PROPERTIES OF STEAM

- **Steam:**
- **Vapour form of water is called steam.**

- **Water is one of the pure substances which can exist in three different phases namely,**
- **In solid phase as ice,**
- **In liquid phase as water,**
- **In gaseous phase as steam.**

In all the three phases it retains the same chemical composition.

Application of steam

- Food processing industry.
- Used as a working fluid in steam engines and steam turbines.
- Used in industries for process heating.
- Washing/sterilizing in hospitals.
- Health clinics / gym.

FORMATION OF STEAM EXPERIMENT

(Constant Pressure)

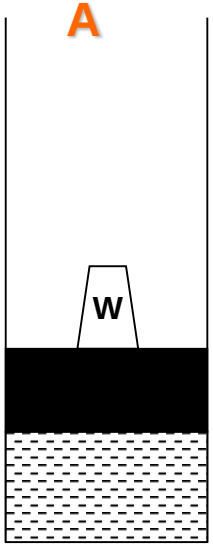


Fig. 1

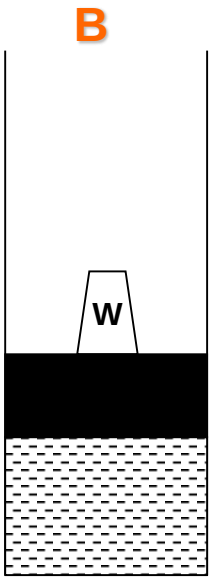


Fig. 2

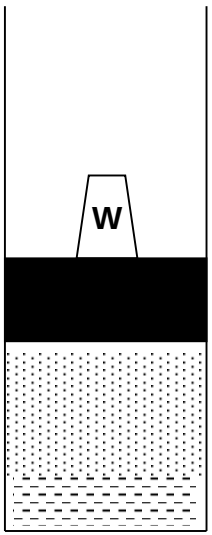


Fig. 3

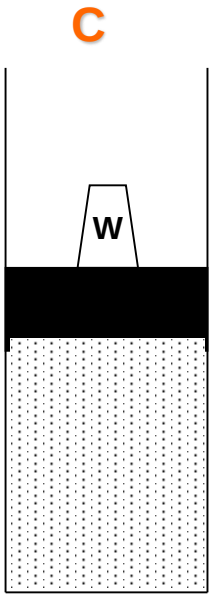


Fig. 4

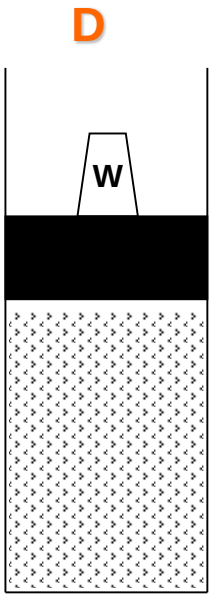
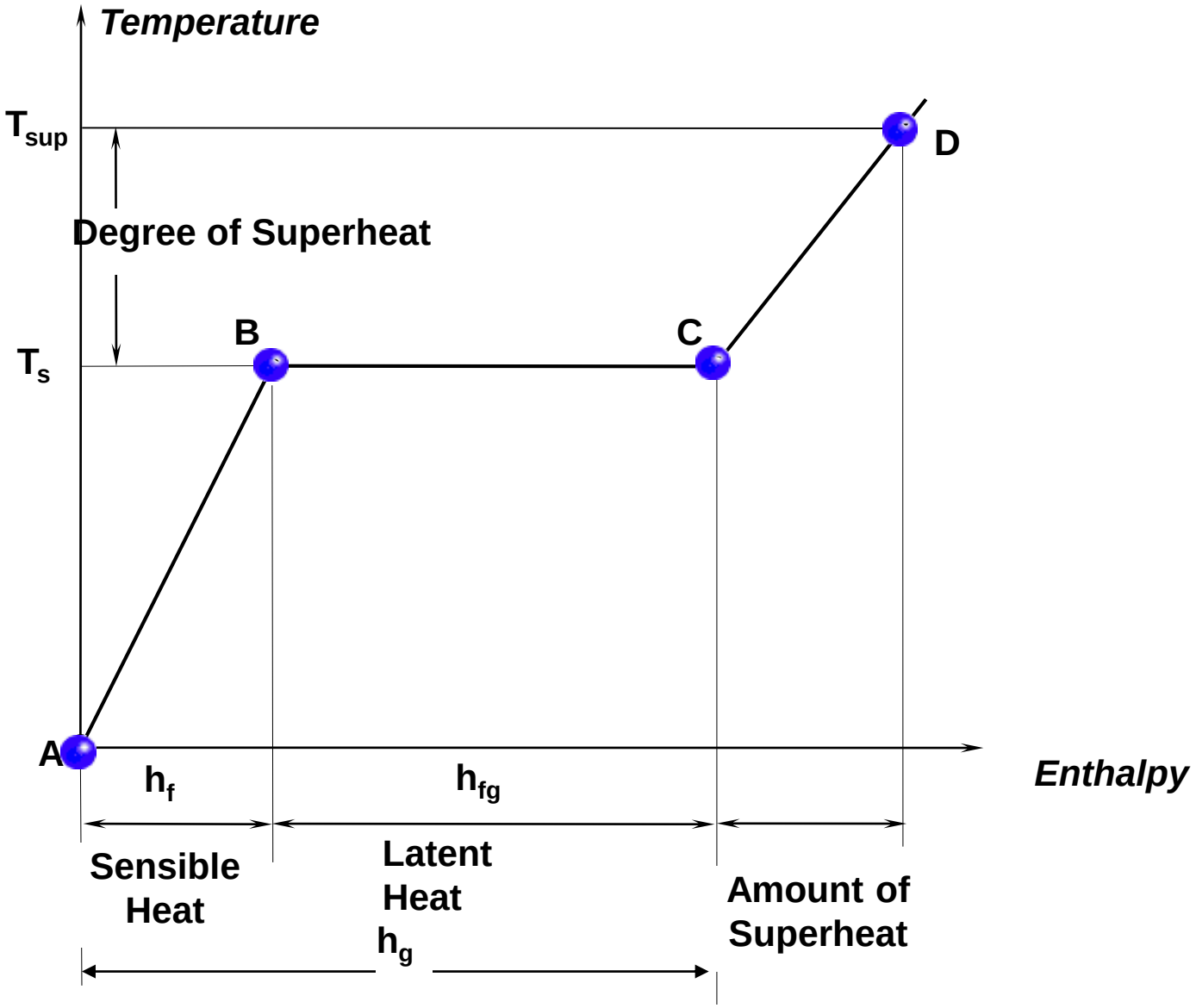
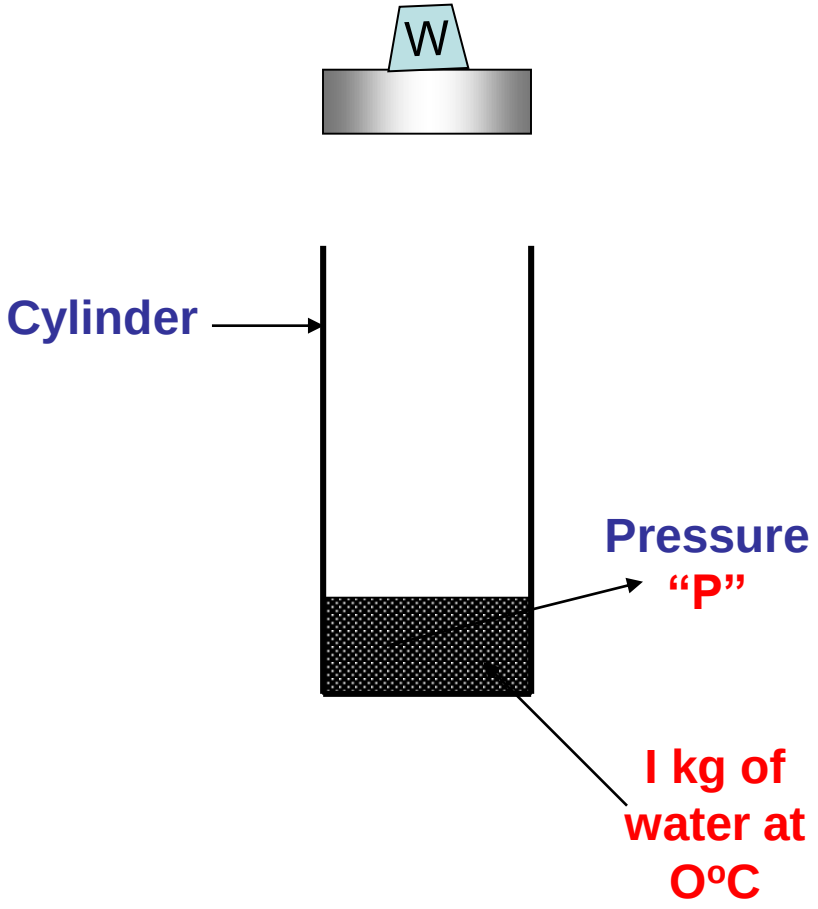


Fig. 5


Temperature
T_{sup}
D
Degree of Superheat
B
C
T_s
A
h_f
h_{fg}
Enthalpy
Sensible Heat
Latent Heat
h_g
Amount of Superheat

Consider 1 kg of water at 0°C taken in a cylinder fitted with a freely moving frictionless piston as shown in figure.



The initial condition of water at 0^{o}C is represented by the point "*A*" on the Temperature – Enthalpy graph

Definitions

- ***Saturation temperature(T_{sat}):*** *It is defined as the temperature at which the water begins to boil at the stated pressure.*

- ***Sensible heat (h_f):*** It is the amount of heat required to raise the temperature of 1 kg of water from 0^0C to the saturation temperature $T_{sat}{}^0$C at a given constant pressure.

- ***Enthalpy of Water :***

$$h_w = m\, C_p\, (T-0)\ kJ/kg$$

Where, m = Mass of water in kg.

C_p = Specific heat of water

= 4.187 kJ/kg K

T= Temperature of feed water in ^oC

- *Latent heat (h_{fg}): (Enthalpy of evaporation)*

  It is the amount of heat required to evaporate 1 kg of water at the saturation temperature in to 1 kg of dry steam at the same saturation temperature at a given constant pressure.

- Superheated temperature (T_{sup}):

  It is the temperature of the steam above the saturation temperature at a given constant pressure.

- *Amount of superheat (AOS): (Enthalpy of superheat)*

  It is the amount of heat required to increase the temperature of 1 kg of dry steam from its saturation temperature to any desired higher temperature at the given constant pressure.

- *Degree of superheat (DOS):*

  It is the difference between the superheated temperature and the saturation temperature.

Different states of steam

The steam as it is being generated can exist in *three* different states,

1. ***Wet steam***
2. ***Dry steam***
3. ***Superheated steam***

Wet Steam:

A wet steam is defined as a two-phase mixture of finely divided water particles and dry steam in thermal equilibrium at the saturation temperature corresponding to a given stated pressure.

- The quality of wet steam is specified by the **dryness fraction** which indicates the amount of dry steam present in the given quantity of wet steam and is denoted as "**x**".

- The dryness fraction of a steam is defined as the ratio of mass of the actual dry steam present in a known quantity of wet steam to the total mass of the wet steam.

$$\text{Dryness fraction, } x = \frac{\text{Mass of Dry Steam present in Wet Steam}}{\text{Total Mass of Wet Steam}}$$

Let,

m_g = Mass of dry steam present in the sample quantity of wet steam

m_f = Mass of suspended water molecules in the sample quantity of wet steam

$$x = \frac{m_g}{m_f + m_g}$$

The dryness fraction of wet steam is always less than 1.

The dryness fraction of dry steam is equal to 1.

Dry Saturated Steam: (Dry steam)

It defined as the saturated steam at the saturation temperature corresponding to a given pressure and having no water molecules entrained in it.

Superheated Steam:

A superheated steam is defined as the steam which is heated to temperature higher than its saturated temperature at the given pressure.

Advantages of Superheated Steam

- **High Energy Content:** Superheated steam possess higher energy compared to dry saturated steam or wet steam at the same pressure, hence its capacity to do the work will be higher.

- **Minimising Chances of Corrosion:** Superheated steam doesn't create any problems like rusting or corrosion of turbine blades / engine cylinder.

Advantages of Superheated Steam:

- **Utilisation of waste energy** : When superheating is done by the exhausting combustion gases in a boiler, there will be a saving of the energy of combustion thereby improving the thermal efficiency of the boiler. Hence superheating does not require extra energy

Disadvantages of Superheated Steam

- **Difficulty in Lubrication: The** high temperature of superheated steam poses problems in lubrication. The lubricant may get burnt at that high temperature.

- **Additional Cost**: Additional cost of Super heater thereby increasing initial investment.

Enthalpy equations

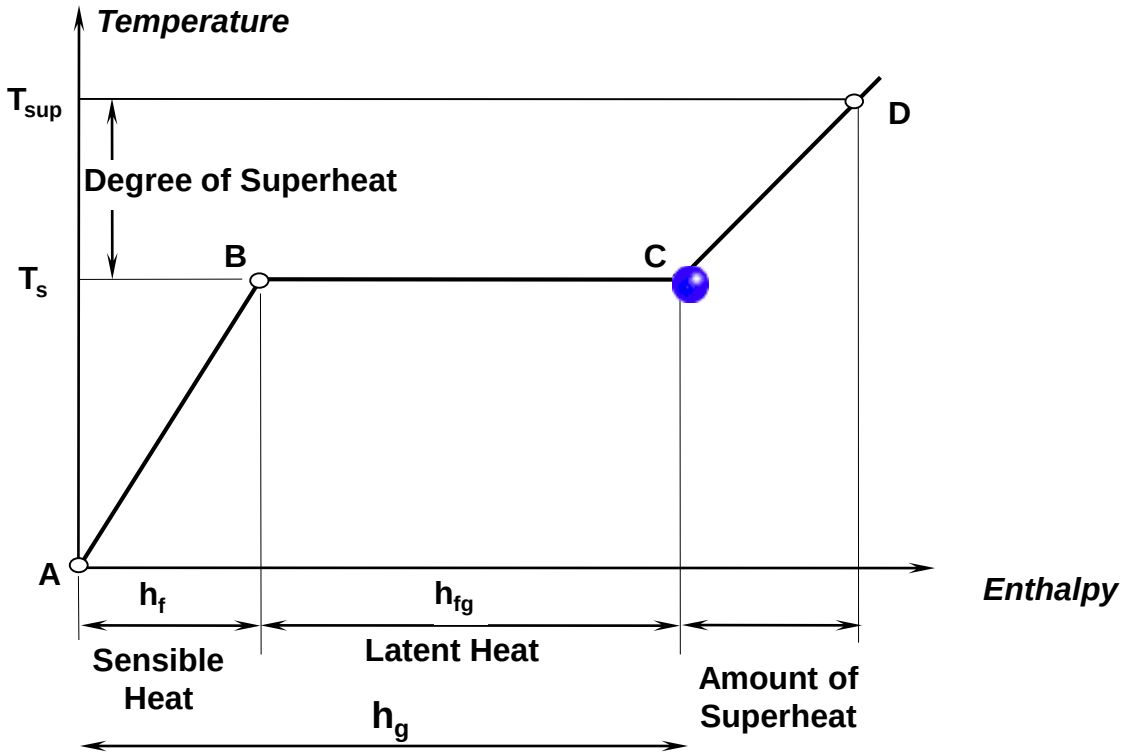
a) Enthalpy of Dry saturated Steam (h_g):

$$h_g = h_f + h_{fg} \quad \text{kJ/kg}$$

Where h_g = Enthalpy of dry steam in kJ/kg.

h_f = Sensible heat in kJ/kg.

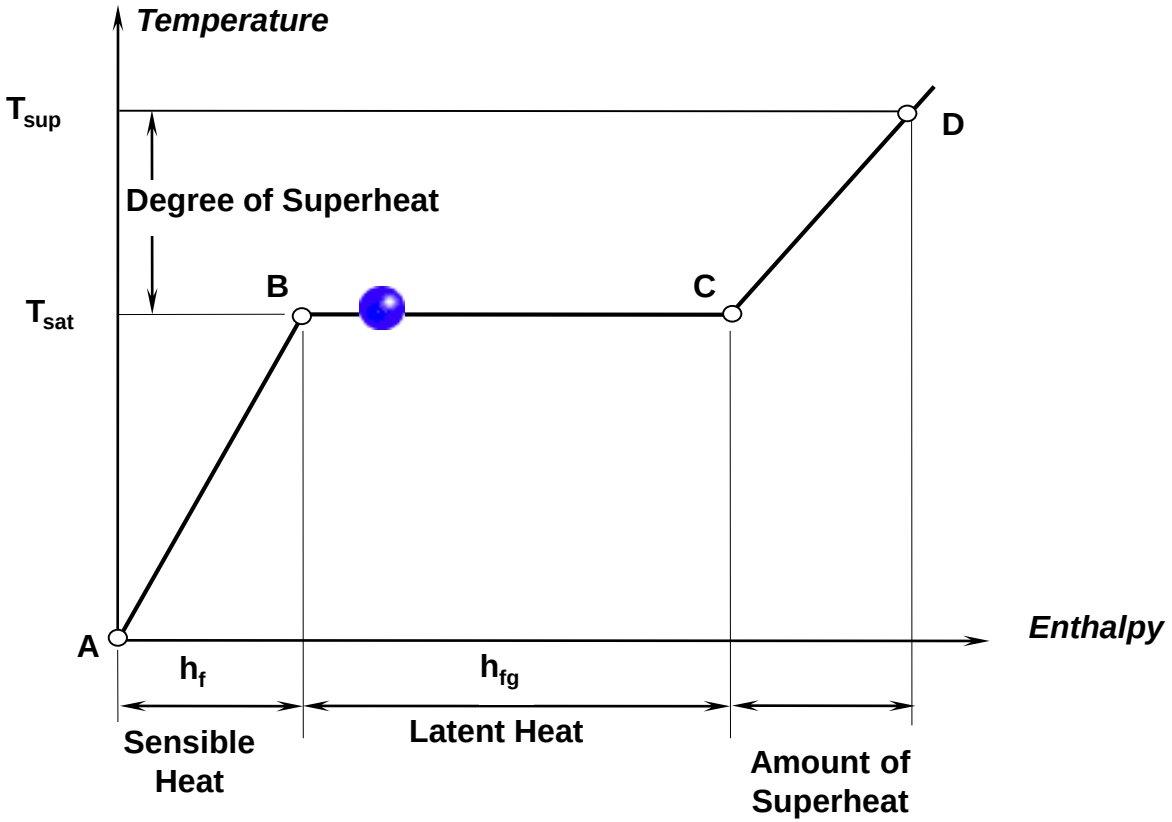
h_{fg} = Enthalpy of evaporation or latent heat in kJ/kg.



b) Enthalpy of Wet Steam (h):

$$h = h_f + x \, . h_{fg} \quad \text{kJ/kg}$$

Where x = Dryness fraction of wet steam 0<x<1



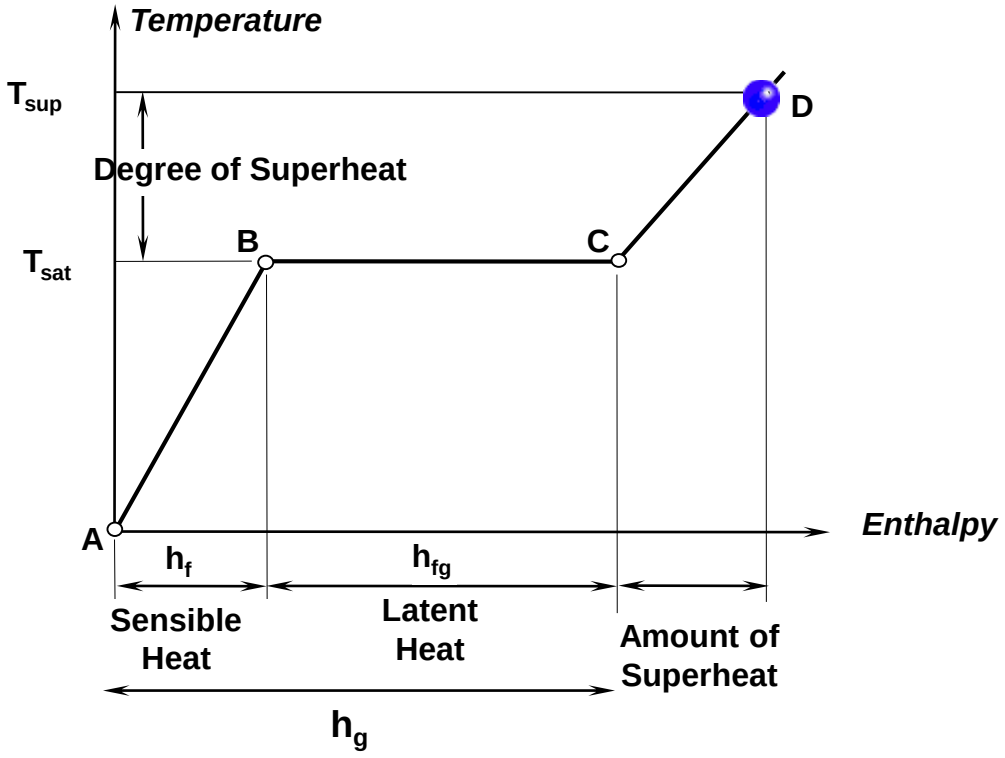
c) Enthalpy of Superheated Steam (h_{sup}):

$$h_{sup} = h_f + h_{fg} + C_{sup}\,(T_{sup} - T_{sat})\ \text{kJ/kg}$$

where h_{sup} = Enthalpy of superheated steam in kJ/kg

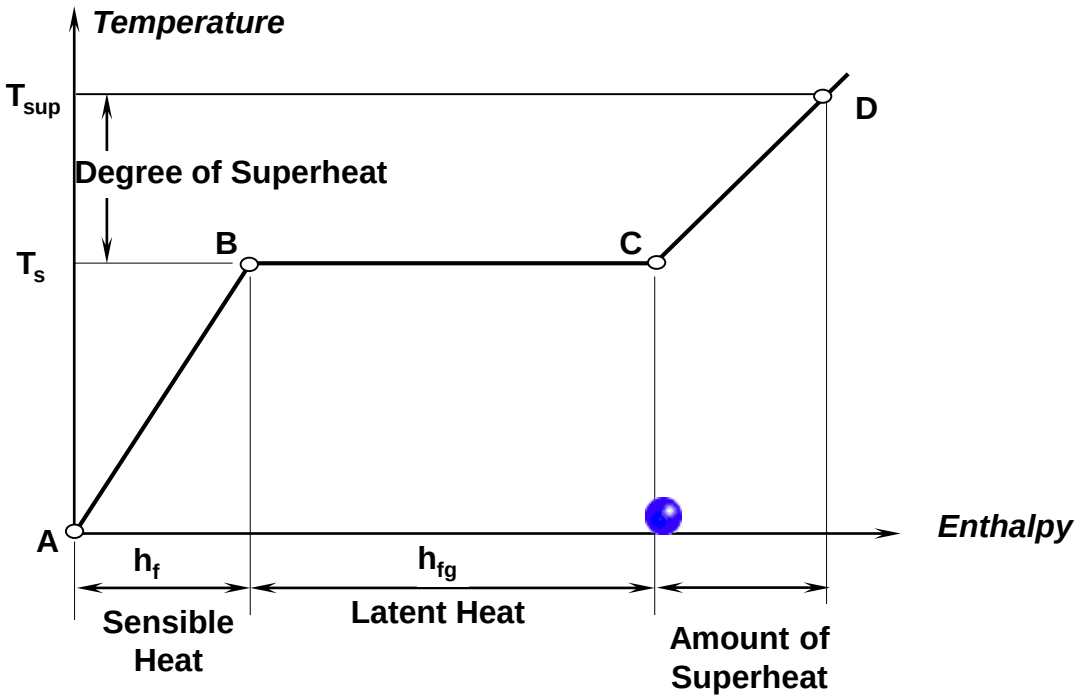
C_{sup} = Specific heat of superheated steam =2.25 kJ/kg K

T_{sup} = Superheated temperature in °C & T_{sat} = Saturation temperature in °C



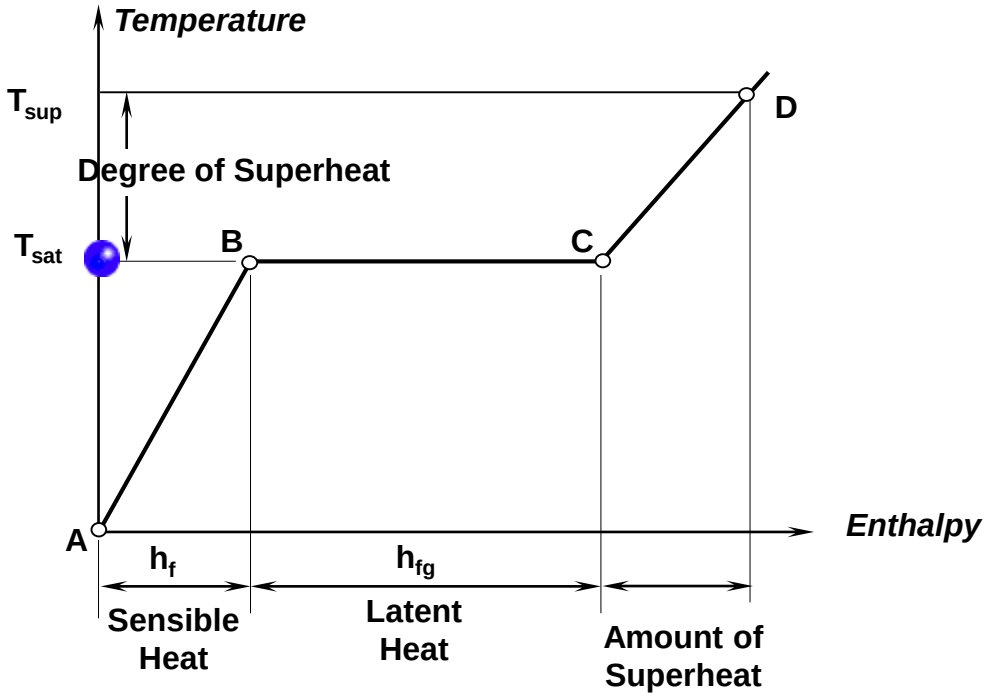
d) Amount of superheat (AOS): (Enthalpy of superheat)

$$AOS = C_{sup}\,(T_{sup} - T_{sat})\ \text{kJ/kg}$$



e) Degree of superheat (DOS):

$$DOS = (T_{sup} - T_{sat})\ ^{0}C$$



a) Enthalpy of Dry saturated Steam:

$$h_g = h_f + h_{fg} \quad \text{kJ/kg}$$

b) Enthalpy of Wet Steam:

$$h = h_f + x \, . h_{fg} \quad \text{kJ/kg}$$

c) Enthalpy of Superheated Steam:

$$h_{sup} = h_f + h_{fg} + C_{sup} (T_{sup} - T_{sat}) \quad \text{kJ/kg}$$

d) Degree of superheat (DOS):

$$DOS = (T_{sup} - T_{sat}) \quad {}^{0}C$$

e) Amount of superheat (AOS):

$$AOS = C_{sup} (T_{sup} - T_{sat}) \quad \text{kJ/kg}$$

f) Boiler Efficiency

- Boiler efficiency is defined as the ratio of heat energy utilized from the boiler to the heat energy supplied to the boiler.

f) Boiler Efficiency

$$\eta = \frac{Q(h_s - h_w) * 100}{m_{fu} * GCV}$$

Where

Q= Quantity of steam generated per unit time(kg/hr.)

hs = Enthalpy of steam generated (kJ/kg)

hw = Enthalpy of feed water (kJ/kg)

mfu = Quantity of fuel consumed per unit time(kg/hr.)

GCV= Gross calorific value of the fuel (kJ/kg)

NUMERICALS ON PROPERTIES OF STEAM

1) Determine the condition and related parameter of the steam in the following cases: (i) Pressure of 10 bar and temperature of 200ºC and (ii) Pressure of 8 bar and enthalpy of 2500kJ/kg. (iii) Steam at 20bar and 300ºC is cooled at constant pressure during which the heat lost is 400kJ/kg. Assume specific heat of superheated steam as 2.25kJ/Kg K.

2) 2 Kg of water at 30ºC is heated at a constant pressure of 5 bar. The total amount of heat added is 500 KJ. Determine the condition and related parameter of water after heat addition. Assume specific heat of water as 4.187kJ/Kg K.

3) 10 Kg. of steam at a pressure of 1.15 MPa and temperature of 250°C loses 27578.2 kJ of heat at constant pressure. Determine the resulting temperature? Assume specific heat of water and superheated steam as 4.187 kJ/kg K and 2.25 kJ/kg K respectively.

4) Two boilers one with super heater and another without super heater are delivering equal quantities of steam into a common main. The pressure in the boiler and in the main is 20 bar. The temperature of the steam from a boiler with a superheater is 350ºC and the temperature of steam in the main is 250ºC. Determine the quality of steam supplied by the other boiler. Assume specific heat of superheated steam as 2.25kJ/Kg K.

5) A dry saturated steam at a pressure of 1 MPa is generated in a boiler. Dry saturated steam leaves the boiler to enter a super heater, where it loses heat equal to 400 kJ/kg. In the super heater, steam is super-heated to temperature of 300ºC. If temperature of feed water is 28ºC, determine:

a) Total heat supplied to feed water in the boiler

b) Dryness fraction of steam at the entry of super heater

c)Total heat supplied in the super heater.

Assume specific heat of water as 4.187kJ/Kg K and that of superheated steam as 2.25kJ/Kg K

6) 600 kg of 10% wet steam at a pressure of 16bar is generated in a boiler per hour. Steam leaves the boiler to enter a super heater. Steam loses heat equal to 300 kJ/kg before entering the super heater. In the super heater, steam is superheated to temperature of 375^0 C. If temperature of feed water is 40^0 C, determine

i) Total heat supplied to feed water per hour to produce wet steam in the boiler.

ii) Total heat absorbed per hour in the super heater.

Assume specific heat of water as 4.187kJ/Kg K and that of superheated steam as 2.25kJ/Kg K

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7) A chemical company planning to install a coal fired boiler in its plant for process heating is weighing different technical options due to investment constraints. The steam generation capacity required is 5000kg per hour at a pressure of 0.56MPa and at a temperature of 220ºC. The feed water is available from a nearby reservoir at an average temperature 30ºC. The coal consumption is 1500 kg/hr, having a calorific value of 24MJ/kg. Assess the improvement in boiler efficiency if the following accessories are used.

i) Economizer which will increase the feed water temperature by 58ºC.and reduce the coal consumption by 14%.

ii) Air Preheater which will reduce the coal consumption by 20%.

iii) Both Economizer and Air Preheater whose combined effect will reduce the coal consumption by 30%.

Assume specific heat of water and superheated steam as 4.187kJ/kg K and 2.25kJ/kg k respectively

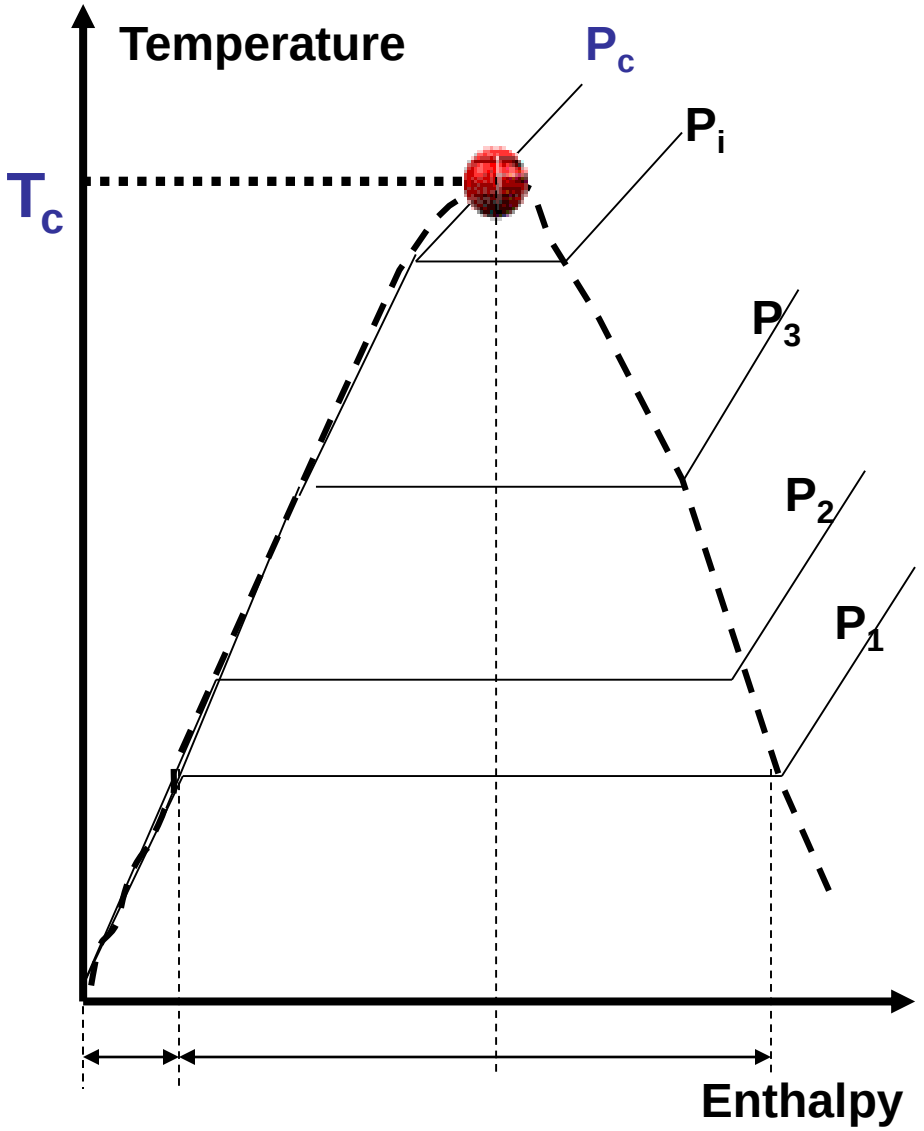
8) A restaurant, daily uses 600 kg of 95% dry steam produced at a pressure of 3bar. The boiler is fitted with an economizer which increases the feed water temperature to 94º C and is fired using wood and paddy husk in equal proportions. The gross calorific values of wood and paddy husk are15500kJ/kg and 12600 kJ/kg respectively. The boiler has been operating with an average efficiency of 78%. Calculate the daily consumption of wood and paddy husk?

Critical Temperature & Pressure.

At a particular pressure water is directly converted into dry steam without going through the phase of evaporation. i.e., $h_{fg} = 0$. This point is called critical point.

$P_c = 221.2$ bar

$T_c = 374.15^0C$



- **Critical pressure:**

  It is the pressure at which the water is directly converted into dry steam without undergoing the phase of evaporation.

- **Critical temperature:**

  It is the corresponding temperature at the critical point.