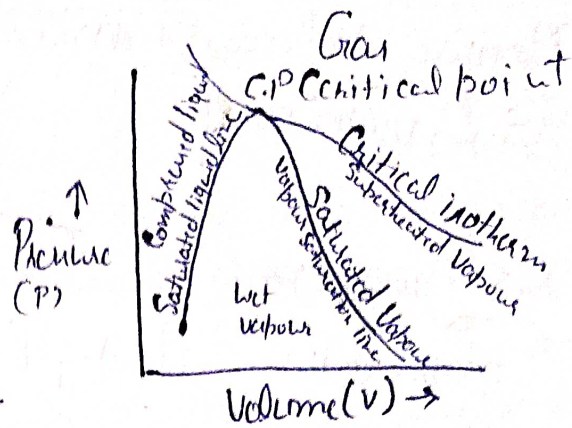


Saturation temperature

The phase change temperature corresponding to the saturation pressure. Sometimes called the boiling temperature.

Saturation pressure

The phase change pressure



Compressed liquid

Liquid whose temperature is lower than saturation temperature. Sometime called subcooled liquid.

Saturated liquid & Saturated Vapour

The steam is called saturated when the molecules escaping from the liquid become equal to the molecules returning to it. The saturated steam has a max. density at a given temperature & in thermal equilibrium with the liquid. The temperature of saturated vapour & the liquid in contact with it is called the saturation point or boiling point. The liquid at its boiling point at a specified pressure is called a saturated liquid.

Wet vapour

The mixture of saturated liquid & dry vapour during the phase change.

Superheated vapour

Vapour whose temperature is greater than the saturation temperature corresponding to the pr. of vapour.

Degree of superheat

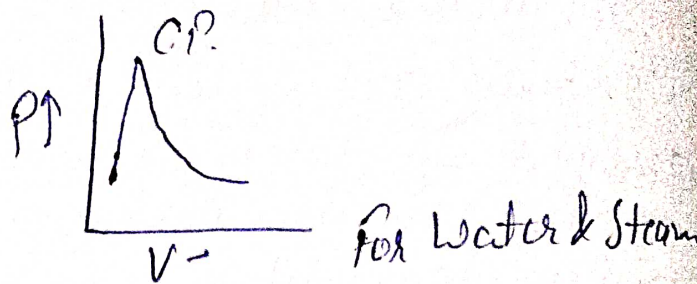
The term used for the numerical amount by which the temperature of a superheated vapour exceeds the saturation temperature.

Critical point - The limit of distinction between liquid and gas.

PROPERTY DIAGRAM IN COMMON USE

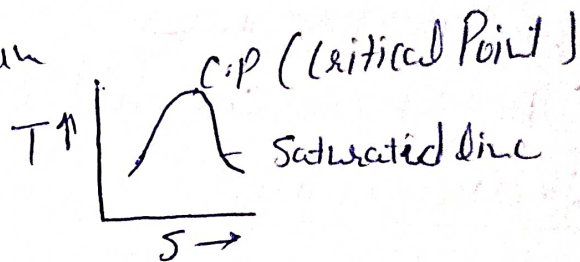
1. P-V Diagram

Pressure-Volume Diagram
- Easily visualised

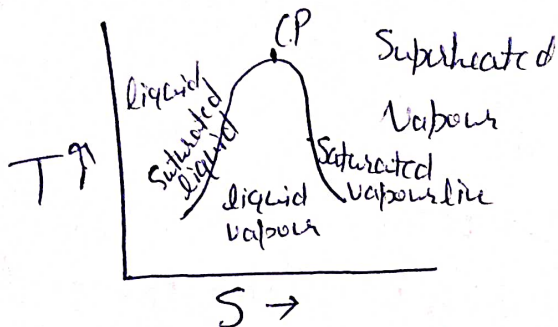


2. T-S Diagram

Temperature-Entropy Diagram



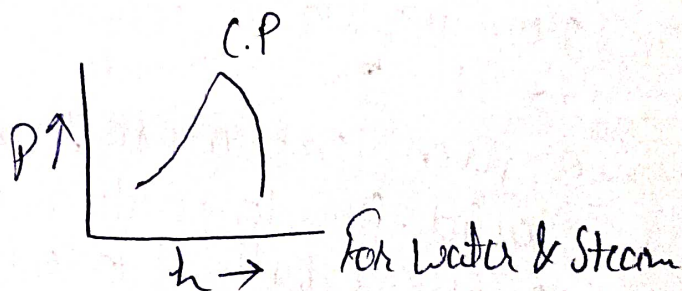
3.



For Water & Steam

3. P-h Diagram

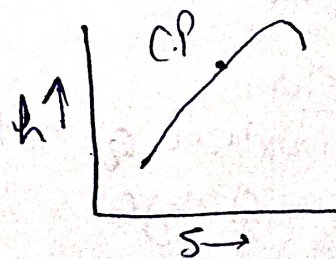
Pressure-Enthalpy chart
These are used in refrigeration work.



4. h-s Diagram

Enthalpy-Entropy chart

The specific enthalpy - specific entropy chart is used for steam plant work.



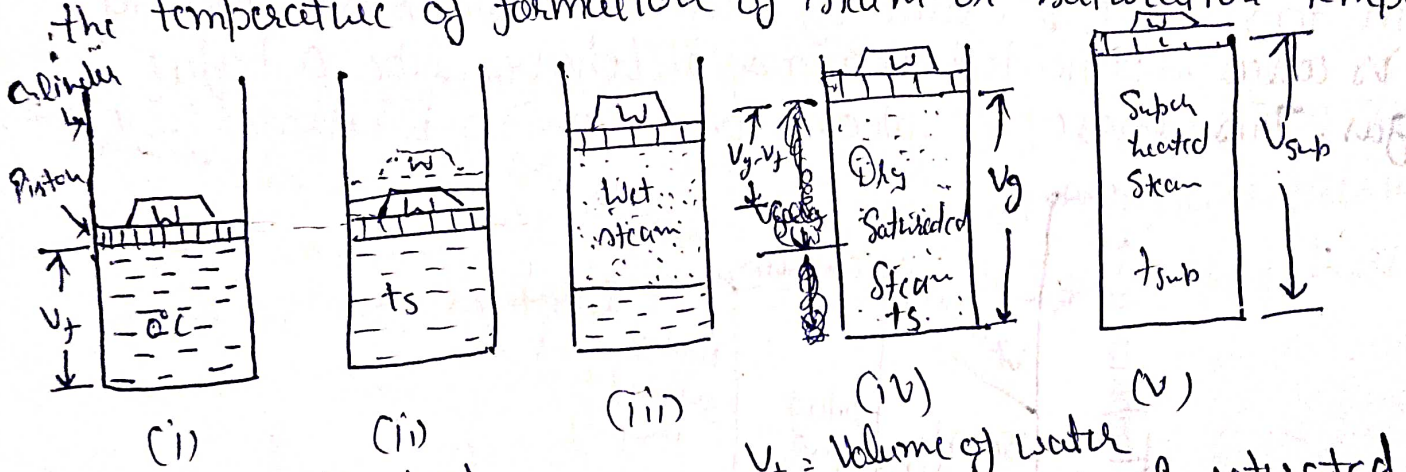
For water & steam

This diagram is also known as Mollier Diagram.

FORMATION OF STEAM AT CONSTANT PRESSURE

(2)

Consider a cylinder fitted with a piston which can move freely upwards & downwards in it. Let, 1 kg of water at 0°C with $v_f \text{ m}^3$ under the piston. Further let the piston is loaded with load W to ensure heating at constant pressure. Now if the heat is imparted to water, a rise in temperature will be noticed & this rise will continue till the boiling point is reached. The temperature at which water starts boiling depends upon the pressure & as such for each pressure (under which water is heated) there is a different boiling point. This boiling temperature is known as the temperature of formation of steam or saturation temperature.



- (i) $t_s =$ Saturation temp.
- $t_{sub} =$ Temp. of superheated steam
- $v_f =$ Volume of water
- $v_g =$ Volume of dry & saturated steam
- $v_{sub} =$ Volume of superheated steam

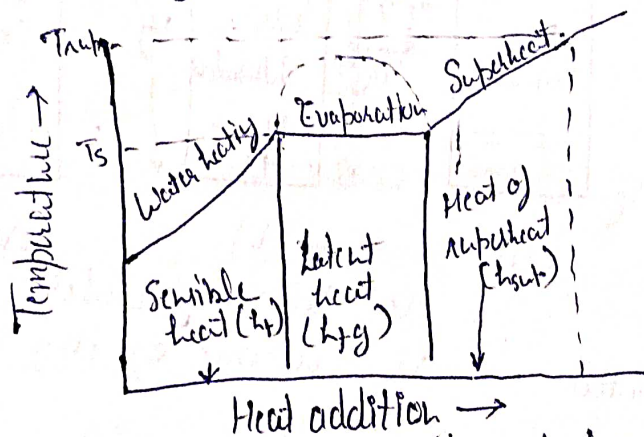
It may be noted during heating up to boiling point that there will be slight increase in volume of water due to which piston moves up & hence work is obtained as shown in (i). This work, however, is so small that it can be neglected.

Now, if supply of heat to water is continued it will be noticed that rise of temperature after boiling point is reached nil but the piston starts moving upwards which indicates that there is increase in volume which is only possible if steam formation occurs. The heat being supplied does not show any rise in temperature but changes water in to vapour state (steam) & in

known as latent heat or hidden heat. So long as the steam is in contact with water, it is called wet steam as in (iii) & if heating of steam is further progressed [as in (iv)] such that all the water particles associated with steam are evaporated, the steam so obtained is called dry & saturated steam. If $v_g \text{ m}^3$ is the volume of 1 kg of dry & saturated steam then work done on the piston will be $P(v_g - v_f)$

where p is constant pressure (due to weight 'w' on the piston)

Again, if supply of heat to the dry & saturated steam is continued at constant pressure, there will be increase in temperature & volume of steam. The steam so obtained is called superheated steam & it behaves like a perfect gas. This phase of steam formation is illustrated in (v).



Graphical representation of formation of steam

IMPORTANT TERMS RELATING STEAM FORMATION

1. Sensible heat of water (h_f). It is defined as the quantity of heat absorbed by 1 kg of water when it is heated from 0°C (freezing point) to boiling point. It is also called total (enthalpy) heat of water or liquid heat invariably. This type of heat is denoted by letter h_f & its value can be directly read from the steam tables.
2. Latent heat or hidden steam (h_{fg}) :- It is the amount of heat required to convert water at a given temperature & pressure into steam at the same temp. & pressure. It is expressed by h_{fg} .

3. Dryness fraction (x)

(3)

The term dryness fraction is related with wet steam. It is defined as the ratio of the mass of actual dry steam to the mass of steam containing it.

If m_s = mass of dry steam contained in steam considered
 m_w = weight of water particles in suspension in the steam considered.

$$\text{Then, } x = \frac{m_s}{m_s + m_w}$$

Thus if in 1 kg of wet steam 0.9 kg is the dry steam & 0.1 kg water particles then $x = 0.9$

4. Total heat or enthalpy of wet steam (h)

It is defined as the quantity of heat required to convert 1 kg of water at 0°C into wet steam at constant pressure. It is the sum of total heat of water & the latent heat & this sum is also called enthalpy.

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

5. Superheated Steam

When steam is heated after it has become dry & saturated, it is called superheated steam & the process of heating is called superheating. Superheating is always carried out at constant pressure. The additional amount of heat supplied to the steam during superheating is called as '~~Degree~~^{Heat} of superheat' & can be calculated by using the specific heat of superheated steam at constant pressure (C_{ps}), the value of which varies from 2.0 to 2.1 kJ/kg depending upon pressure & temperature.

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

If T_{sup} , T_s are the temperatures of superheated steam in K & wet or dry steam, then $(T_{sup} - T_s)$ is called

'degree of superheat'.

Superheated steam behaves like a gas & therefore it follows the gas laws. The value of n for this type of steam is 1.3 & the law for the adiabatic expansion is $PV^{1.3} = \text{Constant}$.

6. Volume of wet & dry steam :-

If the steam has dryness fraction of x , then 1 kg of this steam will contain x kg of dry steam & $(1-x)$ kg of water. If v_f is the volume of 1 kg of water & v_g is the volume of 1 kg of perfect dry steam (also known as specific volume), the volume of 1 kg of wet steam

$$= \text{Volume of dry steam} + \text{Volume of water}$$

$$= x v_g + (1-x) v_f$$

$$= x v_g + v_f - x v_f$$

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

$$\boxed{V = v_f + x v_g}$$

7. Volume of superheated steam

As superheated steam behaves like a perfect gas its volume can be found out in the way as gases.

If v_g = Specific volume of dry steam at pressure p

T_s = Saturation temp. in K

T_{sup} = Temp. of superheated steam in K

V_{sup} = Vol. of 1 kg of superheated steam in pr. p.

Then

$$\frac{P v_g}{T_s} = \frac{P V_{sup}}{T_{sup}}$$

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

OR

THERMODYNAMIC PROPERTIES OF STEAM & STEAM TABLES (4)

Basic thermodynamic properties are

P (Pressure)

T (Temperature)

v (Volume)

u (Internal energy)

h (Enthalpy)

S (Entropy)

These properties must be known at different pressure for analysing the thermodynamic cycles used for work producing devices. The values of these properties are determined theoretically or experimentally & are tabulated in the form of tables which are known as 'Steam Tables'. Tabulated values are also available for superheated steam. It may be noted that steam has only one saturation temp. at each pressure.

External Workdone during evaporation

When water is evaporated to form saturated steam, its volume increases from v_f to v_g at a constant pressure, & thus external work is done by steam due to increase in volume. The energy for doing the work is obtained during the absorption of latent heat. This work is called external work of evaporation & is given by $P(v_g - v_f)$

$$\text{External work of evaporation} = P(v_g - v_f)$$

Internal latent heat

$$\text{Internal latent heat} = h_{fg} - Pv_g$$

Entropy of wet steam

$$S = S_f + x S_{fg}$$

or $S = S_f + x \frac{h_{fg}}{T_s}$

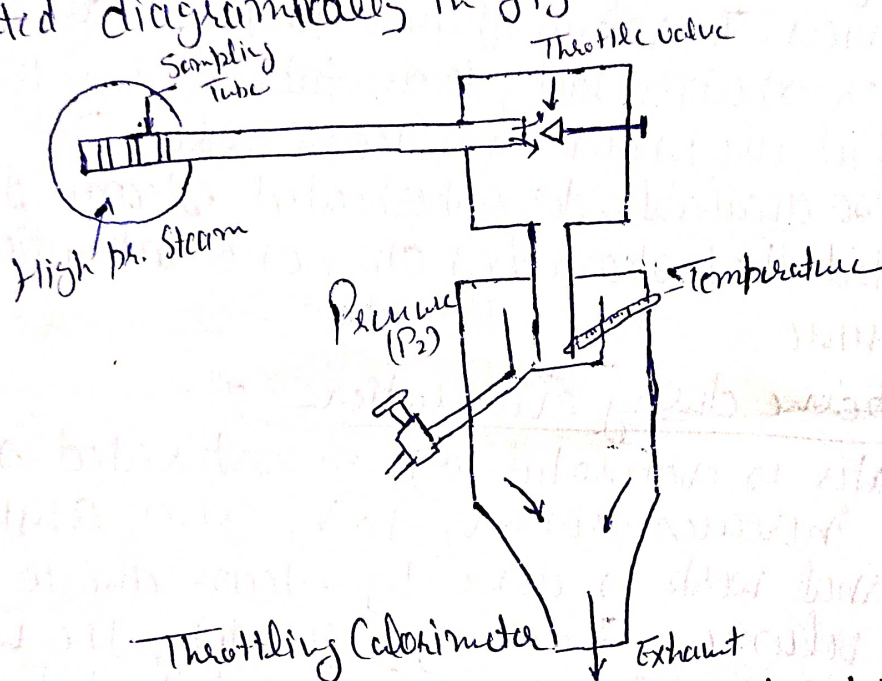
Entropy of superheated steam

$$S = S_f + S_{fg} + C_{ps} \log_e \left(\frac{T_{sup}}{T_s} \right)$$

$$S = S_f + \frac{h_{fg}}{T_s} + C_{ps} \log_e \left(\frac{T_{sup}}{T_s} \right)$$

Measurement of dryness fraction by throttling calorimeter

The dryness fraction of wet steam can be determined by using a throttling calorimeter which is illustrated diagrammatically in fig



The steam to be sampled is taken from the pipe by means of suitable positioned & dimensioned sampling tube. It passes in to an insulated container & is throttled through an orifice to atmospheric pressure. Here the temperature is taken & the steam ideally should have about 5.5 k of superheat.

The throttling process is shown on h-s diagram by line 1-2. If steam initially wet is throttled through a sufficient large pr. drop, then the steam at state 2 will become superheated. State 2 can be defined by the measured pr & temp.

$$h_2 = h_1 = h_{f1} + x_1 h_{fg1} \quad \text{at } p_1$$

$$\text{where } h_2 = h_{f2} + h_{fg2} + C_{ps} (T_{sup2} - T_{s2})$$

$$x_1 = \frac{h_2 - h_{f1}}{h_{fg1}}$$

