

Properties of Steam

**Subject : Elements of Mechanical
Engineering**

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Introduction

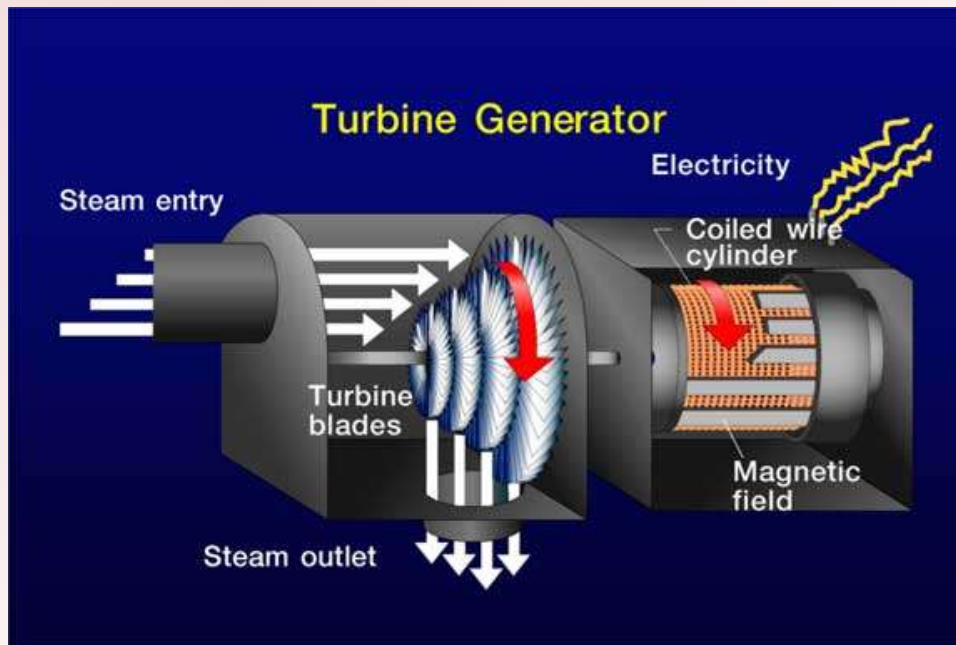
- ➔ Steam may be defined as water vapours suspended in air.
- ➔ It can be classified in wet, saturated or superheated.
- ➔ Vapours may be considered as a fluid in gaseous state as it may contain liquid particles and it's temperature is not far from it's boiling point.

- Note : wet steam do not obey gas laws of Boyles and Charles as it's not a pure gas.



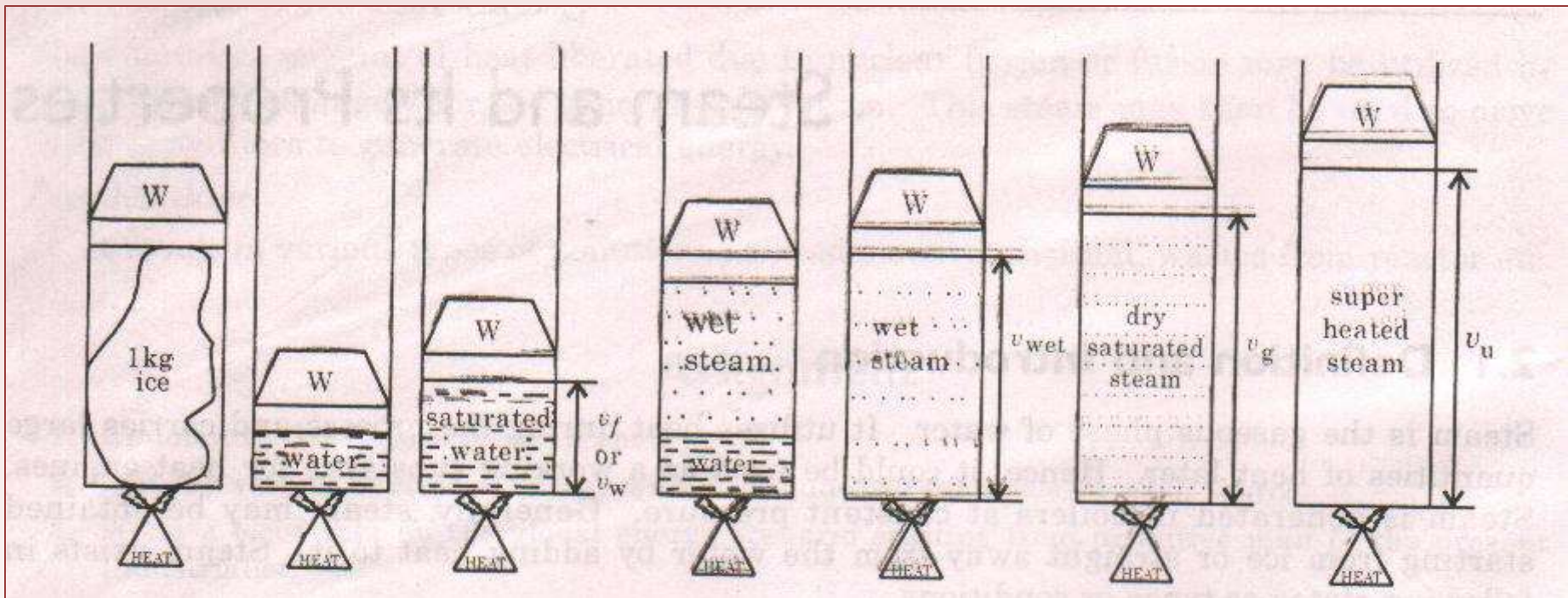
Introduction

➔ It is produced by heating of water and carries large quantities of heat within itself. Hence, it could be used as a working substance for heat engines and steam turbines.



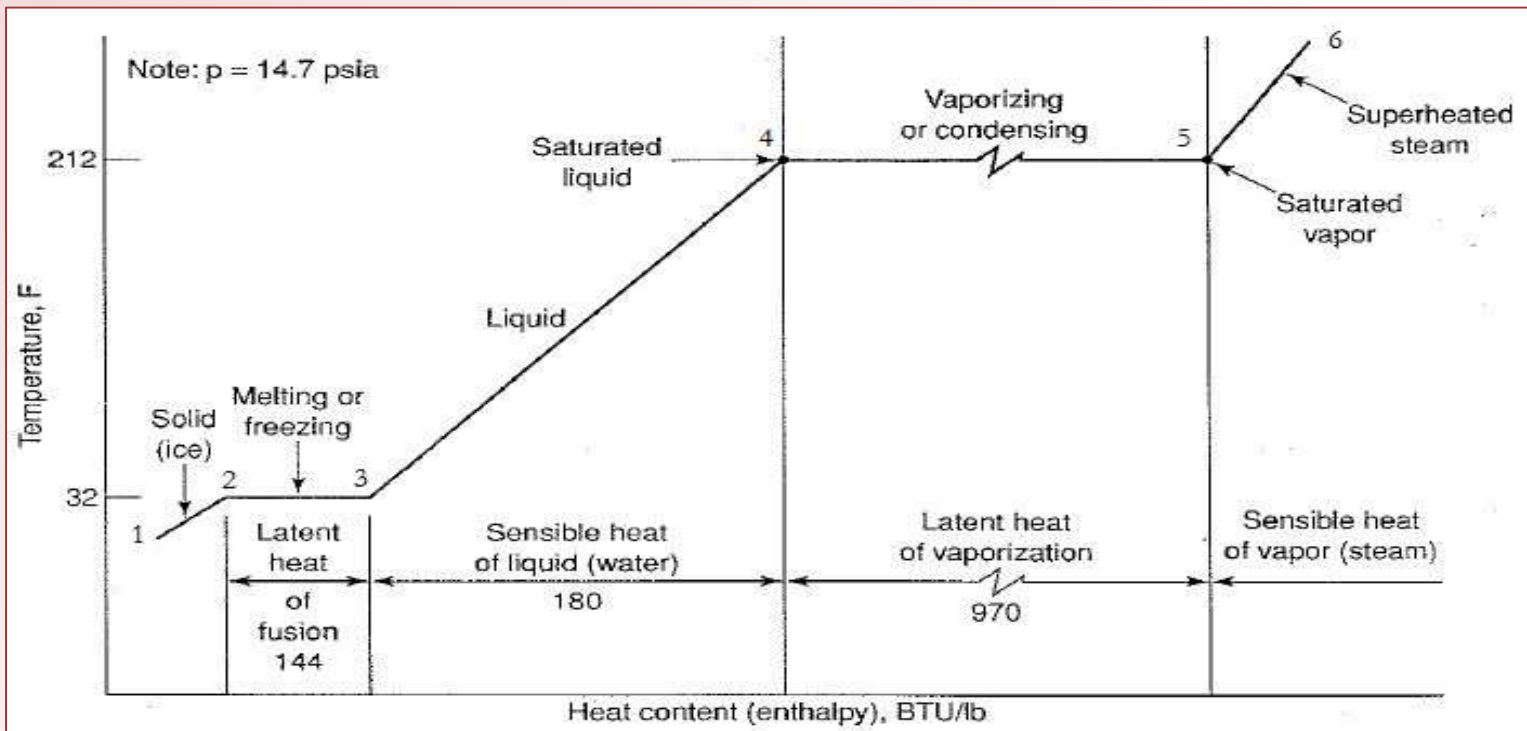
Constant pressure formation of steam

- Steam is generated in boilers at constant pressure.
- Consider a unit mass of ice at -20 degree Celsius and 1 atm contained in a cylinder-piston system. Let the ice be heated slowly so that it's

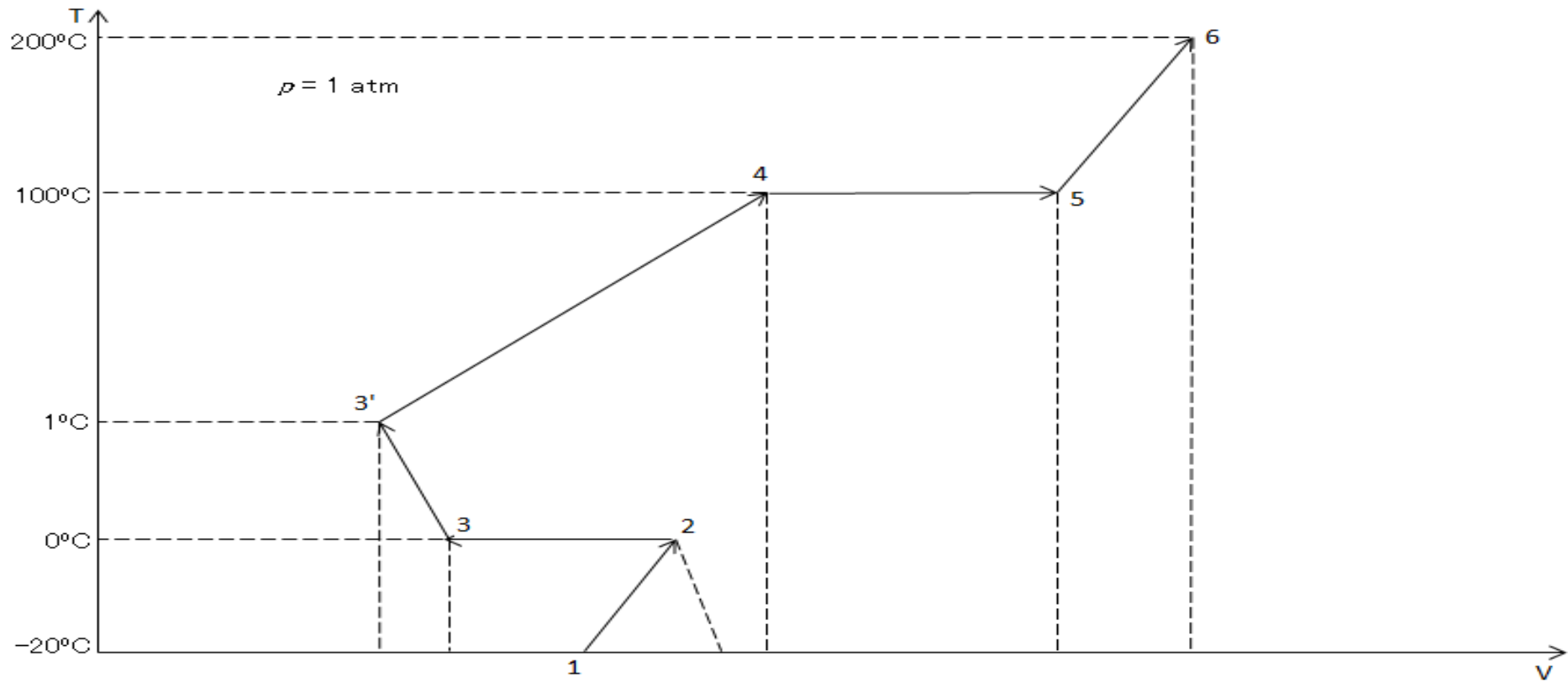


[constant pressure T-h diagram for steam]

➔ Let the state changes be plotted on temperature – heat added condiments, as shown in figure below.



[T-V diagram for phase changes of ice into steam]

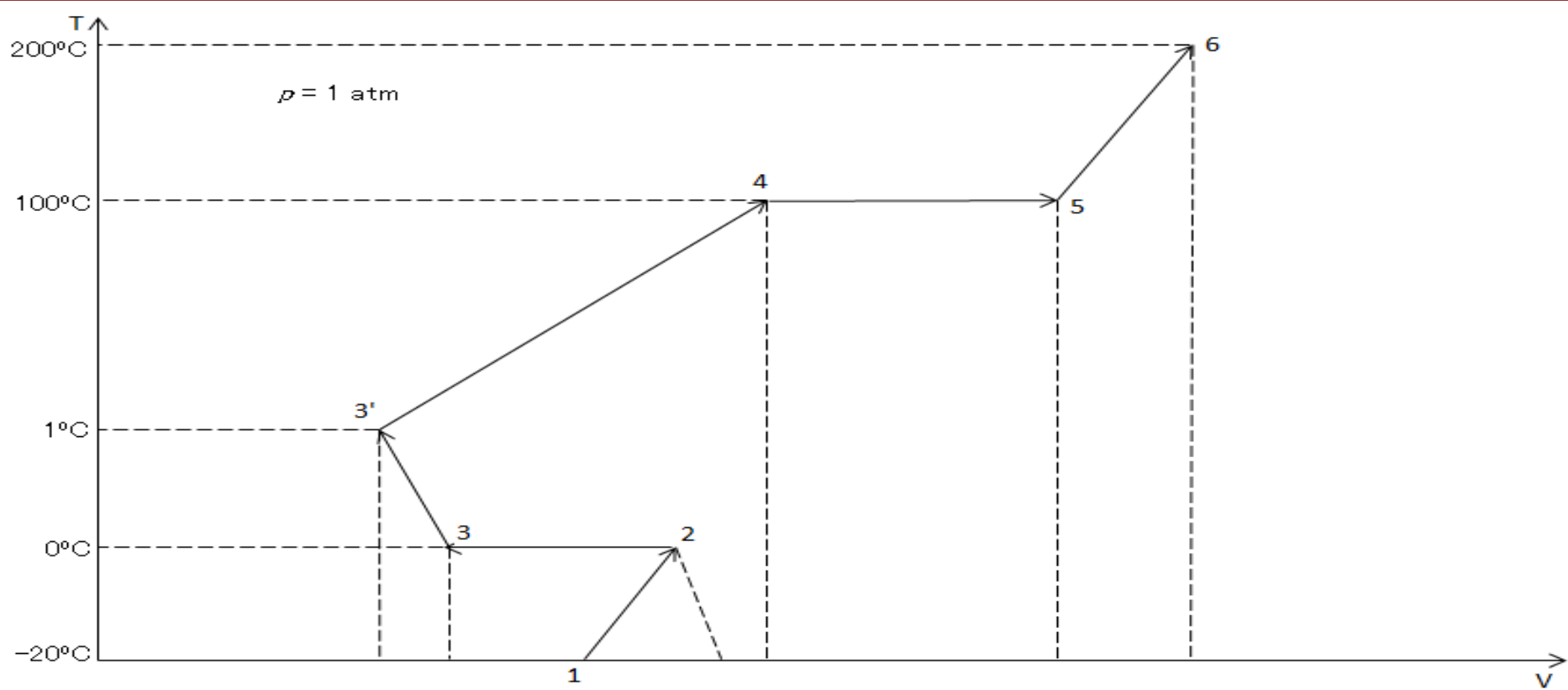


1 – 2 : Volume increases from V_1 to V_2 as ice temperature increases to 0°C .

2 – 3 : The volume of water decreases as ice melts at 0°C .

3 – 3' : The volume of water slightly decreases from 0°C to 4°C .

[T-V diagram for phase changes of ice into steam]

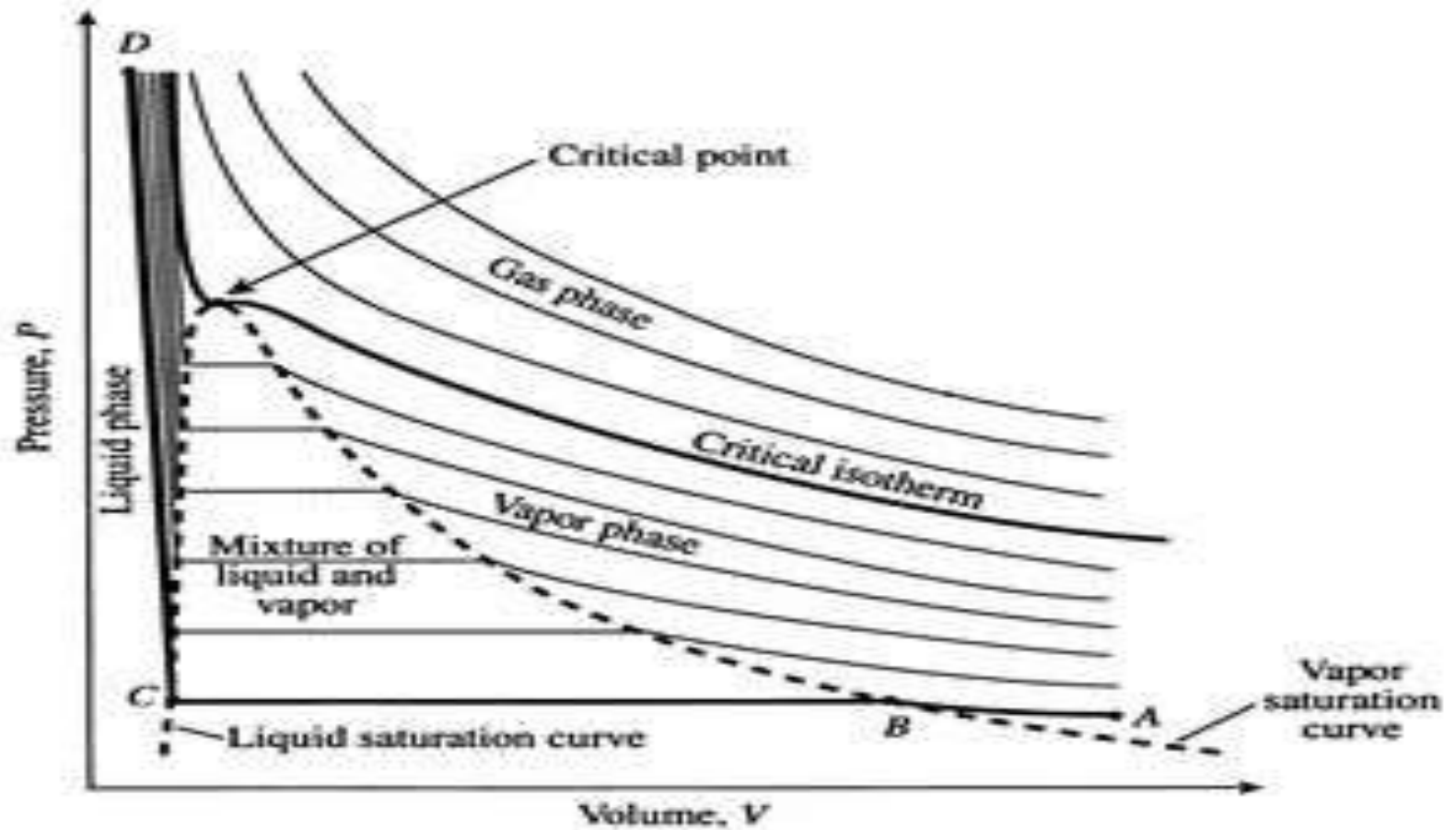


3' – 4 : The volume of water increases due to thermal expansion.

4 – 5 : There is a large increase in volume of water due to formation of steam.

5 – 6 : The volume of vapour increases.

[Saturated curve on p-v diagram]



[T-s diagram for a pure substance]

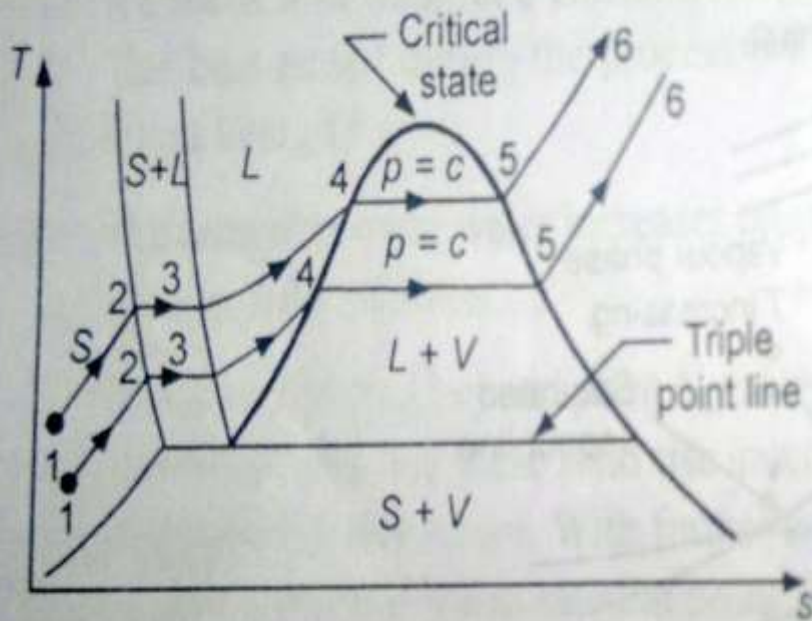


Fig. 4.6 Phase equilibrium diagram on TVs coordinates.

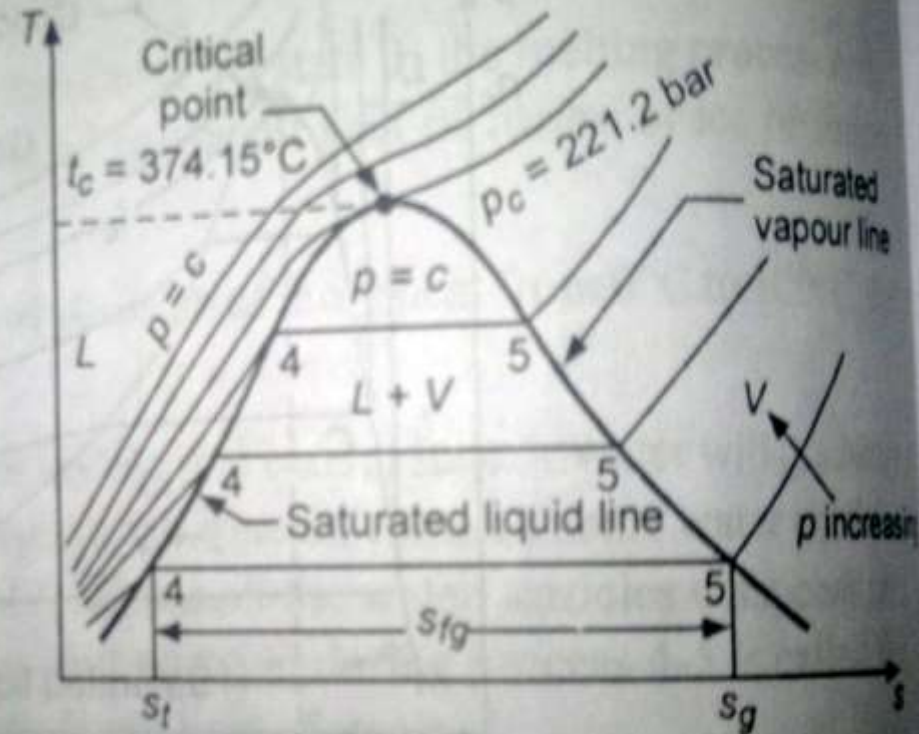


Fig. 4.7 Saturation (or vapour) dome for water.

Properties of steam

1. Enthalpy or Total heat of water (h_f)

- It is defined as the quantity of heat required to raise the temperature of one kg of water from 0°C to its boiling point or saturation temperature corresponding to the pressure applied. It is also called enthalpy of saturated water or liquid heat and is represented by h_f .

$$\begin{aligned} H_f &= \text{specific heat of water}(c_{pw}) \times \text{rise in temperature} \\ &= 4.187 \times \Delta t, \text{ kJ/kg} \end{aligned}$$

Properties of steam

2. Enthalpy of wet steam

- It may be defined as the quantity of heat required to convert one kg of water at 0 C, at constant pressure, into wet steam.

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

When steam is dry saturated , then $x = 1$

and

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

3. Latent heat of steam (h_{fg})

- Latent heat of steam at a particular pressure may be defined as a quantity of it required to convert one kg of water at it's boiling point into dry steam at the same pressure. It is denoted by h_{fg} .

Properties of steam

4. Dryness fraction (x)

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

➤ Let

- m_s = mass of dry steam, kg
- m_w = mass of water vapoure in steam, kg
- x = dryness fraction of the sample

then,

$$x = \frac{m_s}{m_s + m_w}$$

for dry steam,

$$m_w = 0 \text{ and } x = 1$$

➤ The quality of steam is the dryness fraction expressed as a percentage.

Properties of steam

➤ Wetness fraction = $1 - x = \frac{m_w}{m_s + m_w}$

The wetness fraction expressed in percentage is called priming.

5.Total Enthalpy of Superheated Steam

- Let
- c_{ps} = specific heat of superheated steam
 - t_s = temperature of formation of steam, C
 - t_{sup} = temperature of superheated heat, C

- Then heat of superheated steam

$$\begin{aligned} h_{sup} &= c_{ps}(t_{sup} - t_s) \\ &= (h_f + h_{fg}) + c_{ps}(t_{sup} - t_s) \\ &= h_g + c_{ps}(t_{sup} + t_s) \end{aligned}$$

Steam Tables

- In actual practice, it is quite cumbersome to calculate the relation between various quantities like pressure, temperature, volume, enthalpy, latent heat and entropy etc. of steam.
- Such quantities have been determined experimentally and recorded in the form of tables, known as steam tables.
- The values of various quantities given in these tables are for a kg of steam which is dry and saturated. Values for unknown pressure or temperature can be calculated by liner interpolation between two consecutive values.

Specific volume of wet steam

The specific volume of steam is the volume of 1 kg of dry steam, and is represented by v_g m^3/kg .

Density of steam = $1/v_g$ kg/m^3

Let v_f = volume of 1 kg of water, m^3/kg .

Then, volume of 1kg of wet steam = $x v_g + (1 - x) v_f$

Now $v_f \ll v_g$

So Volume of 1 kg of wet steam = $x v_g$

Density of wet steam = $\frac{1}{x v_g}$ kg / m^3

Specific volume of superheated steam

- The volume of superheated steam at a given pressure can be found by assuming the superheated steam behaves as a perfect gas obeying gas laws.
- Let
 - p = pressure under which the steam is superheated.
 - v_g = specific volume of dry saturated steam
 - T_s = temperature of formation of steam in K according to p
 - T_{sup} = temperature to which steam is super heated in K
 - v_{sup} = superheated volume of steam at pressure p .

So according to charle's law ,

$$v_{sup} = \frac{T_{sup}}{T_s} \times v_g$$

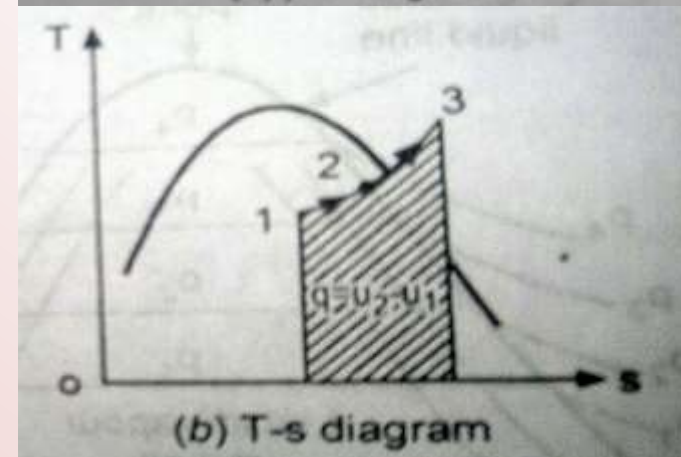
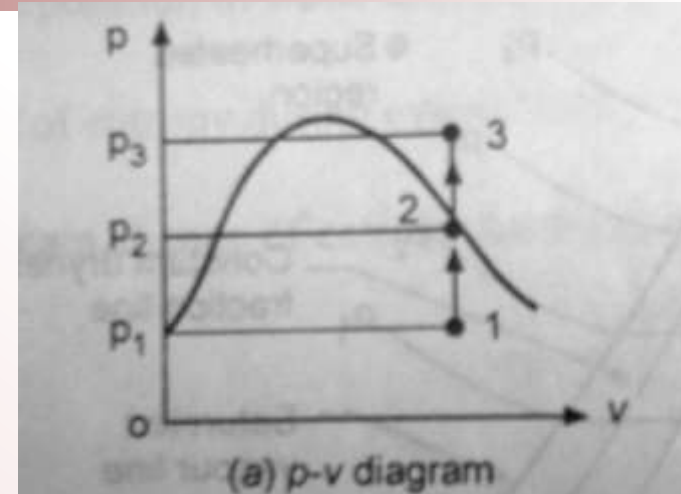
Various Processes for steam

1. Constant volume process

➤ The constant volume heating process is shown on p-v and t-s diagram in figures.

➤ $dv = 0$, so $dW = 0$

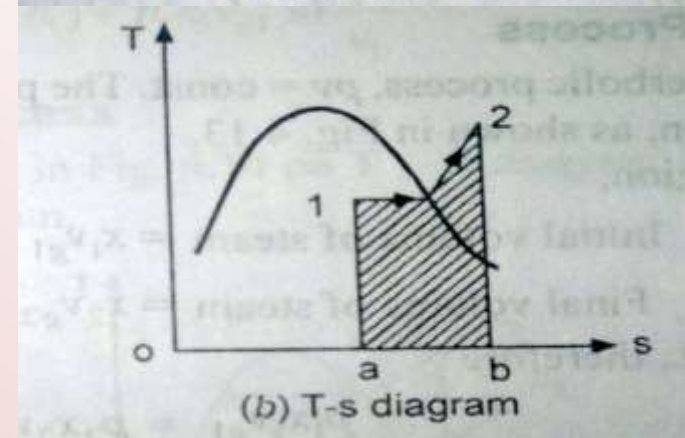
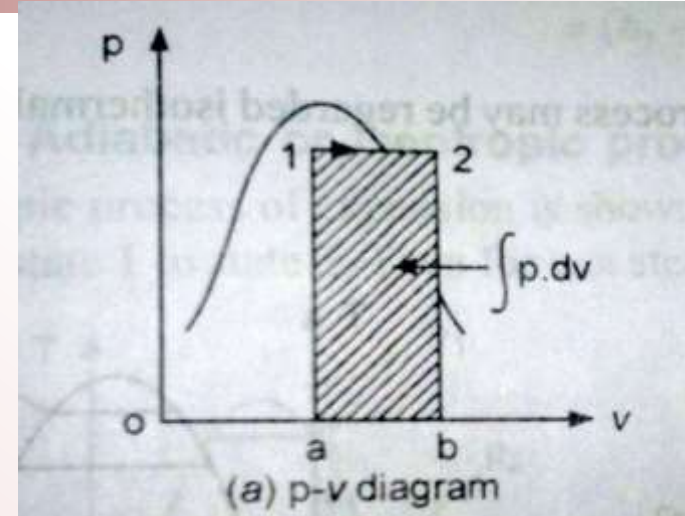
➤ $q = u_2 - u_1$



Various Processes for steam

2. Constant pressure process

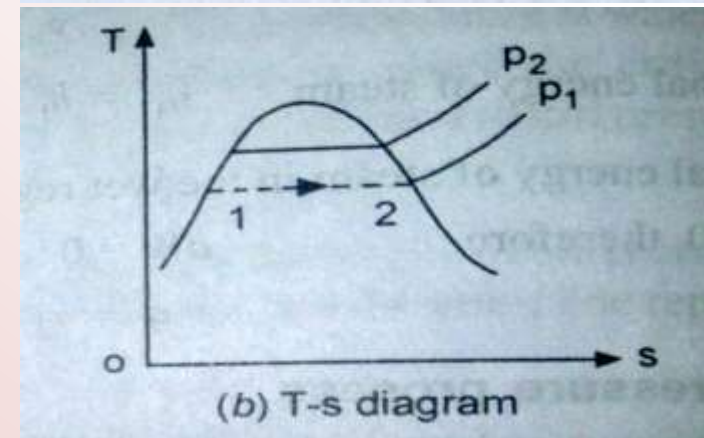
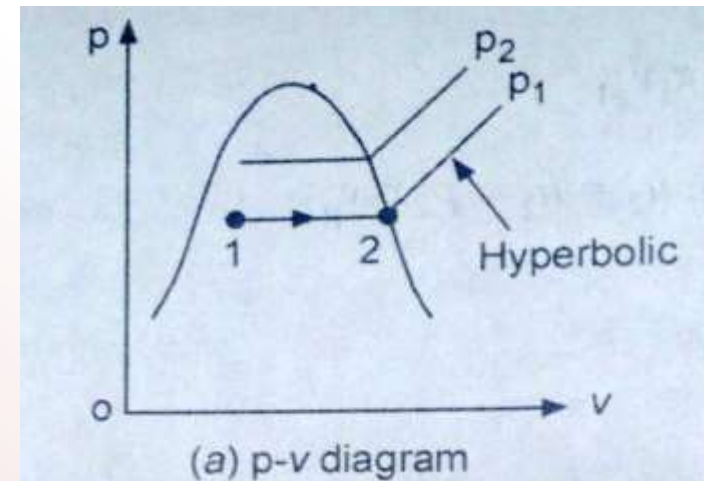
- The constant pressure heating process is shown in figure. In this case, $p_1 = p_2 = p_3$.
- Since p is constant, therefore, latent heat of steam and specific volume will remain same.
- Thus $v_{g1} = v_{g2} = v_{g3}$
 $h_{fg1} = h_{fg2} = h_{fg3}$
- $q = (x_1 - x_2) h_{fg}$ (For wet steam)
 $q = h_{sup} - h_s$



Various Processes for steam

3. Isothermal Process

- The isothermal heating process shown in figure. The isothermal process for wet steam will be same as the constant pressure process. But in the superheated region the steam will behave as a gas and shall follow Boyle's law, $pv = \text{const}$.
- Therefore, the process will be hyperbolic. In the wet region.
- $q = h_2 - h_1$ and $w = p_1 v_1 (1 - x_1)$



Various Processes for steam

4. Hyperbolic Process

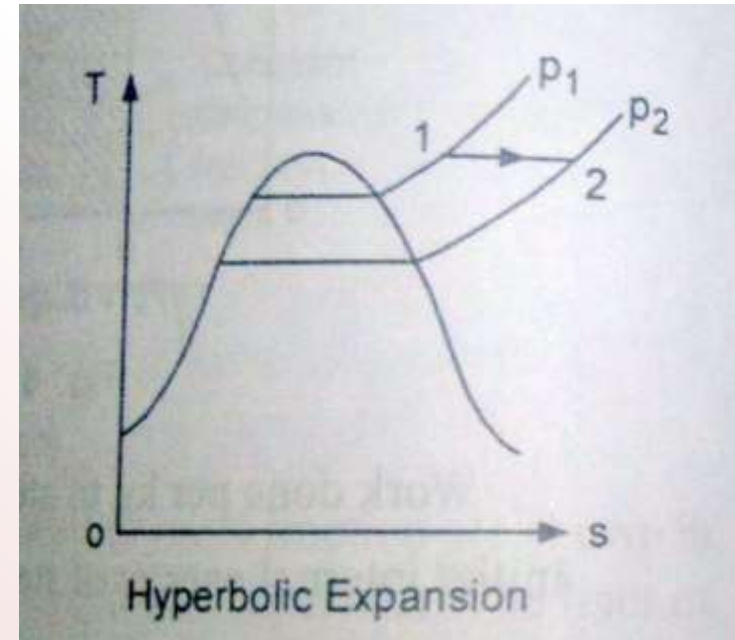
- During a hyperbolic process, $pv = \text{const.}$ The process may be regarded isothermal but only in the superheated region, as shown in figure.

- Change in Internal energy,

$$\begin{aligned} u_2 - u_1 &= (h_2 - p_2 x_2 v_{g2}) - (h_1 - p_1 x_1 v_{g1}) \\ &= h_{s2} - h_1 \text{ for wet steam} \end{aligned}$$

- Work done,

$$W = p_1 v_1 \ln(v_2/v_1) + p_1 x_1 v_{g1} \ln(v_2/v_1)$$



Various Processes for steam

5. Reversible Adiabatic or Isentropic process

➤ The isentropic process of expansion is shown in figure. On T-s diagram. Let the steam be expanded from state 1 to state 2.

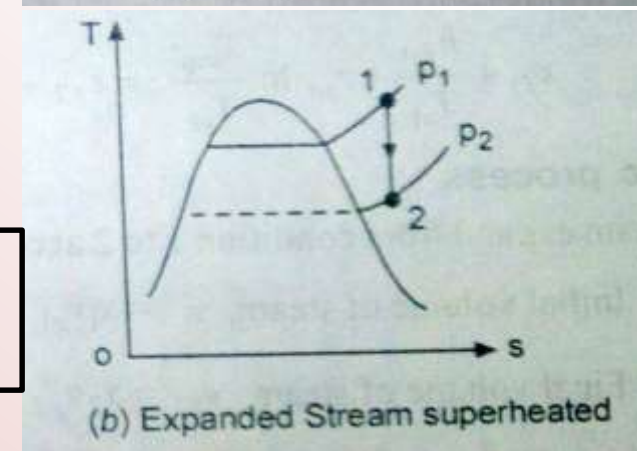
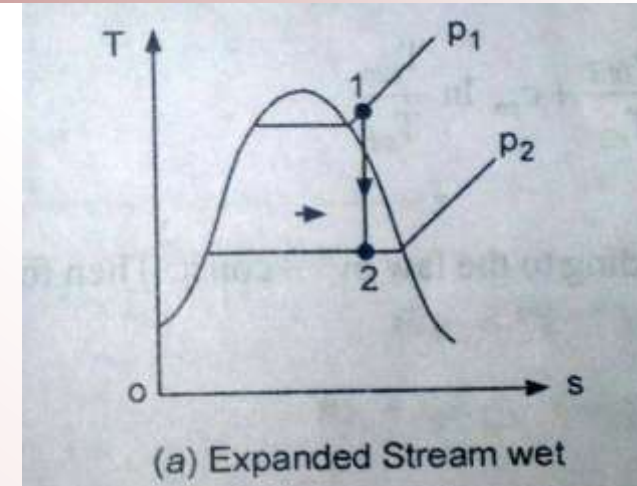
➤ For wet steam

$$x_2 = \left[(s_{f1} - s_{f2}) + \frac{x_1 h_{fg1}}{T_{s1}} \right] \times \frac{T_{s2}}{h_{fg2}}$$

➤ For superheated steam

$$q = 0, \quad w = u_1 - u_2$$

$$\text{So, } s_{f1} + \frac{h_{fg1}}{T_{s1}} + c_{ps} \ln \frac{T_{sup}}{T_{s1}} = s_{f2} + \frac{h_{fg2}}{T_{s2}} + c_{ps} \ln \frac{T_{sup}}{T_{s2}}$$



Various Processes for steam

6. Polytropic process

➤ A **polytropic process** is a thermodynamic process that obeys the relation:

$$pv^n = C$$

where p is the pressure, v is specific volume, n , the **polytropic index**, is any real number, and C is a constant. This equation can be used to accurately characterize processes of certain systems, notably the compression or expansion (including with heat transfer) of a gas and in some cases liquids and solids.

➤
$$W = \frac{P_1 x_1 v_{g1} - p_2 x_2 v_{g2}}{n - 1}, \quad q = w + (u_2 - u_1)$$

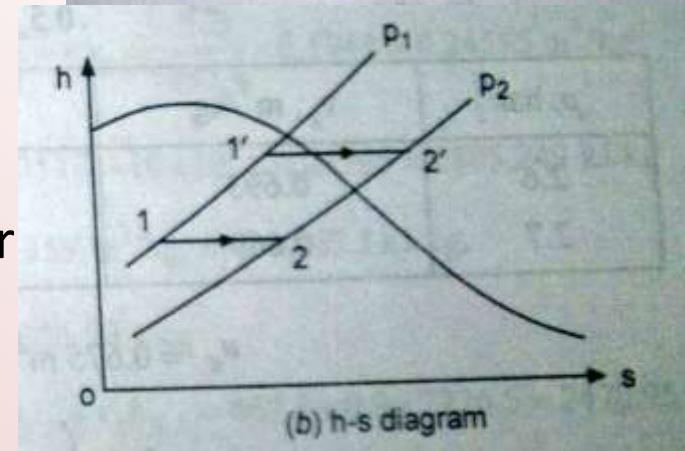
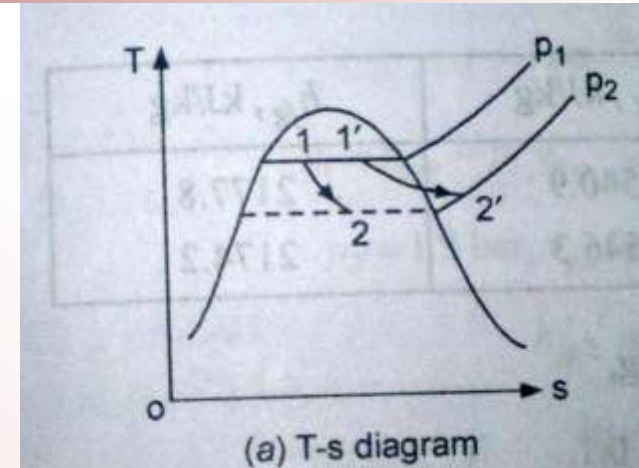
➤ ($n=1.13$ for wet steam and 1.3 for superheated steam)

➤
$$P_1 (x_1 v_{g1})^n = p_2 v_2^n$$

Various Processes for steam

7. Throttling Process

- **Throttling** is a process in which the flow of fluid is restricted by closing the valve partially. Now imagine there are students in a class room and as the bell rings they started moving out.
- Now if the door is opened partially then there will be clusters form by the students. In flow of fluid there is restriction to flow. now as students form clusters they pushing other students and in the same way fluid particles start rubbing with other molecules and as a result friction is there and as friction is one of the biggest reason for any process to make it irreversible.



Determination of dryness fraction of steam (x)

- There are four methods of determining of dryness fraction of steam.
1. Barrel calorimeter
 2. Separating calorimeter
 3. Throttling calorimeter
 4. Combined separating and throttling calorimeter

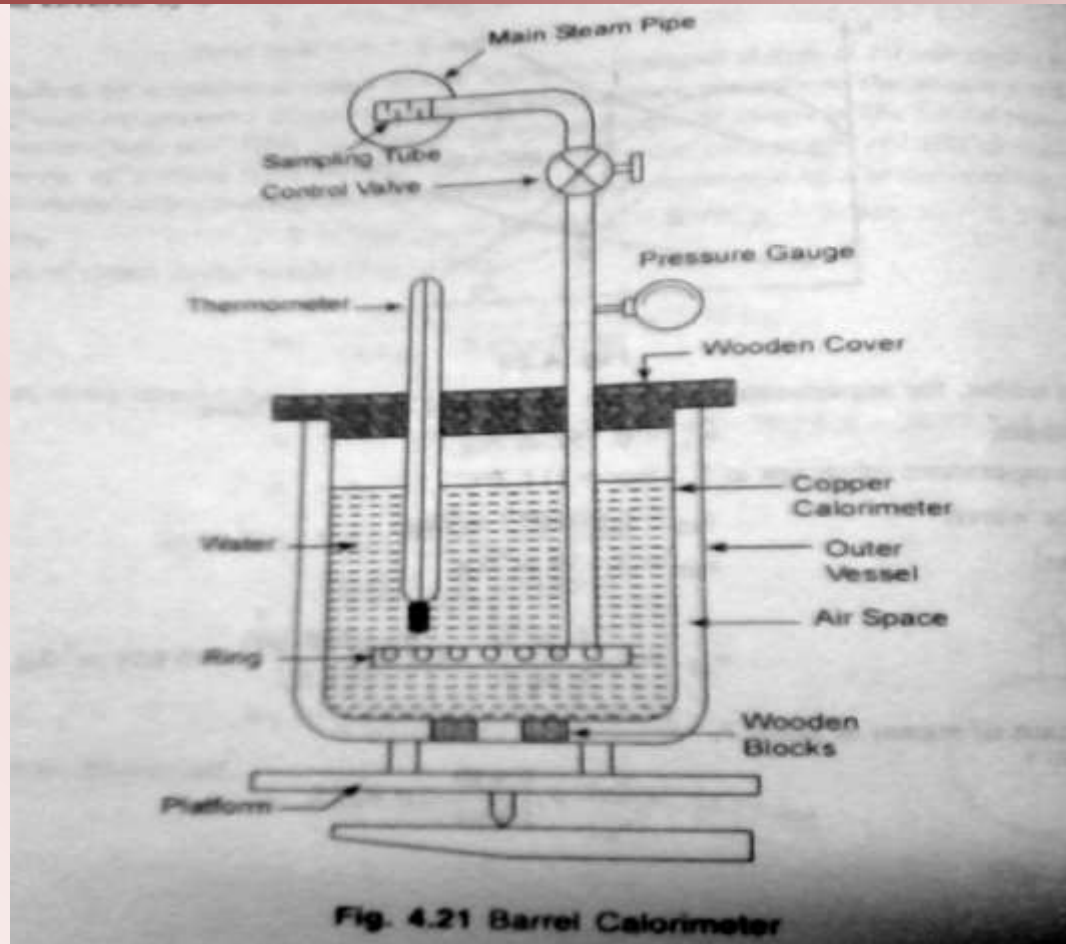
Determination of dryness fraction of steam (x)

1. Barrel calorimeter

- Here known amount of water is filled in the calorimeter. Then certain quantity of steam from the main pipe is taken into the calorimeter. Steam and water mixes together and so condensation of steam takes place and mass of water in the calorimeter increases. Latent and sensible heat of steam is given to water and its temperature will increase.
- Amount of heat lost by steam = Heat gain by water and calorimeter
The dryness fraction x of the steam can be calculated.

- $$x = \frac{(M_w + m_c) c_{pw}(t_2 - t_1) - m_s c_{ps}(t_s - t_2)}{m_s h_g}$$

Determination of dryness fraction of steam (x)

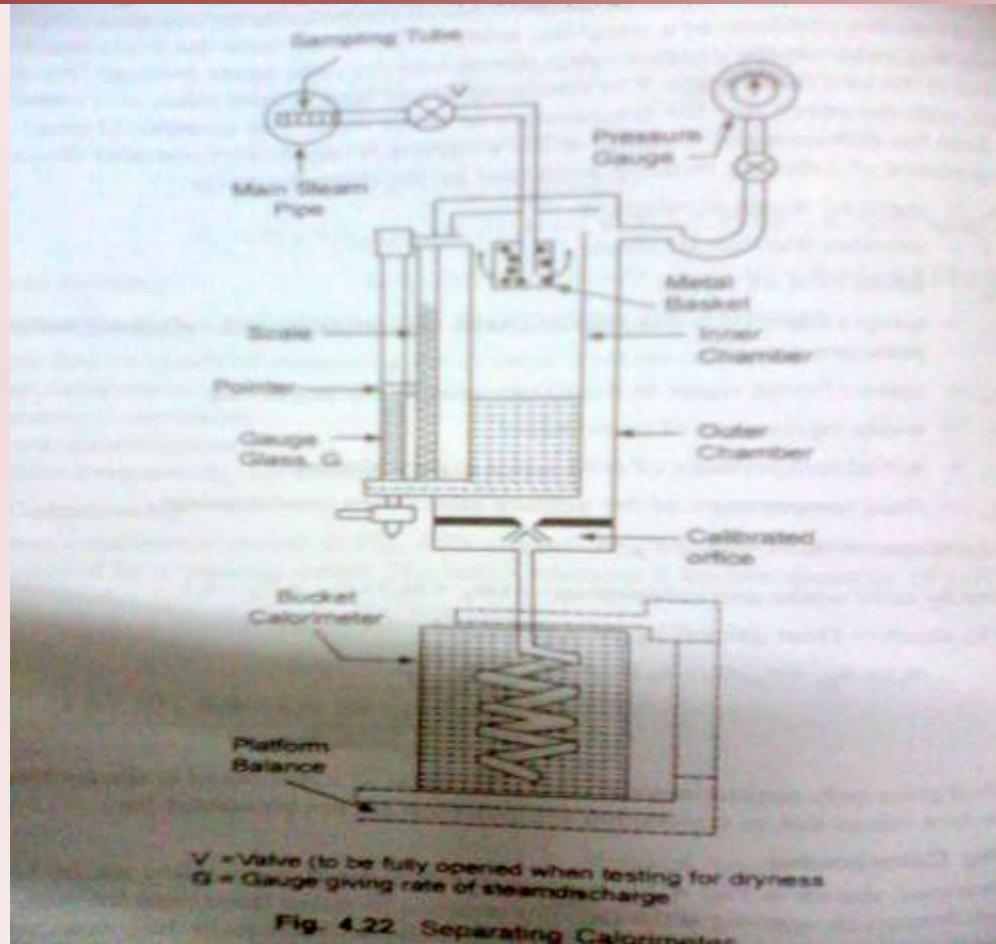


Determination of dryness fraction of steam (x)

2. Separating calorimeter

- In this type of calorimeter water particles from the steam are separated first in the inner chamber and its mass m_w can be measured. The dry steam is then condensed in the barrel calorimeter and its mass m_s can be calculated from the difference in mass of water of barrel calorimeter. So dryness fraction $x = m_s / (m_s + m_w)$
- Limitation: It gives approximate value of x as total separation of water particles from the steam is not possible by mechanical means.

Determination of dryness fraction of steam (x)



Determination of dryness fraction of steam (x)

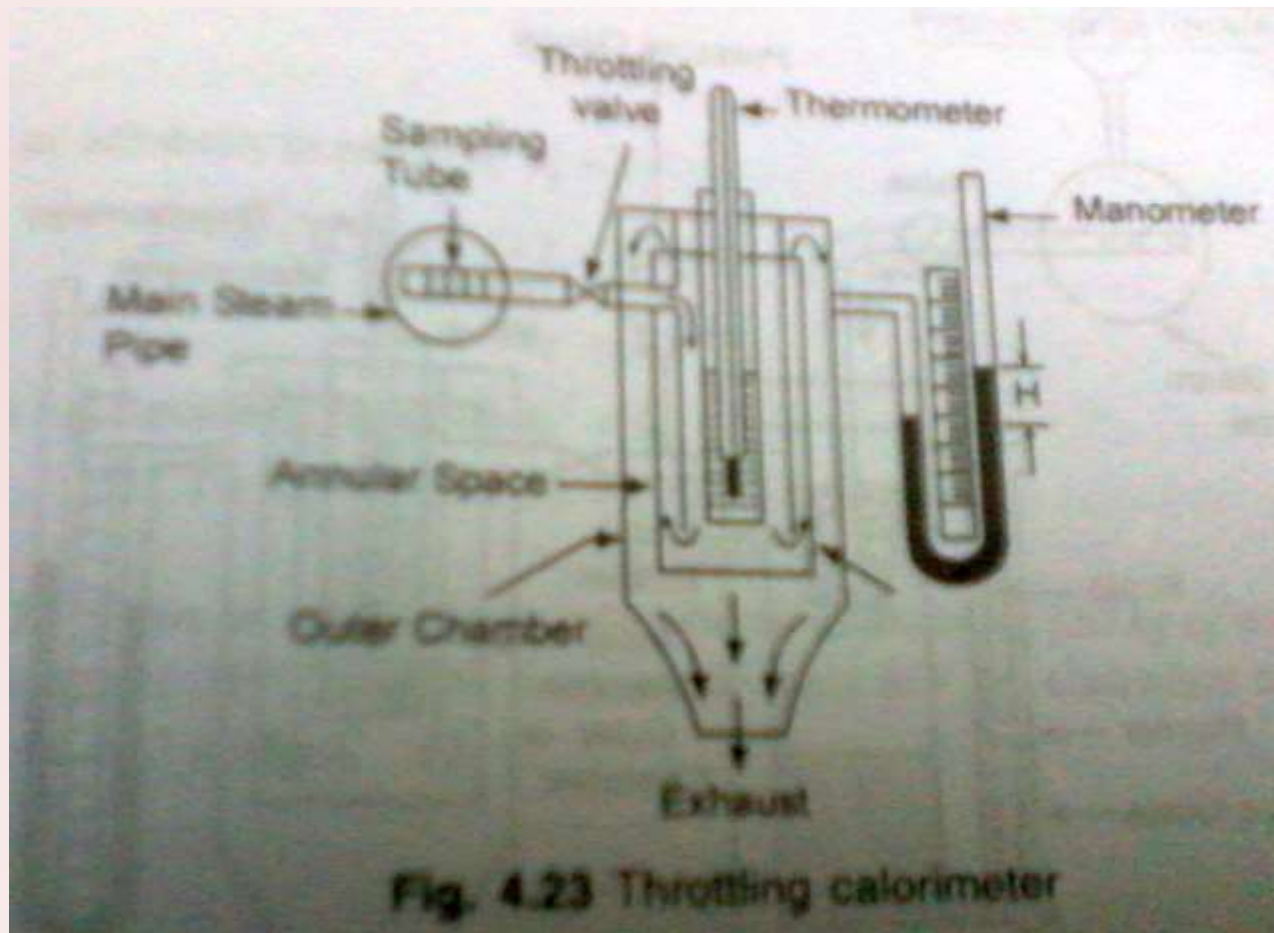
3. Throttling process

- In this calorimeter a throttling valve is used to throttle the steam. The pressure of steam reduces after throttling. Pressure and temperature of steam before and after throttling is measured. Enthalpy of steam before and after throttling remains constant. To measure dryness fraction condition of steam after throttling must be superheated steam.

Enthalpy of stem before throttling = Enthalpy of stem after throttling

- Limitation: Steam must become superheated after throttling. That means it is not very useful for steam containing more amount of water particles.

Determination of dryness fraction of steam (x)



Determination of dryness fraction of steam (x)

4. Combined separating and throttling calorimeter

- The limitations of separating and throttling calorimeters can be overcome if they are used in series as in this type of calorimeter. It gives accurate estimation of dryness fraction.

$$x = x_1 \cdot x_2$$

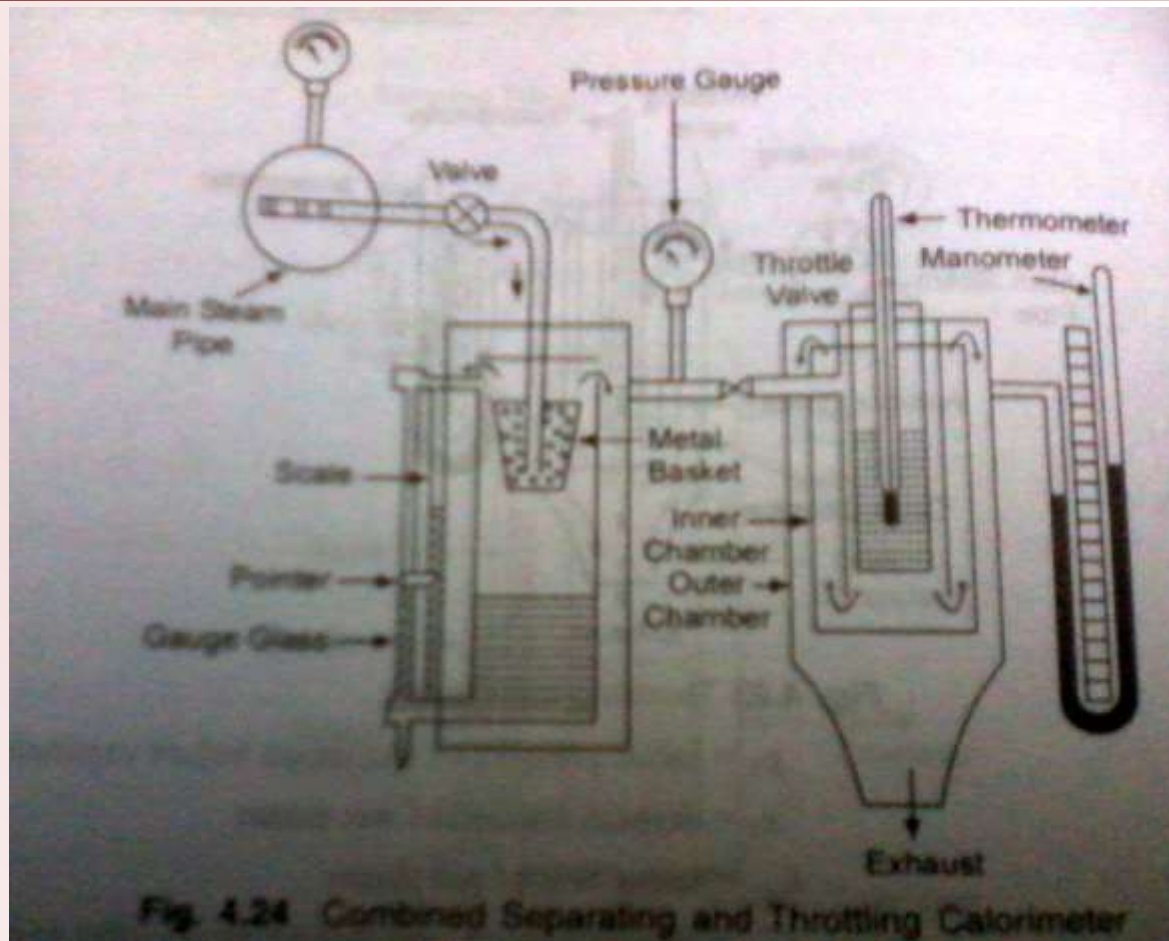
x_1 = dryness fraction of steam measured from separating calorimeter.

x_2 = dryness fraction of steam measured from throttling calorimeter.

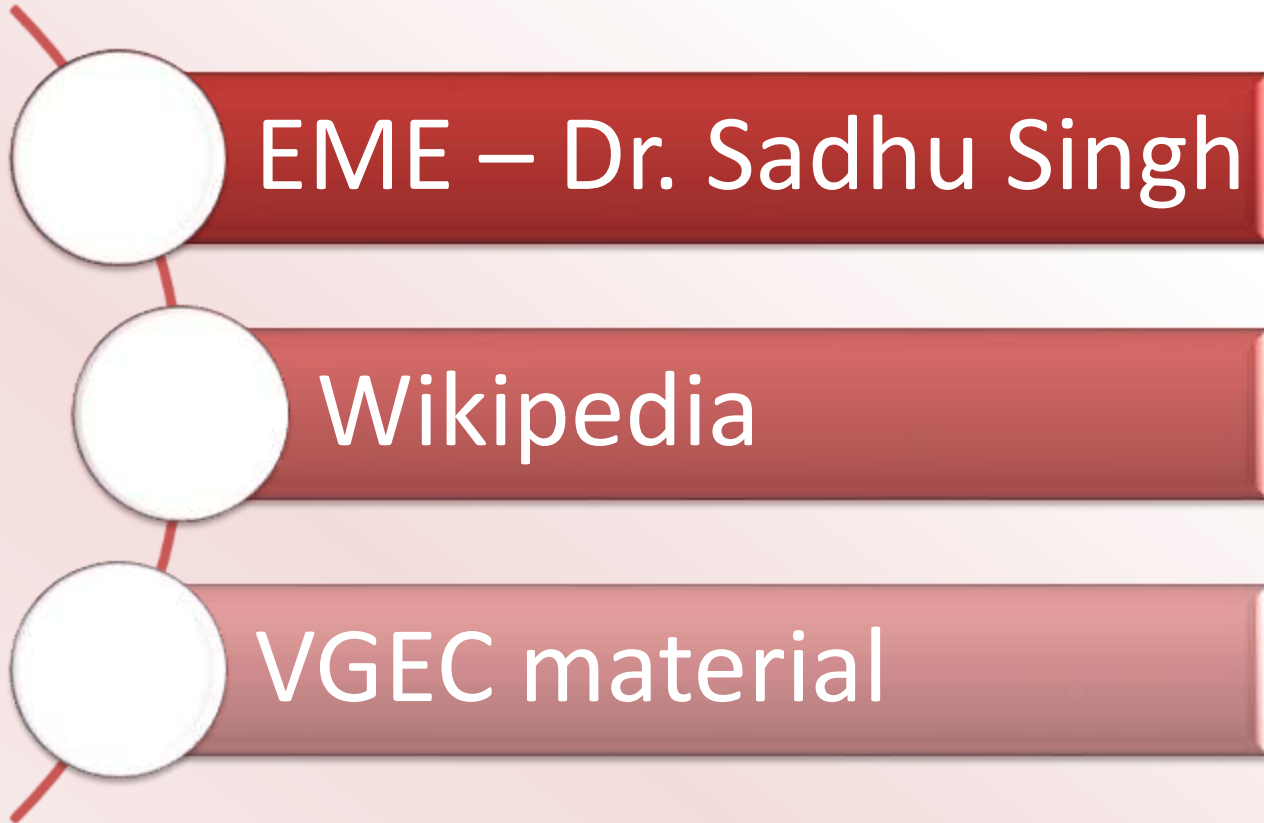
- $$x_1 = \frac{(h_2 - hf_1) + cps (tsup - ts_2)}{h_{fg1}}$$

- $$x_2 = \frac{m_s}{m_s + mw}$$

Determination of dryness fraction of steam (x)



Refrances



Thank you!