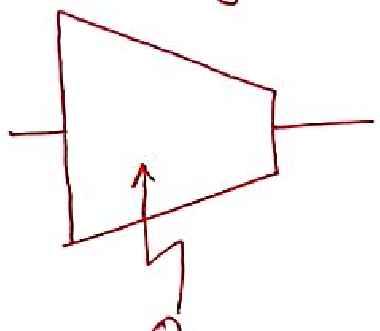
Entropy change associated with CV_2

$$\Delta S_{cv_2} = c_p \ln\left(T_2/T_h\right)$$

(13)

$\dot{m} = 100\ Kg/h = 100/3600\ Kg/s$

$P_1 = 40 MPa$
$T_1 = 800°C$
$C_1 \sim 0$



Q_{1-2}

$P_2 = 0.1\ MPa$
$x_2 = 0.9$

$T_{surr} = 450°C$

$S_{gen} = 0.1\ S_{surr}$

At state 1

$h_1 = 3972.8\ KJ/Kg$
$s_1 = 6.66\ KJ/KgK$

Using SFEE

$$\dot{m}(h_1 + 0) + Q_{1-2} = \dot{m}\left(h_2 + \frac{C_2^2}{2000}\right) + \cancel{W_{1-2}}^{\,0} \quad —(1)$$

At state 2

$h_2 = x h_g + (1-x) h_f$
$= 0.9 \times 2674 + 0.1 \times 417.5$
$= 2448.35\ KJ/Kg$

$S_2 = x S_g + (1-x) S_f$
$= 0.9 \times 7.35 + 0.1 \times 1.3$
$= 6.745\ KJ/KgK$

$v_2 = 1.52\ m^3/Kg$

(a)

Entropy generation

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

$$0.1\ \Delta S_{surr} = \dot{m}(s_2 - s_1) + \Delta S_{surr}$$

$$-0.9\ \Delta S_{surr} = \frac{1}{36}(6.745 - 6.66)$$

$$\Delta S_{surr} = -2.623\ W/K = \frac{-Q_{1-2}}{T_{surr}}$$

$$Q_{1-2} = 2.623 \times 723\ W = 1896.43\ W = 1.89\ KW$$

(b)

from eq^n (1)

$$\dot{m}(h_1 - h_2) + Q_{1-2} = \dot{m}\frac{C_2^2}{2000}$$

$$\sqrt{\left(\frac{1}{36}(3972.8 - 2448.35) + 1.89\right) \times \frac{2000}{\dot{m}}} = C_2$$

$$\sqrt{(1524.45 + 68.04) \times 2000} = 1784.65\ m/s$$

ⓒ Exist area

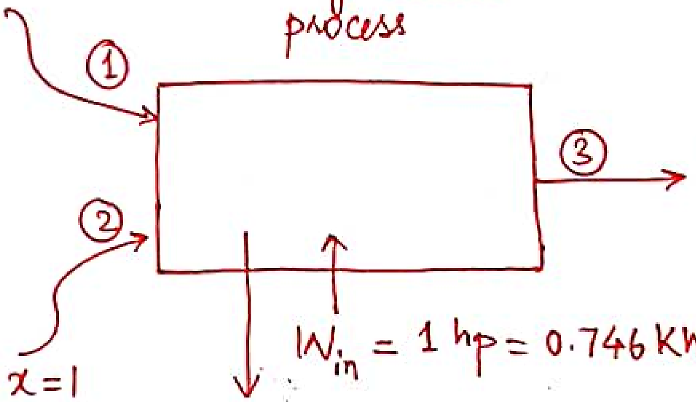
$$\dot{m} = \rho_2 A_2 C_2$$

$$\frac{100}{3600} = \frac{1}{v_2} A_2 C_2$$

Solve (14)

sat liq $x=0$
$h_1 = 419.17$ KJ/Kg $\begin{cases} 0.2 \text{ Kg/s} \\ 100°C \end{cases}$

steady isobaric process



Mixture $x = ?$

$W_{in} = 1$ hp $= 0.746$ KW

$h_2 = 2675.6$ KJ/Kg $\begin{cases} \text{Sat. vap } x=1 \\ 0.5 \text{ Kg/s} \\ 100°C \end{cases}$

$Q_{out} = 75$ KW

$T_{surr} = 100°C$

Isobaric process
$P_3 = P_2 = P_1 = P_{sat}$ @ $100°C$

Using SFEE

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 + Q_{1-2} = \dot{m}_3 h_3 + W_{1-2}$$

$$(0.2 \times 419.17) + (0.5 \times 2675.6) + (-75)$$

$$= \dot{m} h_3 + (-0.746)$$

$$\dot{m}_3 h_3 = 1347.38 \qquad \because \dot{m}_3 = \dot{m}_1 + \dot{m}_2 = 0.7 \text{ Kg/s}$$

$$h_3 = \frac{1347.38}{0.7} = 1924.82 \text{ KJ/Kg}$$

$$x(2675.6) + (1-x)\,419.17 = 1924.82$$

$$\boxed{x_3 = 0.667}$$

(b) Entropy production rate (of sys.) $\boxed{x_3 = 0.667}$

$$\dot{S}_{gen} = \Delta S_{sys} + \Delta S_{surr}$$

$$= (m_3 s_3) - (m_1 s_1 + m_2 s_2) + \frac{Q_{out}}{T_{surr}}$$

$$= (0.7 \times 5.33) - (0.2 \times 1.3072 + 0.5 \times 7.35) + \frac{75}{373}$$

$$= (3.731) - (3.93) + \frac{75}{373}$$

ve (15)

$m = 0.1\ Kg$
(water vapour)

$v_1 = 2.17\ m^3/Kg$

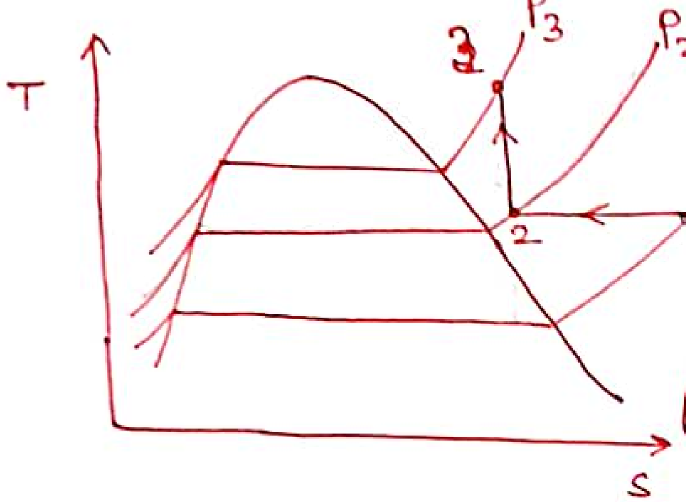
$T_1 = 200°C$
$P_1 = 0.1\ MPa$

Isothermal process

$T_1 = T_2 = 200°C$

adiabatic process

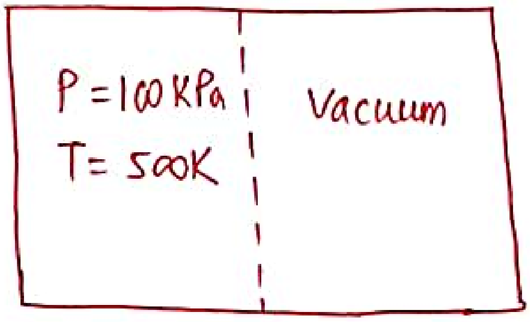
$S_3 = S_2$
$v_3 = \frac{6.1}{100} v_1 = 0.13\ m^3/Kg$



$T_3 = T_1 = 200°C$

$v_3 = 0.061\, v_1 = 0.13\ m^3/Kg$

16



Insulated tank

$Q_{1-2} = 0$

free expansion

$W_{1-2} = 0$

Volume gets doubled

from the 1st law

$$\cancel{Q}_{1-2} = \Delta U + \cancel{W}_{1-2}$$

$$U_1 = U_2$$

$$\therefore T_1 = T_2$$

a) for an isothermal process

$$P_1 V_1 = P_2 V_2$$

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

$$\boxed{P_2 = 50 \text{ KPa}}$$

b) change in entropy

$$\Delta S_{uni} = \Delta S_{sys} + \cancel{\Delta S}_{surr}$$

$$= C_v \cancel{\ln\left(\frac{T_2}{T_1}\right)} + R \ln\left(\frac{V_2}{V_1}\right)$$

$$\boxed{\Delta S_{uni} = 8.314 \ln(2) \quad \text{J/mol·K}}$$