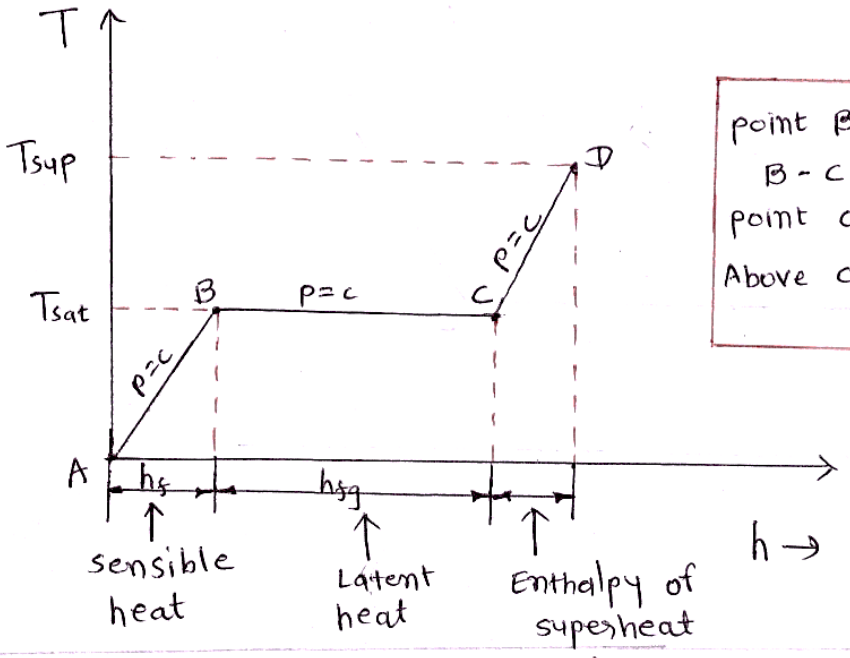
Chapter – 4 Properties of Steam

* Steam formation :-



point B = saturated liquid
B - C = wet steam
point C = dry steam
Above C = superheated steam

→ Saturation temperature :- The temperature at which water starts boiling for given pressure

→ Sensible heat :- Heat added upto saturation temperature
[It changes the temp. of water]

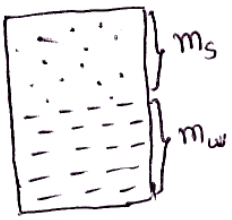
→ Latent heat :- Heat that does not change the temp. of water is called latent heat.
[It changes the phase of water]

→ Types of steam

① Wet steam :- Water molecules and steam both are in equilibrium i.e. mixture of water and steam

* Dryness fraction (x) :- Ratio of mass of actual dry steam in wet steam to total mass of wet steam

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



$m_s + m_w$ = Total mass of wet steam

* Wetness fraction (y) :- Ratio of mass of water in wet steam to total mass of wet steam

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

Now, Dryness fraction + Wetness fraction

$$= x + y$$

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

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

$$= 1$$

(2) Dry steam :- steam at saturation temperature having no water molecules

(3) Superheated Steam :- Steam at temperature greater than saturated temperature

* Degree of superheat = $T_{sup} - T_{sat}$

⇒ Equations of specific Enthalpy (h), Specific volume (v) and specific internal energy (u) for wet, dry and superheated steam :-

(1) Wet steam :-

$$h_{wet} = h_f + x \cdot h_{fg} \quad kJ/kg$$

(h_f, h_{fg} — From steam table)

$$v_{wet} = x \cdot v_g \quad m^3/kg$$

(v_g — From steam table)

$$u_{wet} = h_{wet} - p \cdot v_{wet} \quad kJ/kg$$

(p in kPa, 1 bar = 100 kPa)

(2) Dry steam :-

$h_{dry} = h_g$ kJ/kg — From steam table

$v_{dry} = v_g$ m^3/kg — From steam table

$u_{dry} = h_{dry} - p \cdot v_{dry}$ kJ/kg — p in kPa, 1 bar = 100 kPa

(3) Superheated steam :-

$h_{sup} = h_g + C_{ps}(T_{sup} - T_{sat})$ kJ/kg

$C_{ps} = 2.1$ kJ/kg

h_g From steam table

$v_{sup} = \frac{T_{sup}}{T_{sat}} \times v_g$ m^3/kg

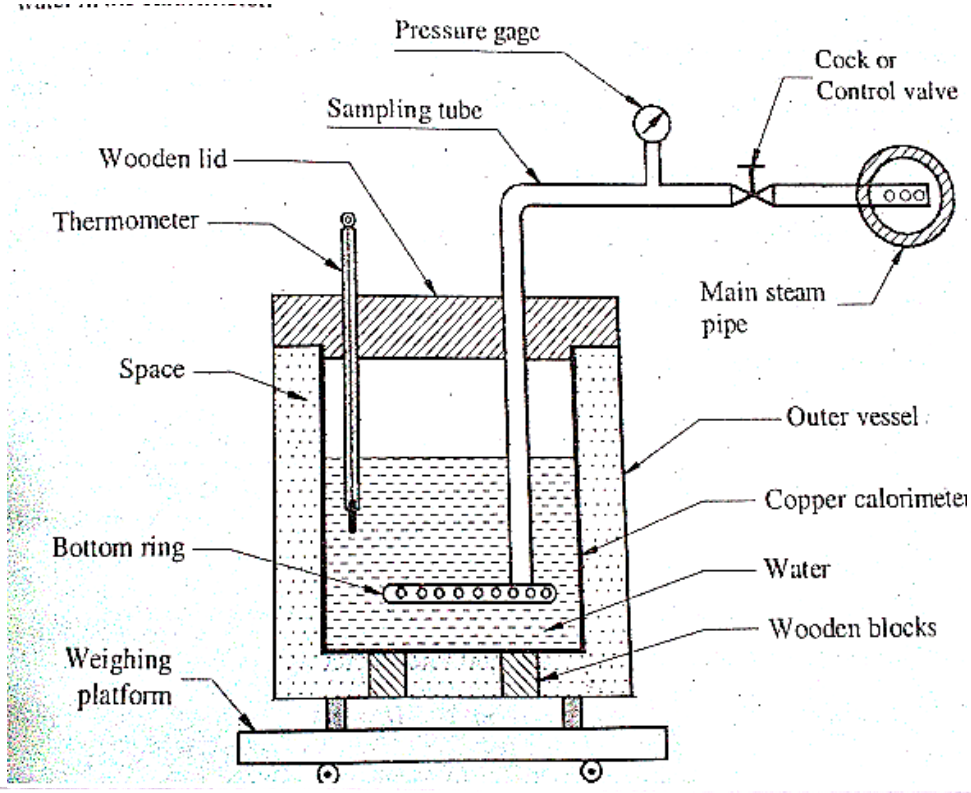
v_g From steam table

T Temperature in kelvin

$u_{sup} = h_{sup} - p \cdot v_{sup}$ kJ/kg — p in kPa, 1 bar = 100 kPa

→ Calorimeters – Used to measure dryness fraction

(1) Bucket / Barrel calorimeter :-



Heat lost by steam = Heat gain by water & calorimeter

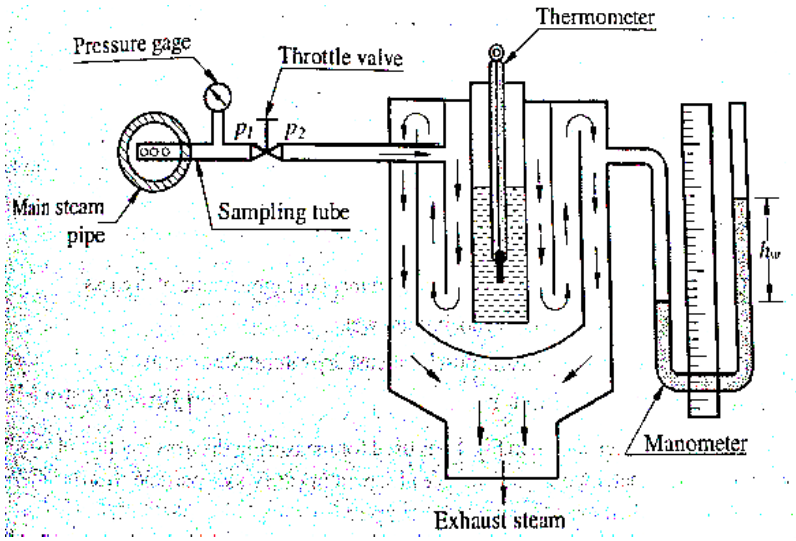
$$m_s (h_{f_1} + x \cdot h_{fg_1} - h_{f_2}) = m_{cal} \cdot C_{cal} (T_2 - T_1) + m_w \cdot C_w (T_2 - T_1)$$

$$= [m_{cal} \cdot C_{cal} + m_w \cdot C_w] (T_2 - T_1)$$

$$= \left[\frac{m_{cal} \cdot C_{cal}}{C_w} + m_w\right] (T_2 - T_1) C_{pw}$$

Term, $\frac{m_{cal} \times C_{cal}}{C_w}$ is called water equivalent of calorimeter

(2) Throttling calorimeter :-



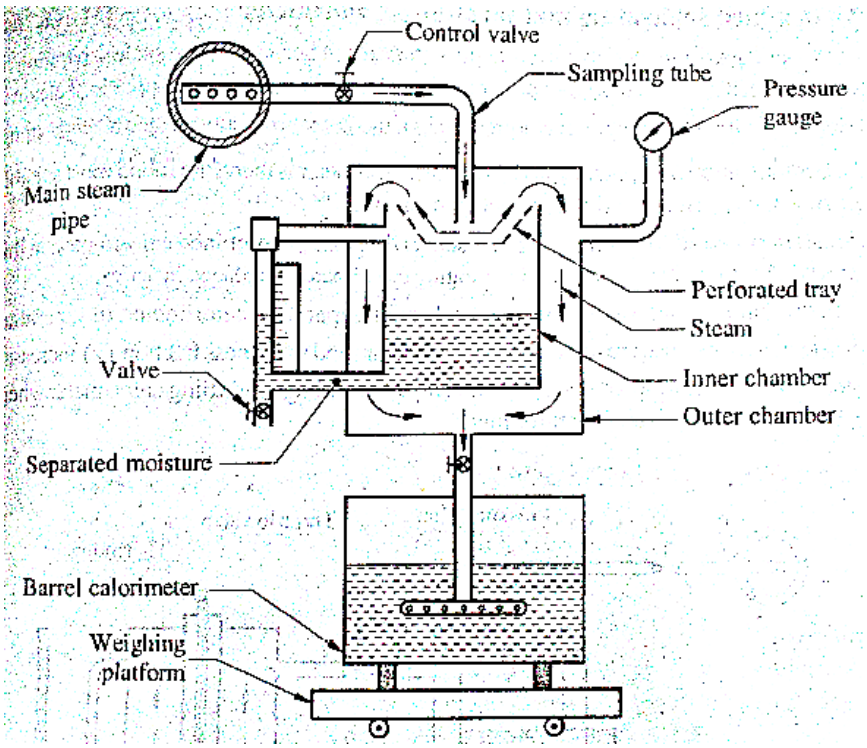
Enthalpy before throttling [Wet steam] = Enthalpy after throttling [superheated steam]

$$\therefore h_{f_1} + x \cdot h_{fg_1} = h_{g_2} + C_{ps} (T_{sup} - T_{sat})$$

$$\therefore x \cdot h_{fg_1} = h_{g_2} + C_{ps} (T_{sup} - T_{sat}) - h_{f_1}$$

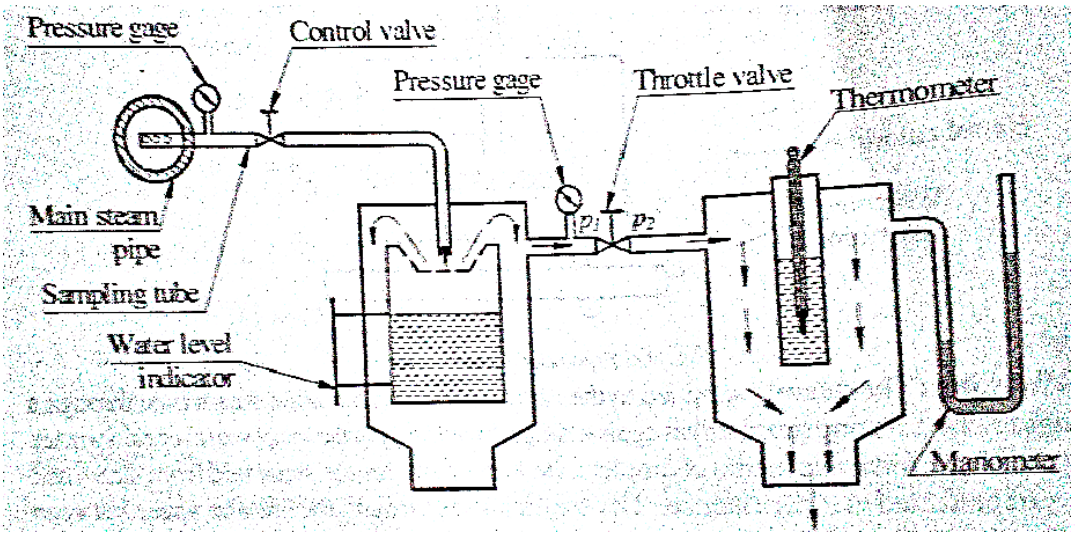
$$\boxed{x = \frac{h_{g_2} + C_{ps} (T_{sup} - T_{sat}) - h_{f_1}}{h_{fg_1}}}$$

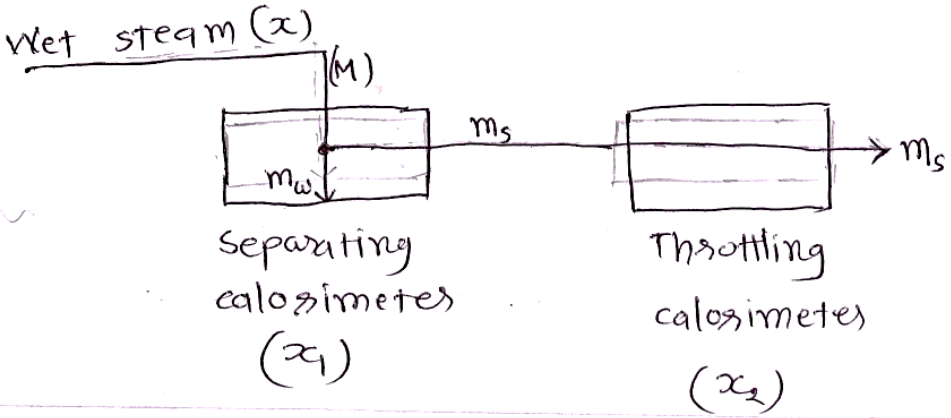
(3) Separating calorimeter



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

(4) Combined separating & throttling calorimeter





Now, $x_1 = \frac{m_s}{m_s + m_w}$ and $x_2 = \frac{h_{g_2} + c_{ps}(T_{sup} - T_{sat}) - h_{s_1}}{h_{fg_1}}$

Now, wetness fraction = $\frac{\text{mass of water}}{\text{Total mass of wet steam}}$

$\therefore$ Mass of water = Wetness fraction $\times$ Total mass of wet steam

from above eqn

(1) Water droplets in steam sample [i.e. entering calorimeter]

$= (1-x)(M) = (1-x)(m_s + m_w)$

(2) Water droplets removed by separating calorimeter

$= (1-x_1)(m_s + m_w)$

(3) Water droplets entering throttling calorimeter

$= (1-x_2) \cdot m_s$

Now, (1) = (2) + (3)

so,

$(1-x)(m_s + m_w) = (1-x_1)(m_s + m_w) + (1-x_2) m_s$

$\therefore (1-x) = (1-x_1) + (1-x_2)\left(\frac{m_s}{m_s + m_w}\right)$

$\therefore 1-x = 1-x_1 + (1-x_2) \cdot x_1$

$\therefore 1-x = 1-x_1 + x_1 - x_1 \cdot x_2$

$\therefore 1-x = 1-x_1 x_2$

$\therefore \boxed{x = x_1 \cdot x_2}$