Common to sections 'D', 'E' & 'F'.

MODULE – 2
BOILERS

Steam boilers:

Definition of boilers:

• 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.

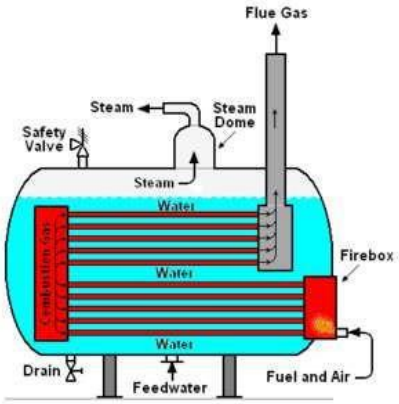
Function of a boiler:

• The function of the 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.

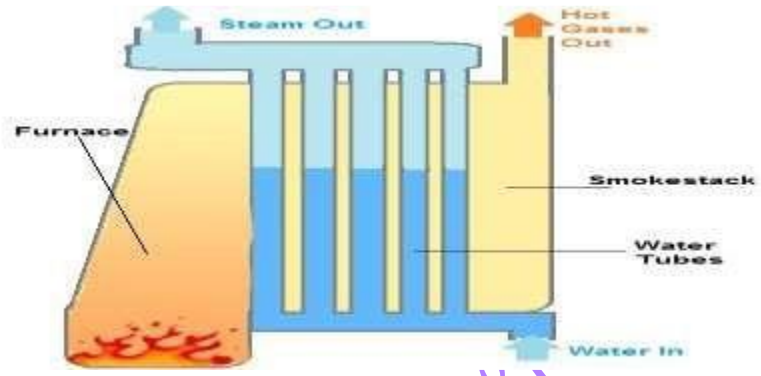
CLASSIFICATION OF BOILERS:

According to the circulation of water and hot gases:-

a) Fire Tube boilers:-In fire tube boilers the hot flue gases produced by the combustion of fuel passes through the tubes which are surrounded by water.
Eg: - Cornish boilers, locomotive boilers, marine boilers and Lancashire boiler.



b. Water Tube boilers: - In water tube boilers water circulated inside the tubes, while the hot gases produced by the combustion of fuels pass around the tubes.
Eg: - Babcock and Wilcox boiler, Stirling boilers…etc.



According to the location of furnace.

a. Internally fired boilers: - If the furnace is situated inside the boiler shell, the boiler is called internally fired boilers. Most of the fire tube boilers are internally fired.

b. Externally fired boilers:-If the furnace is situated outside the boiler shell, the boiler is called externally fired boilers. Water tube boilers are always externally fired.

According to the circulation of water.

I. Natural circulation: - In these boilers, water is circulated by natural convection currents that are set up due to the temperature difference.

II. Forced circulation: - water is circulated with the help of pump driven by a motor. Forced circulation is used only in high pressure and high capacity boilers like La mont boilers and Benson boilers, etc...

According to the axis of the shell.

a) Vertical boilers: - axis of the boilers shell is vertical. Ex:-Cochran boilers.

b) Horizontal boilers:-axis of the boilers shell is horizontal. Ex:-Babcock &Wilcox boilers, Lancashire boilers.

According to their uses.

1) Stationary boilers

2) Locomotive boilers

3) Marine boilers, etc…..

BABCOCK & WILCOX BOILER:

It is a horizontal, externally fired, natural circulation, water tube boiler.

It consists of mainly four parts:

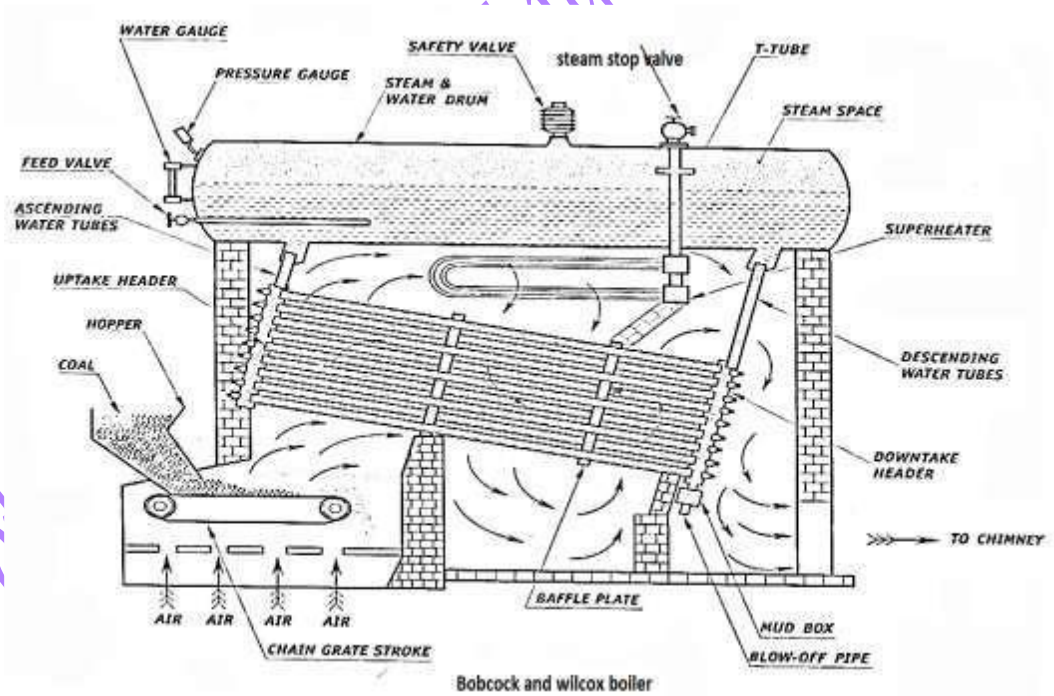
(a) **Steam and water drum** – It is filled with three-fourths water. It stores the feed water and steam.

(b) **Water tubes** – number of water tubes are connected through downtake header and uptake header in which water circulates as shown in fig.

(c) **Baffle plates**- it is placed across the water tubes .it deflect the hot gases coming out from the furnace to allow the hot gas pass around water tubes.

(d) **Internal furnace**– it burns the coal to produce hot flue gases.

(e) **Super heater** – it is set of U-tubes just below the boiler drum, it converts the steam into superheated steam.



Bobcock and wilcox boiler

Working: - Water is introduced into the boiler drum through the feed valve. Water descends into the down take headers, into the water tubes and then into the uptake headers. The hot flue gases from the furnace pass over the water tubes. The path of the hot gases is guided by the baffle plates as shown in the fig., and passes out to the chimney. As the hot gases pass over the water tubes, the water gets converted into steam. This steam due to low density rises up the tube through the uptake headers and reach the top of boiler drum. This sets up a natural circulation of water. The steam collected in the boiler is wet. This is made to pass through the super heater U-tubes just below the boiler drum. The hot gases on their way out pass over these tubes hence converting the steam into superheated steam. The superheated steam in then passed out to the turbine through the steam stop valve. For safety the boiler consists of safety valve, steam stop valve, blow-off pipe, and pressure gauge etc.

Lancashire boiler:

It is a horizontal, internally fired, natural circulation, fire tube boiler.

• This boiler consists of a large horizontal cylindrical shell placed on the brick wall. Two large flue tubes are placed inside the shell, which carry the hot flue gases.

• The boiler shell is filled with water to three-fourths of its volume and the remaining space is the steam space.

• Hot flue gases from the combustion are made to pass through the flue tubes.

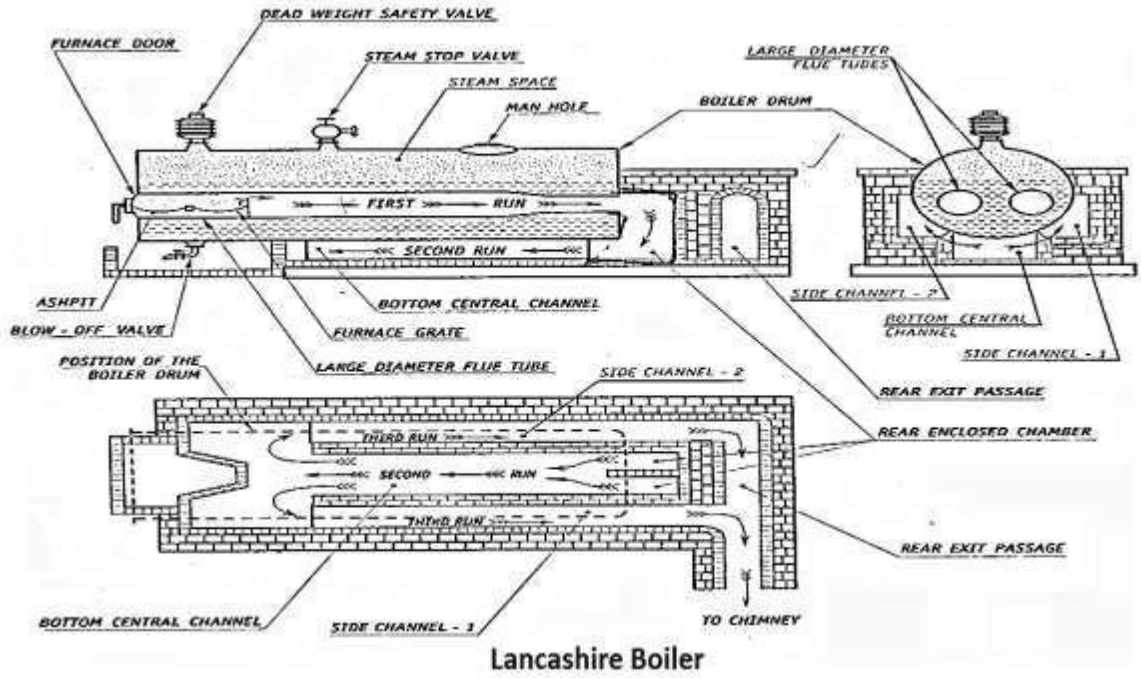
• In the first run it passes from the front end to the rear end of the boiler.

• At the rear end they are made to pass to the bottom central channel.

• In the bottom central channel the hot gases travel from rear end to the front end of the boiler. This is the second run.

• At the front end the hot gases enter into side channels 1 and 2 and travel to the rear end of the boiler. This is the third run.

• At the rear end hot gases coming out of channels 1 and 2 are made to exit to the chimney through the rear exit passage.



Lancashire Boiler

During the first, second and third pass the heat transfer takes place between hot flue gases and the water in the shell, converting water into steam.

• The steam gets accumulated in the steam space at the top.

• Super heater (set of U-tubes) is placed at the rear end of the shell.

• For safety the boiler consists of safety valve, steam stop valve, blow-off valve, pressure gauge, etc.

BOILER MOUNTINGS AND ACCESSORIES: MOUNTINGS:

1) Water level indicator: It indicates the level of water in the boiler drum.

2) Pressure gauge: Indicates the pressure of the steam in the boiler.

3) Safety Valves: When the pressure inside the boiler drum exceeds the desired level, the safety valves blows off the excess steam from the boiler.

4) Steam stop valve: It regulates the flow of steam from the boiler.

5) Feed check valve: It checks the level of water in the boiler drum.

6) Blow off valve: Its function is to remove periodically the sediments and impurities collected at the bottom of the boiler.

7) Fusible plug: It is a device used to extinguish the fire in the furnace.

ACCESSORIES:

1. Economizer: The function of an economizer is to heat the feed water, before being supplied to the boiler, using the products of combustion (flue gas) discharged from the boiler.

2. Air preheater: The function of an air preheater is to preheat the air being supplied to the furnace for combustion.

3. A super heater: is a device used to convert saturated steam or wet steam into dry steam.

4. Feed pump: pumps the water into the boiler at high pressure.

5. Steam separator: it is used to separate the water particles is present in the steam before enters the turbine or engines.

6. Steam trap: it is used to drain off the condensed water accumulated in the steam pipes and steam separator without allowing the escape of high pressure steam from it.

Sl no	WATER TUBE BOILERS	FIRE TUBE BOILERS
1.	In water tube boilers, water is circulated inside the tubes and hot gases surround the water tubes	In fire tube boilers, hot gases pass inside the tube and water surrounds the tubes.
2.	Furnace is situated outside the boilers shell.	Furnace is situated inside the boiler shell
3.	Water circulates between the drum and the tubes maintaining a closed circuit.	Water circulates within the boilers drum only.
4.	Combustion space is large, complete combustion of fuel is possible	Combustion efficiency is low. Combustion takes place in a small space within the boiler shell.

5.	Steam generation rate is fast.	Steam generation rate is slow
6.	Evaporating capacity is high	Rate of evaporation is low
7.	Thermal efficiency is high	Thermal efficiency is low
8.	All parts of water tubes boilers are easily accessible for cleaning, inspection and repair	Cleaning, inspection and repairing is difficult due to inaccessible parts.
9.	High cost	Low cost
10.	Used in power plants	Used in process industries.

HYDRAULIC TURBINES

WATER TURBINES

A water turbine is a hydraulic prime mover that converts the energy of falling water into mechanical energy in the form of rotation of shaft. The mechanical energy in turn is converted into electrical energy by means of an electric generator.

Water turbines are classified based on the following factors:

Type of energy available at the inlet of the turbine:

(a) Impulse turbine: The energy available at the inlet of the turbine is only kinetic energy. Example: Pelton wheel, Girad turbine, Banki turbine, etc.

(b) Reaction turbine: Both pressure energy and kinetic energy is available at the inlet of the turbine.

Example: Kaplan turbine, Francis turbine, Thomson turbine, etc.

Based on the head under which turbine works:

a) High head turbine: Head of water available at the inlet of the turbine ie, above

300 m. Example: Pelton wheel.

b) Medium head turbine: Head of water available at the inlet of the turbine ranges from 50 m to 150 m. Example: Francis turbine.

c) Low head turbine: Head of water at the inlet will be less than 50m. Example: Kaplan Turbine.

Based on the direction of flow of water through the runner:

a) Tangential flow turbine: Water flows along the tangent to the runner. Example: Pelton wheel.

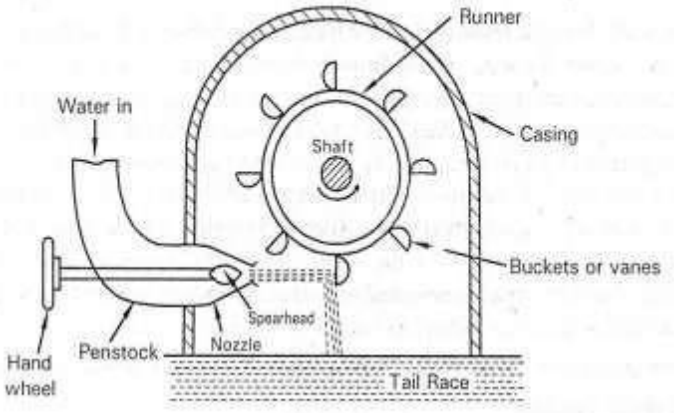
b) Axial flow turbine: Water flows in a direction parallel to the axis of rotation of the runner. Example: Kaplan turbine.

c) Radial flow turbine: Water flows in a radial direction through the runner. Radial flow turbines are further classified into inward radial flow and outward radial flow turbines. Example: Thomson turbine, Girad turbine, Old Francis turbine.

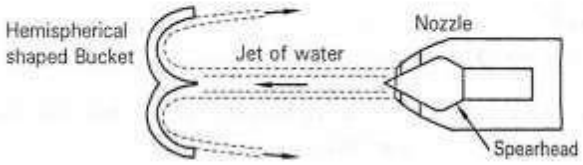
d) Mixed flow turbine: Water flows racially into the runner and leaves axially, Example: Modern Francis turbine.

1) PELTON WHEEL TURBINE

Pelton wheel is a tangential flow impulse turbine, used for high heads and small quantity of water flow. Figure shows the schematic diagram of a Pelton wheel. The Pelton wheel consists of the following parts: nozzle with spear head, shaft, rotor, buckets, casing, and tailrace.



(a) Pelton Wheel



(b) Flow of water on bucket

Working:

In operation, water from the reservoir (dam) having potential energy flows through the penstock and enters the nozzle. As water flows through the nozzle, the potential energy of water is completely converted into kinetic energy in the nozzle. The high velocity jet of water issuing from the nozzle impinges on the curved blades fixed around the runner wheel.

The impulse force due to the high velocity jet of water sets the runner wheel into rotary motion. Hence, the shaft coupled to the runner wheel also rotates thereby doing useful work. Thus, the potential energy of the water is converted into mechanical work. After performing work, the water freely discharges to the tailrace. The work produced at the output shaft is used to drive a generator to produce electricity the electricity is then transmitted to a substation where transformers increase voltage to allow transmission to homes, office, and factories.

Advantages:

1) Simple in construction and easy maintenance.
2) To drive more power multiple jets (2 to 6) Pelton wheel may be used.

Disadvantages:

1) A lot of head loss occurs when the river discharge is low.

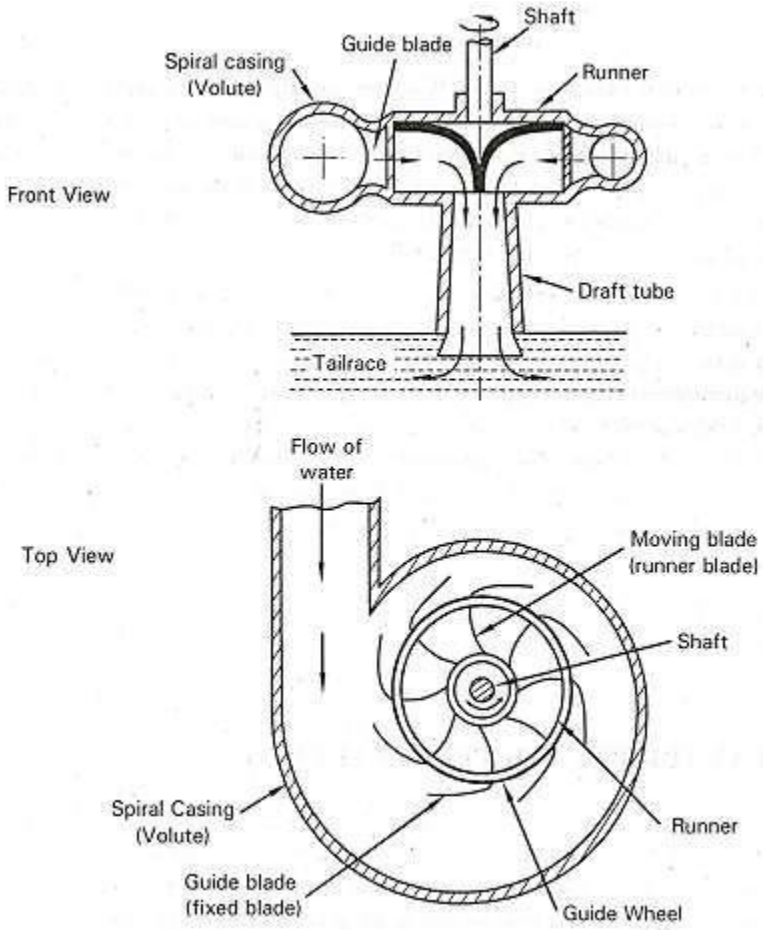
2) FRANCIS TURBINE

Francis turbine is a mixed flow reaction turbine used for medium heads. It was the first Hydraulic turbine with radial flow, designed by American scientist James Francis. Figure shows the front and top views of a Francis turbine. Francis turbine consists of the following parts: spiral casing (volute), runner, shaft, guide blade (fixed blade), guide wheel, moving blade (runner blade).

Working:

In operation, water from the reservoir (dam) flows through the penstock and enters the spiral casing. As the water flows through the tapered spiral casing, a part of its potential energy is converted into kinetic energy. Water flows through the guide blades, gets deflected and then flows radially inwards to the outer periphery (outer diameter) of the runner. The water then moves over the moving blades in the radial direction and is finally discharged to the tailrace axially from the centre of the runner via a draft tube.

During its flow over the runner blades, the blade passages act as nozzle, and the remaining part of the potential energy is converted into kinetic energy. It is important to note at this point, that the jet of water does not impinge on the runner. In fact, they are leaving the runner at high velocity. So, the momentum is converted into force as in the case of impulse turbine. Since the water leaves the blades at high velocity, there is a reaction force on the runner. This force sets the runner into rotary motion. Hence the shaft connected to the runner also rotates thereby doing useful work. The shaft in turn drives the generator to produce electricity.



Advantages:

1) No head loss occurs even at low discharge of water.

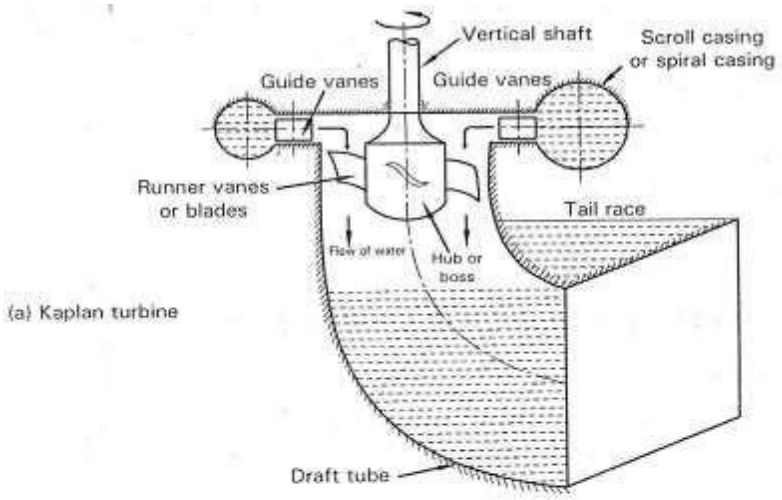
Disadvantages:

1) Eddy losses are more

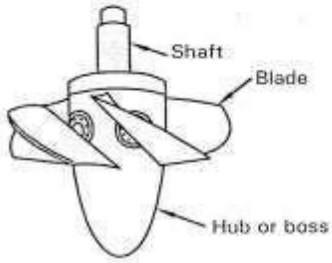
2) Since the spiral casing is grounded, runner is not easily accessible. Hence dismantling is difficult.

3) KAPLAN TURBINE

The Kaplan turbine is a low head reaction turbine in which water flows axially, Figure shows the rotor and front view of a Kaplan turbine. Kaplan turbine consists of the following parts: guide vanes, runner vanes, shaft, spiral casing, tailrace, hub, and blade.



(a) Kaplan turbine



(b) Kaplan turbine runner

Working:

Kaplan turbine is an axial flow reaction turbine and is used where large quantity of water is available at low heads. The turbine consists of a hub or boss fixed to a vertical shaft. The runner blades attached to the hub are adjustable, and can be turned about their axis to take care of change of load. The runner has only 4 to 8 blades. Similar to Francis turbine, Kaplan turbine also has a ring of fixed guide blades at the inlet to the turbine. The inlet is a scroll shaped tube surrounding the fixed blades. In operation, water from the reservoir flows through the penstock and enters the spiral casing. A part of the potential energy of water is converted into kinetic energy in the spiral casing.

The water then moves through the guide blades (fixed blades), gets deflected and then flows axially through the runner blades as shown in figure. During its flow over the runner blades, the blade passages act as nozzle, and the remaining part of the potential energy is converted into kinetic energy. The water leaves the runner blades at high velocity, and as a result, a reaction force is set up causing the runner to rotate at high speeds. Hence the

shaft connected to the runner also rotates thereby doing useful work. The shaft in turn drives the generator to produce electricity. The water discharging at the centre of the runner enters the draft tube whose end is immersed into the tailrace as in Francis turbine.

Advantages:

1) Simple in construction and requires less space.

2) Eddy losses are almost eliminated.

Disadvantages:

1) Cavitation is likely to occur due to high velocity flow of water.

Difference between impulse water turbine and reaction water turbine:

SI No.	**Reaction Water Turbine**	**Impulse Water Turbine**
1.	Reaction turbines are used for low and medium heads. Example Francis and Kaplan turbine.	Impulse turbines are used for high heads. Example Pelton turbine
2.	Pressure drop occurs in both fixed and moving blades.	No pressure change occurs at the turbine blades
3.	Part of the pressure energy is converted to kinetic energy in the spiral casing, and the remaining in the blade passages that acts as nozzle.	Pressure energy is completely converted to kinetic energy in a nozzle.
4.	Reaction turbines rotate faster given the same head and flow conditions.	Comparatively low.
5.	Reaction turbines require more sophisticated fabrication because of the use of larger and more intricately profiled blades and casings.	Comparatively ease in fabrication.
6.	Reaction turbines must be encased to contain the water pressure (or suction), or they must be fully submerged in the water flow.	Relatively not necessary

Difference between Francis and Kaplan turbine:

Sl no	Francis turbine	Kaplan turbine
1	It is a mixed flow turbine	It is an axial flow turbine
2	Medium head turbine, requires medium quantity of water	Low head turbine, requires large quantity of water
3	Number of guide vanes are around 16 to 24	Number of guide vanes are around 3 to 8
4	The runner is supported by a driving shaft	The runner is the extension of the vertical shaft
5	Guide vanes are assembled with the help of links and levers to act as valves	Guide vanes are made adjustable for smooth flow of water. They are so designed and fixed around the hub
6	Requires large space	Requires less space due to sloped vanes
7	Eddy losses are impossible to avoid	It is almost eliminated
8	Cavitation do not occurs	Cavitation is likely to occur
9	Draft tube is of simple elbow type	Draft tube is of circular to rectangular type

HYDRAULIC PUMPS

Introduction to Hydraulic Pumps

A hydraulic pump is a device that transfers energy to fraise liquid from a lower level to a higher level, or circulate a liquid in a closed system. Typical examples of a pump include, pumping of water from a sump to an overhead tank, or circulating a coolant water for agriculture & irrigation works, municipal water works & drainage system, in steam power plants for condensing water, condensate, feed water into the boiler drum, etc., circulate liquid in machine tools & other systems etc.

Classification of Pumps

1) Centrifugal pump, which makes use of centrifugal force of a rotary element known as impeller to impart energy to the liquid

2) Reciprocating pump, which imparts energy to the liquid by the reciprocating action of the piston inside the cylinder

3) Rotary pump, which consists of rotating members, traps fluid in its closed casing thereby building & raising the pressure of the fluid & in turn discharges the high pressure fluid. The rotating members may be gears, vanes or screws.

Specification of Hydraulic Pumps

1) Max discharge pressure

2) Max discharge flow

3) Discharge size

4) Horsepower

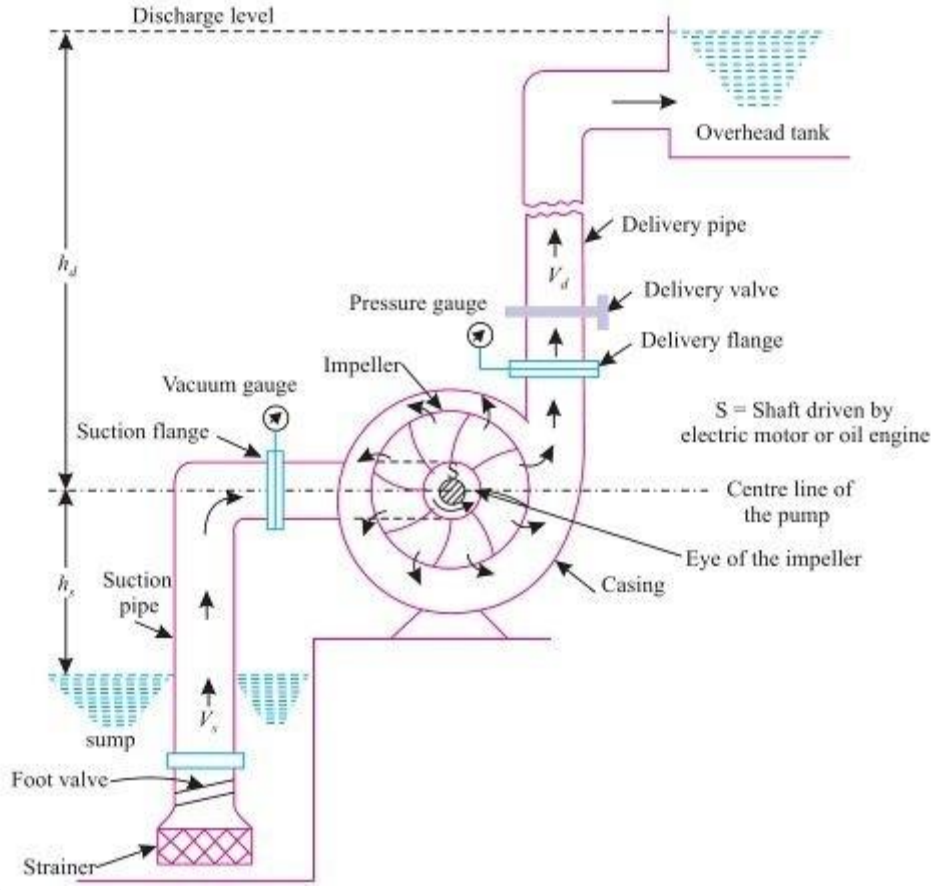
5) Pump type & its features

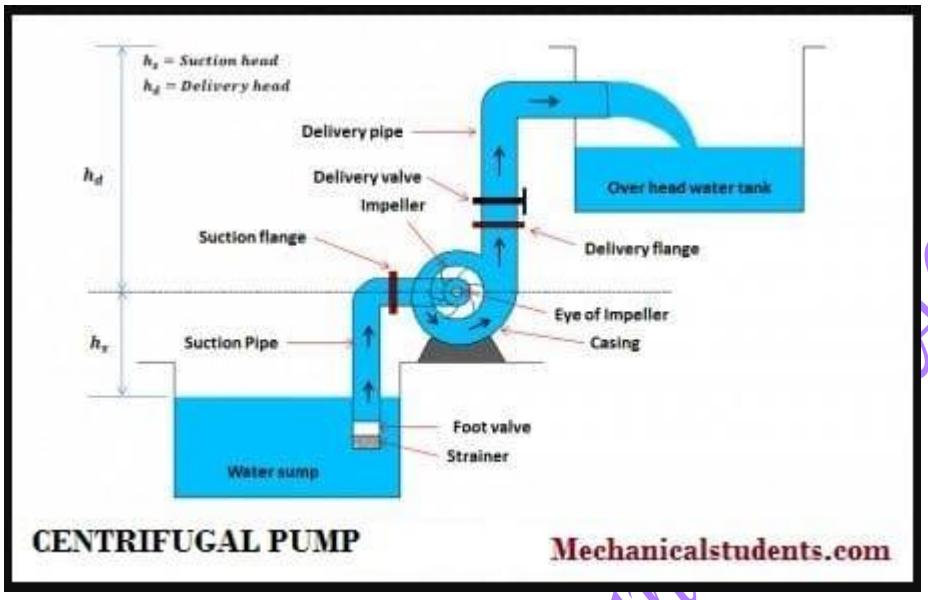
6) Power source

7) Housing material

Centrifugal Pump

These pumps makes use of centrifugal force of a rotary element known as impeller to impart energy to the liquid. Is is most widely used hydraulic pump for various applications. The details of the centrifugal pump are shown in figure and briefed as follows:





Construction:

1) **Impeller**: it is the principal rotating part of the pump. It is a wheel provided with a series of backward curved blades (vanes). The impeller is mounted on a shaft, which is connected to the shaft of the electric motor..

2) **Volute Casing**: is an air tight chamber surrounding the impeller. It is designed with its cross-section gradually increasing so that the velocity of the flow decreases resulting in an increase in the pressure of the fluid.

3) **Suction Pipe**: is a circular pipe with its upper end connected to the center of the impeller, which is known as eye of the impeller. The lower end of the suction pipe is immersed in sump or reservoir from where the liquid is to be lifted. The lower end of the suction pipe is fitter with a foot valve and a strainer as shown in the figures. The strainer avoids entry of any foreign matter into the suction pipe, while the foot valve is a non-return or one way valve that opens only in upward direction so as to prevent draining out when pump is stopped. Foot valve also helps in priming of the pump.

4) **Delivery Pipe**: is also a circular pipe with is lower end connected to the outlet of the pump (casing), while the upper end is connected to the tank, where the liquid is to be pumped or

stored. In the delivery pipe, a control valve known as delivery valve is provided for regulating the fluid flow. The delivery valve is closed prior to the starting & stopping of the pump in order to prevent any possible backflow from the delivery pipe & consequent damage to the pump assembly.

Operation

In operation, when the electric motor is switched ON, the impeller rotates creating a suction at the suction pipe. Due to the suction created, the water from the sump starts flowing into the casing through the eye of the impeller. The centrifugal force created by the rotating impeller acts on the water causing it to flow radially outward & towards the outlet of the casing. As the water flows through the casing, its velocity reduces due to increasing cross-sectional area of the casing. The decrease in velocity increases the pressure of water flowing through the casing. The pressure reaches to the max at the outlet of the pump (casing). The water flows through the delivery pipe into the overhead tank.

It is important to note that when the fluid is discharged to the delivery, a partial vacuum is created near the eye of the impeller, which in turn causes the liquid from sump which is at atmospheric pressure to rush through the suction pipe to reduce the fluid that is being discharged. Thus water is pumped continuously from sump through the delivery pipe.

Advantages:

1) Suitable for all types of fluids
2) Simple & compact
3) Delivers uniform flow. O/P flow is steady & consistent
4) Can be mounted horizontally or vertically
5) Easy maintenance

Disadvantages:

1) Relatively poor suction power. When the pump end is dry, the rotation of the impeller, even at high speeds is not sufficient to lift liquid into the pump. The pump must be primed before pumping can begin.
2) Develops cavitation resulting in structural failures of the impeller blades
3) Not suitable for air/gases

4) Magnetic resonance in centrifugal pump results in small loss of energy.

Cavitation: in centrifugal pumps, refers to the phenomenon of formation of vapors bubbles & its subsequent collapse in the low pressure region around the impeller. Cavitation can be identified by a clear audible noise & vibrations caused by the violent collapse of vapour bubbles. It occurs when the velocity of the liquid increases to the point where the consequent pressure drop reaches the pressure of vaporization of the liquid. When this happens, vapour pockets or bubbles form in the liquid & then later collapse when subjected to higher pressure at some other point in the flow. The collapse of the vapour bubbles creates high energy shock waves inside the liquid, which then travels and strike the impeller causing significant damage to the impeller blade &/or the pump housing. The power consumption for pump operation increases & also there is a decreased flow &/pressure.

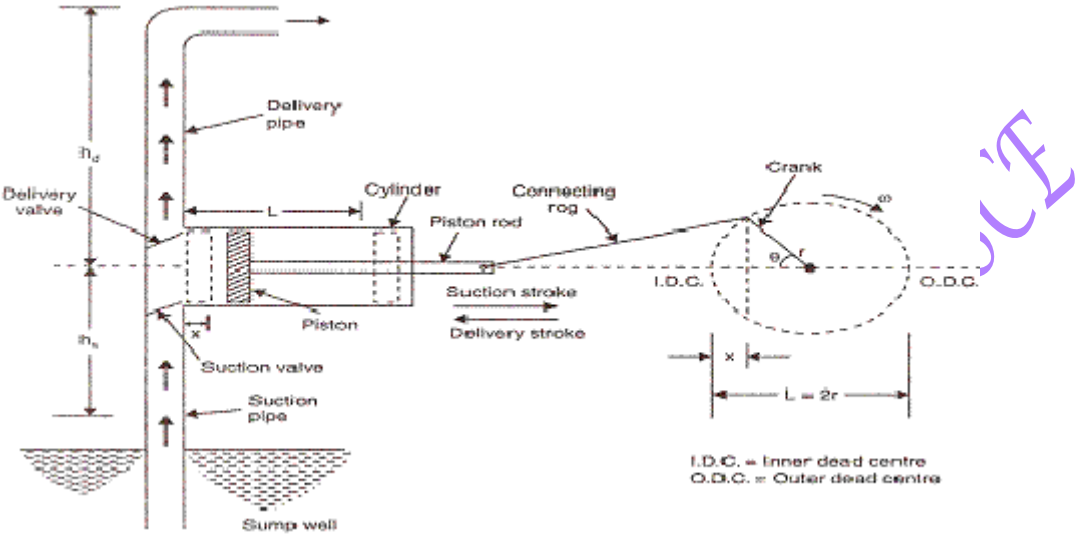
Priming: It is the process of filling liquid into the casing, suction pipe & delivery pipe upto the delivery valve before starting the pump. Priming is required in order to remove the air trapped in the pump, thereby reducing the risk of pump damage during start-up

Reciprocating Pump:

Reciprocating pumps operates on the principle of increasing the pressure energy of the liquid by pushing the liquid using a piston or plunger that reciprocates in a closed fitting cylinder. The details of the reciprocating pump is as shown in figure and briefed as follows:

Construction:

The pump consists of a cylindrical shaped piston reciprocating inside a closely fitted cylinder. The connecting rod forms a link b/w the piston & shaft of the electric motor. The crank is a level with one end connected to the lower end of te connecting rod, while the other end connected to the shaft of the electric motor. The crank & the connecting rod are thus operated by means of power source. The rotary motion of the crank is converted to reciprocating motion of the piston by means of connecting rod. The lower end of the suction pipe is immersed in the sump or reservoir from where the liquid is to be lifted up, while the upper end of the pipe links to the cylinder inlet. Similarly the lower end of the delivery pipe is connected to the cylinder outlet, while the upper end is connected to the discharge point, where the liquid is to be pumped. Both the pipes are provided with valves, respectively called suction valve & delivery valve, which are non-return or one way type.



Operating: when the electric motor is switched ON, the crank rotates, transferring the motion to the piston, which moves to & fro inside the cylinder. When the crank starts rotating from one point to another as shown in figure, the piston moves towards the right of the cylinder, creating partial vacuum in the cylinder. Since atmospheric pressure acting on the water surface in the sump is greater than the suction pressure inside the cylinder, water from the sumo is forced in the suction pipe to move into the cylinder. The force of the liquid opens the suction valve, causing it to move into the cylinder. The delivery valve remains closed during this action, with this process, the crank completes 180° rotation. In the next half-cycle, the crank starts to move from right to left of te cylinder. This movement increases the pressure of the liquid inside the cylinder more than the atmospheric pressure. Hence suction valve closes and delivery valve opens. The liquid is forced into the delivery pipe to get discharged to required destination.