

UNIT - IV - PROPERTIES OF PURE SUBSTANCES

Steam - formation and its thermodynamic properties
- P-V, P-T, T-V, T-S, h-s diagrams. PVT-Surface.
Determination of dryness fraction. Calculation of
workdone and heat transfer in non flow and flow
processes using Steam table and Mollier chart.

Course objective :-

Teach the various properties of steam through
steam tables and Mollier chart.

Course outcome :-

Apply the second law of thermodynamics in
evaluating the various properties of steam through
steam tables and Mollier chart.

01. Explain steam formation with relevant sketch and
label all salient points and explain every point in
detail.

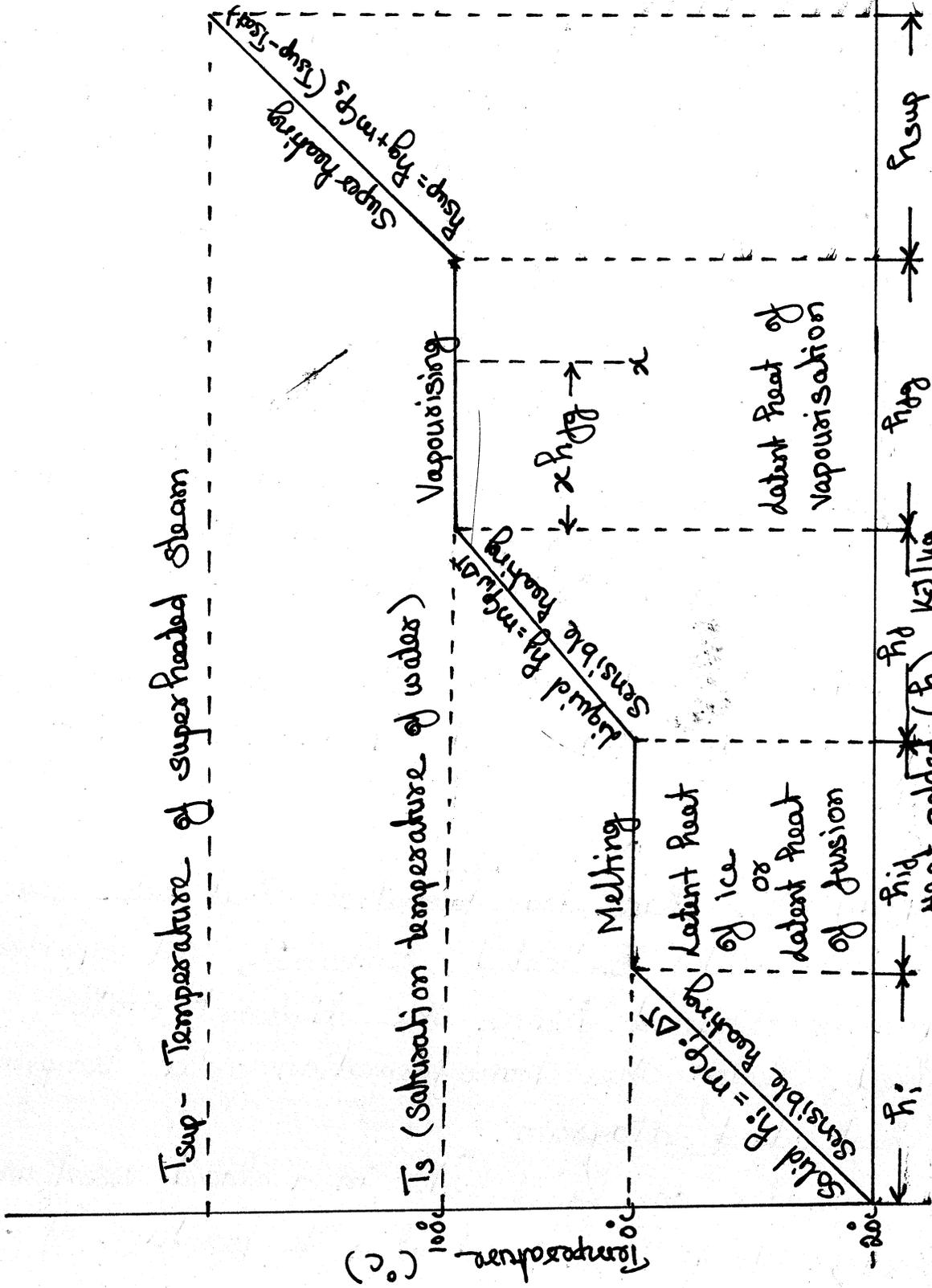
or

Explain the phase transformation that takes place
when ice (solid) is heated continuously till superheated
steam is obtained. Name the different states
involved. Sketch the transformation on a 'temperature'
vs 'heat added' diagram.

Consider one kg of water in a closed vessel under
a pressure of p (N/m^2) at a temperature of $-20^\circ C$
If the water is gradually heated when the pressure

$C_{p_i} = 2.1 \text{ kJ/kg}$
 $C_{p_w} = 4.2 \text{ kJ/kg}$
 $C_{p_s} = 2.1 \text{ kJ/kg}$

T_{sup} - Temperature of super heated steam



Formation of steam (under atmospheric pressure 1.01325 bar)

remains constant, the following changes will occur.

- a) The temperature of the ice will increase till it reaches the freezing temperature of water i.e. 0°C . It is shown by the line 1-2 in fig.
- b) When more heat is added after the point-2, the ice starts melting. At the same time there is no change in temperature till the whole of the ice has been melted and converted into water. This process is represented by a line 2-3 in fig. The heat added during this process (period) is called latent heat of fusion of ice or latent heat of ice.
- c) On further heating, the water reaches its boiling point or saturation point. 4. At a given pressure, the temperature at which a pure substance starts boiling is called the saturation temperature T_{sat} . Similarly, at a given temperature, the pressure at which a pure substance starts boiling is called the saturation pressure P_{sat} . Both saturation temperature and pressure are the functions of each other. At atmospheric pressure, the boiling point of water is 100°C . The amount of heat added during heating of water from 0°C to saturation

temperature of 100°C is known as sensible heat of water. It is denoted by h_f .

$$h_f = m C_{p_w} (T_2 - T_1)$$

d) On further heating beyond 4, the water will gradually ~~heated~~ converted into steam, when the temperature remains constant. At this stage the steam will have some water particles suspended in it. This steam is called wet steam. The same process continues till all water particles are converted, and it becomes dry steam. The line 4-5 in fig represents this process.

e) The amount of heat added during heating of water from boiling point to dry saturated stage is called latent heat of vapourisation or enthalpy of vapourization or latent heat of steam. It is denoted by h_{fg} .

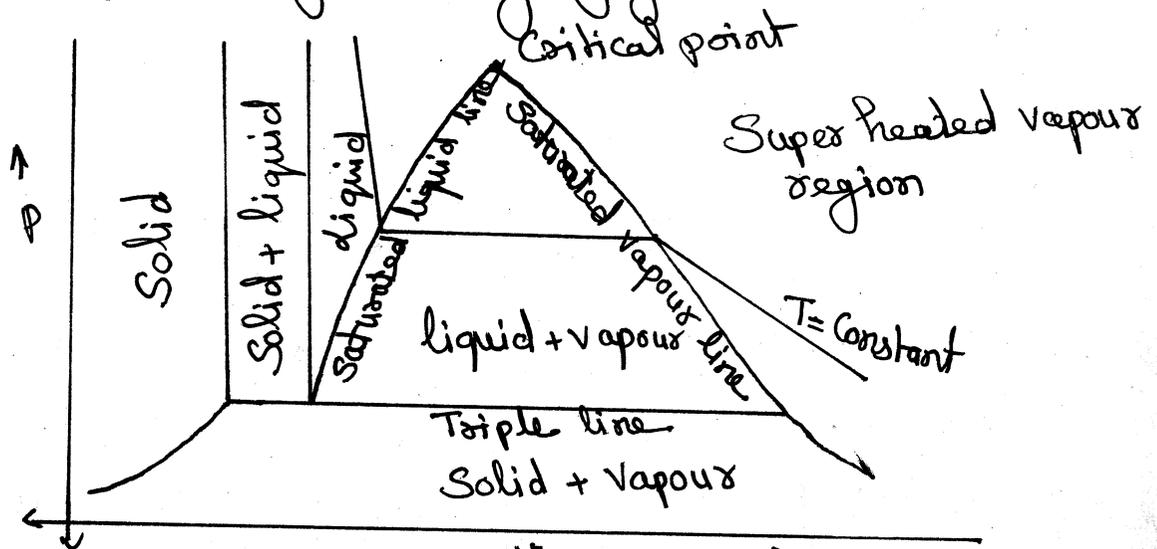
f) When the dry steam is further heated, the temperature rises again. This process is called 'superheating' and the steam obtained is called superheated steam. The heat supplied during this process is called Superheat enthalpy or heat of superheat. It is denoted by ' h_{sup} '

$$h_{sup} = h_{fg} + C_p (T_{sup} - T_{sat})$$

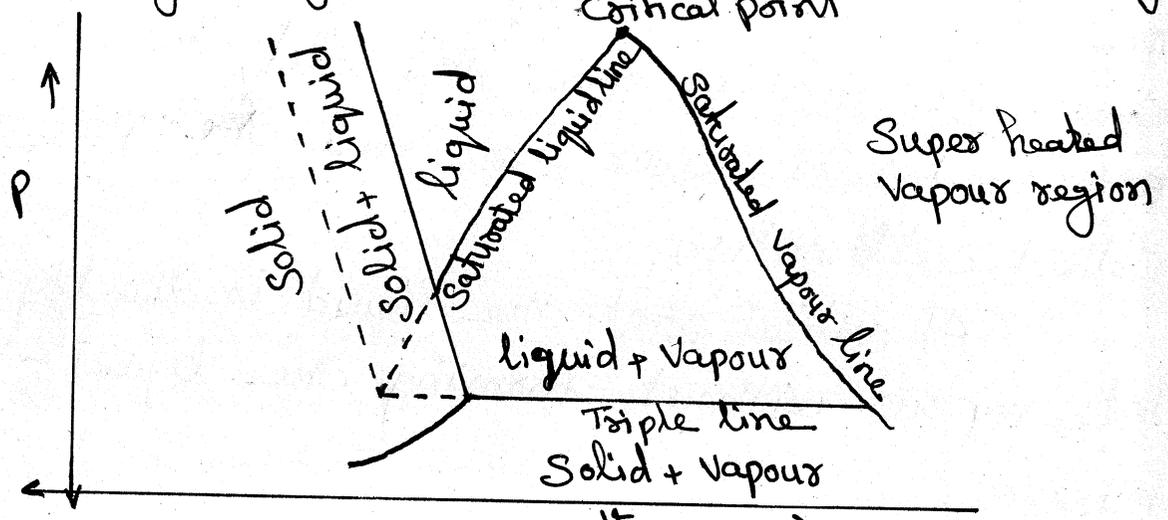
2. Draw P-V, P-T, T-V, T-S diagram of pure substance and explain various regions of the diagram in detail.

a) P-V-diagram:-

In this diagram the specific volume is taken in x-axis and pressure is taken in Y axis. The state changes of a pure substance when it is slowly heated at various constant pressures are shown in the following figures.



P-V diagram of substance which expands on freezing



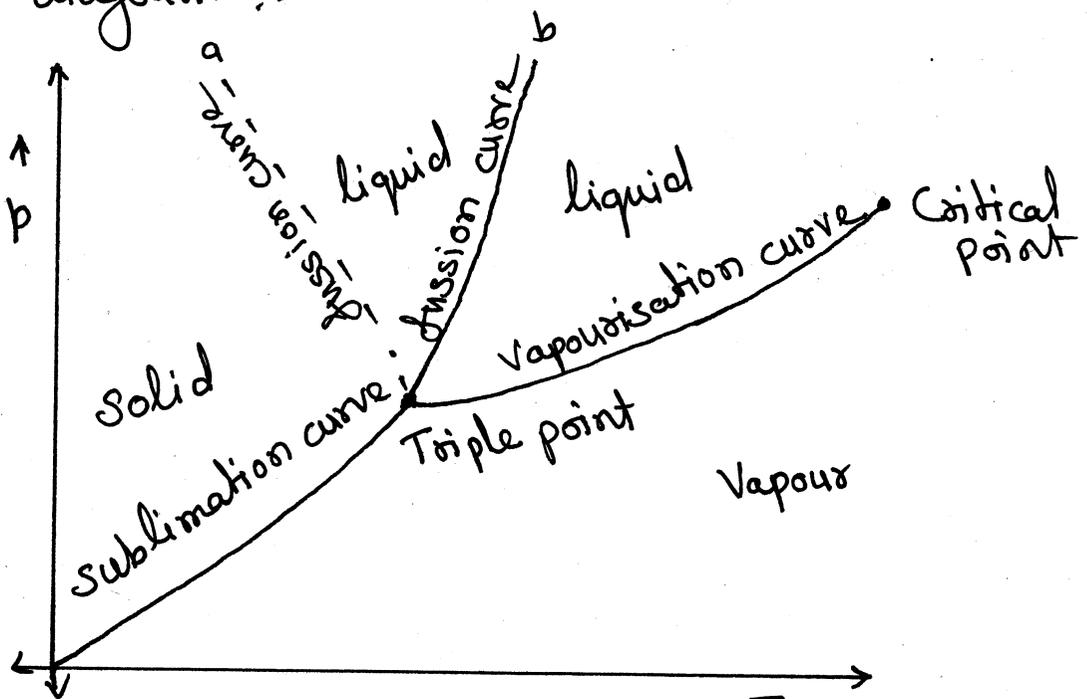
P-V diagram of substance which expands on freezing

Most of the substance contract during a solidification or freezing process. Some substance such as water expand on freezing. These two figures differ only in the solid-liquid saturation region. The point at which the saturated liquid curve meets the saturated vapour curve is known as critical point. The corresponding temperature, pressure are called critical temperature and critical pressure. For water the critical temperature is 374.15°C and critical pressure is 22.12 MPa . As the pressure increases, the latent heat of vapourization decreases and becomes zero at the critical point.

The triple point line represents the state at which solid, liquid and vapour phase exist in equilibrium. For water, the triple point temperature is 0.01°C and the triple point pressure is 0.6113 kPa . No substance can exist in liquid phase at a pressure below the triple point pressure. Below the triple point pressure the solid state is directly converted into vapour phase and the process is called sublimation.

At critical point the liquid is directly converted into vapour without forming the liquid vapour mixture.

b) P-T-diagram :-



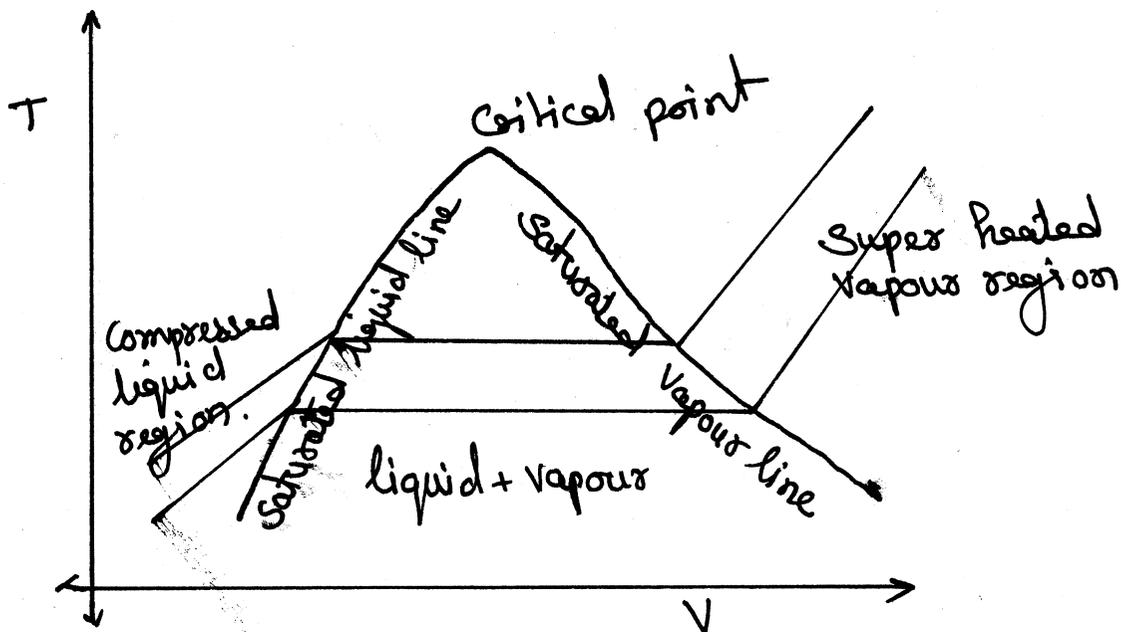
P-T diagram of a pure substance

- a - fusion curve for pure substance which expands on freezing.
- b - fusion curve for pure substance which contracts on freezing.

- Solid - liquid → melting or fusion
- liquid - solid → freezing
- liquid - vapour → vapourization
- Vapour - liquid → Condensation.
- Solid - vapour → Sublimation
- Vapour - solid → deposition or desublimation.

The slope of sublimation and vapourization curve for all substance are positive. The slope of fusion curve is positive for the substance which contracts on freezing and negative for the substance which expands (water) on freezing.

c) T-V - diagram.



T-V diagram of a pure substance

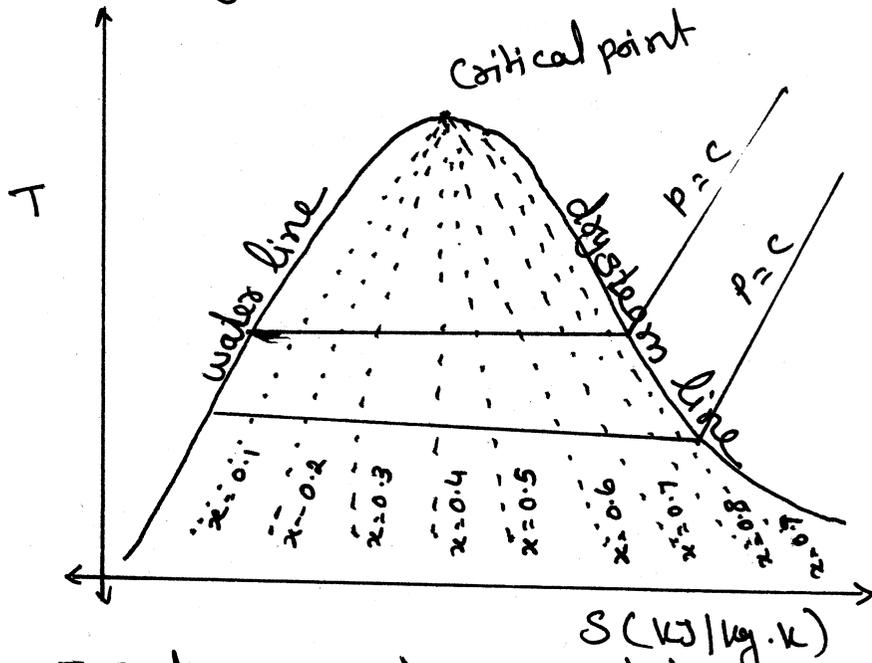
The general shape of T-V diagram of a pure substance is similar to P-V-diagram but the constant pressure lines have an upward trend.

The region in which the actual temperature is less than saturation temperature corresponding to that pressure is called sub cooled or under cooled region.

$$\text{Degree of sub cooling} = T_{\text{sat}} - T_{\text{act}}$$

The region in which the actual pressure is less than saturation pressure corresponding to that temperature is called as compressed liquid region.

d) T-S diagram



T-S diagram of pure substance

T-S is the plot of saturation temperature of water and steam corresponding to the various absolute pressures against the entropies at that saturation temperatures. The left side of the water line the water exist as liquid. The right side of the dry steam line the water exist as super heated steam. In between the water line and dry saturated steam line water exist as wet steam. Therefore the dryness fraction lines (constant quality lines) are represented in these regions as shown in figure. The value of various quantities are directly read from the diagram.

An isothermal process is represented by a horizontal line and a reversible adiabatic process is represented by a vertical line. In this diagram constant volume lines are plotted in the wet region and constant pressure lines are plotted in the super heated region.

3. Briefly explain the 'dryness fraction and wetness fraction of steam.

Dryness fraction:-

It is defined as the ratio of the mass of the dry steam actually present to the mass of the total steam. It is denoted by 'x'.

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

where

m_g - mass of dry steam in kg.

m_f - mass of water vapour in suspension.

This term is applicable only for wet steam.

For dry steam, $m_f = 0 \Rightarrow x = 1$

The dryness fraction when it is expressed in percentage (i.e. $100x$) is called quality of steam.

Wetness fraction:-

It is defined as the ratio of the mass of water vapour in suspension to the total steam.

$$\begin{aligned} \text{Wetness fraction} &= \frac{m_f}{m_f + m_g} \\ &= \frac{m_f}{m_f + m_g} + 1 - 1 \\ &= 1 - \left[1 - \frac{m_f}{m_f + m_g} \right] \\ &= 1 - \frac{m_f + m_g - m_f}{m_f + m_g} = 1 - \frac{m_g}{m_f + m_g} \end{aligned}$$