Properties of Pure Substance

Steam

Steam is a vapour. It is used as the working substance in the operation of steam engines and steam turbines.

A vapour is a partially evaporated liquid carrying in it particles of liquid and it can be liquified by minor changes in temperature or pressure. Steam as a vapour would not obey the laws of perfect gases unless it is in a highly dried condition. Steam in such a dried state is known as superheated steam and it is assumed to behave like a perfect gas when highly superheated.
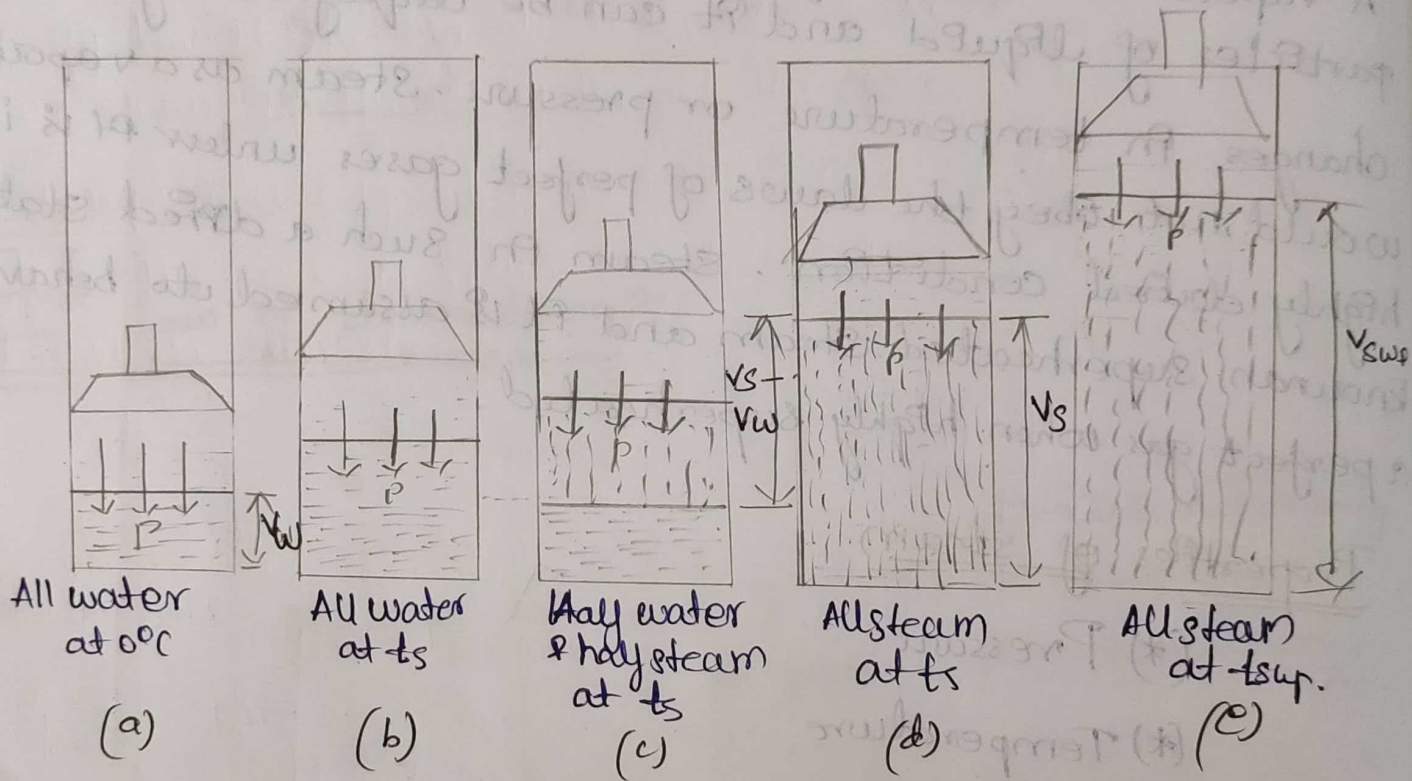
Properties of steam

(*) Pressure

(*) Temperature

(*) Specific volume

(*) Enthalpy

(*) Entropy

Pressure, temperature and volume can be given their actual absolute values, whereas enthalpy and entropy are purely relative quantities. They are measured relatively from convenient datum condition of the water at 0°C Thus, the enthalpy, the internal energy and the entropy of water at 0°C are assumed to be zero. All their values measured above this temperature are considered positive and those measured below are taken as negative.

Formation of steam at constant Pressure

Consider a cylinder fitted with frictionless piston which may be loaded to any desired pressure p bar as shown :-

Properties of steam

All water at 0°C	All water at ts	Half water & half steam at ts	All steam at ts	All steam at tsup.
(a)	(b)	(c)	(d)	(e)

(i) The kilogram of water initially at temperature 0°c in the cylinder under the piston and the piston exerts a constant pressure P bar.

(ii) Let the area of the piston be one square metre and the volume of one kilogram of water be v_w m³.

(iii) The length in the cylinder occupied by water will be v_w m. Now let heat be supplied to the water in the cylinder

(iv) The temperature of water will rise when sensible enthalpy to supplied. The rise in temperature at which water boils depends upon the pressure on it.

(V) The Given pressure there is one and definite boiling point. The boiling point is called the saturation temperature (t_s) or the temperature of steam formation. Water boils at 99.63°C when the pressure on it is 1 bar and at 184.09°C when the pressure on it is 11 bar.

(vi) The water will expand slightly during the rise of temperature. The increase in volume of water causes the piston to move up slightly as shown. Fig (b). The work is done in moving the piston against the pressure p. This work however is only a small portion of the heat added to water during the rise in temperature and may be neglected in general.

(vii) The next stage, the actual production of steam. If the heating of this one kilogram of water is continued. after the boiling is reached. It will be noticed that there is no further increase in temperature.

(viii) A mixture of steam and water is called wet steam. If the heating of this wet steam is further continued and as soon as last particle of water in suspension in wet disappears, the steam produced is known as dry saturated steam.

(ix) The process of formation of steam is completed. The water is entirely evaporated and the volume of steam below the piston is $v_s\,m^3$. The piston will rise to accommodate this increased volume and will occupy length $v_s\,m$ of the cylinder.
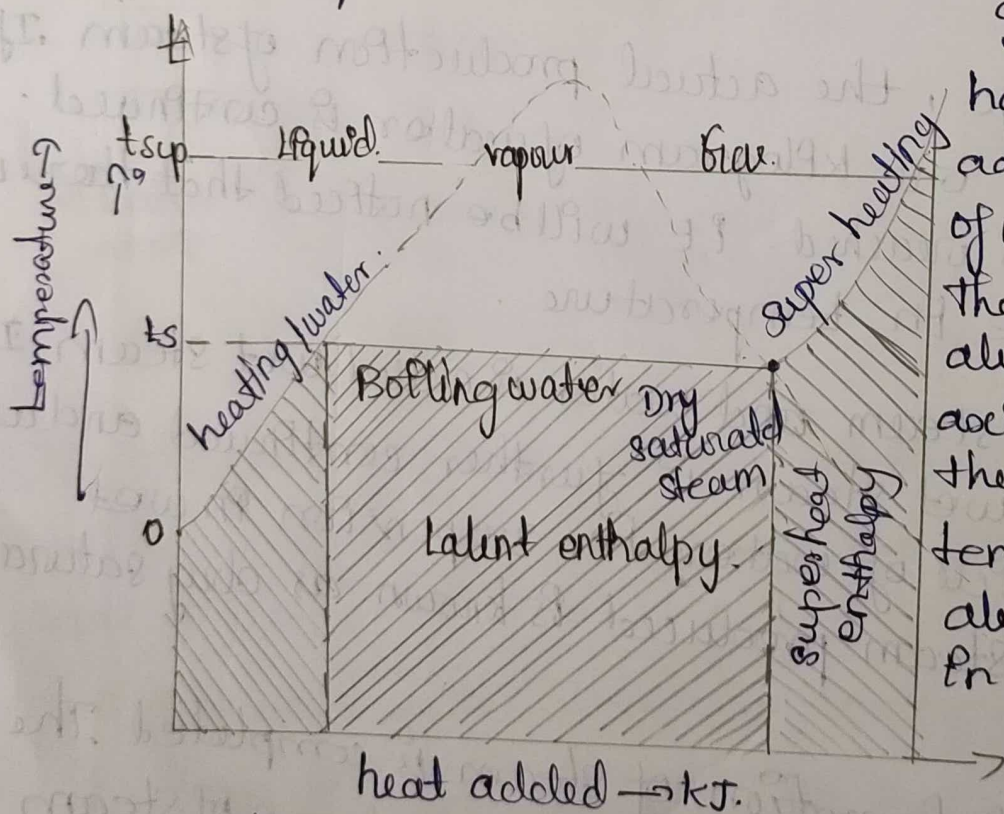
• The work done on the piston during the change of volume of the steam from v_w to v_s.

$$= \frac{10^5 \, p(V_s - V_w)}{10^3} \text{ kJ} \quad \text{where } p \rightarrow \text{is the pressure in bar.}$$

If p is in kPa, then the above expression is written as

$$\text{workdone} = p(V_s - V_w) \text{ kJ}$$

Finally the if further heat Q added to one kilogram of dry steam in the cylinder at the constant pressure, the temperature of steam will arise and there will be further increase in volume of steam as. The steam produced is known as superheated steam.

During the first stage of heating the temperature of water will begin to rise until the water will begin to rise until the water boils at a temperature which depends upon the pressure in the cylinder. After the boiling temperature is reached, steam begins to be formed during which time the temperature remains constant.

graphically that what happens when heat is added to one kilogram of water Initially at 0°c the heat added is plotted along the horizontal axis in kJ units while the corresponding temperature are plotted along the vertical axis in centigrade units.

Enthalpy: For reasons too long to explain here, the term heat content is not recommended for use in thermodynamics. The terms formely known as "heat of water" (sensible heat), "heat of evaporation" (latent heat) and "total heat of steam" are now known as the "enthalpy of (saturated) water", "enthaply of evaportion" and "enthalpy of saturated steam" respectively. Similarly the term total heat of superheated steam is now known as "enthalpy of superheated steam". Enthalpy of evaporation is the difference between enthalphy of dry saturated steam and enthalpy of water. [In enthaply the pressure should be constant]

$$\Delta H = \Delta E + P \Delta V$$

Enthalpy of water The amount of heat absorbed by one kilogram of water in being heated from the freezing point (0°C) to the boiling point ts is known as the enthalpy of the saturated water and is denoted by the symbol h.

Enthalpy of Evaporation The enthalpy of evaportion is defined as the amount of heat required to convert one kilogram of water at a given temperature ts and a pressure p into steam at same temperature and pressure.

Enthalpy of dry saturated steam It is the sum of enthalpy of saturated water and enthalpy of evaporation and is defined as the quantity of heat required to raise the temperature of one keilo gram of water from freezing point to the temperature of evaporation ts and then convert it into dry saturated steam at that temperature and pressure. It is denoted by the symbol Hs. The enthaply of one kg of dry saturated steam, Hs = enthalpy of (saturated) water + enthaply of evaporation. $(Hs = h + L \text{ kJ/kg})$
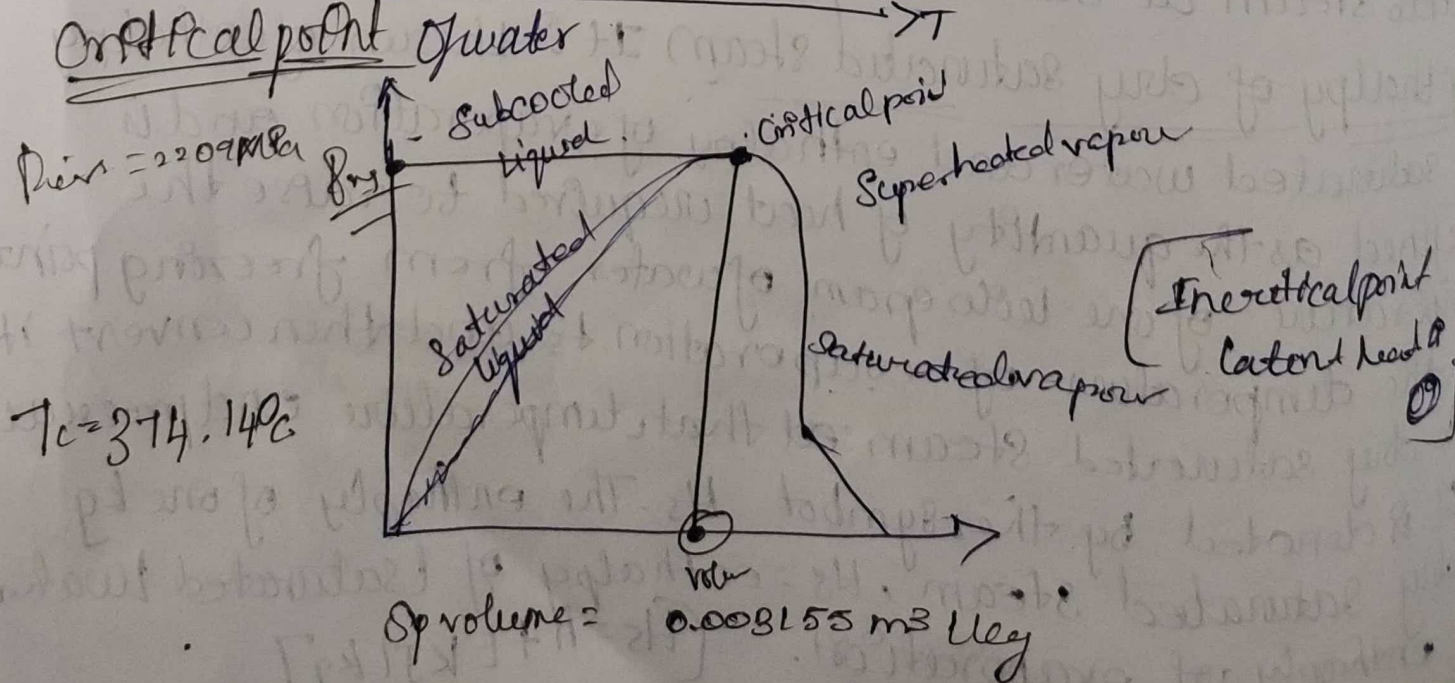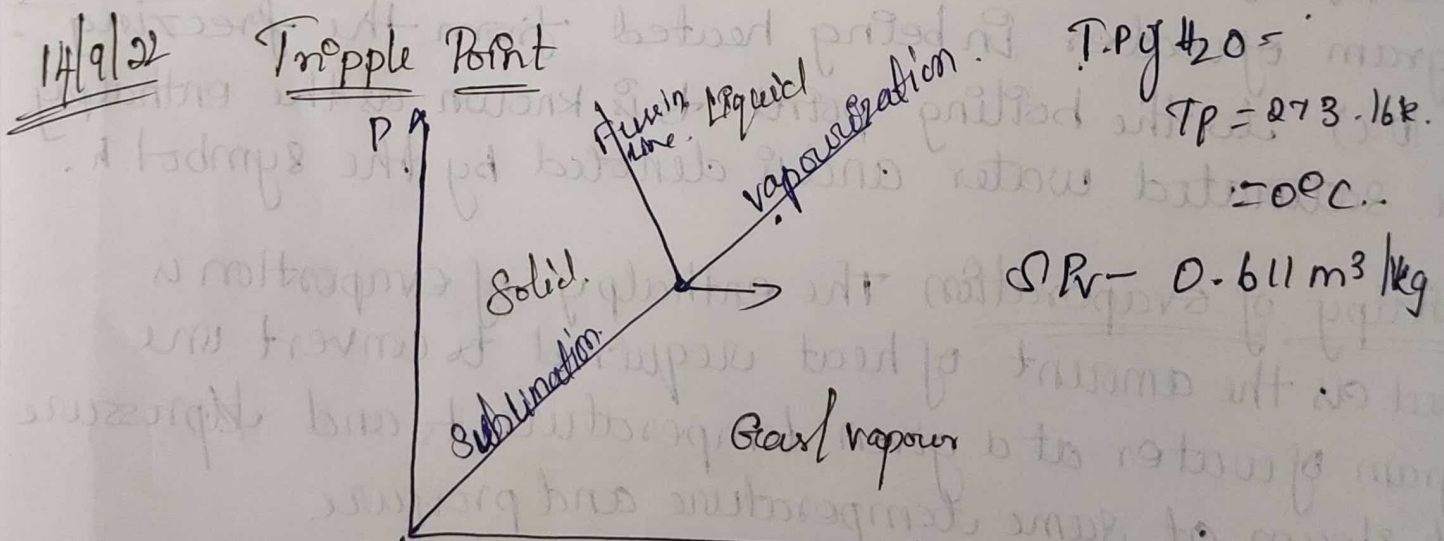
Wet steam The steam in the steam space of a boiler generally contains water mixed with it in the form of a mist. Such a steam is termed as wet steam. The quality of steam as regards its dryness is termed as dryness fraction. Dryness fraction is usually expressed by the symbol x or q. Dryness fraction is often spoken as the quality of wet steam.
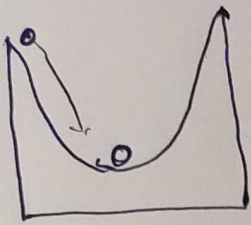
$m_s \longrightarrow$ mass of dry steam contained in the steam considered and.

$m =$ mass of water in suspension in the steam considered.

$$\boxed{\underline{\underline{\text{Dryness fraction}}} \qquad x = \frac{m_s}{m_s + m} \xleftarrow{\text{mass of steam}}}$$

14/9/22 <u>Tripple Point</u>

T.P of H_2O :

$TP = 273.16 k.$

$= 0°C.$

$SP_r = 0.611 \, m^3/kg$

<u>Critical point of water</u>

$P_{cr} = 2209 \, MPa$

$Tc = 374.14°C$

Sp volume = $0.003155 \, m^3/kg$
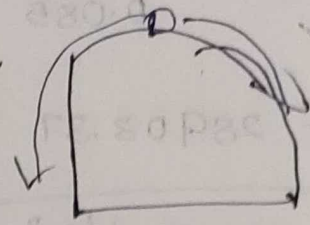
In center they will come. from any point of starting takingplace.

unstable equilibrium

Stable equilibrium

Latent heat $\longrightarrow$ Temperature Increase constant
volume change

Sensible heat $\longrightarrow$ volume constant
Temperature change.

Ex.

① 1 kg of gas expansions at constant pressure from
Temperat 0.085 m3 to $0.13 m^3$. The initial temperature
of the gas is $22.5°c$ Find the final temperature net
heat transfer changing internal energy and pressure
of gas..

Given,. $m = 1 kg$

Pressure $=$ constant

$V_1 = 0.085 m^3$

$V_2 = 0.13 m^3$ $(22.5 + 273)$

$T_1 = 22.5°C$ $\Rightarrow 295.5°k$ $= 295.5$

To find , P_1 W, Q , ΔU T_2

(i) Pressure

$PV = MRT$

$P = \dfrac{MRT}{V}$

$$P = \frac{1 \times 8 \cdot 314 \times 295 \cancel{K}}{0.085}$$

2456.7

$$P_{w} = 28903.37 \ N/m^2$$

$$\boxed{P \approx 28903 \ N/m^3}$$

(ii) Workdone :

$$WD = P\Delta V$$

$$= P(v_2 - v_1),$$

$$= 28903 \ (0.013 - 0.085)$$

−0.072

$$= 1300.63 \ Joules$$

$$\left[\text{Some energy is loss so } (-)\right]$$

$$\boxed{WD = -1300.63 \ Joules}$$

(iii) **Net Heat Transfer**

$$Q = W \qquad \rightarrow \text{actual formula.}$$

$$\left[\begin{array}{l}\text{Some heat is loss.} \\ \text{heat energy is into negative work}\end{array}\right]$$

$$Q = -W$$

$$Q = -(-1300.63 \ J)$$

$$Q = 1300.63 \ J$$

(iv) **change In Internal Energy**

$$\Delta u = Q + W$$

$$\Delta u = 0$$

$$\left[\text{1st law of thermodyn}\right]$$
(+) is two formula is
then

(v) $T_2 \to$ Final temperature.

At, Pressure = constant

$$V \alpha T$$
$$V = T$$

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

$$\Rightarrow \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{0.085}{295.5} \neq \frac{0.13}{T_2}$$

$$T_2 = \frac{V_2 \times T_1}{V_1}$$

$$= \frac{0.13 \times 295.5}{0.085}$$

$$= 451.94 \, K$$

$$T_2 = 178.94 \, ^{\circ}C$$

$(451.94 - 273)$
$= 178.94$.

② 5 kg of air at 40°C and 1 bar is heated in a reversible unfollow constant pressure until the volume is double so find Ⓐ change in the volume Ⓑ work done Ⓒ change in internal energy Ⓓ change in enthalpy.

Given :- M = 5 kg
$T_1 = 40°C$
$= 313 \, k$
$V_1 = 2V_2 = V_2$
$P_1 = 1 \, bar = 100 \, Nm^2$

To find

(a) change in $V = V_2 - V_1$

(b) W?

(c) Δu

(d) ΔH

(i) $V_2 - V_1$

$$P_1 V = mRT_1$$

$$V_1 = \frac{mRT_1}{P_1}$$

$$V_1 = \frac{5 \times 8314 \times 313}{100}$$

$$\boxed{V_1 = 4.49 \ m^3}$$

$$V_1 = 2V_1$$

$$= 4.49 \times 2$$

$$\boxed{V_2 = 8.98 \ m^3}$$

$$\boxed{V_2 - V_1 = 4.49 \ m^3}$$

(ii) Work done

$$W = P\Delta v = P(V_2 - V_1)$$

$$= 100 (4.49)$$

$$\boxed{W = 4.49 \ kJ}$$

(iii) change in temperature

$$\Delta u = mC_v \Delta T$$

$$= 5 \times 0.718 \times (T_2 - T_1)$$

$C_v \rightarrow$ specific heat @ Constant volume

C_v is value is const

C_v value for air
$= 0.7184 \ kJ/kg$

Energy Balance

Energy Entering + heat entering = Energy leaving
the c.v   CV   the c.v

+ work transfer + Stored Energy

CP → specific
heat @ constant
Pressure.

$$M_1\left(P_1 v_1 + \frac{c_1^2}{2} + z_1 g + u_1\right) + Q = M_2\left(P_2 v_2 + c_2^2 + \right.$$

$$\left. \frac{}{2} \right.$$

$$\left. z_2 g + u_2\right) + W$$

cv → control
volum

$$M_1 = M_2 = M$$

$$m\left(u_1 + P_1 v_1 + \frac{c_1^2}{2} + z_1 g\right) + Q = M\left(u_2 + P_2 v_2 + \frac{c_2^2}{2} + z_2 g\right) + W$$

$$\boxed{h = u + Pv}$$

$$\boxed{m\left(h_1 + \frac{c_1^2}{2} + z_1 g\right) + Q = m\left(h_2 + \frac{c_2^2}{2} + z_2 g\right) + W}$$
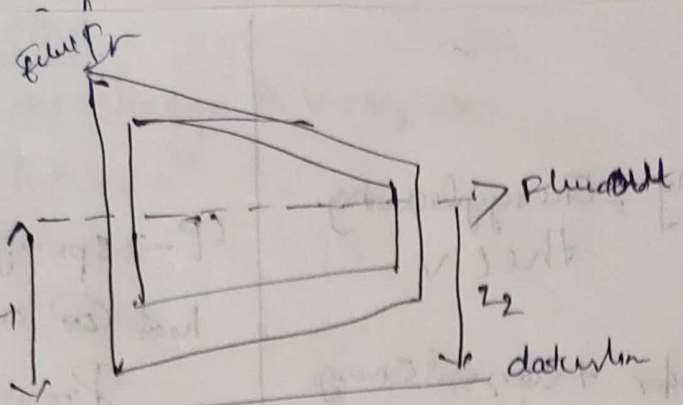
steady flow
Energy Equal.

$$\boxed{m=1}$$

$$h_1 + \frac{c_1^2}{2} + z_1 g + \frac{Q}{m} = h_2 + \frac{c_2^2}{2} + z_2 g + \frac{W}{M}$$

$$h_1 + \frac{c_1^2}{2} + z_1 g + q = h_2 + \frac{c_2^2}{2} + z_2 g + w$$

$$\boxed{q - W = h_2 - h_1 + \frac{c_2^2 - c_1^2}{2} + \left(z_2 - z_1\right)g} \quad kJ/kg$$

Nozzle

Let $Q = 0$

$z_1 = z_2 = 0$ $W = 0$

$M_1 = m_2$

z_1

z_2

datum line

$$m\left(h_1 + \frac{c_1^2}{2} + 0\right) + 0 = m\left(h_2 + \frac{c_2^2}{2} + 0\right) + 0$$

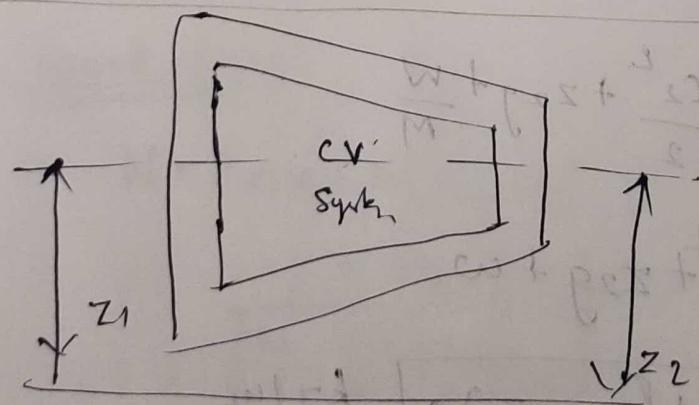$$\Rightarrow h_1 + \frac{c_1^2}{2} = h_2 + \frac{c_2^2}{2}$$

$$h_1 - h_2 = \frac{c_2^2 - c_1^2}{2}$$

$$2(h_1 - h_2) = c_2^2 - c_1^2$$

$$\sqrt{2(h_1 - h_2) + c_1^2} = c_2$$

$$c_2 > c_1 \Rightarrow c_1 = 0$$

$$\boxed{\sqrt{2(h_1 - h_2)} = c_2}$$

CV
System

z_1

z_2

$z_1 = z_2 = 0$ $Q = 0$

$c_1 = c_2 = 0$ $w = +ve$

$$m\left(h_1 + \frac{c_1^2}{2} + z_1 g\right) + Q = m\left(h_2 + \frac{c_2^2}{2} + z_2 g\right) + w$$
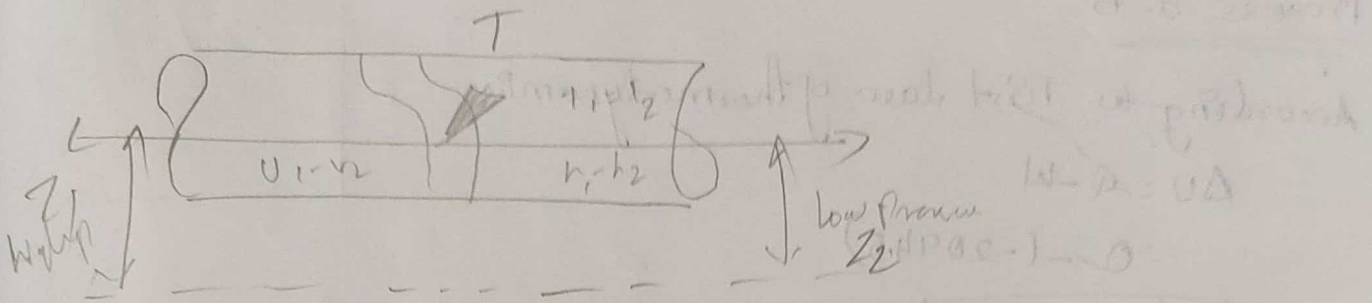
$$mh_1 = mh_2 + w$$

$$w = mh_1 - mh_2$$

$$w = m(h_1 - h_2)$$

Cashere $h_1 > h_2$

Throttling device

$$\Delta PE = 0$$

$$\Delta KE = 0$$

$$W, Q = 0$$

$$\boxed{h_1 = h_2}$$

$$h = c_p$$

$$c_p T_1 = c_p T_2 \qquad \boxed{T_1 = T_2}$$

$M_1 = M_2 = M$

① A fluid system undergoes process a-b, b-c, c-d and d-a to complete a cycle during one cycle; the total negative heat transfer in 84 kJ. The system completes 100 cycles per minute. The energy transfer are tabulated. Below. Estimate the Amount of work done (kJw)

Process	$Q\left(kJ/min\right)$	$W\,(kJ/min)$	$\Delta u\,(kJ/min)$
a-b	0	-20945	20945
b-c	20945	0	20915
c-d	2094	~35800	37700
d-a	?	?	?

Soln :. Given:.

① Process a-b

According to First law of thermodynamics

$$\Delta U = Q - W$$
$$= 0 - (-20945)$$
$$\boxed{\Delta U = 20945} \ kJ/m^i$$

(ii) Process (b-a)

$$\Sigma Q = (Total \ heat \ transfer) \times No \ of \ cycles$$

$$= -84 \times 100$$

$$\boxed{\Sigma Q = -8400 \ kJ/min}$$

$$\Sigma Q = Q_{a-b} + Q_{b-c} + Q_{c-d} + Q_{d-a}$$

$$\boxed{Q_{d-a} = -81439 \ kJ/min}$$

$$\Sigma Q = \Sigma W$$
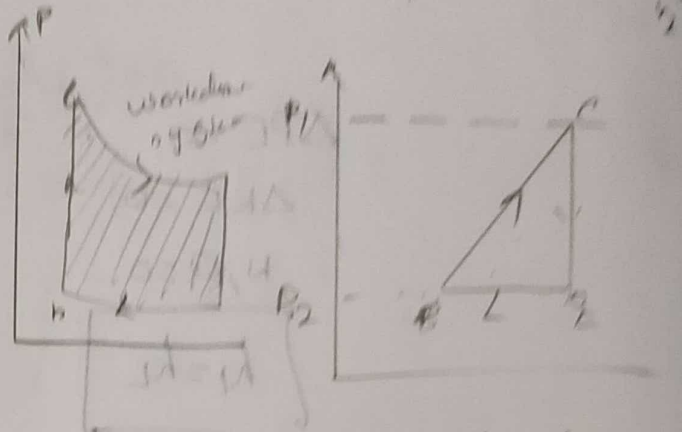$$-8400 = \Sigma W$$

$$W_{d-a} = 48151 \ kJ/min$$
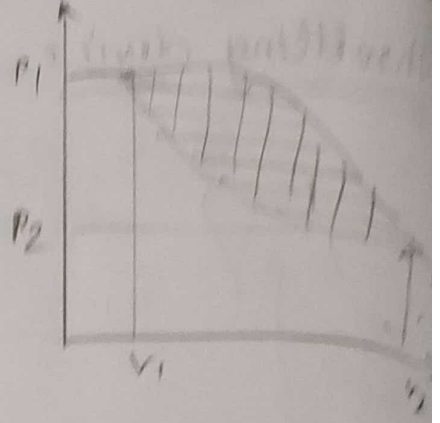
Amount of workdone

$$\Sigma W = -8400 \ kJ/min$$

watts - J/sec

$$= \frac{-8400 \times 1000}{1000 \times 60}$$

$$= -0.4 \ W \times 1000$$

worktdone by the 8ystem =
Head obsered,
By the system.

$$\boxed{= -140 \ kW}$$
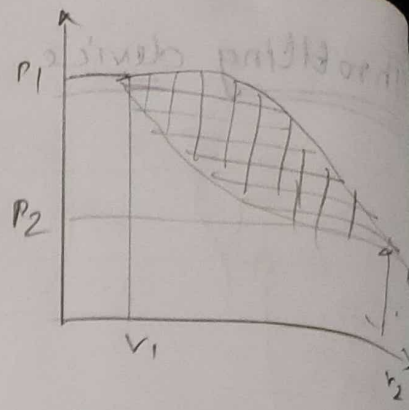
Soln : Given:

① **Process a-b**

According to First law of thermodynamics

$$\Delta U = Q - W$$
$$= 0 - (-20945)$$
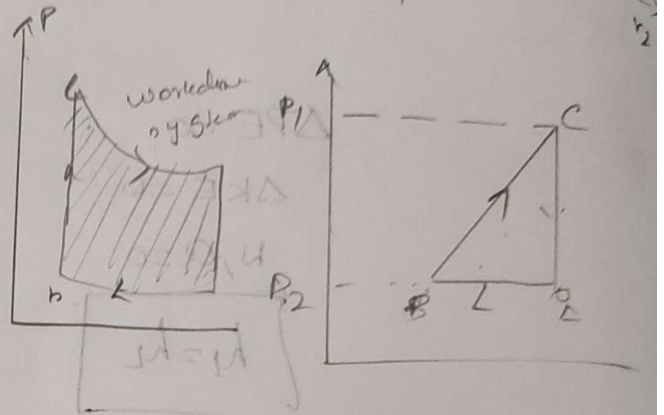$$\boxed{\Delta U = 20945} \text{ kJ/m}^i$$

(ii) **Process (b-a)**

$$\Sigma Q = (\text{Total heat transfer}) \times \text{No}$$
$$\text{of cycles}$$

$$= -84 \times 100$$
$$\boxed{\Sigma Q = -8400 \text{ kJ/min}}$$

$$\Sigma Q = Q_{a-b} + Q_{b-c} + Q_{c-d} + Q_{d-a}$$

$$\boxed{\begin{array}{l} Q_{d-a} = -31439 \text{ kJ/min} \end{array}}$$

$$\Sigma Q = \Sigma W$$
$$-8400 = \Sigma W$$

$$W_{d-a} = 48151 \text{ kJ/min}$$

Amount of workdone

$$\Sigma W = -8400 \text{ kJ/min}$$

$$\text{watts} - \text{J/sec}$$

$$= \frac{-8400}{1000 \times 60} \times 100$$

$$= -0.4 \text{ W} \times 1000$$

worledone by the stepxtem >
Heat absorbed.
by the system

$$\boxed{= -140 \text{ kW}}$$