Steam and Its Properties

Definition and Introduction

Steam is the gaseous phase of water. It utilizes heat during the process and carries large quantities of heat later. Hence, it could be used as a working substance for heat engines. Steam is generated in boilers at constant pressure. Generally, steam may be obtained starting from ice or straight away from the water by adding heat to it. Steam exists in following states or types or conditions.

(i) Wet steam (saturated steam)
(ii) Dry steam (dry saturated steam)
(iii) Superheated steam
(iv) Supersaturated steam water, which is one of the Pure Substance, exists in three phases:

(i) Solid phase as ice (freezing of water)
(ii) Liquid phase as water (melting of ice)
(iii) Gaseous phase as steam (vaporization of water)

Water could be used as coolant and water vapor is used as a working fluid for the operation of Steam Engines and Steam Turbines.

Formation of Steam

temperature-Enthalpy Diagram t-h diagram)
The graphical representation of transformation of 1 kg of ice into 1 kg of superheated steam at constant pressure (temperature vs. enthalpy) is known as t-h diagram. shows the various stages of formation of steam starting from ice shows the correspomding t-h diagram.

(a) Consider 1 kg of ice in a pistion -cylinder arrangement as shown. it is under an Absolute Pressure say P bar and at temperature –t 0 C (below the freezing point). Keeping the pressure constant, the gradual heating of the ice leads to note the following changes in it, These are represented on a t-h diagram on heating, the temperature of the ice will gradually rises from p to Q i.e from – t C till reaches the freezing temperature 0.
(b) Adding more heat, the ice starts melting without changing in the temperature till the entire ice is converted into water from Q to R. The amount of heat during this period from Q to R is called Latent heat of fusion of ice or simply Latent heat of ice.
(c) Continuous heating raises the temperature to its boiling point t C known as Saturation Temperature. The corresponding pressure is called saturation pressure. it is the stage of vaporization at 1.01325 bar atmospheric pressure (760mm of hg at 100'C). As pressure increases, the value of saturation temperature also increases. The amount of heat added during R to S is called Sensible Heat or Enthalpy of Saturated Water or Total Heat of Water (h, or h "'). During the process, a slight increase in volume of water (saturated water) may be noted. The resulting volume is known as Specific volume of Saturated Water (Vf or vW).
(d) On further heating beyond S, the water will gradually starts evaporate and starts convert it to steam, but the temperature remains constant. As long as the steam is in contact with water, it is called Wet Steam or Saturated Steam.
(e) On further heating the temperature remains constant, but the entire water converts to steam. But still it will be wet steam. The total heat supplied from $O^{O}C$ is called Enthalpy of Wet Steam (h wet). The resulting volume is known as Specific Volume of Wet Steam (v wet)
(f) On further heating the wet steam, the water particles, which are in suspension, will start evaporating gradually and at a particular moment the final particles just evaporates. The steam at that moment corresponding to point T is called Dry Steam or Dry Saturated Steam. The resulting volume is known as Specific Volume of Dry Steam (vg). This steam not obeys the gas laws. The amount of heat added during S to T is called Latent Heat of Vaporization of Steam or Latent Heat of Steam (hfg). During the process, the saturation temperature remains constant. The total heat supplied from O'C is called Enthalpy of Dry Steam (hg).
(g) On further heating beyond point T to U the temperature starts from ts to tu, the point of interest. This process is called Super heating. The steam so obtained is called Super Heated Steam. It obeys gas laws

(Boyle's Law and Charle's Law) to some extent by behaving like a prefect gas. The resulting temperature from T to U (tu. – ts) is called Degree of Superheat. The amount of heat supplied during T to U is called Heat of Superheat = C P (tu - ts), where Cp is the mean specific heat of the Superheated steam. It is given in Steam Tables as Cp = 2.25 kJ/kgK. The Total heat supplied from OOC is called enthalpy of Superheated Steam (hu). The resulting volume is known as Specific Volume of Superheated Steam (vu).

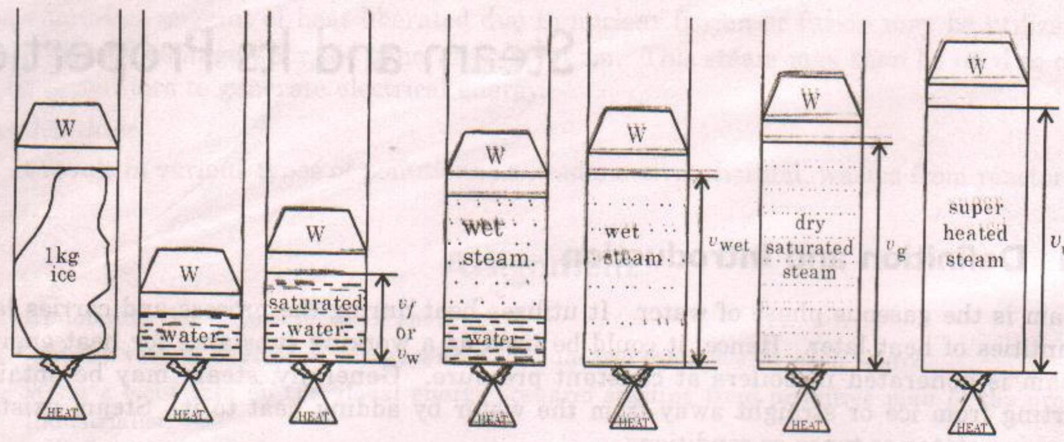

Fig 2.1 *Formation of Steam at Constant Pressure*

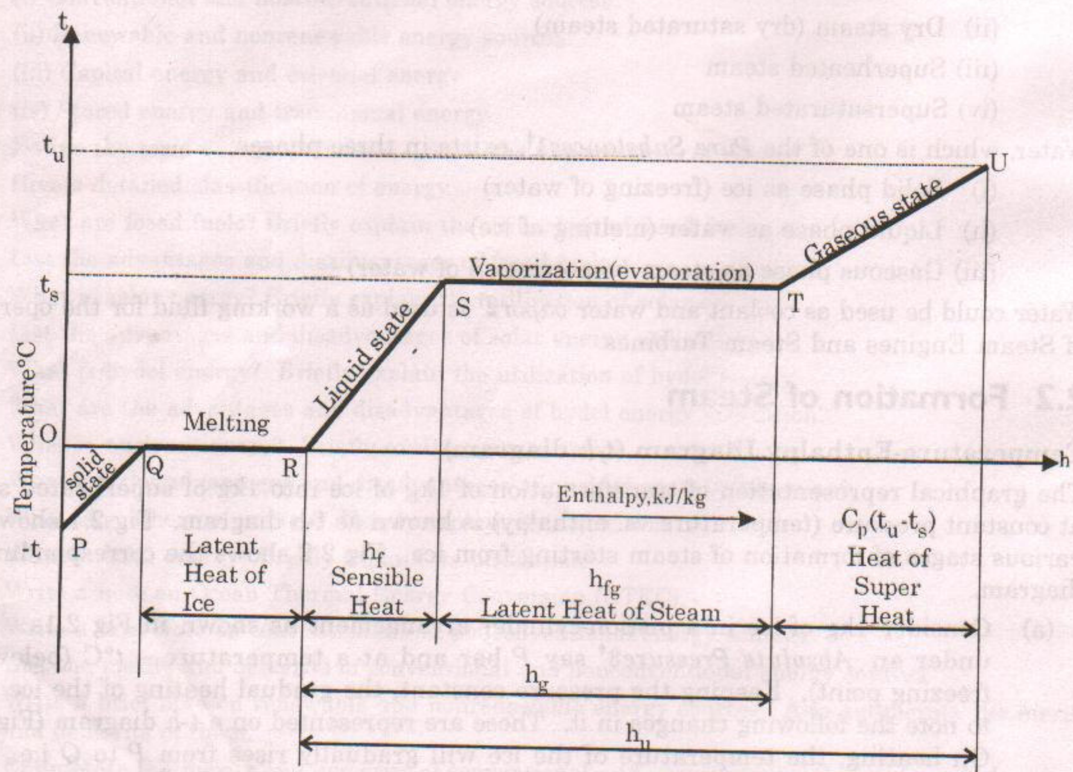

Fig 2.2 *Temperature-Enthalpy Diagram of Formation of Steam at Constant Pressure*

Dryness Fraction of Saturated Steam (x or q)

It is a measure of quality of wet steam. It is the ratio of the mass of dry steam (mg) to the mass of total wet steam (mg +mf), where mf is the mass of water vapor.

X= mg
mg + mf

Quality of Steam

It is the representation of dryness fraction in percentage: Quality of Steam = x X 100

Wetness Fraction

It is another measure of quality of wet steam. It is the ratio of the mass of water vapor (mf) to the mass of total wet steam (mg +mf)

Wetness fraction in mf = (1-x)
mg +mf

Priming

It is the representation of wetness fraction in percentage.
Priming = (I - x) 100
Note: Quality + Priming = 100%

Density of Steam (p), kg/m3

It is the mass of steam per unit of volume of steam at the given pressure and temperature. It is the reciprocal of the specific volume.

P= 1/v

Internal (True) Latent Heat (internal Energy of Steam) (U), kj/kg

It is the energy required to change the phase. Hence, it is the actual heat energy stored in the steam above O'C. It may be calculated by subtracting the external work of evaporation from the enthalpy. U=h-E

External Work of Evaporation (E), kj/kg

It is the fraction of the latent heat of vaporization which does an external work in moving the piston at constant pressure due to increase in volume.

Enthalpy (h), kj/kg

It is the total amount of heat received by 1 kg of water from O"C at constant pressure to convert it to desired form of steam. It is the sum of the internal energy and work done at constant pressure process, which is equal to change in enthalpy.

Let U Internal energy, dU = Change in internal energy
h Enthalpy (heat received), A = Change in enthalpy
Q Heat supplied, dQ = Change in heat supplied
P Pressure, dP = Change in pressure
v Volume, du = Change in volume
Then by definition Enthalpy Internal energy + Work done
h = U + PV

From 1st Law of thermodynamics, dQ = dU + d(Pv)
= dU + V dP + P dv
= dU + d(Pv) - v dP
= d (U + Pu) - v dP
since, for a constant pressure process, dP = 0
dQ = d(U + Pv)

Advantages of Superheated Steam

(h) At a given pressure, its capacity to do the work will be comparatively higher.
(i) It improves the thermal efficiency of boilers and prime movers
(j) It is economical and prevents condensation in case of Steam turbines

Disadvantages of Superheated Steam

(i) Rise in Superheated temperature poses problems in lubrication
(ii) Initial cost is more and depreciation is higher

Constant Pressure Thermodynamic Process of Steam

If the wet steam is heated at constant pressure, its dryness fraction changes from x, to During the process the temperature remains constant (Isothermal) till it becomes dry saturated. It may be represented by a horizontal line AB on p-v diagram

Hence Isothermal and constant pressure Processes are identical. The adiabatic expansion of wet steam follows the curve CD. A B. The law for such expansion is approximately pV1.3 = constant. Once the steam becomes saturated, the further heating will not be isothermal. Hence as soon as the steam becomes superheated it behaves like a perfect gas and will follow hyperbolic law (PV = constant) at constant temperature. Hence isothermal and hyperbolic processes are identical for superheated steam.

Steam Tables

It is the compilation of experimental results of the thermodynamic properties (viz specific volume, internal energy, sensible heat, latent heat, saturation temperature etc.) of 1 kg of steam in a tabular column. These are available either on pressure basis or on temperature basis. These tables are useful for steam engineering calculations, as vapors do not obey gas laws. The pressures in the steam tables are in bar (absolute). In case of gauge pressures, they must be converted in to absolute pressure by adding atmospheric pressure to them. All the values given in the steam tables are reckoned above O*C. If the initial temperature of water is other than O'C, the enthalpy of steam will be calculated from the steam tables by deducting the amount of heat contained initially by the water.

Super Saturated Steam

The steam having lesser temperature and greater density with respect to the steam table values for a particular saturation pressure is called super saturated steam. This condition is obtained when it is cooled by its own expansion in a nozzle. but it is very unstable and the steam soon resumes the saturated condition.