UNIT - 1

Syllabus:

Introduction to Energy Systems: concept of heat and work, Steam formation, Types of steam, Steam properties. Introduction to boilers, working of Babcock and Wilcox boiler.

Concept of Heat and Work:

Thermodynamics deals with systems on the boundaries of which there are heat and work interactions. The word 'heat' in thermodynamics simply means heat transfer, whereas the term 'heat-content' of a body means internal energy which is defined as the sum of all the microscopic forms of energy of a system.

• The internal energy is a property although heat is not a property because a body contains energy, but not heat. Therefore, heat is energy in transition. A hot metallic body contains energy, but this energy is called heat when it passes through the outer surface of the body (system boundary) to the surrounding.

• Heat transfer is the science that deals with energy transfer from one system to another or within a system or from a system to its surroundings by virtue of temperature difference between them. Temperature is known to be the measure of hotness and coldness.

• Thermodynamics, on the other hand, deals with systems in equilibrium and may be used to predict the amount of energy required to change a system from one equilibrium state to another. It may not be used to find how fast this change will take place since the system is not in equilibrium during the process.

• According to the first law of thermodynamics, during an interaction between a system and its surroundings, the amount of energy lost by a system equals to the amount of energy gained by the surroundings. It deals with conservation of energy, that is, energy can be transformed from one form to another.

• Heat transfer supplements the first and second laws of thermodynamics by providing additional rules, which may be used to estimate the rate and mode of heat energy transfer that will take place under certain specified conditions.

Engineering Heat Transfer

• Heat transfer is widely applied in many branches of Science and Engineering. It plays an important role in the design and performance of equipments employed in the power and process industries, automobiles, refrigeration and air conditioning plants, electrical and electronic appliances which in turn determine their feasibility and cost.

• The dimensions of boilers, refrigerators, heaters and heat exchangers depend upon both the amount and rate of heat to be transferred. Operation of turbine blades, combustion chamber of engines, transformers, computers and several electronic devices depend mainly on the rate of cooling. Also, heat transfer analysis is done to avoid overheating and damage of such equipment's.

• Modern electric and electronic plants require efficient dissipation of thermal energy. The miniaturization of electronic systems, from the level of toys to high power computers and automated machines, has caused a drastic increase in the amount of heat generation comparable in magnitude to that in a nuclear reactor. There failure rate increases drastically with temperature.

• Problems related to heat transfer during high speed flows in case of aircrafts, rockets, missiles and satellites are of great concern as this results in extreme rise in the viscous stresses or friction that raise temperature of the surface. A thorough heat transfer analysis is most important for the proper sizing of fuel elements in the nuclear reactor cores to prevent burnout. The utilization of solar energy, which is abundantly available, also requires knowledge of heat transfer and fluid flow for proper design of the related equipment's.

Modes of Heat Transfer

There are three modes of heat transfer, namely conduction, convection and radiation.

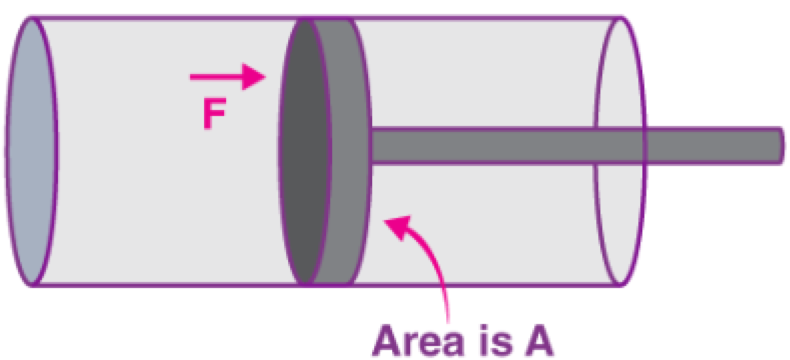
Conduction: Conduction is the energy transfer from a region of high temperature to a region of low temperature which may be within a medium or between media when in direct physical contact. That is, the energy in case of conduction is transmitted by direct molecular communication without appreciable displacement of the molecules.

Convection: Convection is the energy transfer that takes place in fluids by the combined action of heat conduction, energy storage and mixing motion. When a fluid flows past a stationary solid surface, the fluid particles touching the surface come to rest, while the adjacent fluid particles away from the surface try to move with a little higher velocity until they again reach the free stream value at some distance from the solid surface. Thus, the transfer of energy from a solid surface to the surrounding fluid that has experienced change in velocity near the surface first takes place by conduction.

Radiation: Radiation is the energy transfer from a body at higher temperature to a body at a lower temperature when they are separated in space. The space in between the bodies may be some transmitting medium or a vacuum. The term radiation is generally referred to all kinds of electromagnetic wave phenomena. But, the radiation exchange which are as a result of temperature and transfer through a media or space, come under heat transfer.

Work Done by a System

Similar to the quantities heat and internal energy, there is another term known as work that is associated with the transfer of energy. Suppose a piston contains gas. If the piston moves outwards, we say work is done by the gas and it is positive. Similarly, if it moves inwards, work is done on the gas and it is negative. Let's take the following figure:



Properties of Steam

Water exists in 3 phases. It exists as ice in the solid phase, exists as water in liquid phase and exists as steam in gaseous phase. The change of phase occurs when either heat is taken out of water or heat is supplied to water. The steam is formed when heat is supplied to water beyond its boiling point.

The steam can be formed in two processes:

1. Constant volume process: Place where area (volume) is restricted. Ex: pressure cooker.

2. Constant pressure process: Place where pressure acting on the water is fixed. Ex: Open vessel like a cylinder, with a piston where piston is free to move.

Formation of Steam at Constant Pressure

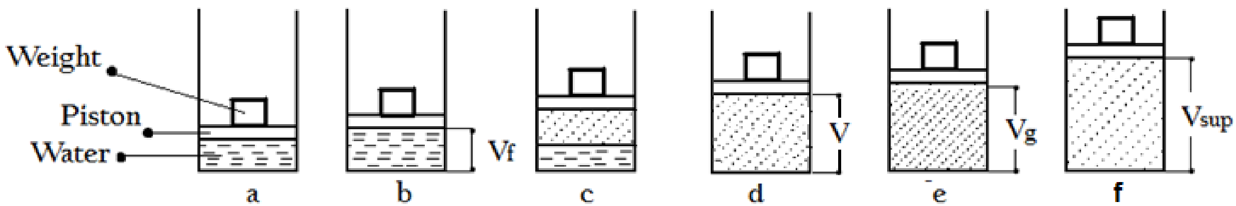


Fig 1.1 Formation of steam at constant pressure

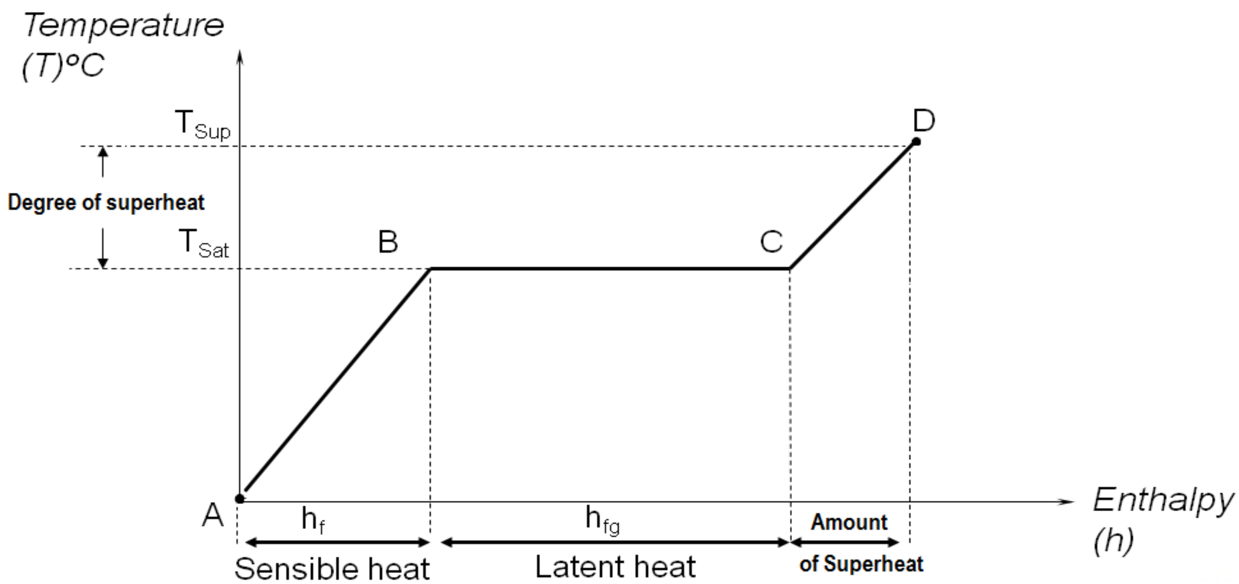


Fig 1.2 Temperature Enthalpy diagram

Consider 1 kg of water at 0^oC taken in a cylinder fitted with a freely moving frictionless piston as shown in *fig.1.1*. A chosen weight is placed over the piston so that the total weight of the piston and the chosen weight exert the required constant pressure ***p*** on the water. This condition of water at 0^0C is represented by the point **A** on the temperature-enthalpy.

When this water is heated at constant pressure, its temperature rises till the boiling point is reached. When the boiling point of water is reached, there will be slight increase in the volume of water as shown in *fig.1.1*. The temperature at which the water boils depends on the pressure acting on it.

This temperature called ***saturation temperature** is defined as the temperature at which the water begins to boil at stated pressure*. This is denoted as $\mathbf{T_s}$. This condition of water at temperature T_s is represented by the point **B** on the graph. The heating of water from 0^0C to T_s°C at constant pressure is represented by the inclined line **AB** on the graph. The saturation temperature, i.e., the boiling temperature, of the water increases with the increase of pressure at which the water is heated.

The amount of heat required to raise the temperature of 1kg of water from 0°C to the saturation temperature T_s°C at a given constant pressure is defined as ***sensible heat*** and denoted as $\boldsymbol{h_f}$. The sensible heat is also called as the *heat of the liquid* or the *enthalpy of the liquid.*

Further addition of heat, initiates the evaporation of water while the temperature remains at the saturation temperature T_s because the water will be saturated with the heat and any other further addition of heat change only the phase from the liquid phase to gaseous phase. This evaporation will be continued at the same saturation temperature T_s until the whole of the water is completely converted into steam as shown in the *fig 1.2*. This point is represented by point **C** on graph. This constant pressure and constant temperature heat addition process is represented by horizontal line **BC** on the graph. *The amount of heat required to evaporate 1kg of water at saturation temperature T_s to 1kg of dry steam at the same saturation temperature at given constant pressure is called* ***latent heat of vaporisation*** *or* ***enthalpy of evaporation*** denoted as $\mathbf{h_{fg}}$.

On heating the steam further at the same constant pressure, its temperature increases above the saturation temperature T_s. The temperature of the steam *above* the saturation temperature at a given

Pressure is called ***superheated temperature***. During this process of heating, the dry steam will be heated from its dry state, and this process is called ***superheating***. The steam when superheated is called ***superheated steam***. This superheating is represented by inclined line **CD** on the graph. *The amount of heat required to increase the temperature of dry steam from* ***saturation*** *temperature to any desired higher temperature at the given constant pressure is called* ***amount of superheat*** *or*

enthalpy of superheat. The difference between the superheated temperature and the saturation temperature is defined as ***degree of superheat***.

Different States of Steam

The steam as it being generated can exist in *three* different states, vis., as wet steam, or dry saturated steam, or superheated steam.

Wet steam

When the water is heated beyond the saturation state at constant pressure it starts evaporation. The steam evolving from the surface of the water entrains finely divided water molecules in it. This entrained water molecules suspended in the steam will be at saturation temperature and will not yet have been absorbed the latent heat and evaporated into steam. Both the entrained water molecule and steam coexist to form a two phase mixture, called ***wet steam*** which will be in thermal equilibrium because both of them will be at the same saturation temperature.

Thus *a wet steam is defined as a two phase mixture of entrained water molecule and steam in thermal equilibrium at the saturation temperature corresponding to a given pressure*.

Dryness Fraction of Steam

A wet steam can be of different qualities, i.e., having different proportion of water molecules and dry steam. Therefore it is necessary to state the qualities of the wet steam. The qualities of the 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 actual dry steam pressure in a known quantity of wet steam to the total mass of the wet steam.*

Let m_g = mass of dry steam present in the sample quantity of wet steam

m_f = mass of suspended water molecule in the sample quantity of wet steam

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

$$X = \frac{mg}{mf + mg}$$

The dryness fraction of the wet steam will be *less than* 1.

Dry Saturated Steam

Steam which is in contact with water from which it has been formed will be in thermal equilibrium with the water (i.e., the heat passing from steam into the water is balanced by the equal quantity of heat passing from the water into the steam) is said to be **saturated steam.** *A saturated steam at the saturation temperature corresponding to a given pressure and having no water molecules entrained in it is defined as **dry saturated steam** or simply **Dry steam.***

Since the dry saturated steam does not contain any water molecules in it, its *dryness fraction will be 1*.

Superheated Steam

When a dry saturated steam is heated further at a given constant pressure, its temperature rises beyond its saturation temperature. The steam in this state is said to be superheated.

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

Enthalpy of Steam

Enthalpy is defined as the sum of the internal energy and the product of pressure and volume. It is denoted as h.

The enthalpy is given by,

$$h = u + pv$$

From the first law of thermodynamics

$$dQ = du + p.dv$$

$$= du + d(pv) - v.dp \quad [\text{as } d(pv) = v.dp + p.dv)$$

$$= d(u + pv) - v.dp$$

From a constant pressure process, dp=0

$$dQ = d(u + pv)$$

i.e $dQ = dh$

Therefore for constant pressure steam generation process, the amount of heat supplied to the water to convert into steam is equal to the change in enthalpy.

Enthalpy of dry saturated steam

The enthalpy of dry saturated steam is defined as the *total amount of heat supplied at a constant pressure to convert 1kg of water into 1kg of dry saturated steam at its saturation temperature*. It is denoted as h_g and will be equal to sum of sensible heat h_f and latent heat of evaporation h_{fg}.

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

Enthalpy of wet steam

Since a wet steam contains water molecules entrained in it, it will have absorbed only a fraction of the latent heat of evaporation proportional to the mass of the dry steam contained in the wet steam. Therefore the enthalpy of wet steam is defined as the total amount of heat supplied at a constant pressure to convert 1kg of water at 0^oC into 1kg of wet steam at specified dryness fraction. It is denoted as h and will be equal to sum of sensible heat h_f and product of dryness fraction and latent heat of evaporation h_{fg}.

$h = h_f + xh_{fg}$ kJ/kg

Enthalpy of superheated steam

To superheat the steam, the heat is supplied at a constant pressure to the dry saturated steam to increase its temperature beyond its saturation temperature. Therefore the enthalpy of superheated steam is defined as the *total amount of heat supplied at a given constant pressure to convert 1kg of water at 0^oC into 1kg of superheated steam at the stated superheated temperature*. It is denoted by h_{sup} and will be equal to sum of enthalpy of dry saturated steam and the amount of superheat. It T_{sup} is the superheated temperature, T_s is the saturated temperature and C_{ps} is the specific heat of saturated steam, then the amount of superheat will be equal to $C_{ps} (T_{sup} – T_s)$

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

Specific volume

Specific volume is the volume occupied by the unit mass of a substance. It is expressed in m^3/kg. For example, if you have 1kg of iron and 1kg of cotton the specific volume of 1kg of cotton will be more than the specific volume of the iron because it requires huge quantity of cotton to make 1kg while it requires less quantity of iron to make 1kg.

Specific volume of saturated water

It is defined as the volume occupied by 1kg of water at the saturation temperature at a given pressure. It is denoted by v_f

Specific volume of dry saturated steam

It is defined as the volume occupied by 1kg of dry saturated steam at a given pressure. It is denoted by v_g

Specific volume of wet steam

When the steam is wet, its specific volume will be equal to the sum of the volume occupied by the dried up portion of the steam in 1 kg of wet steam and the volume occupied by the entrained water molecules in the same 1 kg of wet steam. If x is the dryness fraction of the steam, then the mass of the water molecules will be equal to (1-x) kg.

Let v be the specific volume of the wet steam.

Then $v = xv_g + (1-x)\, v_f \ m^3/kg$

Generally, at low pressures v_f value will be very low when compared with v_g and is hence often neglected.

Hence $v = xv_g \ m^3/kg$

Specific volume of superheated steam

It is defined as the volume occupied by 1kg of superheated steam at a given pressure and superheated temperature. It is denoted by v_{sup}.

The superheated steam behaves like a perfect gas, therefore its specific volume is determined approximately by Charles law.

Let

v_g = Specific volume of dry saturated steam at pressure p.

T_s = Saturation temperature at pressure p.

T_{sup} = Superheated temperature

V_{sup} = Specific volume of superheated steam at pressure p.

$$\frac{vg}{Ts} = \frac{Vsup}{Tsup}$$

Or $V_{sup} = \frac{Tsup}{Ts\ X\ vg}$

External work of evaporation

When the heat is supplied at constant pressure to water at saturation temperature, it absorbs the latent heat of vaporation and evaporates into dry saturated steam. Due to the change from the liquid phase to the gaseous phase, there will be a large increase in volume of the dry saturated. Therefore the latent heat of vapourisation supplied during the evaporation not only changes the phase of the substance but also does an external work in moving the piston at constant pressure due to increase in volume. The volume increases from v_f to v_g. 'The fraction of the latent heat of vaporization which does an external work is called ***external work of evaporation***.

External work of evaporation per kg of dry saturated steam = p ($v_g - v_f$)
At low pressures v_f is very small when compared with v_g and is hence neglected.

External work of evaporation per kg of dry saturated steam = pv_g
External work of evaporation per kg of wet steam = pxv_g
External work of evaporation per kg of superheated steam = pv_{sup}

Internal latent heat

The latent heat of evaporation at a given pressure comprises of the energy required to do external work and the energy required to change the phase. The energy required to change the phase is called *true latent heat* or *internal latent heat.* The internal latent heat is obtained by *subtracting* the external work of evaporation from the latent heat of evaporation.

Internal latent heat of dry saturated steam $(h_{fg} - pv_g)$ kJ/kg

Internal energy of steam

Since the latent heat of evaporation comprises of internal latent heat and the external work of evaporation, the enthalpy or the total heat energy of a dry saturated steam at a given pressure will be equal to the sum of the sensible heat, internal latent heat and the external work of evaporation. But the heat energy of external work of evaporation is not present in the steam as it has been spent in doing the external work. Therefore the actual energy stored in the steam comprises of only the sensible heat and the internal latent heat. This actual energy stored in the steam is called internal energy.

It is obtained by subtracting the external work of evaporation from the enthalpy and is denoted by u.

The internal energy of the steam is defined as the difference between the enthalpy of the steam and the external work of evaporation.

Internal energy of dry steam: $u_g = h_g - pv_g$ kJ/kg

Internal energy of wet steam: $u = h_f + xh_{fg} – pxv_g$ kJ/kg

Internal energy of superheated steam: $u_{sup} = h_{sup} - pV_{sup}$ kJ/kg

Advantages of superheated steam

1. The heat content of superheated steam is high and hence its capacity to do work is greater.
2. As there is no moisture content in superheated steam, erosion/corrosion of turbine blades are minimized.
3. Superheating is done in a superheated, which obtains heat from waste burnt gases. This improves efficiency of the boiler.
4. While expanding in a steam turbine it reduces and in extreme cases prevents the condensation, thus giving better economy.

Disadvantages of superheated steam

1. The high superheated temperatures poses problem in the lubrication.
2. Higher depreciation and initial cost.

Problem 1: Determine the density of 1 kg of steam initially at a pressure of 10 bar absolute, having a dryness fraction of 0.78. If 500 kJ of heat is added at constant pressure, determine the condition and internal energy of the final state of steam. Take specific heat of saturated steam as 2.1 kJ/kgK.

Solution:

Given, m=1 kg, p=10 bar = 1000 kPa., x=0.78, heat added = 500 kJ.

We know that heat added at constant pressure is nothing but increase in enthalpy.

Let, h_1 = initial enthalpy,

h_2 = final enthalpy,

then, $h_2 = h_1$ + heat added.

Initial enthalpy:

From steam tables, at 10 bar,

$h_f = 762.6$ kJ/kg $\quad$ $v_g = 0.19430\ m^3/kg$

$h_{fg} = 2013.6$ kJ/kg

$h_1 = h_f + x\ h_{fg} = 762.6 + 0.78x2013.6 = 2333.2$ kJ/kg

Final enthalpy:

$h_2 = h_1$ + heat added = 2333.2 + 500 = 2833.2 kJ/kg.

From steam tables, at 10 bat

$h_g = 2776.2$ kJ/kg, $\quad t_{sat} = 179.9\ ^oC$.

Since h2 is greater than h_g, steam is superheated.

Enthalpy of superheated steam:

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

$2833.2 = 2776.2 + 2.1\ (T_{sup} - 179.9)$

therefore, $T_{sup} = 207\ ^oC$

Specific volume of steam:

Specific volume of superheated steam,

$v_2 = v_g\ .\ T_{sup} / T_{sat}$

$T_{sat} = 179.9 + 273 = 452.9$ K

$$T_{sup} = 207 + 273 = 480 \text{ K}$$

$$v_2 = 0.19430 \text{ x } 480/452.9 = 0.20592 \text{ m}^3/\text{kg}.$$

Internal energy:

Internal energy of superheated steam,

$$u_2 = h_2 – pv_2 = 2833.2 – 1000\text{x}0.20592 = 2627.2 \text{ kJ/kg}.$$

Problem 2: what is the enthalpy of 5 kg of steam under the following conditioning? (i) 0.8 bar absolute pressure and 90% dry, and (ii) 20 bar absolute pressure at 300^{o}C. Take specific heat of superheated steam as 2.25 kJ/kg.

Solution:

(i) p = 0.8 bar, x = 90% = 0.9.

Enthalpy of wet steam per kg

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

For m kg,

$$H = m(h_f + x\, h_{fg}) = 5(391.7 + 0.9\text{x}2274.1) = 12191.95 \text{ kJ}.$$

(ii) Pressure =20 bar, temperature = 300^{o}C

From steam tables at 20 bar, t_{sat} = 212.4^{o}C

Since t_{sat} is less than the temperature of steam, the steam is superheated.

From steam tables at 20 bar, h_g = 2797.2 kJ/kg.

Enthalpy of superheated steam per kg

$$h_{sup} = h_g + c_{PS}(T_{sup} – T_{sat})$$

For m kg,

$$H_{sup} = m\{h_g + c_{PS}(T_{sup} – T_{sat})\} = 5\{(2797.2 + 2.25(300-212.4)\} = 14971.5 \text{ kJ}.$$

Problem 3: Find the internal energy of 2.5 kg of steam at 20 bar when (i) it is wet and its dryness fraction is 0.9, (ii) it is superheated to 350^{o}C. Take specific heat of steam as 2.3 kJ/kgK

Solution:

Given, m = 2.5 kg, p=20bar.

(i) steam is wet, x=0.9

From stem table at 20 bar,

h_f =908.5 kJ/kg.

h_{fg} = 1888.7 kJ/kg

. Enthalpy of wet steam

$h = h_f + x\ h_{fg} = 908.5 + 0.9x1887.7 = 2608.33$ kJ/kg.

Form steam tables at 20 bar,

$v_g = 0.09955\ m^3/kg$.

Specific volume of wet steam,

$v = x\ v_g = 0.9x0.09955 = 0.089595\ m^3/kg$.

Specific internal energy,

$u = h – pv = 2608.33 – 2000x0.089595 = 2429.14$ kJ/kg.

Therefore, internal energy for m kg of steam,

$U = mu = 2.5x2429.14 = 6072.85$ kJ.

(ii) steam is superheated to 350ºC:

From steam tables, at 20 bar,

$t_{sat} = 212.4^oC$, $h_g = 2797.2$ kJ/kg, $v_g = 0.09955\ m^3/kg$.

Enthalpy of superheated steam,

$h_{sup} = h_g + c_{PS}(T_{sup} – T_{sat}) = 2797.2\ (350-212.4) = 3113.68$ kJ/kg.

Specific volume of superheated steam,

$v_{sup} = v_g\ .\ T_{sup} / T_{sat}$

$T_{sup} = 350 + 273 = 623$ K

$T_{sat} = 212.4 + 273 = 485.4$ K

$v_{sup} = 0.09955 \text{ x } 623/485.4 = 0.12777\ m^3/kg$.

Specific internal energy,

$u_{sup} = h_{sup} – pv_{sup} = 3113.68 – 2000x0.12777 = 2858.13$ kJ/kg.

Therefore, internal energy for m kg of steam,

$U_{sup} = mu_{sup} = 2.5x2858.13 = 7145.34$ kJ.

Problem 4: Steam is at 9 bar pressure and dryness fraction 0.98. Find the quality and temperature of steam when (i) the steam looses 50 kJ/kg at constant pressure, and (ii) steam receives 150 kJ/kg at constant pressure.

Solution:

From steam tables, at 9 bar,

h_f =742.6 kJ/kg,

h_{fg} = 2029.5 kJ/kg,

h_g = 2772.1 kJ/kg,

t_{sat} = 175.4°C,

Given,

x_1 = 0.98.

Initial enthalpy of steam,

$h_1 = h_f + x_1 h_{fg} = 742.6 + 0.98x2029.5 = 2731.51$ kJ/kg.

(i) Steam looses 50 kJ/kg at constant pressure,

$h_2 = h_1 – 50 = 2731.51 – 50 = 2681.51$ kJ/kg.

Since h_2 is less than hg, steam is wet.

Enthalpy of wet steam,

$h_2 = h_f + x_2 h_{fg}$

$2681.51 = 742.6 + x_2 x2029.5$

x_2 = 0.955.

(ii) Steam receives 150 kJ/kg of heat.

$h_2 = h_1 + 150 = 2731.51 + 150 = 2881.51$ kJ/kg.

Since h_2 is greater than h_g, steam is superheated.

Enthalpy of superheated steam,

$h_2 = h_g + c_{ps}(t_{sup} – t_{sat})$

$2881.51 = 2772.1 + 2.1 (t_{sup} – 175.4)$

t_{sup} = 227.5°C.

Objective: We try to solve some more problems on steam. We discuss about boiler classifications based on different criteria.

Problem 5: 2 kg of wet steam is heated at a constant pressure of 2 bar until its temperature increases to 150^{o}C. The heat transferred is 2100 kJ. Find the initial dryness fraction of steam. Take the specific heat of steam as 2.1 kJ/kg. The properties of steam at 2 bar pressure are given below-

p (bar)	t_s (^{o}C)	v_f (m^3/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)
2	120.23	0.001061	0.8857	504.5	2706.5

Solution:

Given, m=2 kg, p = 2 bar = 2000 kPa. T_2=150^{o}C, heat added = 2100 kJ.

$h_{fg} = h_g - h_f$ = 2706.5 – 504.5 = 2202 kJ/kg.

Since t_2 is greater than t_{sat}, steam is superheated in the final state.

Enthalpy of superheated steam,

$$h_2 = h_g + c_p (t_{sup} – t_{sat}) = 2706.5 + 2.1 (150-120.3) = 2769.2 \text{ kJ/kg.}$$

Total heat added = 2100 kJ.

Heat added per kg of steam = 2100/2 = 1050 kJ/kg.

Final enthalpy of steam,

$$h_2 = h_1 + 1050 \text{ kJ/kg.}$$

Therefore,

$$h_1 = h_2 – 1050 = 2769.2 – 1050 = 1719.2 \text{ kJ/kg.}$$

Since h_1 is less than h_g, steam is wet.

Enthalpy of wet steam,

$$h_1 = h_f + x_1 h_{fg}$$

$$1719.2 = 504.5 + x1x2202$$

Initial dryness fraction,

$$x_1 = 0.5516$$

Boilers or Steam Generator

Various types of fossil fuels are the sources from which heat energy is derived to produce the steam which inturn run the steam engines and steam turbines. Steam is produced in a closed vessel called boiler. In practice the steam is mainly used for two purposes: 1) Power generation and 2) Process heating. In power generation, the steam is used to run the steam turbines in thermal power plants. As a process heater, steam is used in textile industry for bleaching, chemical industries, hotels for washing utensils, hospitale for sterilizing etc.

Definition of a Boiler: Boiler is defined as a closed metallic vessel in which the water is heated beyond its boiling point by the application of heat liberated by the combustion of fuels to convert it into steam.

Function of a Boiler: Function of a boiler is to supply the steam at the required constant pressure with its quality as either dry, or as nearly as dry or superheated. Constant pressure of the steam is maintained by keeping the steam generation rate and steam flow rate equal.

Classification of Boiler: Boilers are classified on the working principle as *fire tube boilers* and *water tube boilers*.

Boiler are classified as follows

a) **Accordig to the circulation of water and hot gases**

- Fire tube boiler
- Water tube boiler

- **Fire tube boiler*:***

  In the fire tube boilers, the hot flue gases produced by the combustion are passed through many tubes and around which the water circulates. The heat is transferred from the hot gases in the tubes to the circulating water outside to generate steam. These boilers are suitable for genarating steam of lower pressure (upto 20 bar).

  Ex: Cochran boiler, Cornish boiler, Lancashire boiler etc.

- **Water tube boiler:**

  In the water tube boilers, the water circulates inside the tubes while hot gases produced by combustion of the fuels pass around them externally. The heat is transferred from the hot gases to the water circulating inside the tubes to generate steam. These boilers are suitable for generating steam at very high pressures.

- Ex: Babcock and Wilcox boilers, Stirling boiler, Yarrow boiler etc.

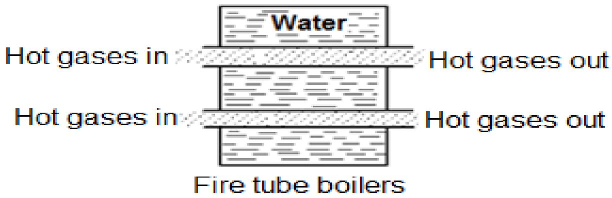


Fig 1.3 Fire tube boiler

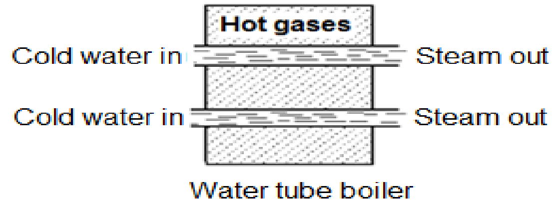


Fig 1.4 Water tube boiler

b) According to the location of furnace

- Internally Fired boiler
- Externally Fired boiler
- **Internally fired boiler:** If the furnace is situated inside the boiler shell, the boiler internally fired boiler. Most of the fire tube boilers are internally fired.
- **Externally Fired boiler:** If the furnace is situated outside the boiler shell, the boiler externally fired boiler. Most of the water tube boilers are externally fired.

c) Accoding to the circulation of water

- Natural circulation
- Forced circulation
- **Natural circulation:** In these boilers, water is circulated by natural convection currents that set up due to the temperature difference. Most of the boilers pf low capacity fall under this category.
- **Forced circulation:** water is circulated with the help of a pump driven by a motor. Forced circulation is used only in high pressure and high capacity boilers viz, La Mont boiler, etc,

d) According to the axis of the shell

- **Vertical boilers**
- **Horizontal**
- **Vertical boilers:** axis of the boiler shell is vertical Ex:Cochran Boiler.

- **Horizontal:** axis of the boiler shell is horizintal Ex: Babcock and Wilcox boilers, Lancashire boiler etc,

Babcock and Wilcox boiler

Babcock and Wilcox boiler is an example of horizontal, multi tubular, water tube boiler. This boiler is used in thermal power stations requiring high quantities of steam at high pressure.

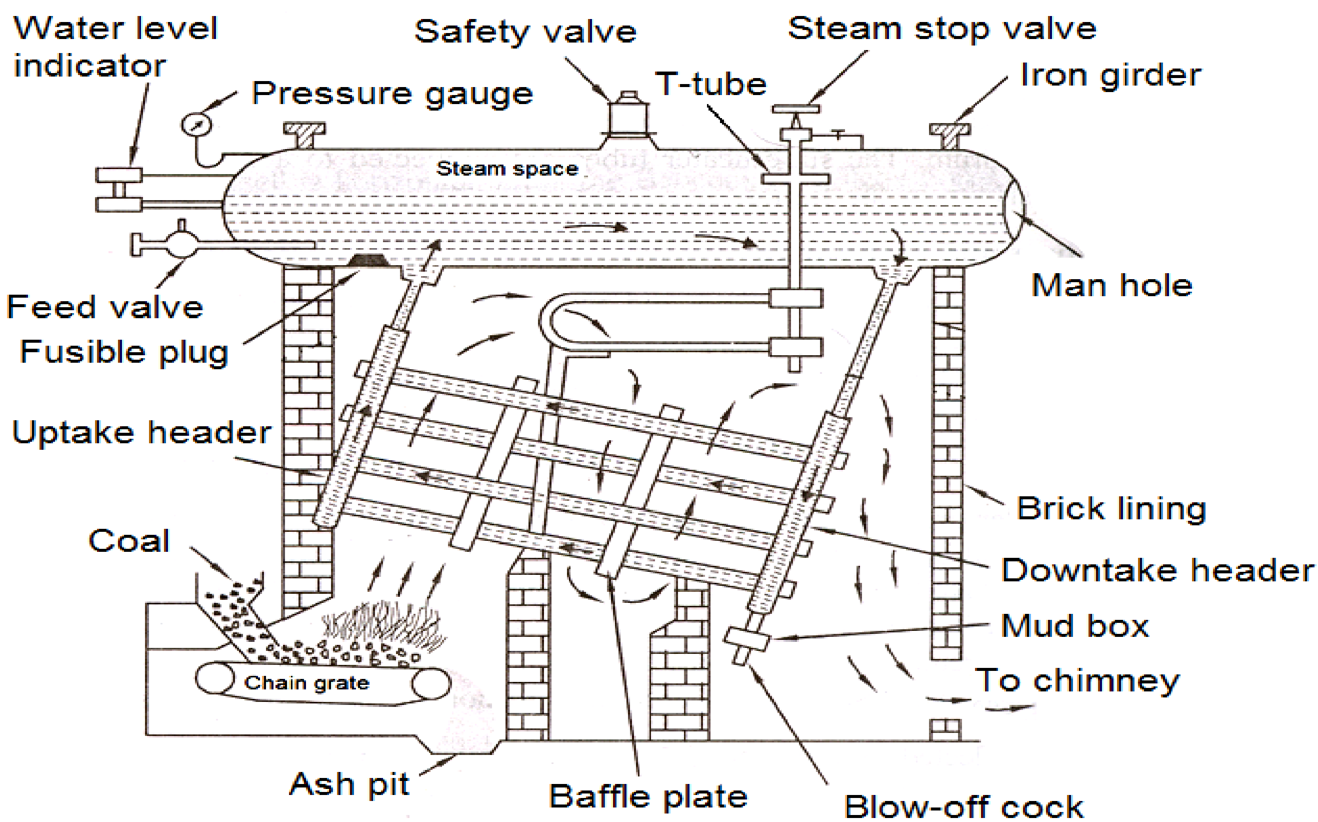


Fig 1.6 Babcock and Wilcox boiler

Construction:

1. Water and steam drum is suspended from the iron girders resting on the iron columns (not shown in fig1.6).
2. A number of inclined water tubes at a very low inclination are connected at their ends to headers. Water tubes are arranged vertically and one behind the other in rows and columns. And all these are connected to headers.
3. A mud box is provided just below the downtake header which collects any sediment present in water. These sediments are removed periodically through the blow off pipe.

4. Continuously moving chain grate stoker is provided below uptake header. The coal fed at the front end of grate is burnt on the moving grate and ash falls at the other end of grate into ash pit.
5. Boiler is fitted with superheater which consists of number of U shaped tubes placed in the combustion chamber below the boiler drum. One end of superheater tubes is connected to a T-tube located in steam space. Other end of superheater tubes is connected to steam stop valve.

Working:

1. Water is introduced into the boiler drum through feed valve which moves down through down take headers and passes up in the inclined water tubes and finally up through uptake header.
2. Coal is fed through the hopper which burns and generates heat as it moves on the chain grate stoker.
3. Hot gases from the furnace grate are compelled by baffle plate to first pass upwards around the portion of water tubes lying in between uptake header and baffle plate, then between two baffle plates and once again between baffle plate and down take header. After this, the hot gas passes out to atmosphere through chimney.
4. During this path of hot gases, the water coming in through down take header and inclined water tubes get evaporated and collects in the top portion of the boiler.
5. When superheated steam is required the steam from steam space moves in through the T-tubes and passes into the superheater where it is superheated by hot gases in combustion chamber. Then the superheated steam passes to turbines through steam stop valve.
6. When superheated steam is not required, the steam from the steam space directly passes out to the turbine through steam stop valve.