FORMATION OF STEAM AND ITS PROPERTIES

22.1 Introduction

Steam, which is gaseous form of pure water, is an excellent working medium in various thermodynamic systems because of its following properties:

1) It can carry large quantities of heat

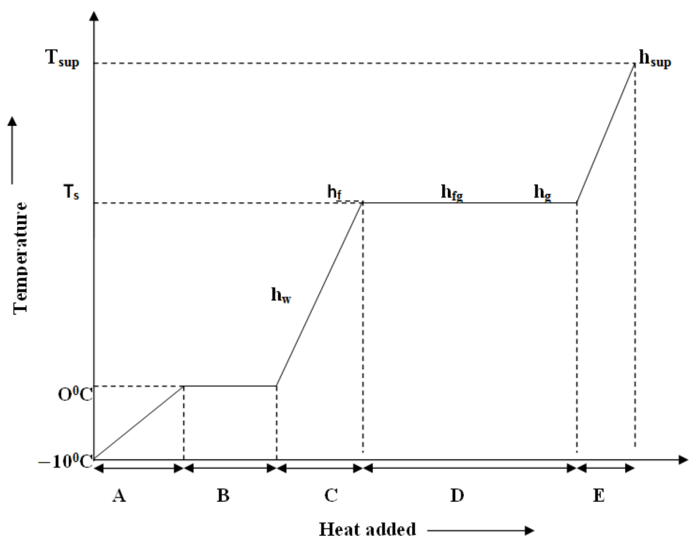
2) It is produced from water which is cheap and readily available

3) It can be used for heating purposes after its duty as working agent is completed.

4) It can be used purely as a heating medium in food processing Industries because of a fast, easily controllable and hygienic method of heating.

Formation of Steam

In general, steam can be formed by boiling water in a vessel. But to use it effectively as a working or heating medium, it has to produce in a closed vessel under pressure. Steam formed at a higher pressure has higher temperature and can be made to flow easily through insulated pipes from steam generator to point of use. A simple arrangement of formation of steam at constant pressure is shown in **Fig. 22.1**.



A = Sensible Heat taken by Ice

B= Latent Heat of Fusion

C = Sensible Heat taken by Water

D = Latent Heat of evaporation

E = Sensible Heat taken by Steam

h_w = Specific enthalpy of water

h_f = Specific enthalpy of saturated water

h_{fg} = Latent heat of evaporation

h_g = Specific enthalpy of dry saturated steam

h_{sup} = Specific enthalpy of super heated steam

Fig. 22.2 Temperature enthalpy curve of formation of steam at constant pressure

Consider 1 kg of ice at temperature -10^{0}C which is below the freezing point. Let it be heated at constant pressure P. The temperature of ice starts increasing until it reaches the melting temperature of ice i.e., 0^{0}C and during this course ice absorbs its sensible heat. On further addition of heat, ice starts melting, its temperature remains constant at 0^{0}C and it absorbs latent heat of fusion and converts completely into water at 0^{0}C.

On further addition of heat, the temperature of water starts rising until it reaches the boiling temperature or saturation temperature corresponding to pressure P. This heat absorbed by water in sensible heat.

Note: Saturation temperature or boiling temperature increases with increase in pressure

After the boiling temperature is reached, it remains constant with further addition of heat and vaporization take place. The water absorbs its latent heat and converts into dry saturated steam remaining at same saturation temperature. The intermediate stage of water and dry saturated steam is wet steam, which is actually a mixture of steam and water.

If further the heat is added, the temperature of this dry saturated steam starts rising from saturation temperature and it converts into superheated steam. This heat absorbed is again the sensible heat. The total rise in temperature of superheated steam above the saturation temperature is called degree of superheat. We must know here that the saturation temperature, latent heat and other properties of steam remain same at constant pressure but varies with the variation of pressure.

Advantages of superheated steam

1) The superheated steam can be considerably cooled during expansion in an engine cylinder, before its temperature falls so low as to cause condensation on cylinder walls which is a direct heat loss.

2) The temperature of superheated steam being higher, it gives a high thermal efficiency in heat engine.

3) It has high heat content and so high capacity of doing work. Thus it results in an economy in steam consumption.

Enthalpy of Steam

To find out the total heat content or enthalpy of any state of water/ steam we have to add all types of heat added i.e., sensible and latent to convert the water to that state starting from some initial state or datum which is assumed as a zero enthalpy point or where the heat content is taken as zero. Generally in engineering calculations the datum is water at 0^0C where it is considered as having zero heat content or zero enthalpy. Enthalpy of one kg of water or steam is called as specific enthalpy.

Specific enthalpy of un-saturated water (h_w)

It is simply the amount of heat required to raise the temperature of one kg of water from 0 ℃ to its actual temperature which is below its saturation temperature. It can be calculated by multiplying actual temperature of unsaturated water with its specific heat which is considered equal to 4.187 kJ/ kg/ K. It is denoted as h_w.

So, $h_w = C_w.t$

Wheret is the temperature of water in ^oC

Note: If water is present at a temperature below its boiling point or saturation temperature, it is called unsaturated water. If water is present at its boiling point i.e. saturation temperature, it is called saturated water.

Specific enthalpy of saturated water (h_f)

It is the quantity of heat required to raise the temperature of one kg of water at 0^0C to its boiling point or saturation temperature corresponding to the pressure applied. It is denoted as h_f. It can be calculated by multiplying the specific heat of water to the total rise in temperature. The specific heat Cp_w of water may be approximately taken as constant i.e., 4.187 kJ/kg K, but in actual it slightly increases with increase in saturation temperature or pressure. Thus

$h_f = C_w\ (t_s$ � $0) = C_p t_s$

Where, t_s = Saturation temperature

Latent heat of steam (h_{fg})

Latent heat of steam at a particular pressure may be defined as the quantity of heat in kJ required to convert one kg of water at its boiling point (saturated water) into dry saturated steam at the same pressure. It is usually denoted by L or h_{fg}. It decreases with increase in pressure or saturation temperature.

Wet and dry steam

Wet steam is that steam in which the whole of water has not vaporized but the un-vapourized water is present in the form of mist/fog suspended in completely vaporized water or steam. Due to this mist the wet steam is visible. However the dry steam i.e., in which the vaporization is complete is invisible or colorless. Any steam which is completely dry and present at saturation temperature is called dry saturated steam.

Dryness fraction

This term refers to quality of wet steam. It is defined as the ratio of the weight of dry steam actually presents to the weight of total wet steam which contains it. It is denoted by x. Thus

$$x = \frac{W_d}{W_d + W}$$

Where W_d = Weight of dry steam in 1 kg of wet steam,

W = Weight of water in suspension in 1 kg of wet steam

Dryness fraction is zero for saturated water and one for dry saturated steam.

Wetness fraction

It is the ratio of the weight of water/ moisture in suspension in a wet steam sample to the total weight of wet steam. It is calculated by subtracting x from 1

$$i.e\ wetness\ fraction, (1 - x) = \frac{W}{W_d + W}$$

Wetness fraction is 1 for saturated water and 0 for dry saturated steam.

Specific enthalpy of wet steam (h_{ws})

It may be defined as the quantity of heat required to convert 1 kg of water at 0^0C into wet steam of a given quality and at constant pressure. It may be denoted by h_{ws}. It is equal to the sum of specific enthalpy of saturated water and latent heat of dry fraction of steam. So

$$h_{ws} = h_f + x.\, h_{fg}$$

Specific enthalpy of dry saturated steam (h_g)

It may be defined as the quantity of heat required to convert 1kg of water at 0^0C into dry saturated steam at given constant pressure. It may be denoted by h_g. It is equal to the sum of specific enthalpy of saturated water and latent heat corresponding to given saturation pressure and temperature. Thus

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

Specific enthalpy of superheated steam (h_{sup})

It is defined as the quantity of heat required to convert 1kg of water at 0^0C into the superheated steam at given temperature and pressure. It may be denoted as h_{sup} and is equal to the sum of specific enthalpy of dry saturated steam and product of specific heat of superheated steam (C_s) to degree of superheat.

$$h_{sup} = h_g + C_s(t_{sup} - t_s)$$

Where, h_g and t_s are the specific enthalpy of dry steam and saturation temperature at corresponding pressure and C_S & t_{sup} are specific heat of superheated steam and temperature of superheated steam at the same pressure.

$$C_S = \frac{h_{sup} - h_g}{t_s - t}$$

The superheated steam behave like the perfect gas and law of expansion has been found to be $pv^{1.3}$ = constant.

Specific Volume of Water/Steam

The volume of a unit mass of water/steam is known as its specific volume

Specific volume of saturated water (v_f)

It is defined as volume of 1kg of water at saturation temperature corresponding to the given pressure. It is denoted by v_f. It can be calculated experimentally. It slightly increases with increase in saturation temperature and hence the pressure. The reciprocal of sp-volume is equal to density.

Specific volume of dry saturated steam (v_g)

It is defined as volume of 1kg of dry saturated steam corresponding to the given pressure. It is denoted by v_g and can be calculated experimentally. As dry saturated steam is a gas, its specific volume decreases with increase in pressure or the saturation temperature.

Specific volume of wet steam of quantity x

It is the volume of 1kg of wet steam and is denoted as

$$v_{ws} = x.v_g + (1-x)\, v_f$$

At low pressure the value of v_f is very small as compared to v_g; so the term $(1-x)\, v_f$ may be neglected. Then volume of 1kg of wet steam = $x.v_g$

Specific volume of Superheated Steam (v_{sup})

It is the volume of 1kg of superheated steam and can be determined by assuming that the steam behaves as a perfect gas i.e., obeys the gas laws. It is denoted by v_{sup}

Let P = pressure under which steam is superheated.

t_{sup} =temperature of superheated steam

v_g = Specific volume of dry saturated steam

t_s = saturation temperature at pressure P.

Since, P = constant, so

$$\frac{v_g}{t_s} = \frac{v_{sup}}{t_{sup}} \text{ or } v_{sup} = v_g . \frac{t_{sup}}{t_s}$$

Entropy of Steam

Specific entropy of saturated water (s_f)

The specific entropy of saturated water at a particular pressure P and saturation temperature T_s is given as the change in entropy during conversion of one kg of water at 0^0C into saturated water at that pressure. The water at freezing point 0^0C or 273 K is considered as datum where, absolute entropy is taken as zero. If C_W is specific heat of water then the change in entropy of 1kg water during temperature change from 273 K to T K is given as

$$s_w = C_W \log_e \frac{T}{273}$$

As the Initial entropy at 273 K is zero, so this change in entropy above 273 K is taken as entropy of water at temperature T. In case of Saturated Water, $T = T_S$.

$$So, specific\ entropy\ of\ saturated\ water, s_f = C_w \log_e \frac{T_s}{273}$$

Change in specific entropy during evaporation, (s_{fg})

During evaporation heat added = h_{fg} = Latent heat of water

Temperature remains constant during evaporation and is equal to saturation Temperature T_S.

$$So \quad S_{fg} = \frac{h_{fg}}{T_s}$$

Specific entropy of dry saturated steam (s_g)

It is the entropy of one kg of dry saturated steam and is given as the sum of entropy of 1kg of saturated water and entropy change during evaporation. It is denoted by s_g.

Thus $s_g = s_f + s_{fg}$

Specific entropy of wet steam

Specific entropy of wet steam is equal to sum of specific entropy of saturated water and change in specific entropy during evaporation of dry fraction of steam. It is denoted by s_{ws}

$$s_{ws} = s_f + x.\ s_{fg}$$

Specific entropy of superheated steam (s_{sup})

It is the sum of specific entropy of dry saturated steam and entropy change during superheating from saturation temp T_S to superheated temp T_{sup}.

Change in entropy during superheating

$$= C_{sup} \log_e \frac{T_{sup}}{T_s} \quad where, C_{sup} = Sp.heat\ of\ super\ heated\ steam$$

Total specific entropy of superheated steam

$$s_{sup} = s_g + c_{sup} \log_e \frac{T_{sup}}{T_s}$$

$$= s_f + \frac{h_{fg}}{T_s} + C_{sup} \log_e \frac{T_{sup}}{T_s}$$