Chapter 3 Properties of Steams

Introduction :

Vapour:-

Under the normal conditions, fluids which can exist in a liquid as well as gaseous state are known as vapours.

Example as a steam as a vapour phase of water, ammonia, freon etc.

They do not obey gas equation and ideal gas law like Boyle's law, Charles law etc.

Under the certain conditions they are used for the approximate calculations.

Pure Substance:-

It is one which has homogeneous molecular structure and invariable chemical composition. Pure substance can exist in any of the three phase such as solid, liquid, and gaseous state,

it may exist in more than one phase.

But its molecular structure and chemical composition is always remain same at all conditions such as water.

Air is not pure substance since, Because at very low temperature gases presents in the air like as N_2, O_2 liquefies at their boiling temperatures and chemical composition and molecular structure of air changes.

Steam Formation:-

Consider 1 kg of the ice at 15 ˚C and the standard atmospheric pressure .

Heat is now added at the constant pressure. Various states passes through by the system is plotted on the T-h diagram.
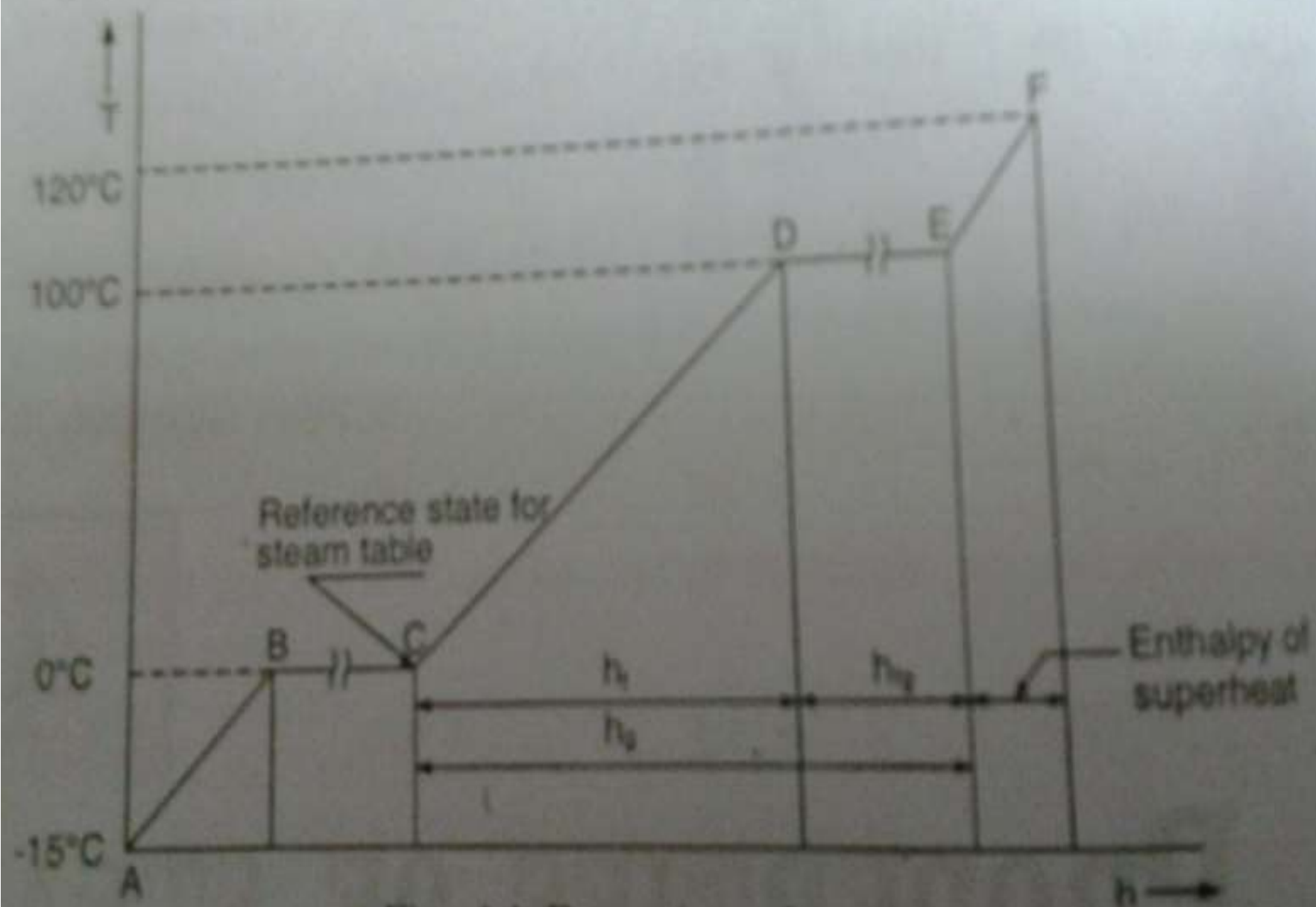
Fig. 4.1 Formation of steam

A-B:- Sensible heat is added to ice and its temperature will increase up to melting temperature 0°C.

B-C:- Latent heat is added and ice starts melting at its melting temperature 0°C.

Ice converts into water from and at 0°C.

This process is known as "latent heat of fusion of ice."

C-D:- On the further addition of heat, water temperature will increase up to its saturation temperature.

Point D is said to be saturated liquid state.

D-E :- During this process temperature remain constant and latent heat is added.

At point D water starts boiling and it continues up to point E.

At point E boiling ends.

Amount of the heat added during this process is called "latent heat of vaporization".

E-F:- On the further addition of heat steam temperature will increase.

Steam having temperature higher than its saturation temperature at particular pressure is called superheated steam.

Steam having state beyond point E is superheated steam.

Difference between temperature of superheated steam and its saturation temperature is called degree of superheat.

Heat difference between T_f and T_e is called degree of superheat.

Enthalpy of Steam:-

From the First law of thermodynamics,

we know that heat added at the constant pressure is equal to enthalpy change of the substance.

$Q = \Delta U + W$

$Q = (U_2 - U_1) + P(V_2 - V_1)$

$Q = (U_2 + PV_2) - (U_1 + PV_1)$

$Q = (H_2 - H_1)$

1. Enthalpy of Saturated Liquid (h_f):-

Amount of heat required to produce 1 kg of saturated liquid point D from the triple point of water point C at the constant pressure is called enthalpy of saturated liquid h_f.

$$h_f = C_{pw} (T_{sat} - 0)$$

From Steam Table

$$C_{pw} = \text{Specific heat of water} = 4.187 \frac{kj}{kg.K}$$

T_{sat} = Saturation temperature at 0°C

2.Enthalpy of Vaporization (h_{fg}) :-

Amount of heat required to convert 1 kg of water from saturated liquid state point D to the saturated vapour state point E is called enthalpy of the vaporization (h_{fg}).

So that h_E- h_D is known as enthalpy of vaporization.

3.Enthalpy of the Dry Saturated Steam:-

Amount of heat required to produce 1 kg of saturated vapour point E from triple point of water point C is called enthalpy of the dry saturated steam (h_g).

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

4.Enthalpy of superheated steam:-

Amount of heat is added to dry saturated steam, it will become superheated.

Amount of heat required to produce 1 kg of superheated steam (point F) from reference state point C is called enthalpy of superheated steam.

We can also write that $h_{sup} = h_g + C_{ps}(T_{sup} - T_{sat})$

5.Heat of the superheat :-

Amount of heat required for the superheating of steam from dry saturated state is called heat of superheat.

Heat of superheat = $C_{ps} (T_{sup} - T_{sat}) \dfrac{Kj}{kg}$

6.Dryness Fraction:-

Ratio of the mass of dry saturated vapour, to the total mass of wet vapour is called dryness fraction. It is designated as by the symbol x.

$$X = \frac{m_S}{m_S + m_W}$$

m_s = mass of dry saturated vapour

m_w = mass of liquid particles in the suspension

7.Quality of Vapour:-

When dryness fraction is expressed in the percentage it is called quality of vapour.

Quality of Vapour = 100.x

8.Wetness Fraction:-Ratio of the mass of wet vapour, to the total mass of the dry saturated vapour and wet vapour is called wetness fraction. It is designated as by the symbol x'.

Wetness Fraction $x' = \dfrac{m_w}{m_s + m_w}$

Thus it is x' = 1-x

9.Priming:-

When wetness fraction is expressed in the percentage, it is called priming.

Priming = 100.x'

10. Enthalpy of Wet Vapour (h):-

One kg of wet vapour having dryness fraction x contains (x kg of dry saturated steam at the saturation temperature (T_{sat})) and ((1-x) kg of liquid particles at the saturation temperature).

So enthalpy of 1 kg of wet vapour is equal to enthalpy of x kg of dry saturated vapour plus enthalpy of (1-x) kg of saturated liquid.

Hence $h = (1-x).h_f + x.h_g$

$\qquad = (1-x) h_f + x (h_f + h_{fg})$

$\qquad = h_f + x. h_{fg}$

Specific enthalpy of vaporization of wet vapour is equal to $x.h_{fg}$

Types of Steams:-

Wet Steam:-

Specific volume of the wet steam can be written

as $v = (1-x) v_f + x. v_g$

At low pressure the specific volume of saturated liquid is negligible compare to specific volume of saturated vapour,

hence generally the term of $(1-x) v_f$ is neglected.

$v = x. v_g$

Superheated Steam:-

For the steam generation at the constant pressure specific volume of the superheated steam can be calculate using

Charles's Law.

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

Now $V_{sat} = V_g$

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

$V_{sat} = V_g$

Steam Table:-

From experimental study various properties of steam like enthalpy, volume, internal energy are tabulated at the various pressure and temperature.

It may be pressure base or the temperature base.

It is tabulated for the specific properties.

Properties are tabulated from triple point of water to critical point of steam.

All the values are calculated with triple point of water as reference point means at 0˚C enthalpy, internal energy and the entropy is taken as zero.

Internal Energy:-

It can be calculate using definition of the enthalpy.

We have h = u + pv

$\qquad$ u = h – pv

To calculate internal energy (u) of saturated, wet or superheated steam, appropriate value of the enthalpy (h) and the specific volume is to be substituted. Here pv is known as work done during evaporation.

Measurement of Dryness fraction

Four types of steam calorimeters are use to measure dryness fraction of steam.

1. Bucket Calorimeter
2. Separating Calorimeter
3. Throttling Calorimeter
4. Combined Calorimeter
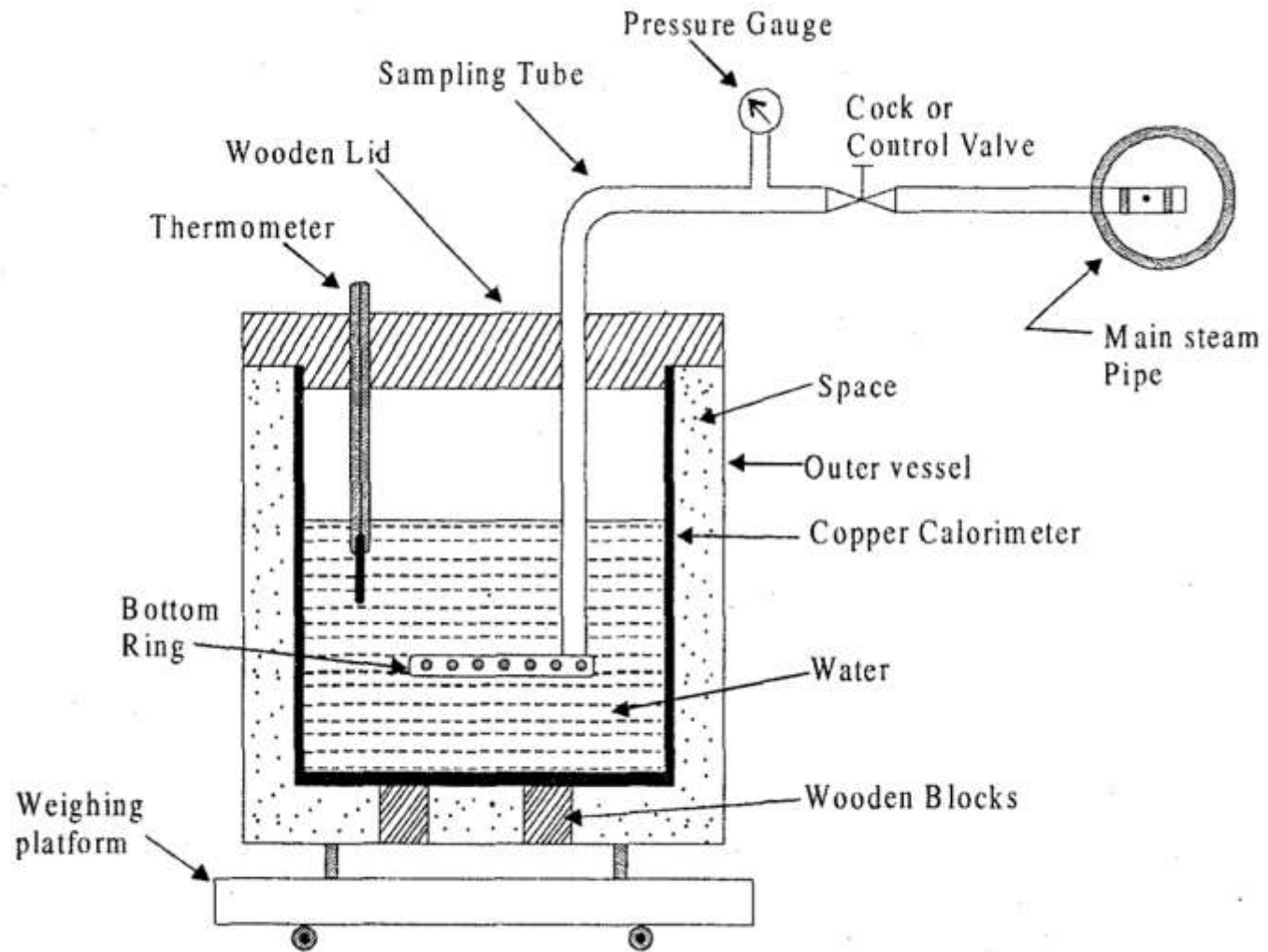
1. Bucket Calorimeter:-

Fig. 4.10 Barrel or Bucket calorimeter.

CONSTRUCTION:

The apparatus shown in Figure consists of a copper calorimeter which is placed on wooden blocks in a vessel.

The vessel is large enough to provide an air space around the calorimeter.

This air space provides insulation to prevent heat loss.

The top cover is made of wood and it closes both the calorimeter and the vessel.

This cover has two holes.

Through one hole, the steam pipe is led into the calorimeter.

The steam is distributed in the water in the calorimeter by the holes in the bottom ring which is connected to the end of the steam pipe.

The thermometer is inserted from the second hole to measure the temperature of water in the calorimeter.

WORKING

The first step of the experiment is to measure the weight of calorimeter.

With the known value of specific heat of copper, the water equivalent of calorimeter is calculated.

Then necessary amount of water is taken, in the calorimeter and its initial temperature is noted.

The calorimeter is places in the vessel.

The top cover is placed in position and the steam pipe is connected to main steam pipe.

The steam comes in contact with water in the calorimeter when steam is passed through the water.

It condenses and gives out its entire enthalpy of evaporation (latent heat) and part of its sensible heat.

Due to heat transfer from steam to water in the calorimeter, the temperature of water increases.

Condensation of steam will increase the mass of water.

Sufficient quantity of steam should be blown in the calorimeter so that sufficient rise in temperature of water and thereby errors are reduced to minimum.

Afterwards the steam cock is closed.

The cock should be opened by such an amount that all the steam gets condensed in water and no steam bubbles escape out of water.

It is happens then the error may be introduce in calculation.

Calculation of dryness fraction of steam

P = Pressure of steam in a steam pipe bar

hf_1 = Enthalpy of saturated liquid at P_1, $\dfrac{kJ}{kg}$

t_1 = Temperature of water and vessel before experiment, °C

t_2 = Temperature of water and vessel after the experiment,

hf_2 = Enthalpy of saturated water after mixing at t_2, $\dfrac{kJ}{kg}$.

hfg_1 = Enthalpy of evaporation of steam, $\dfrac{kJ}{kg}$

m_s = Mass of steam condensed. kg

m_w = Mass of water in calorimeter. kg mcal

m_{cal} = Mass of Calorimeter, kg

C_{pw} = Specific heat of water, $\dfrac{kJ}{kg\ K}$

C_{pc} = Specific heat of calorimeter, $\dfrac{kJ}{kg\ K}$

x = Dryness fraction of steam

Heat lost by the steam = Heat gain by water and calorimeter

$$\therefore m_s (h_{f_1} + x h_{fg_1} - h_{f_2}) = m_{cal} C_{pc}(t_2 - t_1) + m_w C_{pw}(t_2 - t_1)$$

$$= (m_{cal} C_{pc} + m_w C_{pw})(t_2 - t_1)$$

$$= \left(\frac{m_{cal} \times C_{pc}}{C_{pw}} + m_w \right)(t_2 - t_1) c_{pw}$$

$(\frac{m_c c_{pc}}{c_{pw}} + m_w)$ is called "water equivalent of the calorimeter.

Dryness fraction of the steam can be calculate from the above equation.

Limitations:

(1) This method is not accurate.

(2) Accuracy decreases as the temperature difference $(T_2 - T_1)$ increases because of the losses are more at higher temperature difference.
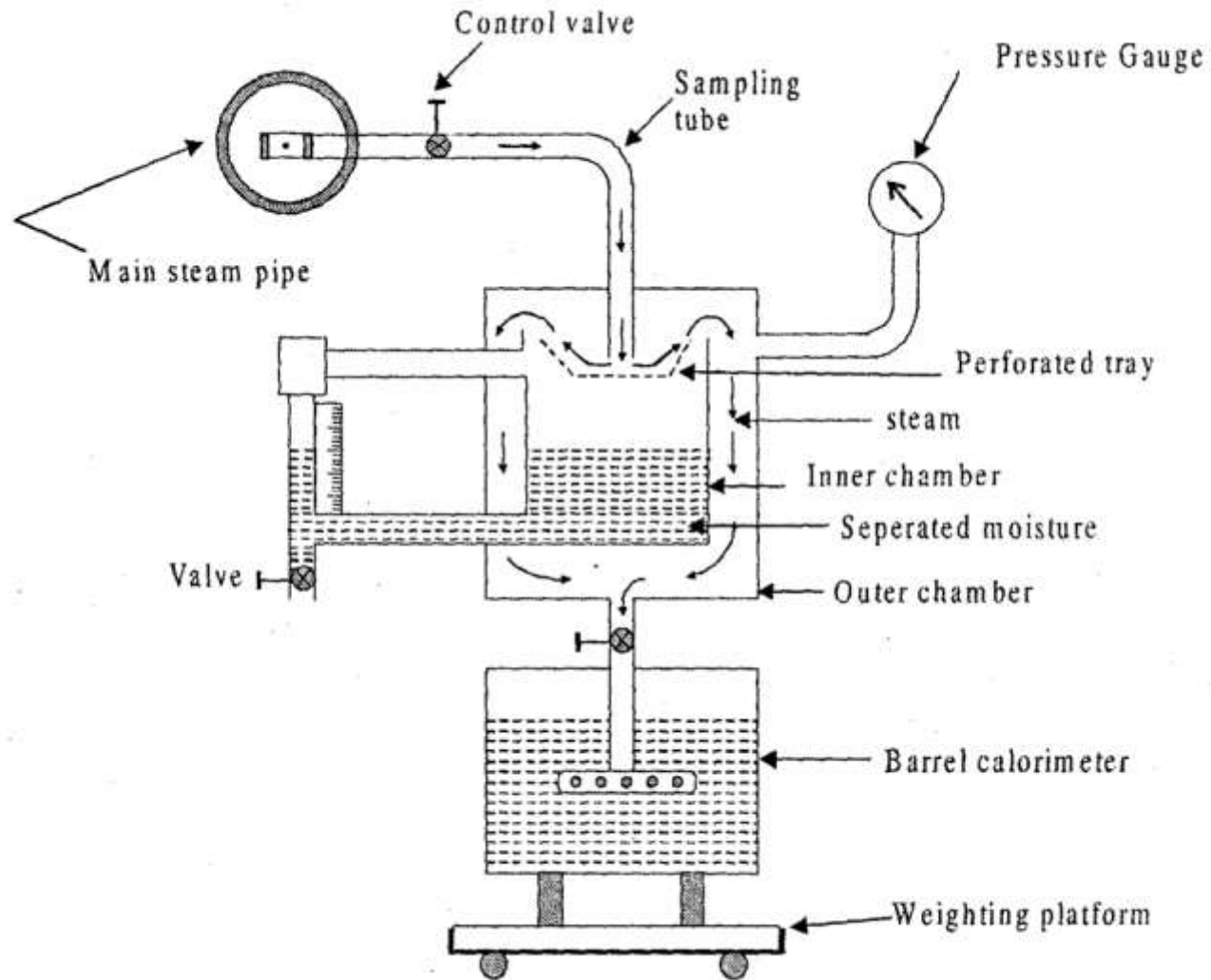
2.Separating Calorimeter:-

Fig. 4.12 Separating Calorimeter.

Construction :

This calorimeter shown in Figure is used for measuring dryness fraction of very wet steam. This calorimeter works on principle of separating the water particles from a sample of steam and finding their mass fraction in the sample.

Separating calorimeter consists of inner chamber and outer chamber. Perforated tray is provided at the top of inner chamber.

Due to inertia of water droplet, wet steam is separated. Separated droplet is collected in inner chamber while steam is condensed in barrel calorimeter.

Control valve and sampling tube performs same functions as that in barrel calorimeter.

Working :

The steam is supplied to the calorimeter from the main steam pipe through a sampling tube.

Entering steam strikes against the perforated tray in the inner vessel of calorimeter.

By centrifugal force and inertia of droplets, the water particles are separated from steam and they are collected in inner chamber.

Dry steam passes through the annular space between inner and outer vessel.

The steam is condensed in barrel calorimeter.

The quantity of steam condensed can be measured by a weighting machine and quantity of water droplet separated can be measure from scale.

(c) Limitations:

This calorimeter gives only approximate value of dryness fraction.
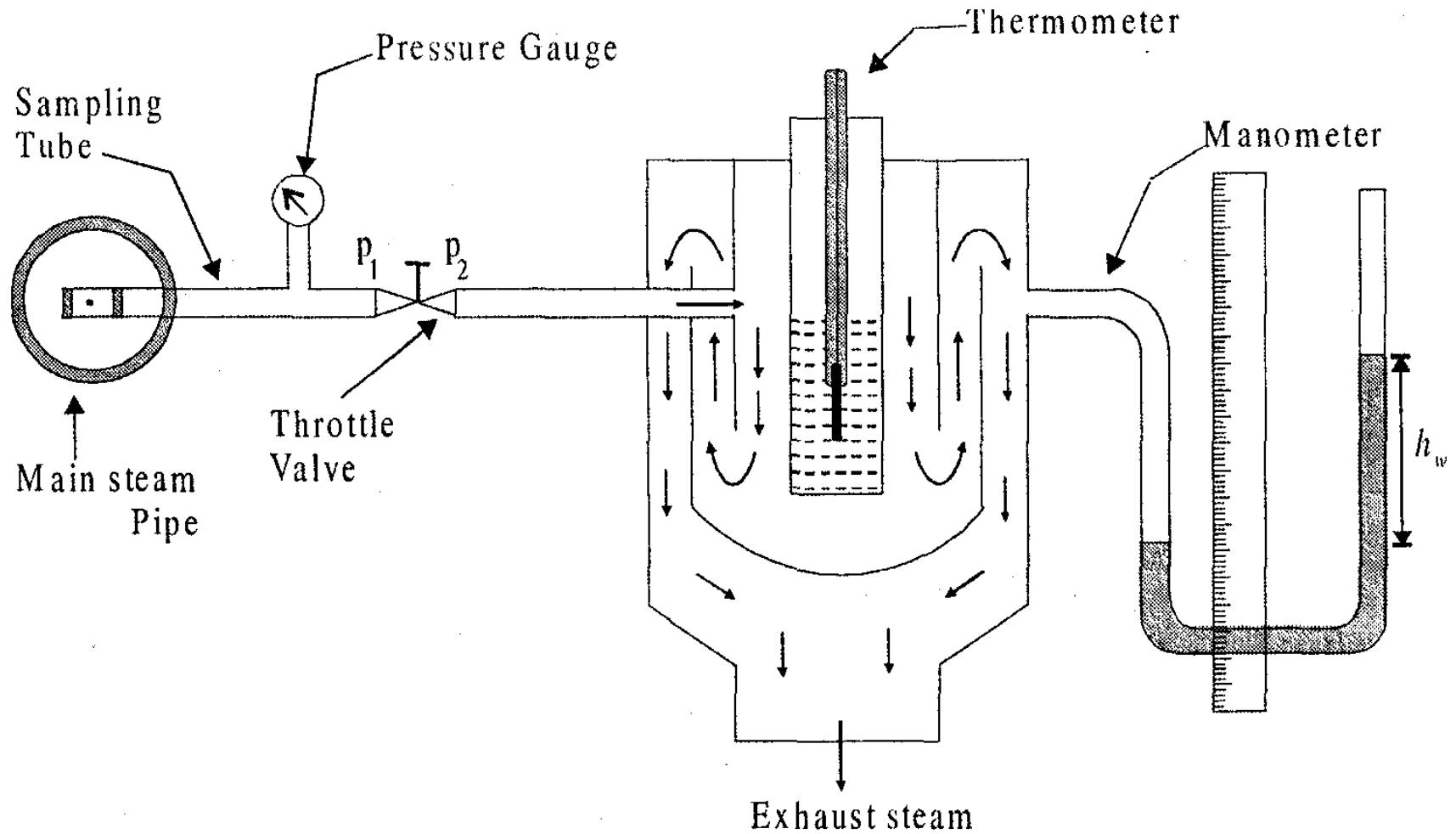
3. Throttling Calorimeter :-

Fig. 4.11 Throttling Calorimeter.

Construction and working :

This calorimeter is shown in Figure is used for finding dryness fraction of steam having very low portion of wet particles i.e. high dryness fraction.

In throttling as explained in Art. 4.8 of (7), total enthalpy remains constant before and after throttling process.

As shown in the figure, the sample of steam at pressure p_1 is taken from the main steam pipe to the throttling calorimeter.

The steam is then passed through the throttle valve where it is throttled to very near atmospheric pressure p_2 The pressure of main steam is measured with the help of pressure gauge before throttling, while the U tube manometer reads the pressure of steam after throttling.

The thermometer reads temperature of steam after throttling.

After this throttling, the steam becomes superheated.

The steam path is shown in Figure.

Calculation of Dryness fraction

P_1 = Pressure of steam before throttling bar

P_2 = Pressure of steam after throttling bar

x = Dryness fraction of steam

h_{fg} = Enthalpy of evaporation at P_1 $\dfrac{kJ}{kg\ K}$

h_{g_2} = Enthalpy of saturated steam at P_2 $\dfrac{kJ}{kg\ K}$

h_w = Height of manometer, mm of water

C_{ps} = Specific heat of super heated steam, $\dfrac{kj}{kg\ K}$

T_{sat} = Saturated temperature of steam at P_2 , K

T_{sup} = Temperature of superheated steam after throttling and it is measure by thermometer.

h_{f_1} & h_{f_2} = Enthalpy of water before and after throttling respectively, $\dfrac{kJ}{kg}$

Enthalpy before throttling = Enthalpy after throttling

Enthalpy at P_1 = Enthalpy at P_2

$$\cdot \; h_{f_1} + x h_{fg_1} = h_{f_2} + h_{fg_2} + C_{ps}(T_{sup} - T_{sat})$$

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

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

(c) Limitations:

(1) This calorimeter is suitable for measurement of higher value of dryness fraction i.e. steam should not be very wet.

(2) After the throttling steam must be at least dry saturated.
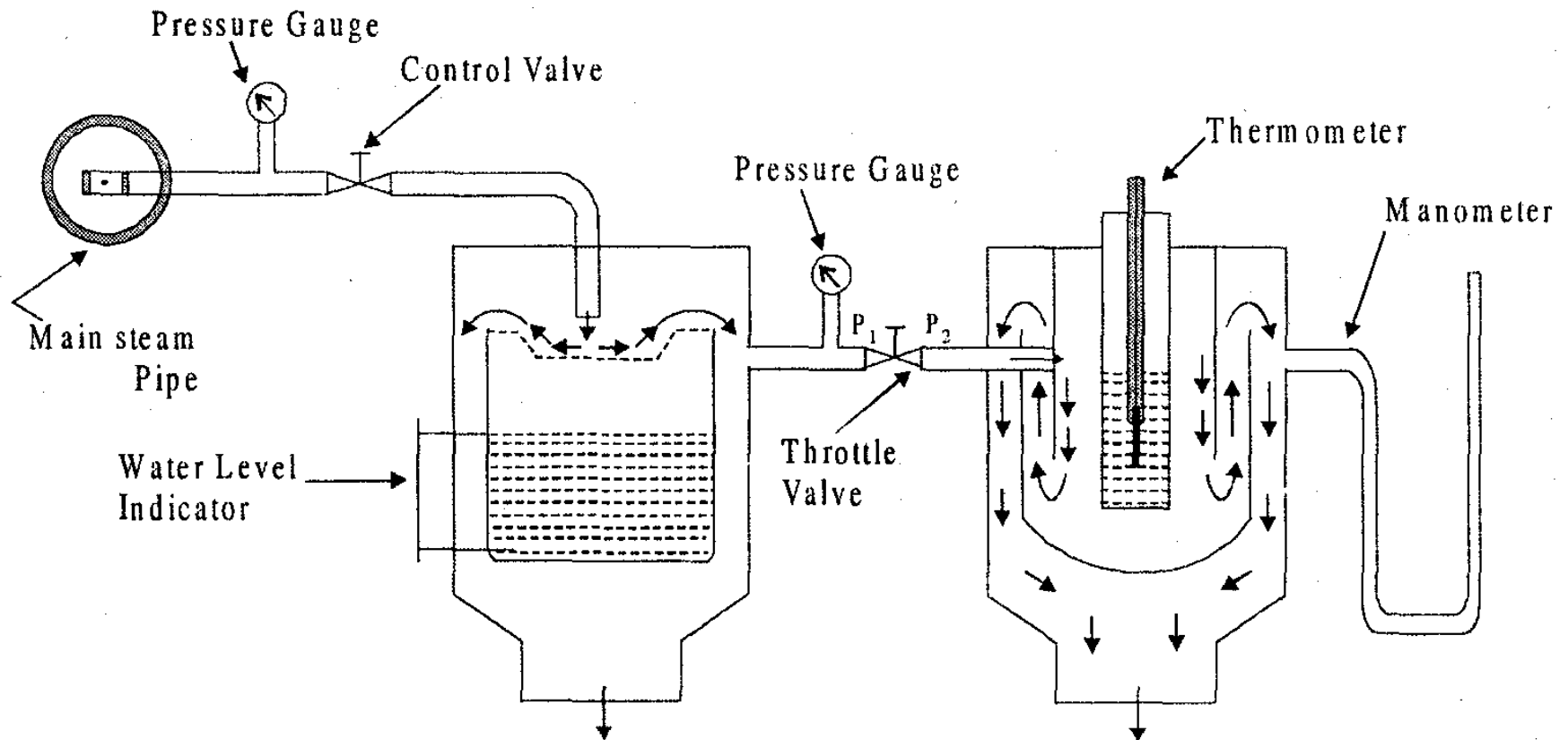
4. Combined Calorimeter:-

Fig. 4.13 Combine Calorimeter

Construction & working:

Separating calorimeter gives only approximate result because of complete separation of moisture by mechanical means is not possible.

Throttling calorimeter is not suitable, if steam is very wet (x >0.9).

Also throttling calorimeter fails if the steam is not superheated after throttling.

A combination of separating and throttling calorimeter is therefore found most suitable for accurate measurement of dryness fraction of steam.

(a) Construction and Working :

Figure shows diagram of combined calorimeter.

In this calorimeter, throttling calorimeter and separating calorimeter are placed in series.

In this calorimeter, steam first passes through separating calorimeter.

In separating calorimeter water particles are separated from wet steam and its dryness fraction (x) increases.

The steam coming from separating calorimeter passes through throttling calorimeter where steam becomes superheated after throttling.

Calculation of dryness fraction:-

x1 is the dryness fraction of the steam measure by separating calorimeter then

$$X_1 = \frac{m}{m+m_1}$$

x2 is the dryness fraction of the steam enters in to throttling calorimeter then x2 can be calculate using the equation

$$h_{f1} + x_2 h_{fg1} = h_{g2} + c_{ps}(T_{sup} - T_{sat})$$

Where h_{f1}, h_{fg1}, h_{g2}, c_{ps}, T_{sup}, T_{sat} has the same meaning as in the case of the throttling calorimeter.

x is the initial dryness fraction of the steam then the original water droplet in the sample is

$(1-x)(m + m_1)$.

From this

$(1-x_1)(m + m_1)$ kg is remove by the separating calorimeter.

$(1-x_2)(m)$ kg is pass through throttling calorimeter.

$(1-x)(m + m_1) = (1-x_1)(m + m_1) + (1-x_2)(m)$

$(1-x) = \dfrac{((1-x_1)(m + m_1) + (1-x_2)(m))}{(m + m_1)}$

$(1-x) = (1 - x_1) + \dfrac{(1-x_2)(m))}{(m + m_1)}$

Now $x_1 = \dfrac{m}{m + m_1}$

So that $1-x = 1 - x_1 + x_1 - x_1 . x_2$

$$X = x_1 . x_2$$

Numericals of Properties of Steam

(1) Calculate the external workdone during the evaporation, internal energy of the steam and internal heat of evaporation for the steam having 10 bar of pressure and the dryness fraction is 0.8.

Solution:

External workdone = ?

Internal energy of the steam = ?

Internal heat of evaporation = ?

P =10 bar , x = 0.8

External work done during the evaporation is equal to p.dv.

Now $dv = x.v_g$

Now at 10 bar of pressure

$v_g = 0.194 \dfrac{m^3}{kg}$

External work done = p.dv

$$= p. \, x.v_g$$

$$= 10 \times 100 \times 0.8 \times 0.194$$

$$= 155.43 \dfrac{kj}{kg}$$

Internal energy of the steam can be calculate by

u = h −pv

So for find out the internal energy we have to find out the enthalpy of the steam at 10 bar pressure with a dryness fraction of 0.8 needs to be calculated. For the wet steam

h = hf + xhfg

At 10 bar of pressure hf = $762.80 \frac{kj}{kg}$

$\qquad$ hfg = $2015.3 \frac{kj}{kg}$

$\qquad$ h = hf + xhfg

$\qquad$ = 762.80 + 0.8x2015.3

$\qquad$ = $2375.04 \frac{kj}{kg}$

u = h − pv

   = 2375.04 − 155.43

   = 2219.61 $\dfrac{kj}{kg}$

Internal heat of the evaporation means change in the internal energy during evaporation.

= u − u_f

Now u_f = h_f − pv_f at 10 bar of pressure.

Now at 10 bar of pressure $v_f = 0.001127 \dfrac{m^3}{kg}$

$u_f = h_f - pv_f$

$\quad = 762.80 - 10 \times 100 \times 0.001127$

$\quad = 761.70 \dfrac{kj}{kg}$

Internal heat of the evaporation $= u - u_f$

$\qquad\qquad\qquad\qquad = 2219.61 - 761.70$

$\qquad\qquad\qquad\qquad = 1457.94 \dfrac{kj}{kg}$

(2) Calculate the enthalpy and internal energy of 1 kg of steam at a pressure of 10 bar and dryness fraction as 0.95.

Solution:

For the wet steam h = h$_f$ + h$_{fg}$

At 10 bar of pressure

h$_f$ = 762.80 $\dfrac{kj}{kg}$

h$_{fg}$ = 2015.3 $\dfrac{kj}{kg}$

$h = h_f + h_{fg}$

$h = 762.80 + 0.95 \times 2015.30$

$\quad = 2677.30 \, \dfrac{kj}{kg}$

Work done during the evaporation

$$= p\,(x.v_g)$$

Now at 10 bar of pressure vg = 0.194 $\dfrac{m^3}{kg}$

So that p (x.v$_g$) = 10 x 100 x 0.95 x 0.194

$$= 184.30\,\dfrac{kj}{kg}$$

Internal Energy u = h – pv

$$= 2677.30 - 184.30$$

$$= 2493 \; \frac{kj}{kg}$$

(3) Find out the external work done during the evaporation and internal energy per kg of the steam at a pressure of 15 bar when steam is having a dryness fraction value is 0.9.

Solution:

At 15 bar pressure

$$h_f = 844.90 \; \frac{kj}{kg}$$

$$h_{fg} = 1947.30 \; \frac{kj}{kg}$$

$$v_g = 0.132 \; \frac{m^3}{kg}$$

External work done during the evaporation

$$= p \times (x.v_g)$$

$$= 1500 \times (0.9 \times 0.132)$$

$$= 178.20 \ \frac{kj}{kg}$$

Now $h = h_f + (x.h_{fg})$ for the wet steam

$$= 844.90 + (0.9 \times 1947.30)$$

$$= 2597.5 \ \frac{kj}{kg}$$

$$u = h - pv$$

$$= 2597.50 - 178.20$$

$$= 2419.30 \ \frac{kj}{kg}$$

(4) 1.5 kg of the steam at a pressure of 10 bar and temperature of 250 °C is expanding until the pressure becomes 2.8 bar. The dryness fraction of the steam is then 0.9. Calculate change in the internal energy.

Solution:

u_1 = specific internal energy at 10 bar 250 °C

u_2 = specific internal energy at 2.8 bar

Dryness fraction $x = 0.9$

T_{sat} at 10 bar pressure = 197.9 ° C

Steam at 250 ° C will be superheat.

At 10 bar h_g = 2778.1 $\dfrac{kj}{kg}$

$$v_g = 0.194 \dfrac{m^3}{kg}$$

Now $h_1 = h_g + C_{ps} (T_{sup} - T_{sat})$ at 10 bar pressure

$$= 2778.1 + 2.1 (250 - 179.90)$$

$$= 2925.30 \dfrac{kj}{kg}$$

Specific volume at state 1 can be calculate as

$$\frac{v_1 (= v_{sup})}{v_g} = \frac{T_{sup}}{T_{sat}}$$

$$v_1 (= v_{sup}) = \frac{T_{sup}}{T_{sat}} \cdot v_g$$

$$v_1 (= v_{sup}) = \frac{250 + 273}{179.90 + 273} \cdot (0.194)$$

$$= 0.224 \frac{m^3}{kg}$$

$u_1 = h_1 - pv_1$

$\quad = 2925.30 - 10 \times 100 \times 0.224$

$\quad = 2701.30 \frac{kj}{kg}$

At 2.8 bar of pressure from steam table

$h_f = 551.40 \dfrac{kj}{kg}$

$h_{fg} = 0.646 \dfrac{kj}{kg}$

$v_g = 0.646 \dfrac{m^3}{kg}$

$h_2 = h_f + x.h_{fg}$

$\quad = 551.40 + 0.9 \times (2170.70)$

$\quad = 2505.0 \dfrac{kj}{kg}$

$u_2 = h_2 - pv_2$

$\quad = h_2 - p \times (x.v_g)$

$\quad = 2505.0 - 2.8 \times (100 \times 0.9 \times 0.646)$

$\quad = 2342.2 \dfrac{kj}{kg}$

Change in the Internal Energy $= U_2 - U_1$

$$= ms\ (u_2 - u_1)$$

$$= -538.70\ Kj$$

Internal energy of the steam is decrease by 538.7 kJ

(5) Calculate the internal energy per kg of superheated steam at 10 bar and a temperature of 300 °C . Find out also change in the internal energy if this steam is expand to 1.4 bar and the dryness fraction value is 0.8.

Solution:

At 10 bar pressure hg = $2778.1 \dfrac{kj}{kg}$

$$\text{Tsat} = 179.9 \text{ °C}$$

$$\text{vg} = 0.194 \dfrac{m^3}{kg}$$

Now h_1 = specific enthalpy of steam at 10 bar and

$\qquad$ 300 °C

$\qquad = h_g + c_{ps} (T_{sup} - T_{sat})$

$\qquad = 2778.1 + 2.1 (300 - 179.9)$

$\qquad = 3030.3 \dfrac{kj}{kg}$

$\quad u_1 = h_1 - p_1 v_1$

Where $v_1 = v_{sup}$

$\qquad$ = specific volume of superheated steam

$$\frac{v_1}{v_g} = \frac{T_{sup}}{T_{sat}}$$

$$V_1 = V_g \cdot \frac{T_{sup}}{T_{sat}}$$

$$= 0.194 \cdot \frac{300 + 273}{179.9 + 273}$$

$$= 0.245 \, \frac{m^3}{kg}$$

$$U_1 = 3030.3 - 10 \times 100 \times 0.245$$

$$= 2785.3 \, \frac{kj}{kg}$$

Now steam is expand to 1.4 bar and x = 0.8

At 1.4 bar $h_f = 458.4 \dfrac{kj}{kg}$

$$h_{fg} = 2232.0 \dfrac{kj}{kg}$$

$$v_g = 1.237 \dfrac{m^3}{kg}$$

h_2 = enthalpy of steam at 1.4 bar and x = 0.8

$h_2 = h_f + h_{fg}$

$\quad = 458.4 + 0.8 \times 2232.0$

$\quad = 2243.90 \dfrac{kj}{kg}$

$v_2 = x \cdot v_g$

$\quad = 0.8 \times 1.237$

$\quad = 0.9896 \, \dfrac{m^3}{kg}$

$u_2 = h_2 - p_2 v_2$

$\quad = 2243.90 - 1.4 \times 100 \times 0.9896$

$\quad = 2105.4 \, \dfrac{kj}{kg}$

Change in the internal energy $= u_2 - u_1$

$\qquad\qquad\qquad\qquad = 2105.40 - 2785.3$

$\qquad\qquad\qquad\qquad = -679.90 \, \dfrac{kj}{kg}$

(6) Combining separating and throttling calorimeter is use to find out dryness fraction of the steam.

Following readings were taken:

Main pressure : 12 bar absolute

Mass of the water collect in separating calorimeter: 2 kg

Mass of the steam condense in throttling calorimeter: 20 kg

Temperature of the steam after throttling: 110° C

Pressure of the steam after throttling: 1 bar absolute

Assume Cp of steam: $2.1 \dfrac{kj}{kg.K}$

Calculate dryness fraction of the steam

Solution:

$$x_1 = \frac{m_S}{m_S + m_W}$$

Here m_s = 20 kg and m_w = 2 kg.

$$x_1 = \frac{m_S}{m_S + m_W} = \frac{20}{20 + 2} = 0.909$$

At 12 bar h_{f1} = 798.60 $\frac{kj}{kg}$, h_{fg1} = 1986.2 $\frac{kj}{kg}$

At 1 bar h_{g2} = 2675.5 $\frac{kj}{kg}$,

T_{sup} = 110°C

T_{sat} = 99°C

For the throttling process

$h_1 = h_2$

Where h_1 and h_2 are the enthalpy of the steam before and after the throttling process

$h_{f1} + x_2 \cdot h_{fg1} = h_{g2} + c_{ps}(T_{sup} - T_{sat})$

$798.6 + x_2 \cdot 1986.2 = 2675.5 + 2.1 \times (110 - 99)$

$x_2 = 0.9566$

Dryness fraction of the steam at inlet to the calorimeter

$x = x_1 \cdot x_2$

$= 0.909 \times 0.9566$

$= 0.8595$

(7) The following information is available from test of
   a combined separating and throttling calorimeter.

(i) Pressure of the steam in a steam main = 9.0 bar

(ii) Pressure after the throttling = 1.0 bar

(iii) Temperature after throttling = 115°C

(iv) Mass of the steam condense after throttling = 1.8kg

(v) Mass of the water collect in the separator = 0.2 kg

Calculate the dryness fraction of the steam in the
main.

Given:

$P_1 = 9$ bar

$m = 1.8$ kg

$P_2 = 1$ bar

$m_1 = 0.2$ kg

$T_2 = 115°C$

$x = ?$

Dryness fraction measure by the separating calorimeter $x_1 = \dfrac{m}{m + m_1}$

$$= \dfrac{1.8}{1.8 + 0.2}$$

$$= 0.9$$

Dryness fraction measured by throttling calorimeter can be calculate by

$h_f + x_2.h_{fg} = h_g + c_{ps} \left(T_{sup} - T_{sat}\right)$

Now from the steam table

At p = 9 bar

$h_f = 742.8 \dfrac{kj}{kg}$, $h_{fg} = 2031.1 \dfrac{kj}{kg}$

At p = 1 bar

$h_g = 2675.5 \dfrac{kj}{kg}$, $T_{sat} = 99°C$

Assuming that cps = $2.1 \dfrac{kj}{kg.K}$

$742.8 + x_2.2031.1 = 2675.5 + 2.1 (115 - 99)$

$x_2 = 0.968$

Dryness fraction of the steam in the main

$x = x_1.x_2$

$= 0.9 \times 0.968$

$= 0.8712$

(8) Determine the enthalpy and the internal energy of 1 kg of the steam at a pressure of 10 bar absolute pressure.

 (i) When the dryness fraction of the steam is 0.85.

 (ii) When the steam is dry and saturated

 (iii)When the steam is superheated to 300°C.

Neglecting the volume of the water and take the Cps as $2.1 \dfrac{kj}{kg.K}$.

Solution:

(i) P = 10 bar and x = 0.85

At 10 bar pressure

h_f = 762.80 $\frac{kj}{kg}$, h_{fg} = 2015.3 $\frac{kj}{kg}$

v_g = 0.194 $\frac{m^3}{kg}$, h_g = 2778.1 $\frac{kj}{kg}$

h = h_f + x.h_{fg}

  = 762.80 + 0.85 x 2015.3

  = 2475.81 $\frac{kj}{kg}$

$u = h - pv$

$\quad = h - p(x.v_g)$

$\quad = 2475.81 - 10 \text{ x } 100 \text{ x } 0.85 \text{ x } 0.194$

$\quad = 2310.91 \, \dfrac{kj}{kg}$

(ii) Dry and Saturated steam

$$h = h_g = 2778.1 \, \frac{kj}{kg}$$

$u = u_g$

$\quad = h_g - pv_g$

$\quad = 2778.1 - 10 \times 100 \times 0.194$

$$\quad = 2584.1 \, \frac{kj}{kg}$$

(iii) P = 10 bar and T = 300° C

At 10 bar pressure Tsat = 179.9°C

h = hg + cps (Tsup − Tsat)

$\quad$ = 2778.1 + 2.1 (300 − 179.9)

$\quad$ = 3030.3 $\frac{kj}{kg}$

$$\frac{v_{sup}}{v_{sat}} = \frac{T_{sup}}{T_{sat}}$$

$$\frac{v_{sup}}{v_{sat}} = \frac{T_{sup}}{T_{sat}}$$

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

$$= \frac{573}{452.9} \cdot 0.194$$

$$= 0.246 \frac{m^3}{kg}$$

$$u = h - pv$$

$$= 3030.3 - 10 \times 100 \times 0.246$$

$$= 2784.3 \frac{kj}{kg}$$

(9) What amount of heat would be required to product 5 kg of steam at a pressure of 5 bar and temperature of 250°C from water at 30°C.

Take c_{ps} = 2.1 $\dfrac{kj}{kg.K}$

Given :

m_s = 5 kg

P = 5 bar

T_i = 250°C

T_f = 30°C

C_{ps} = 2.1 $\dfrac{kj}{kg.K}$

C_{pw} = 4.187 $\dfrac{kj}{kg.K}$

h_1 = enthalpy of the water at 30°C

$\quad$ = 4.187 x 30

$\quad$ = 125.61 $\dfrac{kj}{kg}$

At 5 bar pressure

T_{sat} = 151.90°C

So that at 250 °C steam will be superheated.

h_2 = enthalpy of the steam at 5 bar and 250°C

$h_2 = h_g + c_{ps} \left(T_{sup} - T_{sat}\right)$

$\quad$ = 2748.7 + 2.1 (250 − 151.90)

$\quad$ = 2954.71 $\dfrac{kj}{kg}$

Amount of the heat required to produce 5 kg of the steam will be

$= m_s (h_2 - h_1)$

$= 5 \times (2954.71 - 125.61)$

$= 14145.5 \text{ kj}$

(10) How much of the heat is required to convert 3 kg 0f water at 30°C in to steam at 8 bar and 210 °C ? Take specific heat of superheated steam as $2.1 \dfrac{kj}{kg.K}$ and that of water as $4.186 \dfrac{kj}{kg.K}$.

Given:-

ms = 3 kg

Tf = 30°C

P = 8 bar

Ti = 210 °C

Cps = 2.1 $\frac{kj}{kg.K}$

Cpw = 4.186 $\frac{kj}{kg.K}$

h1 = enthalpy of the water at 30°C

= 4.186 x 30

= 125.58 $\frac{kj}{kg}$

At 8 bar Tsat = 170.4°C

So at 210°C steam will be superheated.

h2 = enthalpy of the steam at 8 bar and 210°C

= hg + cps (Tsup – Tsat)

= 2769.1 + 2.1 (210 – 170.4)

= 2852.26 $\frac{kj}{kg}$

Amount of heat required to be added to convert 3 kg of water at 30°C in to steam at 8 bar and 210°C

$$= m_s (h_2 - h_1)$$

$$= 3 (2852.2 - 125.58)$$

$$= 8180.04 \text{ kj}$$