1. SOURCES OF ENERGY

Give a brief classification of energy sources.

Answer: The energy sources can be grouped and classified as below:

I . Conventional Energy Resources

- Water (Hydro)
- Fossil fuel energy
- Nuclear energy

II. Non-conventional Energy Resources

- Solar energy
- Wind energy
- Tidal energy
- Ocean thermal energy
- Geothermal energy
- Biogas energy

Characteristics of a good source of fuel

- It should have a high energy output per unit mass or volume.
- It should be easily available.
- It should be easy to store and transport.
- It should be economical.

The classification based on the possibility of renewability of energy sources.

- **Renewable Energy Sources:** These are the sources which are freely available in nature i.e., solar, lunar, wind, geothermal etc. As some of these sources are reaching the earth from the outer atmosphere such sources are called incoming or celestial energy. These are inexhaustible sources. Hence these are called renewable energy sources. These are environmental friendly.
- **Nonrenewable Energy Sources:** These are the sources which can be extracted from the earth's crust due to their accumulation over the period of time. i.e., fossil fuels, nuclear fuels, heat traps etc. These have been in use for several decades. Now such sources are depleting at a faster rate and may get exhausted in the forth coming years. In such a case, these, sources can not be immediately replenished. Hence these are called as exhaustible or nonrenewable energy sources. These pollute the environment. Hence these are not environmental friendly.

Comparison between Renewable and Nonrenewable Energy Sources

Sl. No.,	Renewable or Non-conventional Energy Sources	Nonrenewable or Conventional Energy Sources
1	These are non-exhaustible	These are exhaustible
2	Freely available	Not freely available
3	Environmental friendly.	Hazardous to environment.
4	Initial cost is high but maintenance cost is minimum.	Both initial and maintenance costs are high.
5	The energy concentration varies from region to region.	It is almost constant in all Regions,
6	Perfect energy utilization equipment's are yet to be designed.	Competitive designs are progressing satisfactorily.
7	Energy transmission costs are high	Energy transmission costs are low.

Conventional and Non-conventional Energy Sources

Conventional Energy Sources:

Presently most of our energy needs comes mainly from fossil fuels such as, coal, petroleum and natural gas, and hydel sources which are relatively cheaper. Although energy is also produced from nuclear fuels, it is not being used on a large scale due to its inherent hazardous nature and high cost of generation of power from nuclear source. Since the fossil fuels and hydel sources are in use over several decades, they are called conventional energy sources.

Non-conventional Energy Sources:

The ever increasing rapid use of the fossil fuels day by day has threatened exhausting of this source very soon. The hydel sources cannot become a major source of energy since it is not available everywhere and also depends on the unpredictable nature of the hydrological cycle. Moreover its cost of generation is also very high because of high initial investments and transmission problems.

Therefore time has come for searching altogether other sources of energy which are inexhaustible to gradually replace the conventional sources. Now the other alternate energy sources that are tried for harnessing are, solar energy, wind energy, tidal energy, ocean thermal energy, bio-energy, fuel cells, solid wastes, hydrogen, etc. These alternate inexhaustible sources of energy are called non-conventional energy sources, List the Advantages and Disadvantages of Renewable energy Resources

Advantages:

1. The renewable energy resources are non-exhaustible.
2. The renewable energy resources can be matched in scale to the need and also they can deliver the energy of the quality that is required for a specific task. A simplest example for this is a water heating device. For water heating, which is a low grade conversion, if we use electrical energy or high premium hydrocarbon fuels, which are high grade energy sources, there will be an improper match between the energy source and the task which reduces the, thermodynamic efficiency. Suppose a solar water heater is used, not only it is cost effective, but there is a perfect match between the energy source and the task since the sun's rays directly heats up the water. The solar water heaters can also be built to suitable sizes which will supply the required quantity of water at the desired temperature.

a. Some of the renewable energy conversion systems often can be built on, or close to the site where the energy is required, which will minimise the transmission costs. For example a windmill for driving a hydraulic pump may be built very close to the water source. A panel of photo voltaic cells used for domestic or street lighting is also an another example.

3. The diversity of renewable energy resources and their technologies offer more flexibility
4. while designing the conversion systems compared to the conventional energy systems.
5. The local or regional self sufficiency in the energy requirement can be achieved either fully or partially by harnessing the locally available renewable energy which otherwise would be left unutilized.
6. Except the biomass energy source, all other renewable energy resources offer pollution free environment and also help in maintaining the ecological balance.

Disadvantages:

1. The intermittent nature of the availability of the energy from the renewable energy resources such as, solar, wind, tidal, etc. is a major setback in the continuous supply of energy.
2. Although the supply of energy from the sun is limitless, there is a definite limit to the rate at which the solar energy is received at the earth as it is dependent on the local atmospheric conditions, time of the day, part of the year and also on the latitude of the place.
3. Some of the renewable energy resources such as wind, tidal, etc. although available in large quantities, they are concentrated only in certain regions.
4. The state of the art in harnessing the renewable energy resources is not yet fully developed to meet the present day energy requirements.

5. Some of the renewable energy conversion systems such as solar cells, automatic tracking systems for solar concentrators, etc. require advanced technologies, hence costlier.
6. The application of renewable energy resources to transport sector has been found to be not viable as on today.

PROPERTIES OF STEAM AND BOILERS

Q. 2.1. With the help of temperature-enthalpy diagram explain the formation of steam at constant pressure.

Ans: The action of heat in the formation of steam from water is illustrated in the fig.2.1 shown below. As the steam is continuously generated, its pressure gradually increases and is supplied from the boilers to the engines or turbines at constant pressure. To know the values of the various properties of steam at a particular pressure, a steam generation experiment is conducted by heating the water from 0^oC at a given constant pressure. Since the steam is generated at constant pressure, the amount of heat energy supplied to convert the water into steam will be equal to its enthalpy.

Consider 1 kg of water at 0^oC taken in a cylinder fitted with a freely moving frictionless piston as shown in fig. A chosen weight is placed over the piston so that the total weight of the piston and the chosen weight exerts the required constant pressure *p* on the water. This condition of water at 0^oC is represented by the point *A* on the temperature-enthalpy graph as shown in Fig.2.2.

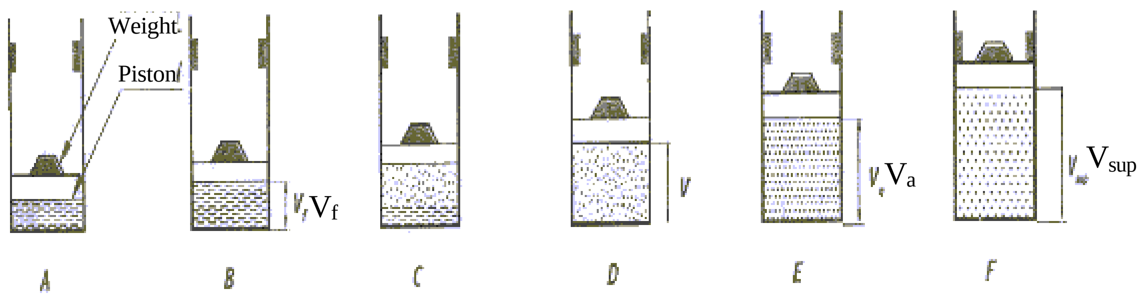


Fig.2.1: Formation of Steam

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 a slight increase in the volume of water as shown in *Fig2.2B.* The temperature at which the water boils depends on the pressure acting on it. This temperature is called as *saturation temperature* and denoted as T_s. The *saturation temperature is defined as the temperature at which the water begins to boil at the stated pressure.* The boiling temperature of the water increases with the increase of pressure at which the water is heated.

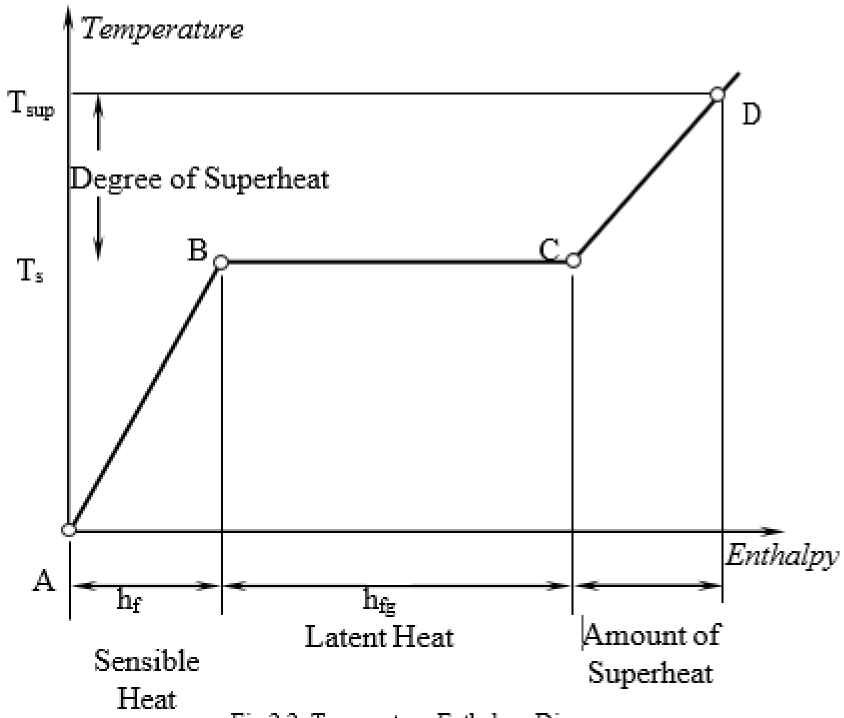


Fig.2.2: Temperature-Enthalpy Diagram

The amount of heat required to raise the temperature of 1 kg of water from 0^0 C to the saturation temperature Ts °C *at a given constant pressure is defined as the sensible heat* and denoted as 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 *Ts* because the water will be saturated with heat and any further addition of heat changes only the phase from the liquid phase to the gaseous phase. This evaporation will be continued at the same saturation temperature *Ts* until the who1e of the water is completely converted into steam as shown in *Fig2.1E.* This constant pressure and constant temperature heat addition process is represented by the horizontal line *BC* on the graph. *The amount of heat required to evaporate 1 kg of water at saturation temperature Ts to* 1 *kg of dry steam at the same saturation temperature at given constant pressure is called latent heat of evaporation* or *enthalpy of evaporation* and denoted as h_{fg}.

On heating the steam further at the same constant pressure, increases its temperature above the saturation temperature *Ts.* 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 of heating is called *superheating.* The steam when superheated ca1led *superheated steam.* This superheating is represented by the inclined line CD on the graph. *The amount of heat required to increase the temperature of dry steam from its 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.*

2.2 What are the advantage and disadvantage of Superheated Steam?

Ans: Advantages of Superheated Steam:

1. At a given pressure, the superheated steam possess more heat energy compared to dry saturated steam or wet steam at the same pressure, hence its capacity to do the work will be higher.
2. When superheating is done by the exhausting combustion gases in a boiler, there will be a saving of the energy of combustion which improves the thermal efficiency of the boiler.
3. 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 problems in the lubrication.
2. Higher depreciation and initial cost.

2.3.Explain briefly the different states of steam.

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

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

Wet Steam:

When the water is heated beyond the saturation state at constant pressure it starts evaporating. A *wet steam is defined as a two-phase mixture of entrained water molecules and steam in thermal equilibrium at the saturation temperature corresponding to a given pressure.*

Dryness Fraction of Steam:

The quality of the 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.*

Let mg = 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

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

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

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 a *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 unity.*

Superheated Steam:

When a dry saturated steam is heated further at the 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 saturated state to temperatures higher than its saturated temperature at the given pressure.

2.4. Explain the following,

i. Enthalpy of steam
ii. Enthalpy of Dry Saturated Steam
iii. Enthalpy of Wet Steam
iv. Enthalpy of Superheated Steam
v. Specific Volume
vi. Specific Volume of Wet Steam
vii. Specific Volume of Superheated Steam

Enthalpy of Steam:

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

Enthalpy of Dry Saturated Steam:

The *enthalpy of dry saturated steam is defined as the total amount of heat supplied at a given constant pressure to convert I kg of water into I kg of dry saturated steam at its saturation temperature. It is denoted as h_g and will be equal to sum of the sensible heat h_f and the 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 I kg of water at O°C to I kg of wet steam at the specified dryness fraction. It is denoted as h and will be equal to sum of the sensible heat and the product of the dryness fraction and the latent heat of evaporation.*

$h = h_f + xh_{fg}$ 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 I kg of water at 0°C into I kg of superheated steam at the stated superheated temperature.* It is denoted as h_{sup} *and will be equal to sum of the enthalpy of dry saturated steam and the amount of superheat.* If T_{sup} is the superheated temperature, T_s is the saturated temperature and C_{ps} is the specific heat of superheated steam, then the amount of superheat will be equal to $C_{ps} (T_{sup} - T_s)$.

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

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

Specific Volume:

The specific volume is the volume occupied by the unit mass of a substance. It is expressed in m^3/kg.

Specific Volume of Saturated Water: *It is defined as the volume occupied by I kg of water at the saturation temperature at a given pressure* and is denoted by v_f.

Specific Volume of Dry Saturated Steam: *It is defined as the volume occupied by* 1 *kg of dry saturated steam at a given pressure,* and 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, and the mass of the water molecules will be equal to (1- x) kg.

Let v is the specific volume of wet steam.

$v = x\, v_g + (1 - x)\, v_f$ m^3/kg Generally, $(1 - x)v_f$ is very low and is often neglected.

$$v = x\, v_g \text{ m}^3/\text{kg}$$

Specific Volume of Superheated Steam:

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

The superheated steam behaves like a perfect gas; therefore its specific volume is determined approximately using 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

From Charles Law,

$$\frac{v_g}{T_s} = \frac{v_{sup}}{T_{sup}}$$

$$v_{sup} = (T_{sup} * v_g)/T_s$$

Problem 2.1: *Find the enthalpy of 1 kg of steam at 12 bar when, (a) steam is dry saturated, (b) steam is 22% wet and (c) superheated to 250°C. Use the steam table. Assume the specific heat of the superheated steam as 2.25 kJ/kgK.*

Solution: From the steam tables at 12 bar, the following values are noted.

T_s = 188°C

h_f = 798.43 kJ/kg

h_{fg} = 1984.3 kJ/kg

(a) Enthalpy of Dry saturated Steam:

$$h_g = h_f + h_{fg}$$
$$= 798.43 + 1984.3 \text{ kJ/kg}$$
$$= 2782.73 \text{ kJ/kg}$$

(b) Enthalpy of Wet Steam:

When the steam is 22% wet, it will be 78% dry. Therefore the dryness fraction x = 0.78

$$h = h_f + x\, h_{fg}$$
$$= 798.43 + 0.78 \times 1984.3$$
$$= 2346.18 \text{ kJ/kg}$$

(c) Enthalpy of Superheated Steam:

$h_{sup} = h_f + h_{fg} + C_{ps}(T_{sup} - T_{sat})$

= 798.43 + 1984.3 + 2.25(250 - 188)

= 2922.23 kJ/kg

Problem 2.2: *Find the specific volume and enthalpy of* 1 *kg of steam at 0.8 MPa. (a) when the dryness fraction is 0.9 and (b) when the steam is superheated to a temperature of 300°C. The specific heat of superheated steam is* 2.25 *kJ/kgK.*

Solution:

From the steam tables at 0.8 MPa = 8 bar, the following values are noted.

T_s = 170.4 °C, *hf* = 720.94 kJ/kg, h_{fg} = 2046.5 kJ/kg, h_g = 2767.5 kJ/kg

v_s = 0.2403 m3/kg, v_f = 0.001115 m^3/kg

(a) Specific Volume of Wet Steam:

$v = x\, v_g$ m^3/kg

= 0.9 x 0.2403

= 2.627 m^3/kg

(b) Specific Volume of the Superheated Steam:

$$v_{\text{sup}} = \frac{T_{\text{sup}}}{T_s} v_g$$

$$= 0.2403 \frac{(300 + 273)}{(170.4 + 273)}$$

= 0.3105 m^3/kg

(c) Enthalpy of Wet Steam:

$$h = h_f + x\, h_{fg}$$

= 720.94 + 0.9 x 2046.5

=2562.8 kJ/kg

(d) Enthalpy of Superheated Steam:

$h_{sup} = h_g + C_{ps}\,(T_{sup} - T_s)$

= 2767.5 + 2.25 (300 - 170.4)

= 3059.1 kJ/kg

Problem2.3: *Two kg of dry saturated steam at* 1 *MPa is produced from the water at 40°c. Determine the quantity of heat supplied. The specific heat of water* C_{pw} = 4.18 *kJ/kg.*

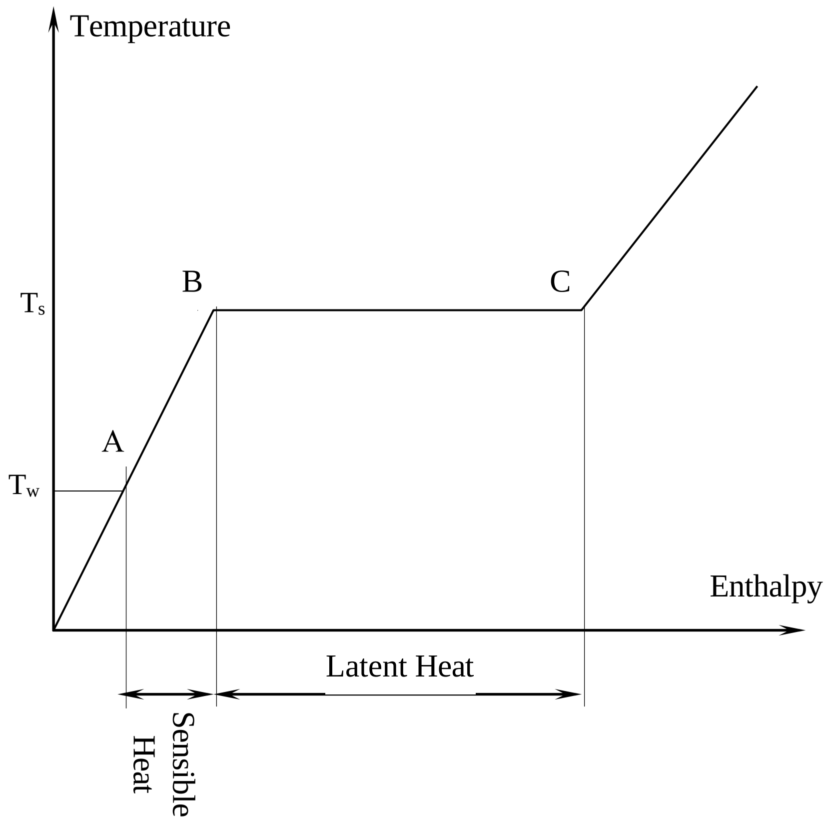
Solution:

p = 1 MPa = 10 bar

At 10 bar from steam tables

T_s = 179.88° C h_{fg} = 2013.6 kJ/kg

In *figure* it is seen that the dry saturated steam at 10 bar, represented at the point C is obtained from the water at a temperature T_w = 40°C, represented by the point *A*.



∴ *Enthalpy (Heat) required* = Sensible heat between the points *A* and *B* + Enthalpy of Evaporation between points B and C

$h_{sup} = C_{pw} (T_s - T_w) + h_{fg}$

= 4.18 (179.88 - 40) +2013.6

= 2598.3 kJ/kg

Total enthalpy required to produce 2 kg of dry saturated steam,

= 2 x 2598.3

= 5196.6 kJ

Problem 2.4: Determine the conditions of steam from the following data:

a) Pressure is 10 bar absolute and temperature 200°C,

b) Pressure is 8 bar absolute and specific volume of 0.22 m3/kg., and

c) Pressure is 12 bar absolute and enthalpy of 2600 kJ/kg.

Solution:

a) P = 10 bar, t = 200°C

From steam tables, at pressure of 10 bar absolute, Saturation temperature t_s = 179.88°C

Since the saturation temperature 179.88 °C is less than given steam temperature of 200°C, therefore the steam is superheated.

∴ Degree of superheat = $t - t_s$ = 200 - 179.88

= 20.12 °C

b) p = 8 bar, v = 0.22 m3/kg.

From steam tables, at pressure of 8 bar absolute, Specific volume of steam V_g = 0.2403 m3/kg.

Since the value of Vg is greater than the given volume of steam, therefore the steam is wet.

$$\therefore \text{Dryness fraction } x = \frac{V}{V_g} = \frac{0.22}{0.2403} = 0.9155$$

c) p = 12 bar, H = 2600 kJ/kg.

From steam tables, at pressure of 12 bar absolute, Specific enthalpy of water $h_f = 798.43$ kJ/kg. Specific enthalpy of steam h_g = 2782.7 kJ/kg.

Since the value of specific enthalpy of steam h_g is greater than the given enthalpy of 2600 kJ/kg., the steam is wet.

Latent heat of evaporation $h_{fg} = h_g - h_f$

= 2782.7 - 798.43 = 1984.27 kJ/kg.

Enthalpy of wet steam $h = h_f + x\, h_{fg}$

i.e., 2600 = 798.43 + 1984.27 x

∴ Dryness fraction x = 0.908

A steam at 10 bar and dryness 0.98 receives 140 kJ/kg at the same pressure. what is the final state of the steam?

From the steam table, at 10 bar the following values of noted.

Ts= 179.9° C, hf= 762.61 kJ/kg h_{fg} = 2013.6 kJ/kg

enthalpy of wet steam add dryness fraction 0.98 is found out.

Enthalpy of the wet steam:

$h=h_f+xh_{fg}$

= 762.61 + 0.98 * 2013.6

= 2735.9 kJ/kg

when 140 kilo joules of heat is added at the constant pressure it's enthalpy will increase,

Enthalpy of the heat addition= 2735.9 + 140

= 2875.9 kJ/kg

At 10 bar the enthalpy of dry saturation steam, hg=2776.2kJ/kg

Since the enthalpy of this team after heat addition is greater than the enthalpy of the dry saturation steam at the same pressure this team is superheated. The Super heated temperature of this team is found as follows.

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

$2875.9 = 2776.2 + 2.25\ (T_{sup}-179.9)$

Tsup= 224.2° C

4. **A mixture of saturated water and saturated steam at a temperature of 250^{O}C is contained in a closed vessel of 0.1m^3 capacity. If the mass of the saturated water is 2kg, find the mass of the steam in the vessel. Also find the pressure, specific volume, dryness fraction and the enthalpy of the mixture.**

Solution:

(a) Since the mixture in the vessel contains saturated water and saturated steam, it will be a wet steam. The pressure of the vessel is found to be from the steam table at T_s = 250 ^{O}C is p = 39.77 bar

At p = 39.77 bar, $v_f = 0.0012513\frac{m^3}{kg}, v_g = 0.05004\frac{m^3}{kg}, h_f = 1085.8\frac{kJ}{kg}, h_g = 1714.6\frac{kJ}{kg}$

(b) *Mass of the steam*

Since the vessel contains saturated water and steam

Volume of the vessel = $m_g v_g + m_f v_f$

0.1 = $m_g * 0.05004 + 2*0.0012513$

$\therefore m_g$ *= 1.95 kg*

$\therefore$ ***total mass of the mixture =*** *1.95 + 2 = 3.95 kg*

(c) *Dryness fraction of the steam*

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

$$x = \frac{1.95}{3.95}$$

x=0.493

(d) *Specific volume of the mixture*

$$v_s = \frac{0.1}{3.95} = 0.02531 m^3/kg$$

(e) *Enthalpy of the mixture*

=1931 kJ/Kg

Total Enthalpy = 2 x 1931= 3862 kJ

Determine the total heat content per unit mass to water when it exists in the following state using steam tables. Assume ambient pressure to be 100 kPa;

i. **10 bar absolute and 300°C**
ii. **100 kPa gauge and 150°C**
iii. **Dry saturated steam 100 kPa absolute**
iv. **Steam at 12bar and 95% quality**
v. **Saturated water at 100 °C**

Solution:

1bar =10^5 Pa

i. **10 bar absolute and 300°C**

At 10 bar, Ts= 179.9 °C h_f= 762.6 kJ/kg h_{fg}= 2013.6 kJ/kg

Since the given temperature of this team is higher than saturation temperature, the steam is superheated. The specific heat of super heated steam C_{ps}= 2.25 kJ/kgK

$$h_{sup}=h_g+C_{ps}(T_{sup}-Tsat) \text{ kJ/kg}$$
$$= 762.6 + 2013.6 + 2.25 (300 - 179.9)$$
$$= 3048.22 \text{ kJ/kg}$$

ii. 100 kPa gauge and 150 °C

Absolute Pressure Of Steam = Gauge Pressure + Ambient Pressure

= 100 + 100

= 200 kPa

= 2 bar

At 2 bar, Ts= 120.2 °C h_f= 504.7 kJ/kg h_{fg}= 2201.6 kJ/kg

Since the given temperature of this team is higher than the saturation temperature, steam is superheated

$$h_{sup}=h_g+C_{ps}(T_{sup}-Tsat)$$
$$= 2706.3 + 2.25 (150-120.2)$$
$$= 2773.35 \text{ kJ/kg}$$

iii. Dry saturated steam 100 kPa absolute

At 0.1 bar, enthalpy of dry saturated steam is obtained directly from steam table

$$h_g=2675.4 \text{ kJ/kg}$$

iv. Steam at 12bar and 95% quality

Ts=188°C h_f=798.4kJ/kg h_{fg} =1984.3kJ/kg

Enthalpy of wet steam

$$h = h_f + xh_{fg}$$

= 798.4 + 0.95 * 1984.3

= 2683.48 kJ/kg

v. Saturated water at 100 °C

At Ts=100°C the enthalpy of water is h_f=419.1 kJ/kg

A Spherical vessel 0.5 metres diameter contains a mixture of saturated water and saturated steam at 300°C. The saturated water occupies 1/4th of its volume and remaining saturated steam. Calculate their masses and dryness fraction of the mixture. Also find the enthalpy of the mixture. How much of the heat is to be added to convert the mixture into dry saturated steam at the same pressure?

From the steam tables, the pressure at the saturation temperature of 300 is p=85.927 and v_f=0.001404m3/kg vg =0.2165m3/kg.

volume of the spherical vessel= 4/3π r^3

= 4/3π (0.25) ^3

= 0.06545 m3

volume of the saturated water = 1/4*0.06545

= 0.01636 m^3

mass of the saturated vapour mf= 0.01636/0.001404

=11.65kg

volume of the saturated steam= ¾*0.06545

= 0.049 m^3

mass of the saturated vapour mg= 0.049/0.02165

= 2.26 kg

dryness fraction of the mixture= mg/mg +mf

=2.26/11.65+2.26

= 0.162

entalphy of mixture

at ts =300 c from the steam tables , hf= 1345kj/kg, h_{fg}=1406 kj/kg h_g=2751 kj/kg

$h = h_f + x\,h_{fg}$

$= 1345+0.162*1406$

$= 1572.77$ kJ/kg

heat to be added to convert into dry saturated steam at same pressure:

heat to be added $= h_s - h_g$

$= 2751-1572.77$

$=1178.23$ kJ/kg

Define boiler. Explain the function of boiler.

Ans: Various types of fossil fuels are the sources from which the heat energy is derived to produce the steam which in turn run the steam engines and the steam turbines. Steam is produced in a closed vessel called *boiler.* In practice the steam is used mainly for two purposes: (i) Power generation, and (ii) Process heating. In power generation, the steam is used to run the steam turbines in thermal power plants. As a process steam, it is used in textile industry for sizing and bleaching. It is used in paper mills for bleaching of the paper. It is also used for processing in chemical industries, sugar factories, pharmaceutical industries, breweries, etc.

Definition of a Boiler

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

Function of a Boiler

The function of a boiler is to supply the steam at the required constant pressure with its quality either dry, or as nearly as dry, or superheated. The steam can be supplied from the boiler at a constant pressure by maintaining the steam generation rate and the steam flow rate equal.

2.6 How boilers are classified?

Ans: Boilers are classified based on the principle of working as: *(i) Fire tube boilers* and *(ii) Water tube boilers.*

1. *Fire Tube Boiler:*

In the fire tube boilers, the hot flue gases produced by the combustion of fuels are led through a tube or a nest of tubes around which the water circulates as shown in *Fig.* 2.3. The examples of this type of boilers are Cochran boiler, Cornish boiler, Lancashire boiler, Locomotive boiler and Scotch Marine boiler. Fire tube boilers are suitable for steady working pressures up to 20 bar.

2. *Water Tube Boiler:*

In the water tube boilers, the water circulates inside the tubes while the hot gases produced by the combustion of the fuels pass around them externally as shown in *Fig.* 2.4. The examples of the water tube boilers are Babcock and Wilcox boiler, Stirling boiler, Yarrow boiler, etc. The water tube boilers are more suitable than the fire tube boilers for the generation of steam at very high pressures and also when the steam is to be raised quickly starting with cold water and fires out.

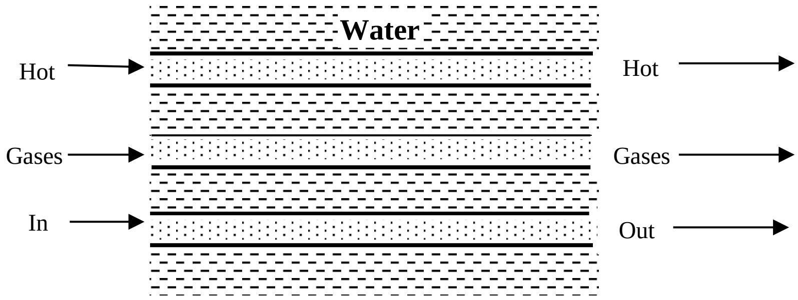
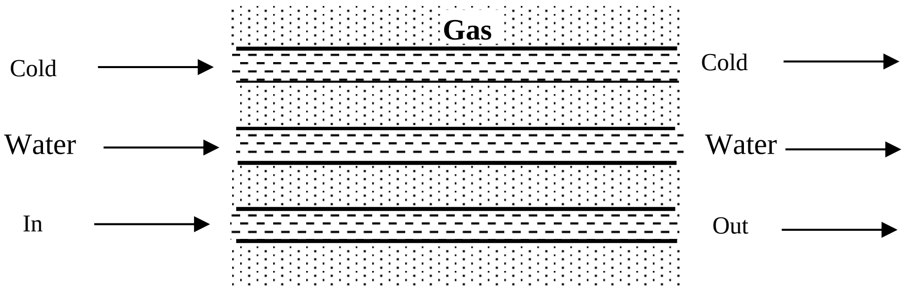


Fig.2.3 Water tube boiler



8 Explain the construction and working of Babcock & Wilcox Boiler. Show the direction of flow of flue gases.

Ans: Babcock and Wilcox boiler shown in *Fig.2.6* is a horizontal, externally fired, natural circulation stationary *water tube boiler.* This boiler raises steam normally between *10bar* to *20bar* at a steam rate of *200 kg per hour.* A high capacity boiler of this type can produce steam upto pressure of about *40bar* and steaming rate as high as *4000 kg per hour.*

Babcock and Wilcox water tube boilers are used in thermal power stations for generating large quantities of steam at high pressures. This boiler is specially suited for thermal power stations, since it is capable of coping up very quickly for the sudden increase in pressure and steaming rate at high peak loads.

Construction:

The Babcock and Wilcox water tube boiler shown in *Fig. 2.6* consists mainly four parts:

(i) water and steam drum, (ii) water tubes, (iii) chain grate stoker, and (iv) superheater tubes.

The *water and steam drum is* suspended from *iron girders* resting on the iron columns, (not shown in figure) and is independent of the brick work setting. A number of *inclined water tubes* at a very low

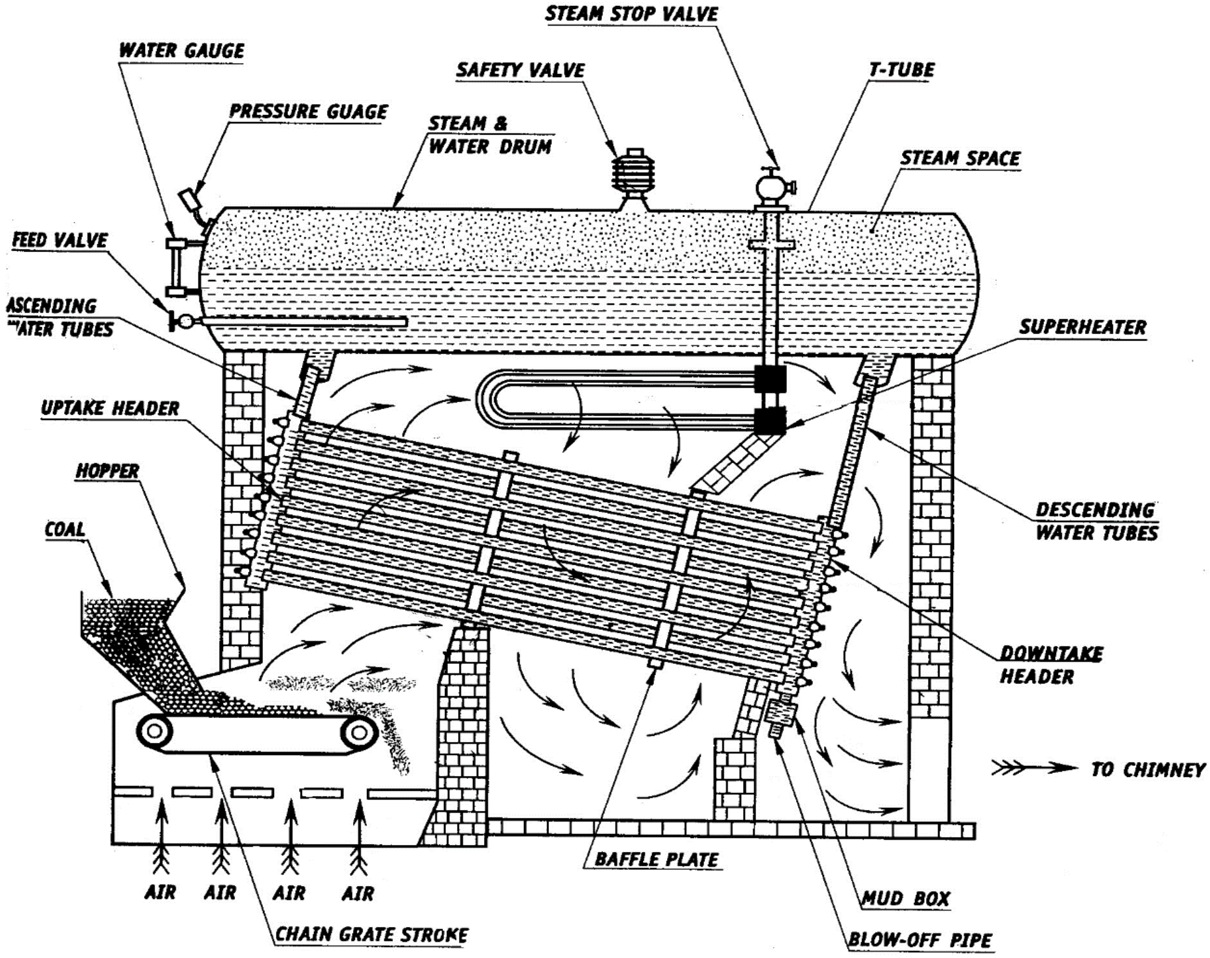


Fig.2.6 Babcock & Wilcox Boiler

inclination are connected at right angles to the end boxes called *headers.* The water tubes will be arranged in. a number of vertical rows, each row consisting of 4 to 5 tubes. In each vertical row, the tubes will be arranged one below the other in a serpentine form. There will be a number of such vertical rows one behind the other. Each one such vertical row of inclined water tubes are connected to one set of two headers. The header shown at the right end of the water tubes is called *down take header* and the other shown at the left end of the water tubes is called *uptake header.* Each of the vertical rows of water tubes which are arranged one behind the other are connected individually to one set of headers which are also arranged one behind the other.

Each set of the headers are intern connected to the boiler strum by one set of two inclined tubes, one at the uptake end and the other at the down take end. A mud box is provided just below the down take header. Any sediment in the water due to its heavier specific gravity will settle down in the mud box and is blown off from time to time through the *blow off pipe.*

The *moving grate* is provided at the front end below the uptake header. The boilers of higher capacity are usually provided with a chain grate stoker, which consists of a slowly moving endless chain of grate bar. The coal fed at the front end of the grate is burnt on the moving grate in the furnace and the residual ash falls at the other end of the grate into the ash pit.

The boiler is fitted with a *superheater*. The superheater consists of number of U-tubes secured at each end to the horizontal connecting boxes and placed in the combustion chamber underneath the boiler drum. The upper box of the superheater tubes is connected to a T-tube, the upper branches of the T-tube being situated in the steam space in the drum. The lower box of the superheater tubes is connected to the steam stop valve mounted over the drum through a vertical tube passing outside the drum.

Water Circuit in the Boiler: The water is introduced into the boiler drum through the *feed valve*. A constant water level is maintained in the boiler drum. The water descends at the rear end into the down take headers and passes up in the inclined water tubes because of reduction in density due to heating. The flow continues to the uptake headers and the drum. Thus a circuit is established between the drum and the water tubes for the flow of water.

Path of the Flue Gases: The hot gases from the furnace grate are compelled by the *baffle plate* to pass upwards around the portion of the water tubes lying in between the combustion chamber and be1ow the water drum, then downwards around the portion of the water tubes in between the baffle plates, then once again upwards between the baffle plate and the downtake header, and finally passes out of the boiler through the exit door and the chimney.

Circulation of the Water: During this path of the hot gases, the hottest gases emerging directly from the grate come in contact with the hottest portions of the water tubes. The water in these portions of the water tubes gets evaporated. The water and the steam mixture from these portions of the water tubes ascend through the uptake headers and reach the boiler drum. Now due to this flow, a continuous rapid circulation of water is established between the boiler drum and the water tubes. The steam gets separated from the surface of the water in the boiler drum.

Superheating of the Steam: The steam from the steam space in the boiler drum is led into the branches of T-tube, and then passes into the upper connecting box of the superheater, then through its V-tubes. Since the superheater tubes are fitted in the combustion chamber and directly exposed to the hot gases, the steam passing in it will be superheated. The superheated steam from the superheater tubes are passed to the steam stop valve through the lower connecting box and the vertical tube fitted outside the drum. From the steam stop valve the superheated steam is passed to the primemover. When the superheated steam is not required, the steam from the steam space directly passes out to the prime mover through the steam stop valve. The boiler is mounted with the essential mountings such as steam stop valve, safety valve pressure gauge and water level indicator as shown at their appropriate places.

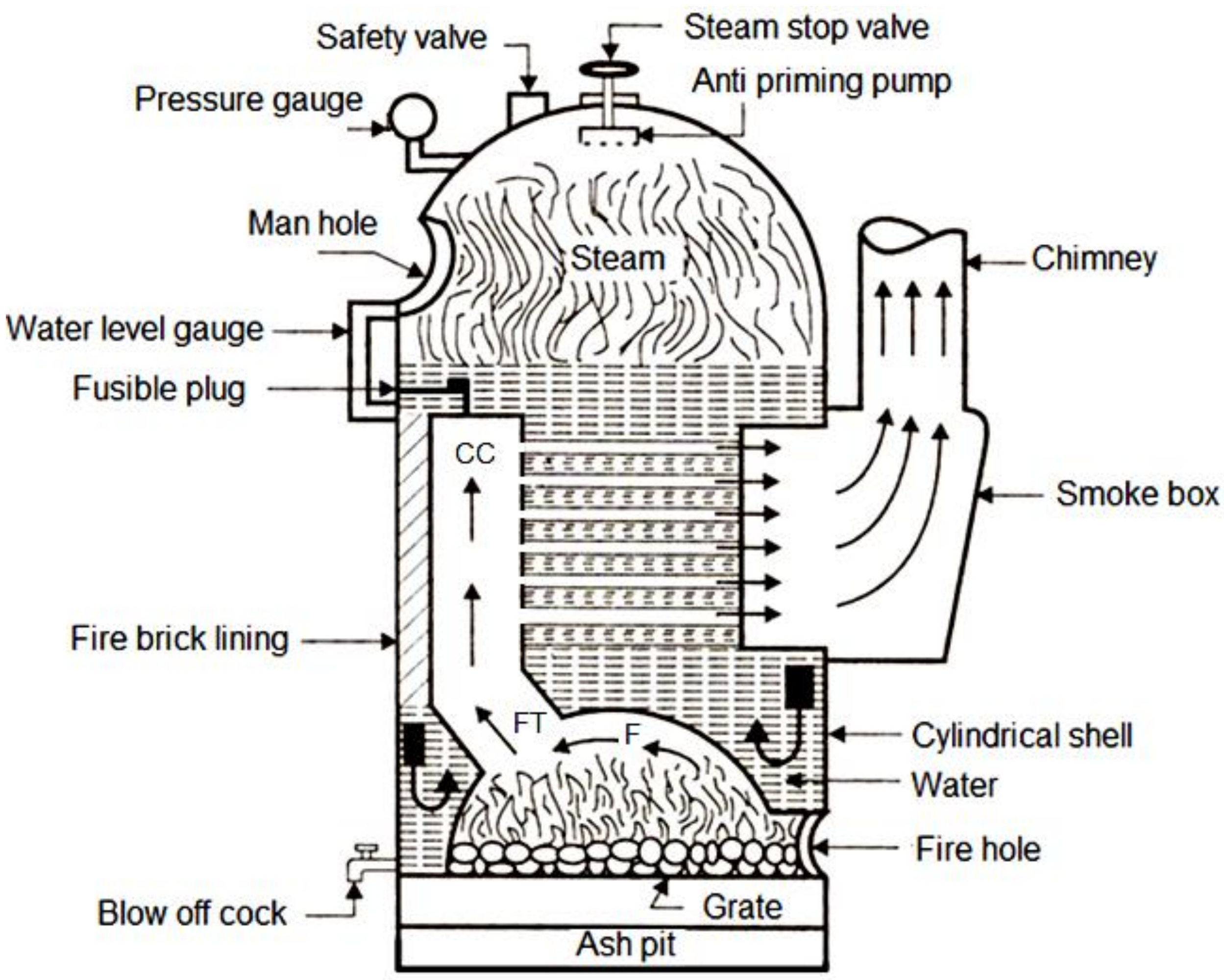
Explain the construction and working of Cochran boiler. Show the direction of flow of flue gases

Cochran boiler is an example for vertical, multi tubular, fire tube boiler. This boiler is used whenever steam at low pressure is required.

Construction:

1. Cochran boiler consists of cylindrical shell with dome shaped top where space is provided for steam to accumulate.
2. Furnace is also dome-shaped like the shell so that the gases can be deflected back till they are passed out through the flue pipe to the combustion chamber.
3. A number of horizontal fire tubes are provided; thereby the heating surface is increased.
4. Combustion chamber is lined with fire bricks on the side of the shell to prevent overheating of the boiler.
5. Chimney is provided for the exit of the flue gases to the atmosphere from the smoke box.
6. Manhole is provided at the top for inspection and repair of the interior of the boiler shell.
7. Grate is placed at the bottom of the furnace where coal is burnt.

   Boiler mountings and accessories are provided on the boiler for optimum performance.



CC - Combustion chamber FT - Fire tubes F - Furnace

Working:

1. Coal is fed into the grate through the fire hole and burnt.
2. The host gases from the grate pass through the flue tubes to the combustion chamber. The hot gases from the combustion chamber flow through the horizontal fire tubes and transfer the heat to the water by convection.
3. The heat transferred from the tubes to the water boils it and produces steam. The steam formed is collected in the hemispherical shell and is removed with the help of steam stop valve.
4. The flue gases coming out of fire tubes pass through the smoke box and are exhausted to the atmosphere through the chimney.

   Ash formed during burning is collected in the ash pit provided just below the grate and then it is removed manually.

2.9 List the Advantages and Disadvantages of Water Tube Boilers over Fire Tube Boilers

Ans: Advantages:

1. ***Steam can be raised more quickly:*** In water tube boilers, the ratio of water content to the steam capacity is comparatively less than the fire tube boiler. Hence water tube boilers can quickly generate steam at the required pressure than the fire tube boiler.
2. ***Steam at higher pressures can be produced:*** The water tube boilers do not contain any tubes inside the boiler drum. Hence the water tube boilers can withstand high pressures for the same wall thickness and the thermal stresses. Therefore water tube boilers can develop higher pressures than the fire tube boilers.
3. ***Higher rate of evaporation:*** In water tube boilers, water is contained in a large number of small diameter tubes; therefore the heating surface of a water tube boiler is more than that of the fire tube boiler. The relatively large heating surface of the water tube boiler increases the evaporation rate. The increased rate of evaporation of the water tube boiler makes it more suitable for large power plants.
4. ***Sediment deposition is less:*** In water tube boilers, the circulation of water is more positive than that of the fire tube boilers; hence there is a less tendency of the deposits to settle on the heating surfaces. This positive circulation also helps the quick generation of steam than the fire tube boiler.
5. ***Suitable for any type of fuel and method of firing:*** Since the water tube boilers are externally fired, the size and proportions of the furnace can be altered to suit any type of fuel and the method of firing which is not possible in the case of fire tube boilers.
6. ***More effective heat transfer:*** The heat transfer in the water tube boilers is more effective than the fire tube boilers since the hot gases flow at right angles to the water tubes.
7. ***Failure of water tubes will not affect the working of boiler:*** Bursting of any of the water tubes does not pose any serious problems, whereas the bursting any of the flue tubes causes serious problems in fire tube boilers.
8. ***Occupies less Space:*** For a given power, water tube boiler occupies less space than that of the fire tube boilers.
9. ***Easy maintenance:*** All parts of the water tube boilers are easily accessible compared to, the fire tube

boilers, for cleaning, repairing and inspection and hence maintenance is easy.

10. ***Easy transportation*:** Water tube boilers can be easily dismantled conveniently transported and erected quickly at the site than a fire tube boiler.

Disadvantages:

1. **Not suitable for ordinary water:** Water tube boilers require relatively pure feed wan because impure feed water forms scale inside the water tubes, consequently there will t overheating and bursting of the water tubes.
2. **Not suitable for mobile application:** Water tube boilers are not suited for mobile purposes.
3. **High initial cost and hence not economical:** The initial cost of the water tube boiler' more than that of the fire tube boiler.

2.10 Write the difference between Water Tube and Fire Tube Boilers.

Ans:

1. **Passage of Hot Gases:** In the water tube boilers, the hot gases pass around a large number of tubes through which m water circulates, whereas in a fire tube boiler the hot gases pass through the flue tubes.
2. **Position of the Furnace:** In the water tube boilers, the furnace will be situated outside the boiler shell whereas in a fire tube boiler, the furnace will be within the boiler shell.
3. **Water Circulation:** In water tube boilers, water will be in continuous circulation between the drum and the tube whereas in the fire tube boilers, the water circulation will be within the drum itself.

2.11 List the boiler mountings and accessories and also mention their functions or uses.

Ans: For the satisfactory functioning, efficient working, easy maintenance and the safety of boilers, they have to be equipped with some type of *fittings* and *appliances.*

The first category, namely fittings, called *boiler mountings,* are required for the complete controlling of the steam generation, measurement of some of the important steam properties, and to provide safety to the boiler. They are fitted directly on the boilers. The essential boiler mountings are:

1. *Two water level indicators*
2. *Pressure gauge*
3. *Two safety valves*
4. *Steam stop valve*
5. *Blow off cock*
6. *Feed check valve*
7. *Fusible plug*

The second category, namely appliances, called *boiler accessories* are required to improve the efficiency of steam power plant and to enable for the proper working of the boiler. The accessories are *not* mounted directly on the boiler. The essential boiler accessories are:

1. *Economiser*
2. *Air preheater*
3. *Superhater*
4. *Feed pump*
5. *Steam separator*
6. *Steam trap*

2.12 Function of the Boiler Mountings and Accessories

Ans: **Boiler Mountings:**

Water Level Indicator: The function of the water level indicator is to indicate the level of the water in the boiler drum.

Pressure Gauge: The function of the pressure gauge is to indicate the pressure of steam in the boiler.

Safety Valves: A boiler is designed to produce steam at it certain rated pressure, called *designed pressure,* however, the working pressures will be less than the *designed pressure.* When the boiler is in operation, either due to the sudden reduced rate of flow of steam out of the boiler, or sudden increased rate of steam generation which may be due to the low water levels or increased rate of combustion, there will accumulation of *excess steam* inside the boiler causing a sudden increase in pressure higher than the designed pressure and pose a danger to the safety of the boiler. At such an instant, the excess steam must be suddenly released from the boiler to reduce the pressure in it. A *safety valve suddenly* blows off the excess of steam from the boiler and shuts off automatically

Steam Stop Valve: A steam stop valve or Junction valve is used to regulate the flow of steam from the boiler.

Feed Check Valve: When the level of water in the boiler falls, it is brought back to the specified level by supplying the additional water called feed water. The pressure inside the boiler will be high therefore the pressure of the feed water has to be raised by a pump before it is fed into the boiler. The feed water at high pressure is fed into the boiler through the *feed check valve.*

Blow off Valve or Cock: The function of the blow off valve is to remove periodically the sediments collected at the bottom of the boiler while in operation. It is also used to empty the water in the boiler when required for periodical cleaning and inspection.

Fusible Plug: Fusible plug is a safety device used to extinguish the fire in the furnace of the boiler when the water level falls too much below the normal level. It is fitted over the crown of the furnace or the combustion chamber.

Boiler Accessories:

Economizer and air preheater: The combustion gases passing out from the boiler will have to be hotter than the water in the boiler; otherwise heat will be transferred from the water to the gases. Thus the gases coming out of the boiler contain large quantity of heat. Therefore maximum amount of heat from the gases should be recovered before it escapes to the chimney. The two accessories that recover heat from the exit gases are: *(i) economizer* and *(ii) air preheater.* In the economizers, the recovery of heat in the flue gases is done by heating the feed water. In the air preheaters, the recovery of heat is done by heating the air supplied for the combustion of the fuel in the furnace.

Superheater: Superheaters are used in boilers to increase the temperature of the steam above the saturation temperature.

Steam trap: Steam trap is a device used to drain off the condensed water accumulating in the steam pipe lines while at the same time the high pressure steam does not escape out of it.

Steam Separator: A steam separator separates the water particles from the steam flowing in the pipe lines.

Feed Pump: A feed pump is a boiler accessory to force the feed water at higher pressure into the boilers.

STEAM TURBINES

Q 3.14 What are Steam Turbines?

Ans: A steam turbine is defined as a prime mover in which the heat energy of the steam transformed into mechanical energy directly in the form of rotary motion. The heat energy of the steam is first converted into kinetic (velocity) energy which in turn is transformed into mechanical energy of rotation. A steam turbine is mainly used as an ideal prime mover to drive the electric generators in thermal power plants to generate electric power. They are also used to propel the ships and to drive the uniform speed machines such as centrifugal gas compressors, textile and sugar industry machineries, etc.

Q 3.15 What are the Propelling Forces in the Steam Turbine

The propelling force in a steam turbine depends mainly on the *dynamic action* of the steam. The steam is made to fall in its pressure by expanding in a nozzle,(*Fig.3.9)* due to this fall in pressure; a certain amount of heat energy is converted into kinetic energy which sets the steam to flow with a greater velocity. The rapidly moving particles of the steam enter the rotating part of the turbine where it undergoes a *change* in the direction of motion which gives rise to *a change of momentum and therefore a force.* This constitutes the driving force of the turbine.

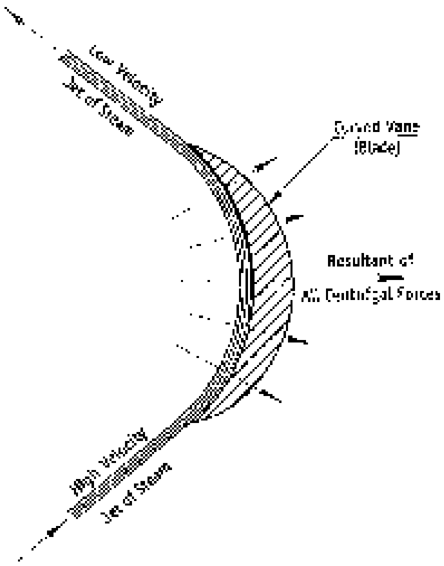


Fig. 3.9: Propelling Forces in Impulse Turbine

Q 3.16 Explain the Expansion of steam in the nozzle.

Ans: A high velocity jet of steam is produced by expanding a high pressure steam in a convergent – divergent nozzle shown in fig. The steam at high pressure and relatively low velocity enters the nozzle and as it passes between the entry and the throat, it expands to a low pressure. Due to this expansion in this portion of the nozzle the enthalpy of the steam is reduced. As there is no external work done and heat transfer in the nozzle, this *loss in the enthalpy of the steam must therefore be equal to the increase in the velocity (kinetic energy) of the steam.* Therefore a jet of steam at high velocity comes out of the throat section of the nozzle. The divergent portion of the nozzle beyond the throat is provided to complete any remaining expansion without the lateral spreading of the high velocity jet of steam.

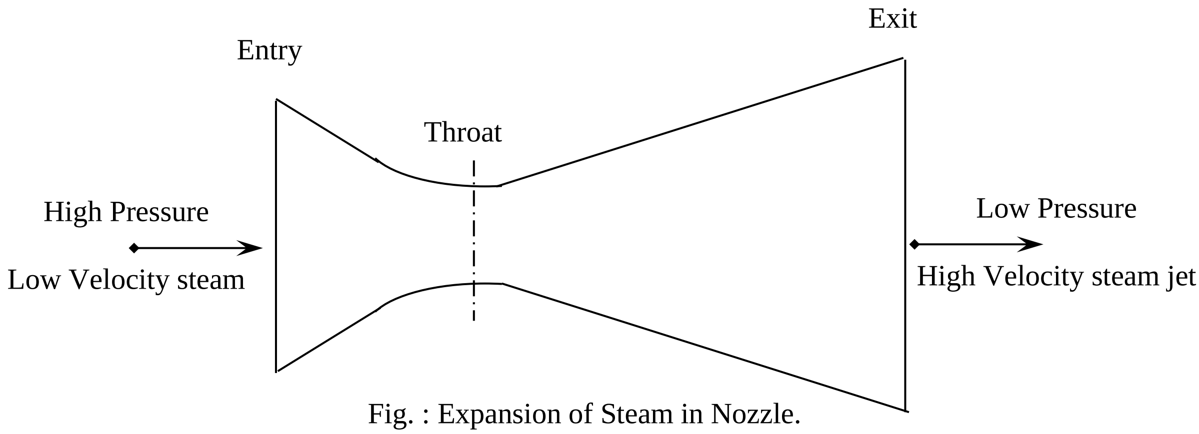


Fig. : Expansion of Steam in Nozzle.

Q 3.17 What is an Impulse Steam Turbine? Explain

Ans: In this type of turbine, *the steam is initially expanded in a nozzle* from high pressure to low pressure. The high velocity jet of steam coming out of the nozzle is made to glide over a curved vane, called *blade,* as shown in *Fig.3.10.* The jet of steam gliding over the blade gets deflected very nearly in the circumferential direction. This causes the particles of steam to suffer a *change in the direction of motion* which gives rise to a *change of momentum* and therefore a *force,* which will be *centrifugal* in nature. The particles of steam exert centrifugal pressures all along their path on the curved surface of the blades as shown in *Fig.3.10* . The *resultant* of all these centrifugal forces acting on the entire curved surface of the blade causes it to move. When a number of such blades are fitted on the circumference of a revolving wheel called *rotor,* as shown in *Fig. 3.10.* They will be moved by the action of the steam, and they in turn set the *rotor* in continuous rotation. The rotation of the rotor makes all the blades fitted on the rim to get exposed to the action of the steam jet in succession.

In the impulse turbines the steam is expanded from its high initial pressure to a lower pressure before it is delivered to the moving blades on the *rotor.* The pressure of the steam over the blades will be at a lower pressure. However, the *velocity of the steam continuously decreases* as *it glides over the blades* owing to the conversion of kinetic energy into mechanical energy of rotation. Thus in the *impulse turbines the mechanical power* is *produced* by *the combined action of the resultant of the centrifugal pressures due the change of momentum and the effect of change of velocity of the steam* as it glides over the blades.

Although there is *no direct impulsive action* on the moving blade *that* is *causing the turbine rotor to rotate, but the impelling action of the jet of steam on the blades drives the rotor to rotate* in *the same direction of the propelling force,* this type of turbine is called *impulse turbine.* The examples of impulse turbines are, De Laval, Curtis and Rateau.

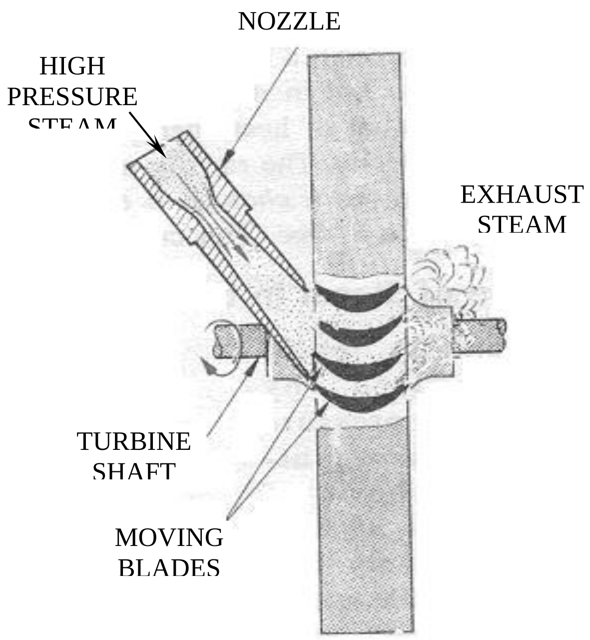


Fig.3.10 Schematic of Impulse Turbine

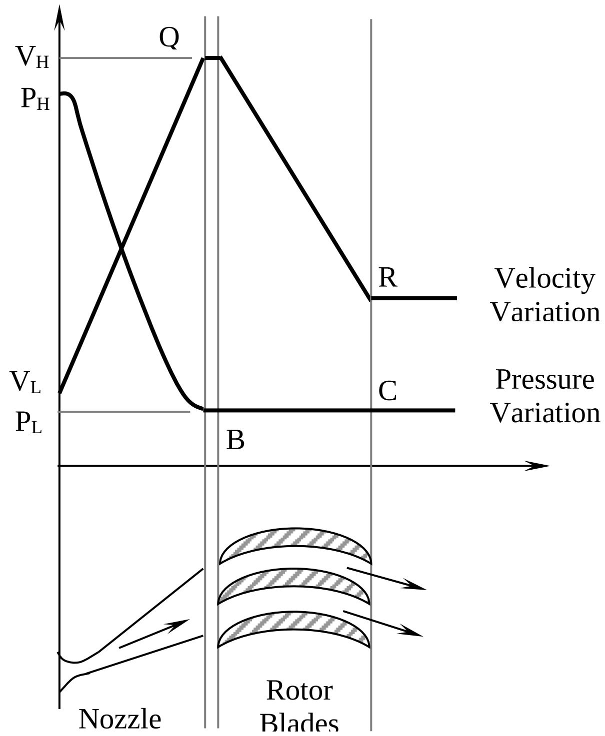


Fig.3.11 Diagrammatic Impulse Turbine

Fig.3.11 shows the diagrammatic representation of an impulse turbine. The lower portion shows the nozzle and the blade, and the top portion shows the variation of pressure and velocity of the steam as it flows through the nozzle and over the blades. Since the expansion of the steam takes place in the nozzle, the pressure drop is represented the curve AB. As there b no change in the pressure of the steam that is passing over the blade, this flow is represented by the horizontal line BC. Since the velocity of the steam in the nozzle increases due to the expansion of the steam, the increase in the velocity of the steam is represented by the curve PQ. As the blades absorb the kinetic energy of the steam as it flows over it, the velocity decreases. This is represented by the curve QR.

Q 3.18 Explain the principle of Reaction Turbine.

In this type of turbine the high pressure steam *does not initially expand in the nozzle* as in the case of impulse turbine, but instead directly passes onto the moving blades, *Fig.3.12,* whose shapes are designed in such a way that the steam flowing between the blades will be subjected to the nozzle effect. Hence the pressure of the steam drops continuously as it flows over the blades causing, simultaneous increase in the velocity of the steam. The increase in the velocity of the steam flowing over the blades develops a force within itself which, enables it to move further, consequently there will be a *backward reaction* to the force causing the *motion of the jet.* Thus the reaction force acting on the blades constitutes a fraction of the propelling force driving the turbine rotor. *In addition to this reaction force, there* is *also the centrifugal force exerted* by *the steam due to the change m the momentum because the* *change* in *the direction of the steam passing over the blades.*

This reduces the velocity of the steam. Thus the net force *acting on the moving blades of* a *reaction turbine is the vector sum of the centrifugal and the reaction forces* as shown by the force diagram shown in *Fig.3.13* below. This type of turbine is called *reaction turbine.*

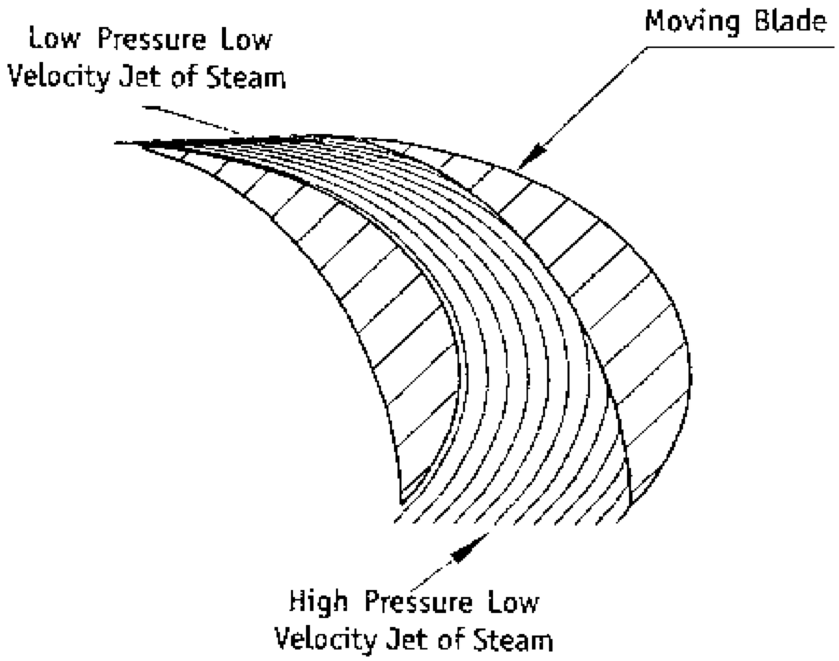


Fig. 3.12: Shape of Blades

The actual reaction turbine, also called impulse-reaction turbine, consists of a number of rows of moving blades fitted on the different rotors keyed to the turbine shaft with alternate rings fixed blades rigidly fixed to the casing of the turbine. Both the fixed and moving blades are designed in the shape of the nozzles. Therefore the expansion of the steam takes place both in the fixed and the moving blades. The fixed blade rings between the two moving blade rotors enables to deflect and guide the steam to enter from one row of moving blades to the next row.

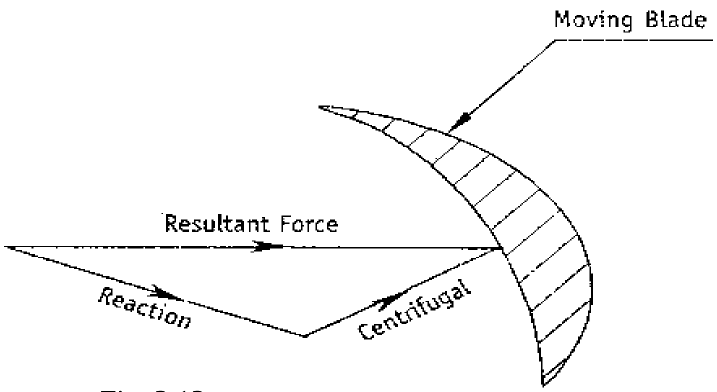


Fig. 3.13: Force Diagram

The high pressure steam passing in the first row of fixed blades undergoes a small drop in pressure causing the increase in the velocity of the steam. It then enters the first row of moving blades where it suffers further drop in pressure and the velocity energy is converted into the mechanical energy of rotation of the rotor. Thus the velocity of the steam decreases. This Continues in further rows of moving and fixed blades till the pressure of the steam is almost completely reduced. The changes in the pressure and velocity of the steam as it flows over the moving and fixed blades are shown in the *Fig.3.14* below.

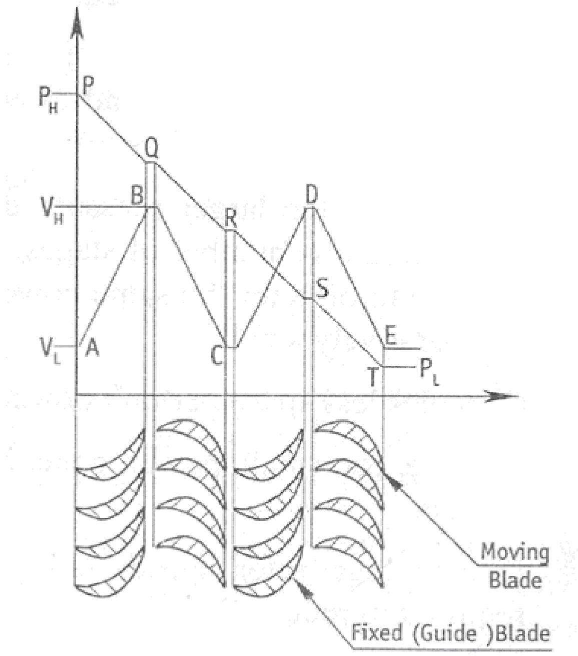


Fig. 3.14: Pressure-Velocity Changes in Reaction Turbine

Q 3.19 Compare Impulse and Reaction Steam Turbines

Impulse Turbine	Reaction Turbine
1. Steam completely expands from a high pressure to low pressure in the nozzle expands before it enters the moving blades.	The high pressure steam continuously expands successively in both the fixed and moving blades.
2. The symmetrical profile of the moving blades provides a uniform section for the *flows* of the steam between them causing no expansion of the steam.	The asymmetrical profile of both the moving and fixed blades provides a varying section for the flow of steam between them which causes the expansion of the steam.
3. The pressure of the steam at both the ends of the moving blades and as well as while passing over them remains constant.	The pressure of the steam at both the ends of the fixed and moving blades and as well as while passing over them are different.

4. Because of the large drop in pressure in the nozzle, and as well as the rotor speeds are high.	Due to the smaller pressure drop over both fixed and moving blades, both the steam speed and the rotor speed are relatively low.
5. Because of the larger pressure drop in the nozzle and less number of stages, size of the impulse turbine for the same power output is comparatively small.	Because of the smaller pressure drop in every stage, and more number of stages, size of the reaction turbine for the same power output is large.
6. Occupies less space per unit power.	Occupies more space for the unit power.
7. Suitable for small power generation prime movers.	Suitable for medium and high power generation prime movers.
8. Due to high rotor speeds compounding is required to reduce the speed.	The speeds are relatively less and hence no compounding is required.

Q 3.20. List the Advantages of Steam Turbines over Heat Engines

1. From the thermodynamic point of view, the steam turbines are advantageous over heat engines, since relatively large fraction of the heat energy of the steam can be converted into mechanical work.
2. Because of the higher power output and higher operating speeds, the thermal efficiency of steam turbines is higher.
3. From the mechanical point of view, the steam turbines are ideal prime movers when compared to the heat engines since the propelling force is applied directly on the rotating element.
4. It is the best suited prime mover for driving high speed machines such as electric, generators, centrifugal gas compressors, etc.
5. The steam turbine is an ideal prime mover for driving machines which require uniform torque and consequent uniform speed as required in certain textile machines.
6. The steam turbines are used for the propulsion of ships of very large tonnage and high speeds which are beyond the range of other prime movers.
7. Steam turbines are ideally suited in thermal power plants as they can take up sudden overloads with only a marginal reduction in their efficiency.
8. Steam turbines can be used for wide range of power applications as they can be built into a sing1e unit of ratings ranging from units of a few kW to over 1000 kW.

Q 3.25. What is a Gas Turbine? Classify it and write briefly about each one.

Ans: A gas *turbine* is similar to a steam turbine, but Instead of applying the heat obtained by the combustion of fuels to produce steam which runs the steam turbines, uses the hot gases of combustion directly to produce the mechanical power. A gas turbine essentially consists of a combustion chamber in which a liquid fuel is burnt in presence of air supplied by a compressor. The air compressor sucks the air from the atmosphere and compresses it, thereby increasing its pressure. In the combustion chamber, the compressed air combines with fuel and the resulting mixture is burned. The burning gases at very high pressures expand rapidly and made to pass over the rings of moving blades mounted on the turbine shaft where its kinetic energy is absorbed by the moving blades imparting rotary motion to the turbine shaft. In most of the gas turbines, both the air compressor and the turbine are mounted on the same shaft. Therefore a part of the power developed by the turbine runs the air compressor while the remaining power is utilized for doing the external work.

The Gas Turbines are classified mainly into two categories, viz., *Closed and Open Cycle Gas Turbines.* The fundamental difference between the two cycles is the course of the flow of the working substance in the cycle of operation. If the flow of the working substance of specified mass is confined within the cycle path, then the gas turbine is said to work on *closed cycle.* Instead if the entire flow of the working substance comes from the atmosphere and is returned to the atmosphere in each cycle, then the gas turbine is said to work on *open cycle.*

Q 3.26. Sketch and explain the Principle of Operation of Closed Cycle Gas Turbine

Ans: Fig.3.18 below shows schematically a simple closed cycle gas turbine plant. It consists of a *compressor,* a *heater,* a *cooler* and the *gas turbine.* Both the compressor and the gas turbine are coupled together or mounted on the same shaft. The high compressed gas coming out of the compressor is heated by an external source in the heater which increases the temperature of the gas. The high pressure and high temperature gas is passed to the gas turbine where it expands to lower pressure driving the turbine shaft producing the mechanical energy of rotation. The gas exhausted from the turbine enters the cooler where it is cooled from the external cooling source. The cooled exhaust gas at lower temperature and pressure enters the compressor where it is compressed to higher pressure and relatively higher temperature and the cycle repeats.

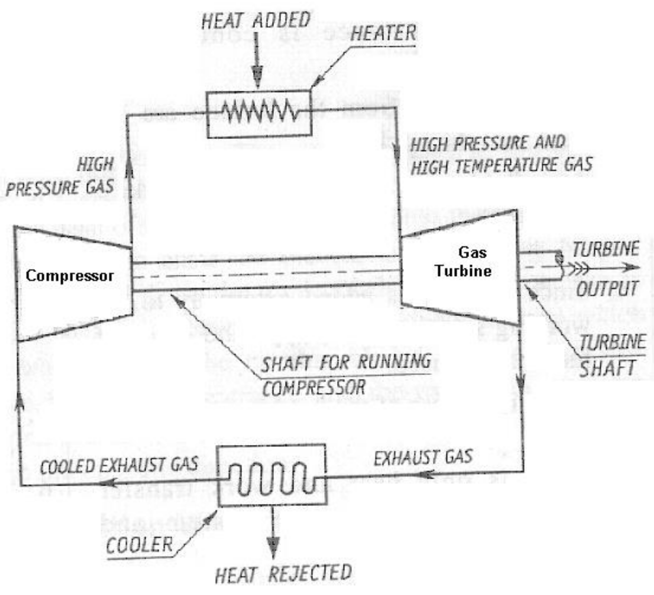


Fig.3.18: Closed Cycle Gas Turbine

Q 3.27. Sketch and explain the Principle of Operation of Open Cycle Turbine

Ans: *Fig.3.19* shows schematically a simple open cycle gas turbine. It consists of a *compressor, combustion chamber* and the *gas turbine:* Both the compressor and the gas turbine are coupled together or mounted on the same shaft. The atmospheric air is drawn into the compressor and compressed to high pressures. The high pressure and relatively high temperature air flows to the combustion chamber where heat is added to the air by the combustion of the fuel in the combustion chamber. The high pressure, high temperature gases are then passed to the turbine, where it expands to lower pressure driving the turbine shaft producing the mechanical energy of rotation. The gas from the turbine exhausted into the atmosphere and is not used any more. Thus the working fluid is replaced in every cycle.

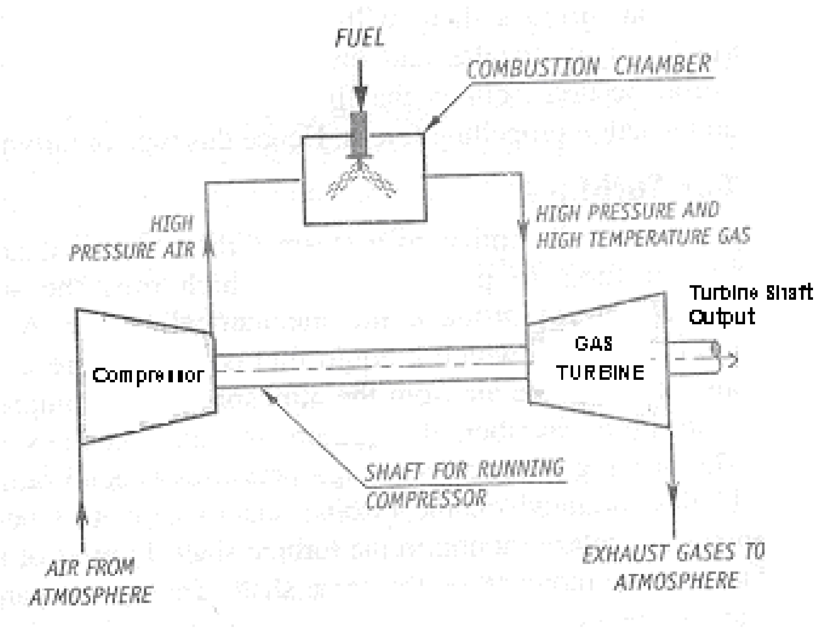


Fig.3.19: Open Cycle Gas Turbine Cycle.

Q 3.28. Differentiate between closed and Open Cycle Gas Turbines

Closed Cycle	Open Cycle
1. Working substance is continuously recirculated.	Working substance is replaced in every cycle.
2. Exhaust gases from the turbine are fed back into the cycle.	Exhaust gases from the turbine exit to the atmosphere.
3. Any fluid may be used as the working substance.	The working substance comprises of the mixture of air and products of combustion of the fuel.
4. Since the heat is added externally to the working substance, any type and grade of fuel may be used,	Since the products of combustion of fuel and air expand in the turbine only high grade fuels have to be used.
5. There is no loss of the working substance.	In every cycle, fresh air is drawn.
6. There is only heat and work transfer takes place between the system and surrounding.	There is mass transfer taking place in addition to heat and work transfer between the system and surrounding,

7. Large amounts of cooling water is required in the cooler.	No cooling water is required as the exhaust gases are not cooled.

Q 3.29. What is a Water turbine? Classify it and write briefly about each one.

Ans: Hydraulic or water turbines are the machines which convert the kinetic and Potential energies possessed by water into mechanical rotary motion or power. In other words, water turbines are the prime movers which when coupled to an electric generator produces electric power. Hydro-electric power can be developed whenever continuously flowing high pressure water is available. By constructing dams across rivers, artificial reservoirs are created. The water is carried from these reservoirs to the turbine stations through large pipes called penstocks.

Water turbines are classified according to various criteria, of which the classification based on type of hydraulic action which converts the hydraulic energy into mechanical energy is the major method of classification. According to this, the water turbines are classified as:

(i) Impulse turbine and *(ii) Reaction Turbine.*

Impulse Water Turbine: In impulse water turbine the whole of the pressure energy of the water is converted into kinetic energy in one or more number of nozzles *before it is passed on to the turbine wheel. The* water comes out of the nozzle in the form of a jet at very high velocities. This high velocity jet is made to strike a series of curved blades mounted on the periphery of a wheel keyed to the turbine shaft. The impulsive force of the jet exerted on the series of curved blades sets up the wheel in rotation in the direction in which the jet is impinging. The water as it flows over the blades will *be at* atmospheric pressure, Since the whole of the pressure, energy of the water is converted into the kinetic energy before it is passed on to the moving blades, an impulse turbine requires *high head and low discharge* at the inlet of the turbine. Examples of the impulse turbines are *Pelton Wheel, Banki Turbine* and *Jonval Turbine.*

Reaction Water Turbine: A reaction turbine requires low head with high rate or flow. The water supplied to the reaction turbine posses both pressure as well as kinetic energies. All the pressure energy of the water is not completely converted into kinetic energy as in the case of the impulse turbine. First the water passes to the guide blades which guide or deflect the water to enter the blades, called *moving blades,* mounted on the turbine wheel, without shock. The water from the guide blades are deflected on to the moving blades where its part of the pressure energy is converted into the kinetic energy which will be absorbed by the turbine wheel. The water leaving the moving blades will be at a low pressure. Thus there is a difference in pressure between the entrance and the exit of the moving blades. This difference in pressure, called *reaction pressure,* acts on the moving blades of the turbine wheel and sets up the turbine wheel in rotation in the opposite direction. The examples of the reaction turbines are *Francis Turbine, Kaplan Turbine and Propeller Turbine.*

Q 3.30. Differentiate between Impulse and Reaction Water Turbines

Ans: Following are the differences between the impulse and the reaction water turbines:

- In the impulse water turbine, the whole of the pressure of energy of the water is converted into kinetic energy before it is passed onto the turbine wheel, whereas in a reaction water turbine the water flows with both pressure and kinetic energies over the moving blades where its part of the pressure energy is converted into the kinetic energy.
- In the impulse water turbine, the pressure of the water will be atmospheric as it flows over the moving blades, whereas in a reaction water turbine, the pressure of the water continuously decreases as it flows over the moving blades.
- In the impulse water turbine, the *impulsive force* of the jet sets up the rotation of the turbine wheel, whereas in a reaction turbine, the *reaction pressure* sets up the rotation of the turbine wheel.
- In the impulse water turbine, the water may be admitted over a portion of the circumference, whereas in a reaction turbine, the water must be admitted over the whole of the circumference of the wheel.
- In an impulse turbine, the water discharges directly from the turbine wheel to the tail race whereas in a reaction water turbine, the water discharges from the turbine into a draft tube from which it discharges finally into the tail race.

Q 3.31. Sketch and explain the Pelton Wheel (or Turbine)

Ans: The *Pelton wheel* is the most commonly used type of *impulse turbine.* It works under a higher head and requires small quantity of water, *Fig.3.20* shows a schematic sketch of a Pelton Wheel. The water from a high head source is supplied to the *nozzle* provided with a *needle*, which controls quantity of water flowing out of the nozzle. The pressure energy of water is converted into velocity as it flows through the nozzle. The jet of water issuing out of the nozzle at high velocity impinges on the curved blades known as *pelton cups,* at the centre as shown in the adjoining fig. The impulsive force of the jet striking on the Pelton cups sets up the pelton wheel to rotate in the direction of the impinging jet. Thus the pressure energy of the water is converted into mechanical energy. The pressure inside the casing of the turbine will be at atmospheric pressure.

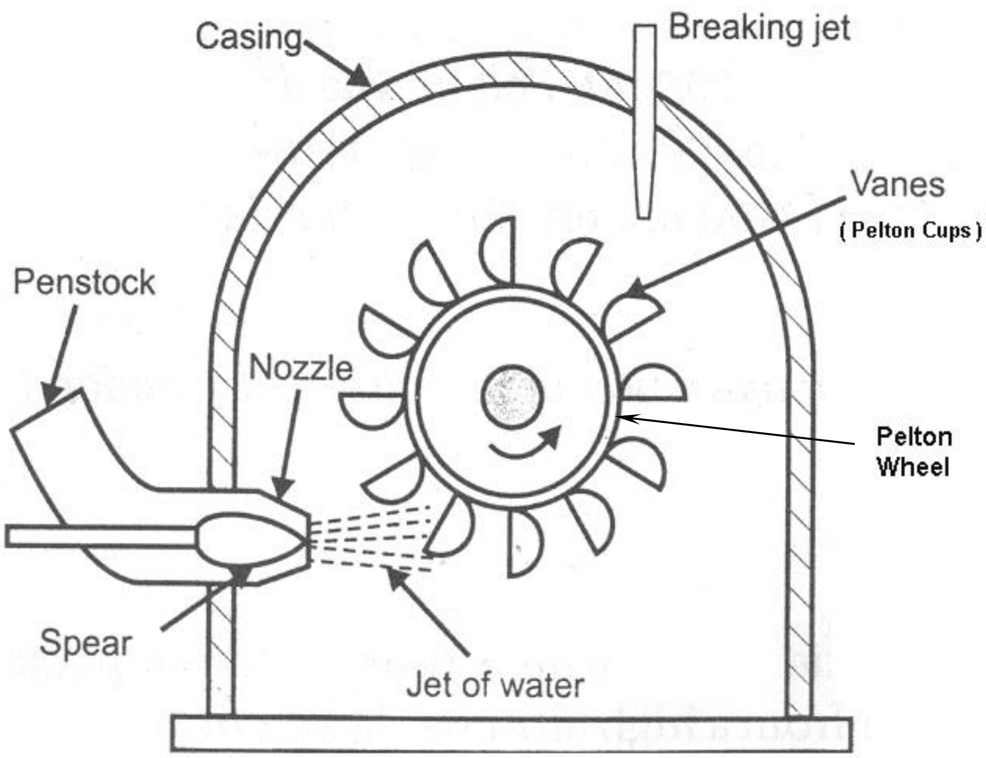


Fig.3.20: Pelton Wheel

Q 3.32. Sketch and explain the Francis Turbine

Ans: The *Frances turbine* is a medium head reaction turbine in which water flows radially inwards. *Fig.3.21* shows a simple schematic representation of the Francis turbine. It consists of a *spiral casing* enclosing a number of stationary *guide blades* fixed all round the circumference of an inner ring of *moving vanes* forming the *runner* which is keyed to the turbine shaft. Water at high pressure enters through the inlet in the casing and flows radially inwards to the Outer Periphery of the runner through the guide blades. From the outer periphery of the runner the water flows inwards through the moving vanes and discharges at the centre of the runner at lower pressure. During its flow over the moving blades it imparts kinetic energy to the runner to set it into rotational motion. To enable the discharge of water at lower pressure, a diverging conical tube called, *draft tube* is fitted at the centre of the runner. The other end of the draft tube is immersed in the discharging side of the water known as *tailrace.*

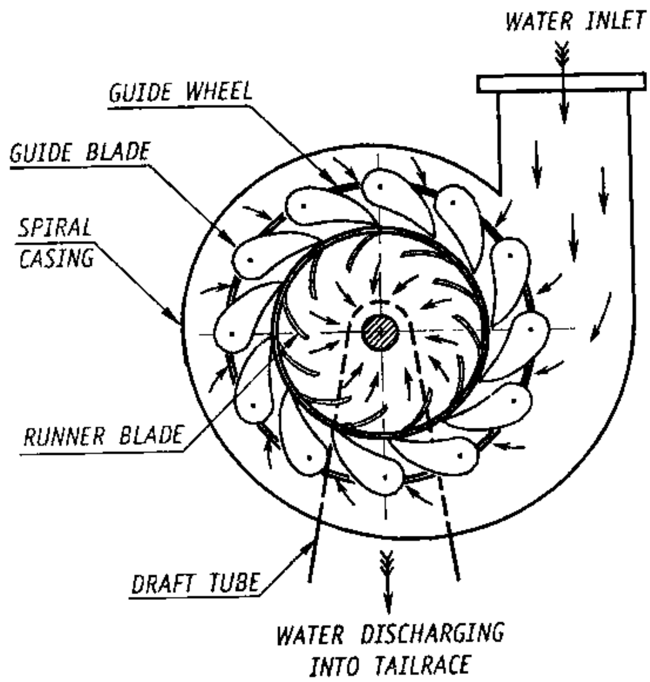


Fig.3.21: Francis Turbine

Q 3.33. Sketch and explain the Kaplan Turbine

Ans: The *Kaplan turbine* is a low head reaction turbine in which water flows axially. *Fig.3.22* shows a simple schematic representation of a Kaplan turbine. All the parts of the turbine are similar to that of the Francis turbine except the runner and the draft tube. The runner of the Kaplan turbine resembles with the propeller of the ship, hence sometimes the Kaplan turbine is also called *Propeller turbine.* The water at high pressure enters the turbine casing through the inlet and flows over the guide blades. The water from the guide blades strikes the runner blades axially imparting the kinetic energy to set it into rotational motion. The water discharging at the centre of the runner in the axial direction into the draft tube which is in L-shape having its discharging end immersed into the tail race.

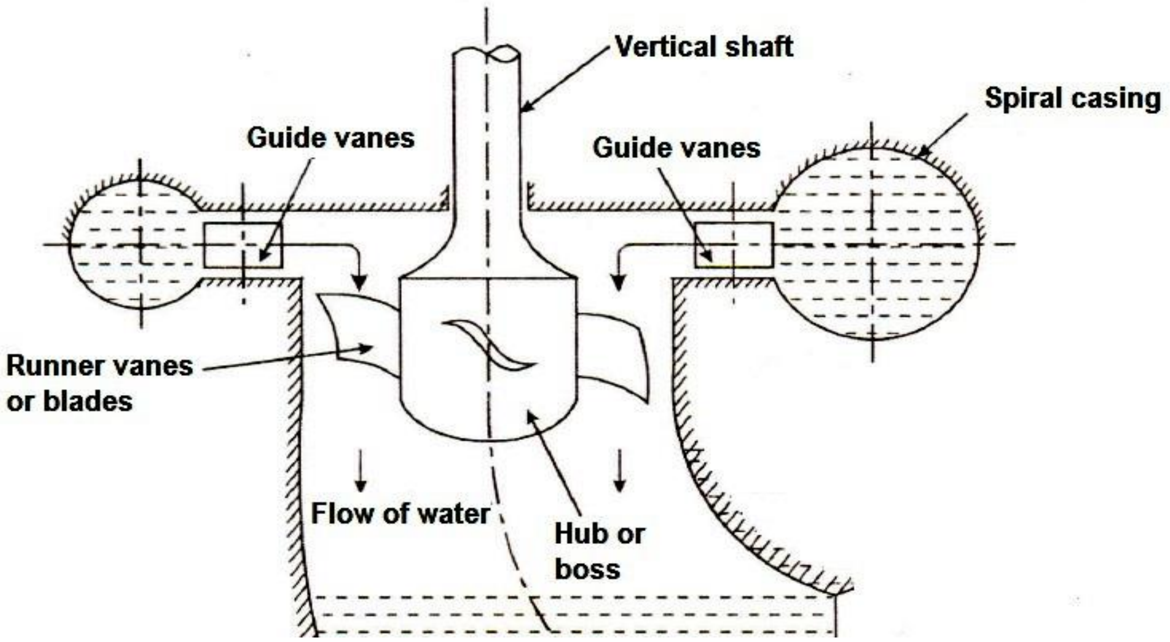
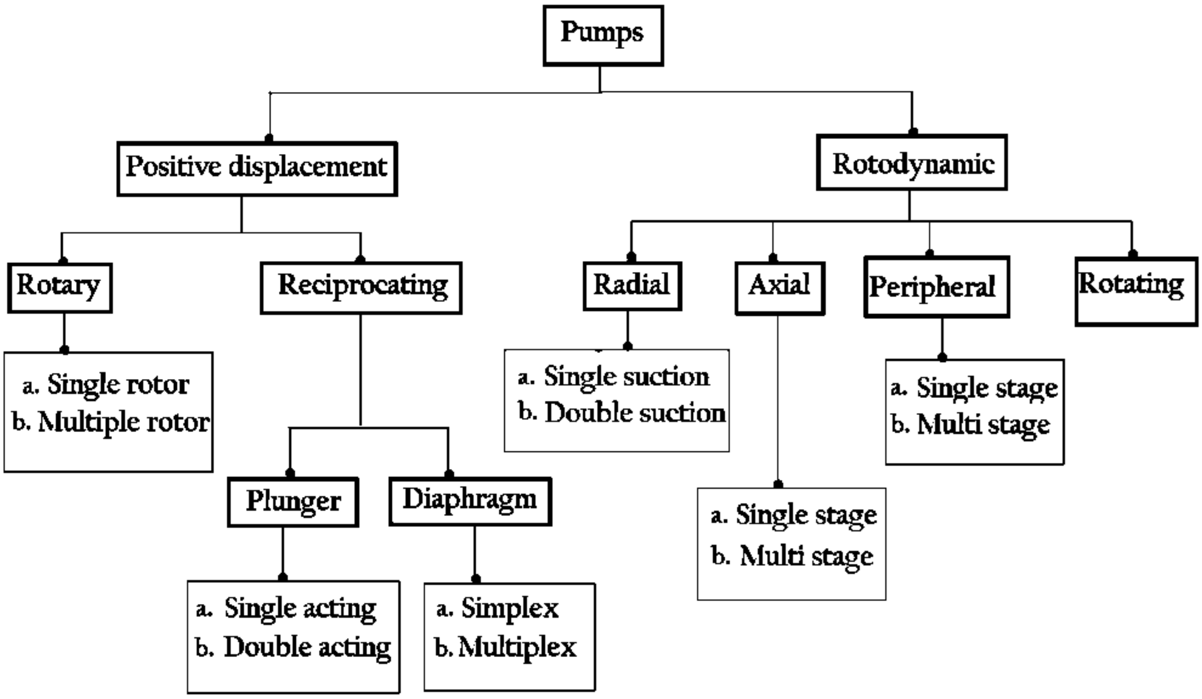


Fig.3.22 : Kaplan Turbine

Pumps & Compressors

Machines which convert mechanical energy into hydraulic energy are called pumps. Pumps are used in various fields where a pressurized or high velocity fluid is required. Application area of pumps include agriculture fields, domestic water pumping, in sewage plants, in petrol and oil processing plants, in chemical refineries, in fire extinguishing vehicles etc.

What are the Classification of pumps



Explain the working priniciple of Centrifugal Pump

Working:

1. The centrifugal pump works on the principle of forced vortex flow which means when certain mass of liquid is rotated by an external torque, rise in pressure takes place.

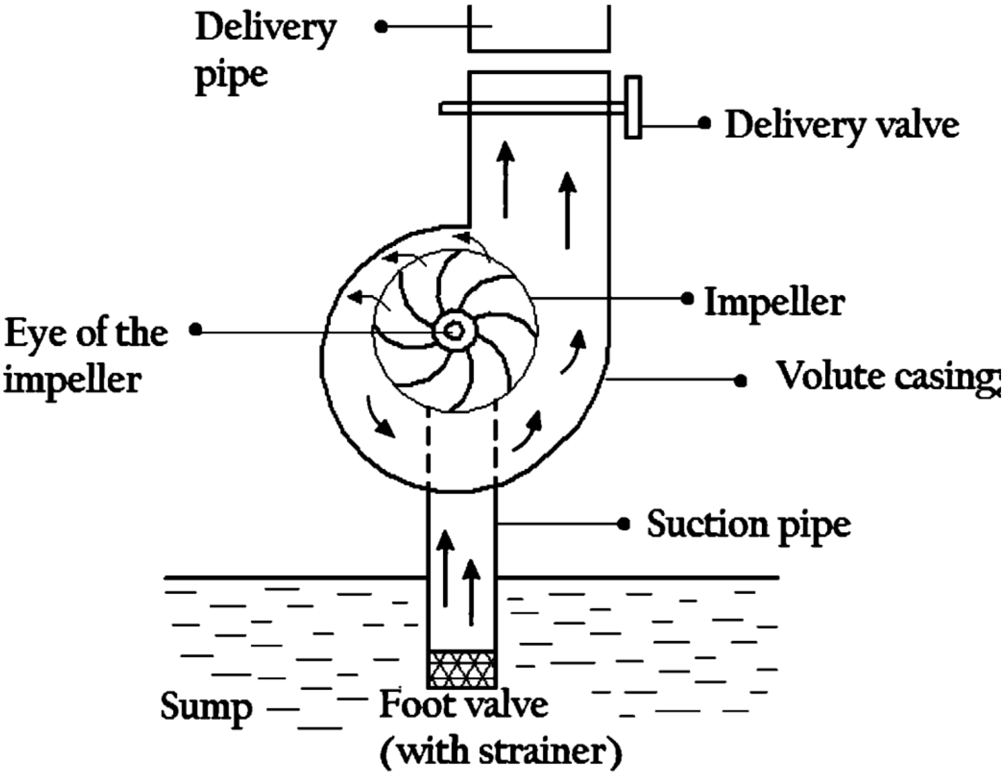
2. The eye of the impeller is connected to the motor through a shaft. When the motor is turned on, the shaft rotates the impeller of the pump.

3. When the impeller rotates, the water is sucked in through suction pipe and rotated by the impeller.

4. This rotating impeller imparts kinetic energy to the water and the high velocity water moves out of the impeller.

5. Now the high velocity water moves towards the delivery pipe through the volute casing of increasing area.

6. Due to this increasing area of volute casing, the kinetic energy and hence the velocity of water reduces gradually. This decrease in velocity of water results in the increase of pressure of water at the delivery pipe



Air compressor

Air compressor is a device which compresses the air or any other gas into required high pressure. The power required for the compression is supplied by an electric motor. Air compressors are used in refrigerators, air conditioners, in pharmaceutical companies, in food and beverage industries etc.

What are the Classification of Air Compressor

Classification of air compressor is given below,

1. According to working

a. Reciprocating air compressor

b. Rotary air compressor

2. According to the action

a. Single acting

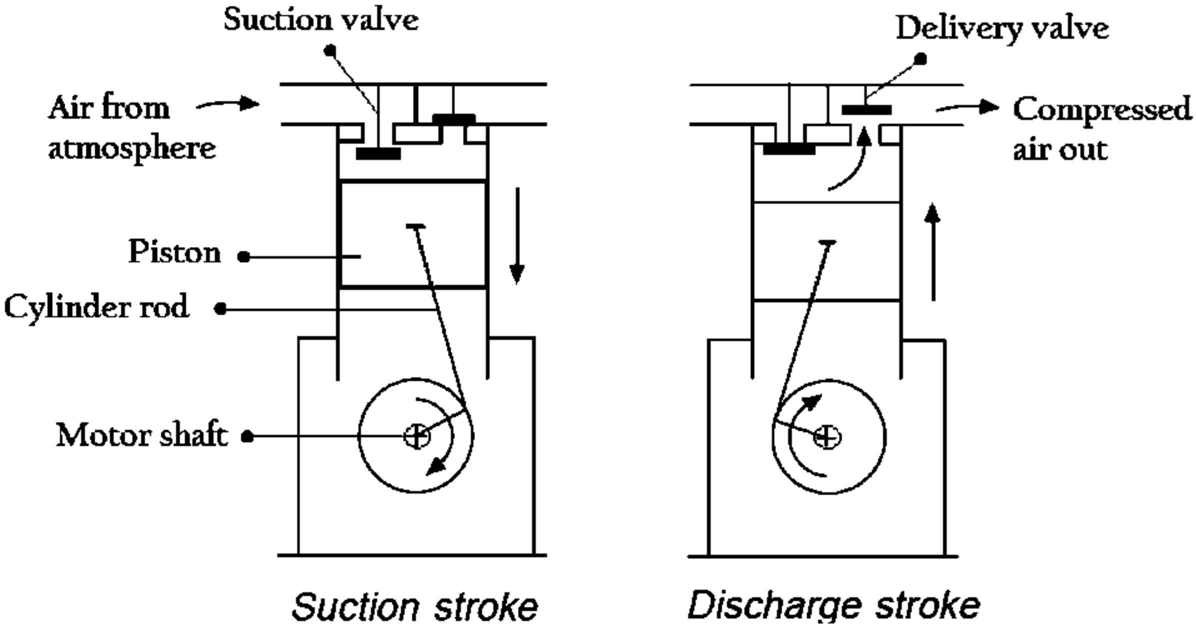
b. Double acting

3. According to number of stages

a. Single stage

b. Multistage

Explain the working priniciple of Single stage air compressor



Working Principle

1. The reciprocating air compressor in its simplest form consists of a cylinder, piston, suction valve and delivery valve.

2. The shaft of electric motor is connected to the cylinder rod which in turn moves the piston up and down.

3. When the piston moves downwards during suction stroke, the pressure inside the cylinder falls below the atmospheric pressure. Due to this pressure difference, the inlet valve opens and air enters the cylinder.

4. Now when the piston moves upwards during discharge stroke, the pressure of the air inside the cylinder starts increasing. And when this pressure reaches discharge pressure, the delivery valve opens and the air is delivered to the storage unit.