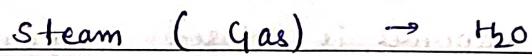
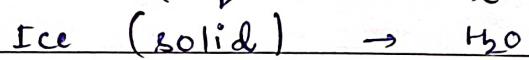
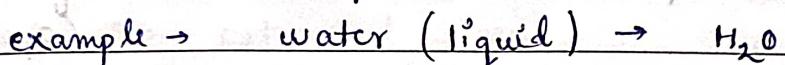


Unit - II - Properties of Pure Substance

A pure substance is one which is having constant chemical composition throughout its mass.

→ It is one component system but may exist in one or more phases.



Phase :-

Phase is a homogenous part of a system.

It is essentially homogeneous chemical and physical state of molecule of which substance is made.
aggregation

Vapourisation :

Vapourisation is the process that involves changes from liquid phase to vapour phase.

water vapour \rightarrow obtained by evaporation

steam \rightarrow obtained by Boiling

Evaporation :

Evaporation is the process of vapour generation only from the surface of a liquid.

→ Molecules having greater ^{velocity} _{energy} K_E break away on the liquid surface & escape to the surrounding atmosphere.

→ When heat is added to the liquid it starts boiling and vapour gets generated both from the free surface liquid and inside also.

Boiling :-

Boiling is the process of vapour generation that take place in the whole mass of liquid. (open vessel)

→ When the vapour is closed vapour escaping from the liquid ful the free surface about the liquid and a fraction of these vapours return back to liquid itself.

Saturated Steam :-

Steam is called saturated when the molecules scattering from the liquid surface becomes equal to the molecules returning to it. It has maximum density. It is thermal equilibrium with a liquid.

Super heated steam :-

Saturated temp

of water $\rightarrow 100^\circ\text{C}$

Latent heat \rightarrow hidden heat

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Thermal equilibrium of liquid and vapour:

saturation point or boiling point is between temperature at which that this happens.

Saturated steam two types -

Wet saturated steam Dry saturated steam

when the saturated vapour contains particle of liquid evenly distributed over the entire mass of the vapour this is called Wet saturated steam

Characteristics :

Dryness fraction

Denoted by : x = mass of dry saturated vapour

Mass of mixture of liquid & vapour

m_g : mass of dry saturated steam

g : dry gas

m_f : mass of saturated liquid

m_w = suspension with its own vapour

$$x = \frac{m_g}{m_f + m_g} = \text{Dryness fraction}$$

$\%$ = Quality of steam

when dryness fraction is expressed in % then

eg.

$m_g : 80 \%$ \rightarrow Dry part

$m_f : 20 \%$ \rightarrow Water particles

$$\chi = \frac{m_g}{m_f + m_g} = \frac{80}{20 + 80} = 0.8$$

generally $\chi = 0.70 - 1.00$, 0.70 , 0.75 , 0.80 etc

$$\chi = \frac{100}{0 + 100} = 0$$

If χ is very b/w $0.70 - 0.80 \rightarrow$ very wet steam

example - Textile, cotton, power plant, steel, chemical, Refinery, Dairy, Drug . paper industry etc

$0.80 - 0.90 \rightarrow$ Quite steam

$0.90 - 1.00 \rightarrow$ Dry steam

Steam Generation

Three stages -

①

Heating of water upto boiling point
Heating of water at constant process

②

Evaporation of boiling water and conversion into dry saturated steam

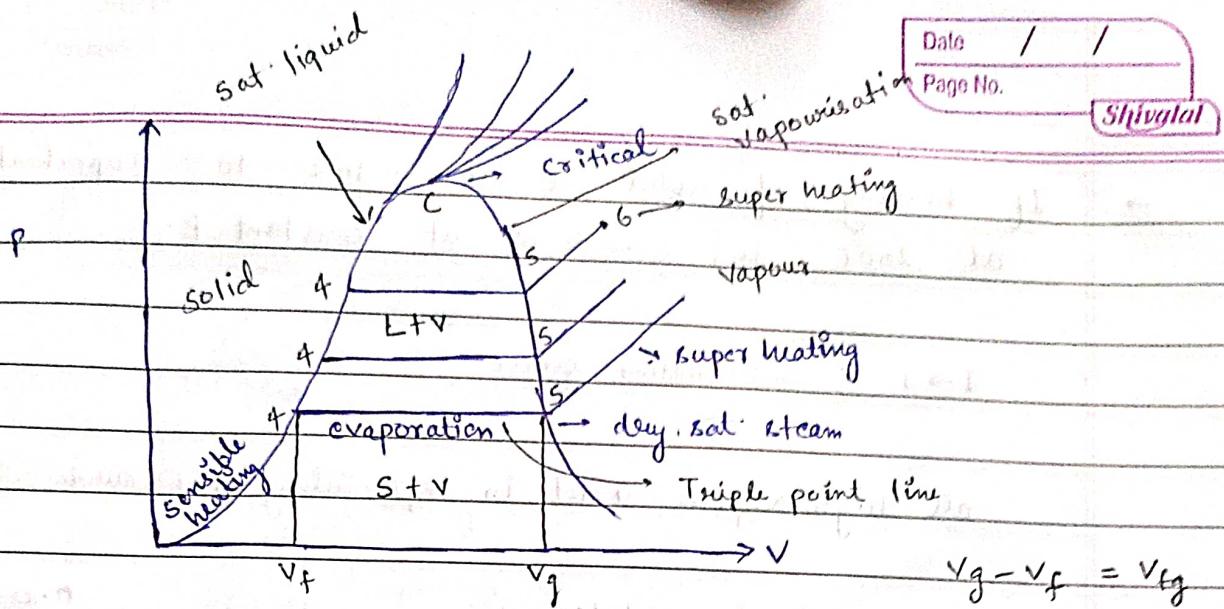
- The horizontal distance b/w sat. liquid line & sat. vapour line become less and less while T being pressure.
- When this distance = 0, then point is critical point
↑
- Latent heat keeps decreasing on increasing pressure at critical point = 0 No phase of evaporation is observed at this.
- Prop. of sat. liquid & and sat. vap. are also almost similar at critical point.

Pressure at critical point = 221.2 bar

Critical Temp = $T_c = 374.15^\circ\text{C}$

Critical Volume = $V_c = 0.00317 \text{ m}^3/\text{kg}$

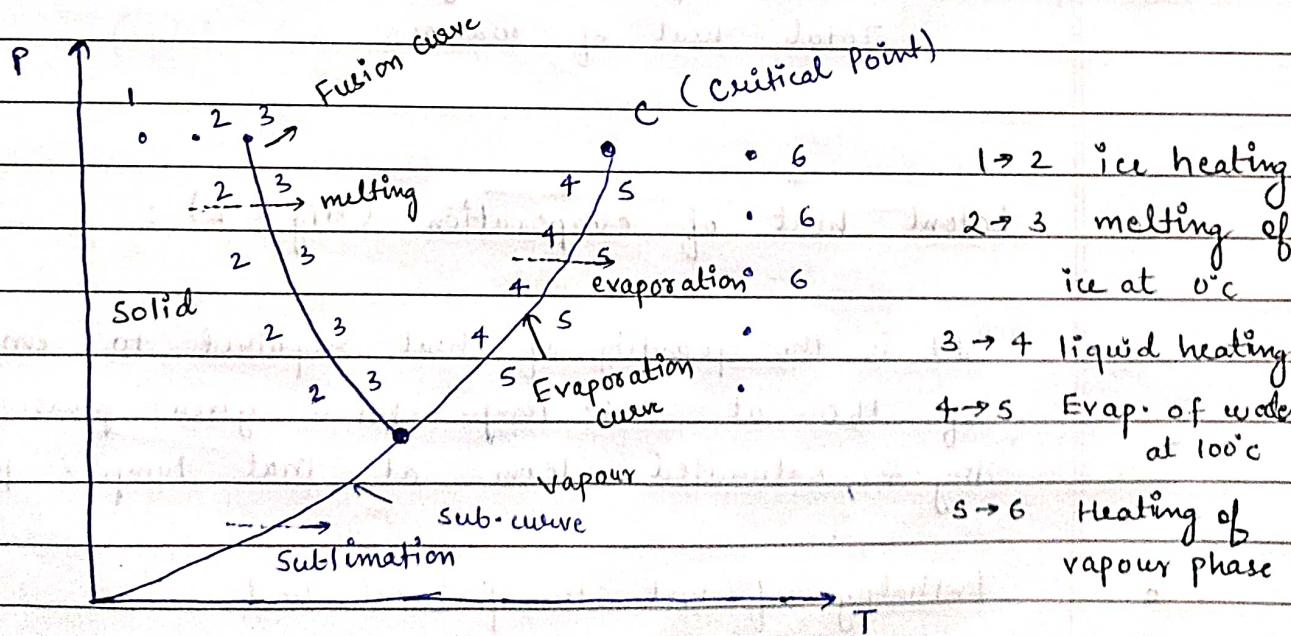
→ Triple point is a line on PV diagram where all the three phases, solid, liquid & gas exist in equilibrium at a pressure below the triple point line the sub. can't exist in liquid phase & substance when heated transforms from solid to vapour known as sublimation by absorbing the latent heat of sublimation directly from surrounding this take place



Phase Equilibrium Diagram

Solid.

- When state changes of a pure substance (CO_2 , ice) upon slow heating at a different const pressure and if the change plotted PT coordinate then the diagram known as Phase eq.b diagram.



- The curve passing from (2, 3) point that is $2-T = \text{fusion curve}$
Solid & liquid phase
co-exist in equilibrium

T-C \rightarrow Vapourisation Curve

4-5 → Vapourisation &
Condensation

→ If heating of solid ice at -10°C to superheated steam at 250°C is considered at constant P.

$T \rightarrow T$: Sublimation curve

all high vapour exist in eqb. along the curve $T\text{-}c$

Triple point for Water

$$0.07^{\circ}\text{C} = 273.16\text{ K}$$

: $4.58\text{ mm of Hg} \approx 0.611\text{ kPa}$

for CO_2 : 3.085 mm of Hg

$$216.55\text{ K}$$

#1

Properties of steam:

- Sensible heat of steam (h_f):

It is the quantity of heat required to rise the temp. at 1kg of water from 0°C to the B.P. are sat. temp. at a given pressure also known as Total heat of water.

- Latent heat of evaporation ($h_{fg} = L$):

It is the quantity of heat required to convert 1kg of H_2O at sat. temp. for a given pressure into dry & saturated steam. at that temp & pressure.

- Enthalpy of wet steam / Total heat:

It is the quantity of heat reqd. to convert 1kg water at 0°C into wet steam at constant pressure this enthalpy of wet steam.

$$h_{\text{wet}} = h_f + x h_{fg}$$

Latent heat part

Sensible
part

dryness fraction

- Total enthalpy of dry saturated steam:

It represents the quantity of heat reqd. to convert 1kg of water at 0°C into dry and saturated steam at that constant pressure

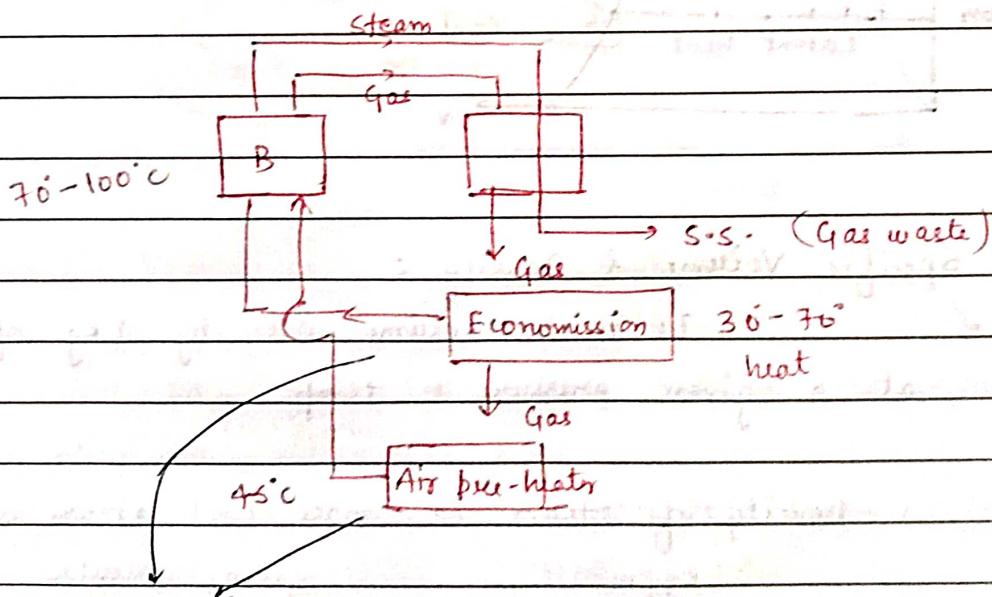
$$h_g = h_f + x h_{fg}$$

But dryness
fraction = 1

no water particles

$$h_g = h_f + h_{fg}$$

- # Super heating done via the gases existing through boiler (uptil dry s.s formation)



both being used to increase boiler efficiency by pre heating hence less load to boiler coil and are called accessories.

slipper
guy

Super heated steam : (h_{sup})

It is the quantity of heat required
to convert 1 kg of water —
into superheated steam at const pressure

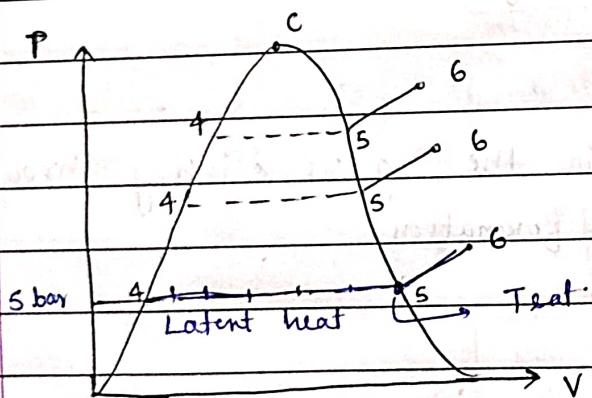
$$h_{\text{sup}} = h_f + h_{fg} + c_p s \times (T_{\text{sup}} - T_{\text{sat}})$$

Total heat of
dry steam \downarrow Superheat

$(T_{\text{sup}} - T_{\text{sat}})$: Degree of superheat

$c_p s \rightarrow$ Specific heat of superheated steam
at constant pressure, P

$\approx 2.0 \text{ to } 2.1 \text{ kJ/kgK}$



steam generation is isobaric

~~isothermal & isobaric~~

Specific volume & Density :

✓ It is the volume occ. by 1 kg of steam
 m^3/kg at a given pressure & temp

Density of steam \rightarrow mass unit steam at a
 kg/m^3 given pressure

Specific volume of dry sat. steam v_g
specific vol. of sat. liquid v_f

Specific Volume of Wet Steam:

It is the volume of 1 kg of wet steam equals the volume of dry portion of steam + vol. of water in suspension.

If x is dryness fraction of wet steam

1 kg of wet steam consist of x kg of dry steam
 $\Rightarrow (1-x)$ kg water in suspension

specific volume of wet steam

$$V_{\text{wet}} = x V_g + (1-x) V_f$$

$$x = \frac{V_{\text{wet}} - V_f}{V_g - V_f}$$

When $x > 80$ and $P < 30$ bar

specific volume of water $\ll V_f \approx 0$

$$V_{\text{wet}} = x V_g$$

Specific Volume of Superheated steam

\rightarrow Dry and sat. steam behaves like a perfect gas obey ~~the~~ all gas laws.

Hence, s.p. volume of superheated steam can be found out by applying CHARLE'S LAW.

→ Applying charles law b/w beginning and end of super heating process $s \rightarrow g$ (graph)

$$V_s = V_g$$

$$V_g = V_{sup}$$

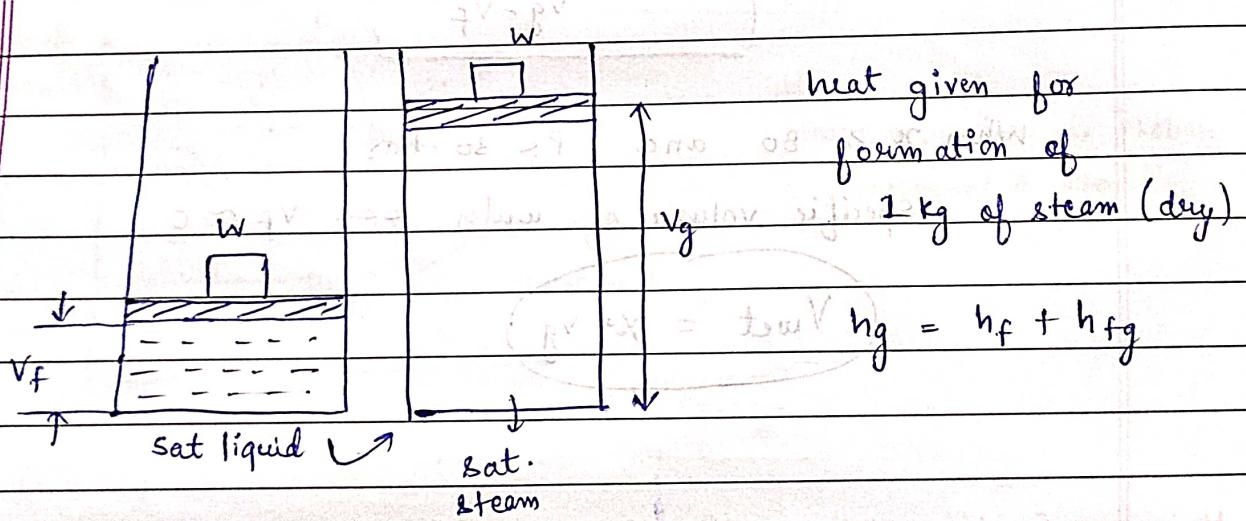
$$\frac{V_g}{T_{sat}} = \frac{V_{sup}}{T_{sup}}$$

$$V_{sup} = \frac{T_{sup}}{T_{sat}} \times V_g$$

#

Internal energy of steam

→ Consider the formation of dry steam at pressure, P from water $0^\circ C$



→ When water evaporates to form steam & its volume increases from V_f to V_g at const. Pressure, P the work is done by steam in lifting its volume.

→ Work is done by steam by lifting weight through vertical height this work is called external work of evaporation.

$$W_{ext} = \int_1^2 P \cdot dV = P \int_1^2 dV$$

$$W_{1-2} = P \int_1^2 (V_g - V_f)$$

→ The actual heat energy stored above freezing point of water is stored in the steam, known as Internal energy of steam.

• Internal energy = $h_g - Pv$

$$U = h_g - Pv \Rightarrow h_g - P(V_g - V_f)$$

$$U = h_g - Pv_g$$

Internal steam Energy for wet steam:

$$\text{Wet steam} = U_{wet} = (h_f + xh_{fg}) - P \times x \times V_g$$

For Dry steam :

$$u_g = (h_f + h_{fg}) - P \cdot V_g$$

for Superheated steam | Total heat :

$$U_{sup} = h_{sup} - Pv_{sup}$$

$$= [h_f + h_{fg} + c_p s (T_{sup} - T_{sat})] - P \cdot V_{sup}$$

#

Entropy : (randomness)

Energy ने चाहिे करने की क्षमता है।

$$Q = mc\delta(T - o)$$

1 kg/L petrol

25000 KJ/kg

→

The capacity and utility of available energy is decided by term entropy which is measure of quality of energy any thermal energy always close from high temp to lower temp. therefore

∴ in practice, entropy is always calculated the difference before and after the energy change from higher temp to lower temp.

#

Entropy of steam

entropy or $ds = \frac{dQ}{T}$
water $T_{1,2}$ at

constant $s_2 - s_1 = \int_{T_1}^{T_2} d\delta$
pressure

(A)

Entropy of Water (s_f): Heating upto saturation Condition

$$\int ds = \frac{dQ}{T} = \int \frac{dp}{dt} (T - o)$$

$$\int ds = \int cp \frac{dT}{T}$$

integrate b/w 1 & 2

$$s_2 - s_1 = c_p \ln \frac{T_2}{T_1}$$

$$\Rightarrow s_f = c_p \ln \frac{T_2}{273}$$

If $0^\circ\text{C} = \text{datum}$

$$s_1 = 0$$

$$\text{and } T_1 = 273\text{K}$$

(B) Entropy of Evaporation (s_{fg}) :

$$s_{fg} = \frac{dQ}{T} = \frac{h_{fg}}{T_{sat}} \quad (\text{for dry sat steam})$$

$$s_{fg} = \frac{x h_{fg}}{T_{sat}} \quad (\text{for wet dry})$$

(C) Entropy of steam :

Wet steam (above 0°C)

$S = \text{Entropy of Water} + \text{Entropy of Evaporation}$

$$S = s_f + \frac{x h_{fg}}{T_s} = s_f + x s_{fg}$$

$$s_{\text{wet}} = s_f + x(s_g - s_f)$$

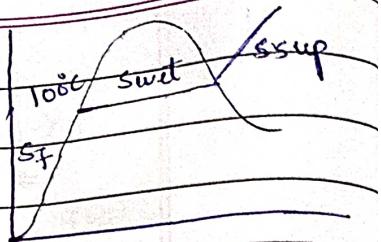
(D) Entropy for Dry-sat steam :

$$S = s_f + s_{fg} = s_f + h_{fg} / T_s$$

$$S = s_f + (s_g - s_f)$$

$$S = S_g$$

Entropy for super heated steam :



$$ds = \frac{dq}{T} \Rightarrow c_p s \frac{dT}{T}$$

$$ds = (c_p)_s \ln \frac{T_{sup}}{T_{sat}}$$

\Rightarrow Total entropy of superheated steam above 0°C

$$s_{sup} = s_f + s_{fg} + c_p s \ln \frac{T_{sup}}{T_{sat}}$$

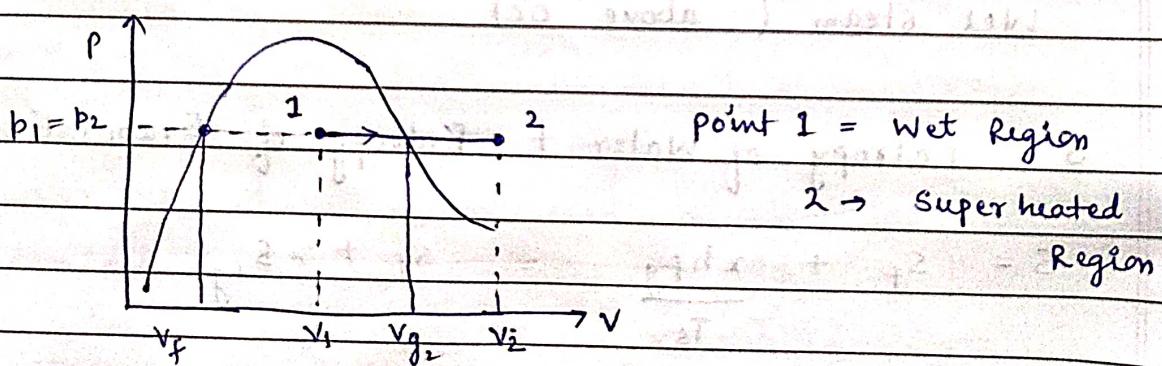
uptill point s

tak ki

only superheated part ki entropy

Steam Process :

(1) Contact Pressure Process



A Work Done during contact process

process for 1 kg of steam

$$W_{1-2} = \int_{\text{sup. sat}}^{v_2} P dv = P(v_2 - v_1)$$

v_1 v_2
wet sup. sat

$$\text{Now, } v_1 = x_1 v_{fg} = x v_{fg}$$

$$h_1 = h_f + x_1 h_{fg} \quad \left\{ v_{sat} = v_g \right\}$$

$$V_2 = \frac{T_2}{T_{sat}} \times V_{sat}$$

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$$V_2 \text{ sup} = V_{g2} \times \frac{T \& sup_2}{T \& at_2} \rightarrow V_g \text{ pe temp}$$

$$h_2 = h_g + c_{ps} (T_{8up_2} - T_{8at_2})$$

B) Change in Internal energy ΔU

$$u = h - Pv$$

$$\Delta u = u_2 - u_1$$

$$\Delta u = (h_2 - h_1) - (p_2 v_1 - p_1 v_1)$$

(c) Heat Transfer

Apply 1st law

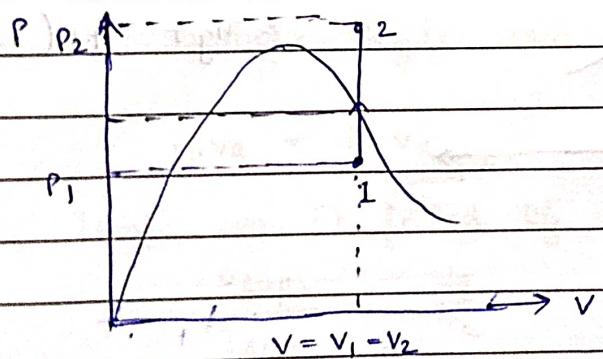
$$Q = W + \Delta U$$

$$g = p(v_2 - v_1) + (h_2 - h_1) - p(v_2 - v_1)$$

$$Q = (h_2 - h_1) = \Delta h$$

2

Contact Volume Process



Specific Volume

$$V_1 = V_2$$

$$V_1 = (1-x_1) V_{f_1} + x_1 \cdot V_{g_1} \quad (\text{Wet Region})$$

$$V_2 = \sqrt{g} u_2$$

$$= Vg_2 \times \frac{T_{sup}}{T_{sat}} \quad (\text{superheated region})$$

$$V_1 = V_2$$

$$(1-x_1) \cdot v_{f_1} + x_1 \cdot v_{g_1} = v_{\text{sup}_2}$$

$$x = \frac{v_{\text{sup}} - v_f}{v_g - v_f}$$

(A) Work Done = $PdV = P(V_2 - V_1)$

$$V_1 = V_2$$

$$W = 0$$

(B) Heat Transfer

Acc. to 1st law of thermodynamics (Q)

$$Q = \Delta u + W$$

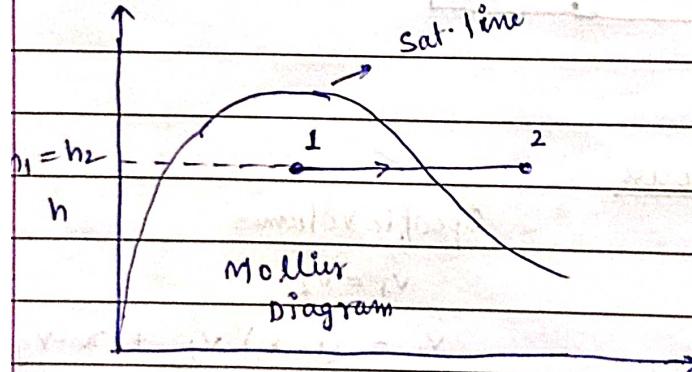
$$Q = u_2 - u_1 + PdV$$

$$Q = u_2 - u_1 + 0 = u_2 - u_1$$

$$Q = (h_2 - P_2 V_2) - (h_1 - P_1 V_1)$$

$$Q = h_2 - h_1 - V(P_2 - P_1)$$

Constant Enthalpy Process



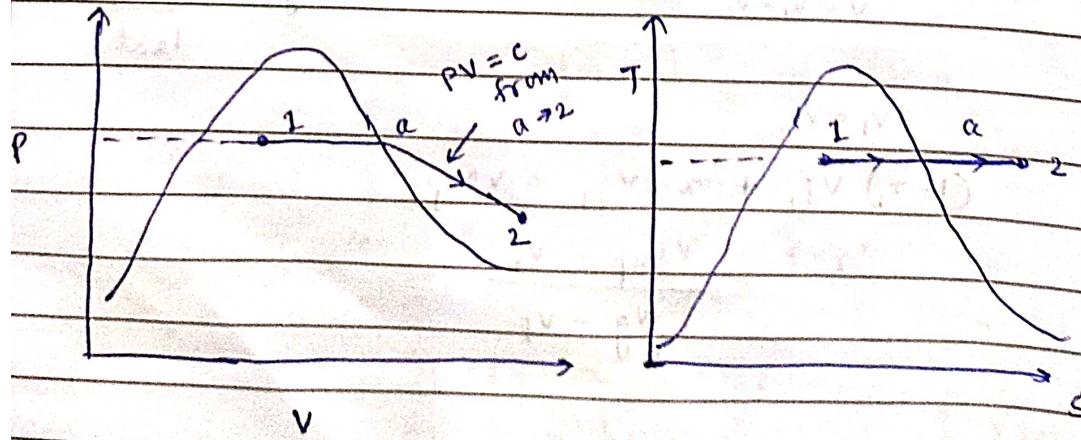
$$h_1 = h_2$$

$$h_1 = h_f + x_1 h_{fg}$$

$$h_2 = h_f + x_2 h_{fg}$$

$$= h_f + c_p s (T_{sat2} - T_{sat1})$$

Constant Temp. Process



$1-a = \text{Isothermal} + \text{Isobaric}$
in T-S and P-V
until dry sat

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$$P_1 = P_a, \quad T_1 = T_a \quad \gamma \text{ wet region}$$

In superheated region ($\text{expn} = \text{process}$)

$a \rightarrow 2 = \text{hyperbolic} \quad (PV = \text{const})$

$$P_a V_a = P_2 V_2$$

process 1-a heating at const T and Pressure until formation of dry S.S.

$$P_1 = P_a = (P_a V_a - \frac{1}{2} \rho u_a^2)$$

$$W_{1-a} = P(V_a - V_1)$$

$$u_a - u_1 = (h_a - h_1) - P(V_a - V_1)$$

$$Q = W + \Delta U$$

$$= P(V_a - V_1) + (h_a - h_1) - P(V_a - V_1)$$

$$Q = h_a - h_1 \quad \text{and } W = 0$$

#

T-S

Process $a \rightarrow 2$

graph

Heating at const Temp till steam become superheated

Following Boyle's law ($PV=c$)

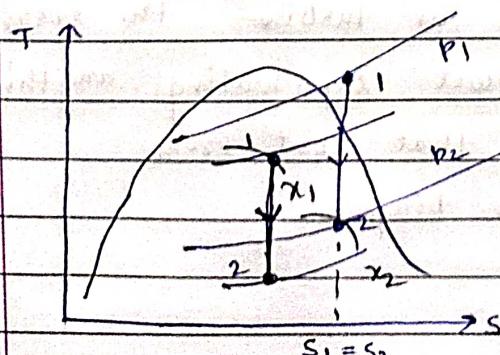
$$P_a V_a = P_2 V_{\text{sup}2}$$

Temp. can be found by charles law

$$\frac{V_{\text{sup}2}}{T_{\text{sup}2}} = \frac{V_a}{T_a}$$

Reversible Adiabatic process

$$\Delta Q = 0, \Delta S = 0$$



Expansion isentropically

$$S_1 = S_2$$

$$S_{f1} + x_1 S_{fg1} = S_{f2} + x_2 S_{fg2}$$

$$s_{\text{sup}_1} = s_2$$

$$s_{g_1} + c_p \ln \frac{T_{\text{sup}_1}}{T_1} = s_{f_2} + x_2 s_{fg_2}$$

Tsat1

$$x_2 = \frac{s_{\text{sup}_1} - s_{fg_2}}{s_{fg_2}}$$

$$s_{fg_2} = \frac{h_2 - h_1}{T_2 - T_1}$$

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

(A) change in Internal energy

$$\Delta u = u_2 - u_1$$

$$= (h_2 - p_2 v_2 x_2) - (h_1 - p_1 v_{\text{sup}_1})$$

$$(h_2 - p_2 v_2 x_2) - (h_1 - p_1 v_{\text{sup}_1}) = (h_2 - p_2 v_2) - (h_1 - p_1 v_{\text{sup}_1})$$

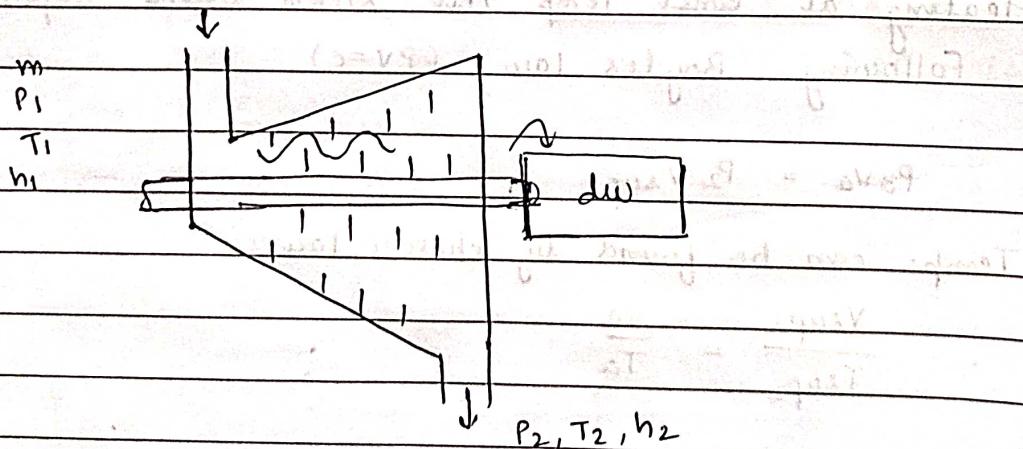
$$(B) Q_{1-2} = 0$$

$$\text{from } 1^{\text{st}} \text{ law; } Q = W + \Delta u$$

$$0 = W + \Delta u$$

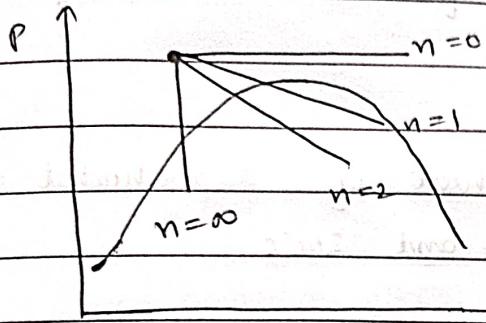
$$W = -\Delta u$$

*Steam
Turbine*



After expansion of steam in turbine, the steam coming out could be dry wet superheating anything we can figure that out from Mollier Diagram.

Polytropic process :



$$p_1 v_1^n = p_2 v_2^n$$

↑
superheated

$$p_1 (x_1 v_{g1})^n = p_2 (v_{sup2})^n$$

OR

$$p_2 (n_2 v_{g2})^n$$

↓ if in wet region
only

$$x_2 = \frac{x_1 v_{g1}}{v_{g2}} \quad \text{OR} \quad v_{sup2} = n_1 v_{g1} \left(\frac{p_1}{p_2} \right)^n$$

$$\frac{v_{sup2}}{T_{sup2}} = \frac{v_{g2}}{T_{sat2}}$$

$$\text{Work Done} = \frac{p_1 v_1 - p_2 v_2}{n-1}$$

$$\Delta u = u_2 - u_1 = (h_2 - p_2 v_2) - (h_1 - p_1 v_1)$$

$$Q = w + \Delta u$$

$$\text{for wet 1 : } h_1 = h_f1 + x_1 h_{fg1}$$

$$\text{for dry 1 : } h_1 = h_f1 + h_{fg1}$$

$$\text{for super 2 : } h_2 = h_f2 + h_{fg2} + c_p s (T_{sup2} - T_{sat2})$$

#

Measurement of Dryness Fraction :

- (1) Bucket / Barrel Calorimeter
- (2) Separating calorimeter
- (3) Throttling calorimeter
- (4) Separating & Throttling calorimeter
- (5) Electrical calorimeter

25/11/23

$$\gamma = \frac{m_s}{m_s + m_f}$$

$$\gamma = \frac{40}{40 + 1.25}$$

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$$m_s = 40 \text{ kg}$$

$$m_f = 1.25 \text{ kg}$$

- A. Calculate the dryness fraction of stem which has 1.25 kg of water in suspension 40 kg steam.

- B. calculate mean specific heat of superheated steam at 1 bar and b/w 150°C and 200°C

$$h_{\text{sup}} = h_g + C_p (T_{\text{sup}} - T_{\text{sat}})$$

corresponding 1 Bar, from steam table

at 150°C, 1 Bar

By M.L. Mathur

Pg No - 11

$$h_g = 2776.4 \text{ kJ/kg}$$

at 200°C, 1 Bar

$$h_g = 2875.3 \text{ kJ/kg}$$

$$2875.3 = 2776.4 + C_p (150 - 200)$$

$$2875.3 - 2776.4 = C_p (-50)$$

- C. A spherical shell of 30 cm radius contains saturated steam and water at 300°C. calculate the mass of each if their volumes are equal.

Soln

Total vol. of spherical shell

$$V = \frac{4}{3} \pi R^3 \Rightarrow \frac{4}{3} \pi \times (0.3)^3$$

$$= \frac{10800 \times \pi}{3} \Rightarrow 113037.34 \text{ cm}^3$$

$$= 0.11304 \text{ m}^3$$

from steam table

corresponding to 300°C temp,

specific volume of saturated

liquid / water

$$V_f = 0.001404 \text{ m}^3/\text{kg}$$

$$V_g = 0.0217 \text{ m}^3/\text{kg}$$

$$\text{Vol. of sat. liquid } V_f = \frac{0.11304}{2} = 0.0565 \text{ m}^3$$

$$\text{Vol. of sat. vapour } V_g = 0.11304 = 0.0565 \text{ m}^3$$

$$\text{mass of liquid } m_f = \text{Vol.} \times \text{density}^2$$

$$\text{Vol. liquid} = 0.0565 \text{ m}^3$$

$$\text{Sp. vol} = 0.001404 \text{ m}^3/\text{kg}$$

Q. Calculate the sp. volume, enthalpy, internal energy and entropy of wet steam at 15 bar pressure having dryness fraction 0.8.

SOLN

(A) Sp. volume

corresponding

$$\begin{aligned} V &= (1-x) V_f + x \cdot V_g \\ &= (1-0.8) 0.001154 + 0.8 \times 0.132 \\ &= 0.2 \times 0.001154 + 0.8 \times 0.132 \\ &\quad 2.308 \times 10^{-4} + \frac{66}{625} = 0.1058 \text{ m}^3/\text{kg} \end{aligned}$$

(B) Total heat / Enthalpy of wet steam

$$\begin{aligned} h_{\text{wet}} &= h_f + x h_{fg} \\ &= 844.9 + 0.8 \times 1947.3 \\ &= 844.9 + \frac{3894.6}{25} = 120137 \text{ J/kg} \end{aligned}$$

(C) Internal energy

$$u = h - PV$$

$$\begin{aligned} PV &= 15 \times 10^5 \text{ N/m}^2 \times 0.1058 \text{ m}^3 \\ &\text{bar m}^3 \qquad \qquad \qquad \text{kg} \end{aligned}$$

N-m = Joules

$$1 \text{ bar} = 10^5 \text{ N/m}^2$$

$$10^3 \times 100 = \text{kJ/s} = \underline{\text{KW}}$$

$$100 PV = \text{kJ}$$

(D) Entropy

$$\begin{aligned} S_{\text{out}} &= s_f + \alpha s_{fg} \\ &= 2.316 + 0.8 \times 4.130 \\ &= 5.619 = 5.619 \text{ J/Kg/KJ} \end{aligned}$$

Q. A pressure cooker having 2 kg of steam at 5 bar pressure and 0.9 dryness fraction. calculate the quantity of heat that is rejected so that quality of steam becomes 60% dry & pressure in temp of steam that exist in cooker after heat ejection.

Soln

\Rightarrow at 5 bar pressure
corresponding to steam table

const. volume

heat rejection $\rightarrow \Delta U$

$$Q = \Delta U = u_2 - u_1$$

$$u_1 = h_1 - p_1 v_1 \rightarrow p_1 x_1 v_{g1}$$

$$(h_1)_{\text{out}} = h_{f1} + x_1 h_{fg1}$$

$$\begin{aligned} u_1 &= h_{f1} + x_1 h_{fg1} = \frac{5 \times 100 \times 0.375}{5 \times 100 \times 0.9 \times 0.375} \\ &= 2369.1 \text{ KJ/kg} \end{aligned}$$

$$u_2 = h_2 - p_2 v_2$$

$$u_2 = h_{f2} + x_2 h_{fg2} = p_2 x_2 v_{g2} - 5 \times 0.6 \times 100 \times 0.375$$

$0.5625 \text{ m}^3/\text{kg}$
const
Vol.

$$x_1 v_{g1} = x_2 v_{g2}$$

$$p_2 = 3.2 \text{ bar}, t_2 = 135.8^\circ\text{C}$$

$$u_2 = 571 + 0.6 \times 2157.3 - 3.2 \times 100 \times 0.6 \times 0.5625 m^3/kg$$

$$u_2 = \frac{8426.9}{50} = 1757.38$$

Total heat transfer

$$Q = 2 \times -612 \text{ kJ} = -1224 \text{ kJ Ans.}$$

- Q. calculate enthalpy, vol., internal energy & entropy of superheated steam at 15 bar pressure & temp 250°C.

$$C_{ps} \rightarrow 2.2$$

Sohm

$$v_g = 0.132 \text{ m}^3/\text{kg}$$

$$T_{sat} = 198.3$$

$$h_f = 844.9 \text{ kJ/kg}$$

$$h_{fg} = 1947.3 \text{ kJ/kg}$$

$$s_f = 2.315 \text{ kJ/kg K}$$

$$s_{fg} = 4.130 \text{ kJ/kg K}$$

- (A) enthalpy of sup. heated steam
total heat 1kg of sup. heated steam

$$h_{sup} = h_f + h_{fg} + C_{ps}(T_{sup} - T_{sat})$$

$$h_{sup} = 844.9 + 1947.3 + 2.2(250 - 198.3)$$

$$= \underline{\underline{3143.9}} \quad \underline{\underline{2893.2}}$$

$$\text{Volume} = v_f + v_g$$

$$u = h_{sup} - pV_{sup}$$

$$s_{sup} = s_f + s_{fg} + C_{ps} \ln \frac{T_{sup}}{T_{sat}}$$

$$\frac{V_{sup}}{T_{sup}} = \frac{v_g}{T_g}$$