ABES ENGINEERING COLLEGE, GHAZIABAD

Subject: Fundamentals of Mechanical Engineering (BME101/201)

Unit 4: Fluid Mechanics and its Applications
Lecture Notes

INDEX

Fluid

Fluid is a substance that continuously deform (Flow) under an applied shear stress/force. Example: Liquid and gas.

Solids (s), liquids (l) and gas (g) are differentiated on the basis of molecular structure (i.e. intermolecular spacing (g>l>s) and intermolecular bonding (g<l<s)). Also, solids have volume and shape, liquids have volume and no shape and gases have volume and shape.

There are two types of fluids:

1. **Real Fluids:**

Real fluids have viscosity, compressibility and surface tension.

2. **Ideal Fluids:**

Ideal fluids are assumed to be incompressible, inviscid and has no surface tension, they are Imaginary and do not exist. For eg. Air and water can be treated as ideal fluids.

Fluid mechanics

Fluid mechanics is that branch of science which deals with the behavior of the fluid (liquids or gases) at rest as well as in motion. Thus; this branch of science deals with the static, kinematics and dynamics aspects of fluids.

1. **Fluid Statics**: The study of fluids at rest is called fluid statics.
2. **Fluid Kinematics:** The study of fluids in motion, where pressure forces are not considered, is called fluid kinematics.
3. **Fluid Dynamics:** If the pressure forces are also considered for the fluids in motion, the branch of science is called fluid dynamics.

Fluid Properties:

There are following properties of fluid, which is enlisted below:

a. Pressure ‘
b. Density or mass density
c. Viscosity
d. Specific gravity
e. Weight density or specific weight

a. Pressure: The pressure at a point is the thrust acting normally per unit area around that point. If a total force F acts normally over a flat surface A, then the pressure is

$$P = \frac{F}{A}$$

If the force is not distributed uniformly over the given surface, then pressure will be different at different points. If a force acts normally on a small area surrounding a given point, then pressure at that point will be

$$P = \lim_{\Delta A \to 0} \frac{\Delta F}{\Delta A} = \frac{dF}{dA}$$

Pressure is scalar quantity, because fluid pressure at a particular point in fluid has same magnitude in all directions. This shows that a definite direction is not associate with fluid pressure. Units of Pressure: SI unit of pressure = Nm^{-2} or Pascal(Pa)

Type of pressure:

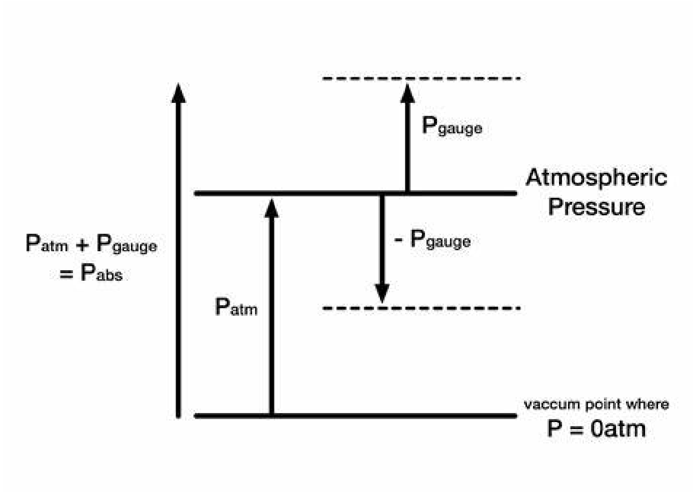
1. **Absolute Pressure**
2. **Gauge Pressure**
3. **Vacuum Pressure**

The pressure on the fluid is measured as reference to either absolute level or atmospheric pressure.

1. **Absolute pressure:** it is defined as the pressure which is measured with reference to absolute vacuum pressure.
2. **Gauge pressure:** it is defined as the pressure which is measured with the help of a pressure measuring instrument, in which the atmospheric pressure is taken as datum.
3. **Vacuum pressure:** it is defined as the pressure below the atmospheric pressure. Mathematically:

Absolute pressure = Atmospheric pressure + Gauge pressure

Vacuum pressure = Atmospheric pressure- Absolute pressure

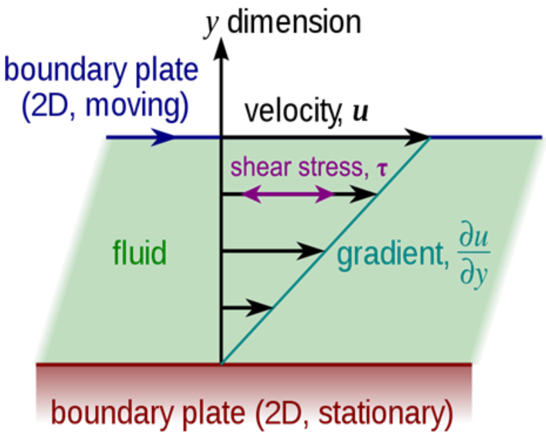


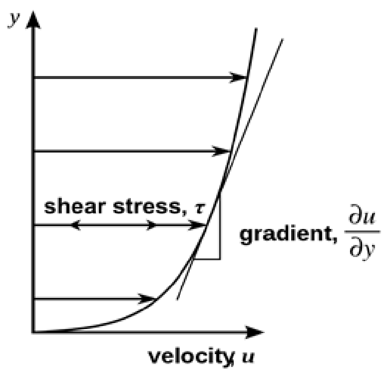
b. Density: The density of any material is defined as its mass per unit volume. If a body of mass M occupies volume V , the it density is Density is a scalar quantity. As liquids are incompressible, their density remains constant at all pressures.

Units of density: SI unit of density= Kgm^{-3}.

$$Density(\rho) = \frac{Mass}{Volume} = \frac{M}{V}$$

c. Viscosity: Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid. When two layers of fluid, a distance 'dy' apart, move one over the other at different velocities, say u and u+du as shown in fig., the viscosity together will relative velocity causes a shear stress acting between the fluid layers. The top layer causes a shear stress on the adjacent lower layer while the lower layer causes a shear stress on the adjacent top layer. This shear stress is proportional to the rate of chance of velocity with respect to y. It is denoted by symbol τ(Tau).





Mathematically;

$$\tau \propto \frac{du}{dy} \tau = \mu \frac{du}{dy}$$

There are Two type of viscosity:

1. Dynamic viscosity
2. Kinematic viscosity

1. **Dynamic viscosity**: Dynamic Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid.

   In other words it is defined as the ratio of shear stress to the velocity gradient. It is representing by μ.

$$\mu = \frac{\tau}{\frac{du}{dy}}$$

Where τ a shear stress, μ is is the dynamic viscosity and du/dy is a velocity gradient. SI unit of dynamic viscosity or viscosity is Ns/m^2 and CGS unit is poise(dyne-sec/m^2).

One Ns/m^2 = 10 poise

2. **Kinematic viscosity:**

It is defined as the ratio between the dynamic viscosity and density. It is represented by greek symbol (υ) called 'nu'. Mathematically,

$$\upsilon = \frac{\mu}{\rho}$$

SI Unit of kinematic viscosity is m^2/sec while in CGS a unit is stoke (cm^2/s).

One stoke = 10^{-4} m^2/s.

d. **Specific Gravity:** Specific gravity is defined as the ratio of the the weight density (or density) of a fluid to the weight density (or density) of a standard fluid. For liquids, the standard fluid is taken water and for gases, the standard fluid is taken as air. Specific gravity is also called relative density. It is dimensionless quantity and denoted by the symbol S.

Specific gravity of liquid(S) = Weight density (density) of liquid/Weight density (density) of water

Specific gravity of gases= Weight density (density) of gas /Weight density (density) of air

Weight density of a liquid = S x 1000 x 9.81 N/m3

Density of a liquid = Sx1000 Kg/m^3

e. **Weight density or specific weight**: weight density or specific weight of a fluid is defined as the ratio of weight density of a fluid to the volume of fluid. In other words; it is defined as the weight per unit volume of fluid. It is represented by w.

Mathematically;

$$w = Weight.of\ fluid \,/\, Volume.of\ \ fluid$$
$$w = \rho.g$$

<u>Newton's law of viscosity</u>: It states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain. The constant of proportionality is called the co-efficient of viscosity. Mathematically, it is expressed as:

$$\tau = \mu \frac{du}{dy}$$

<u>Newtonian Fluid and Non-Newtonian Fluids:</u>

Newtonian Fluid: Fluids which obey the newton's law of viscosity is called Newtonian fluids. A real fluid, in which the shear stress is directly proportional to rate of shear strain (or velocity gradient), is known as a Newtonian fluid.
Example: Water, mineral oil, gasoline and alcohol etc.

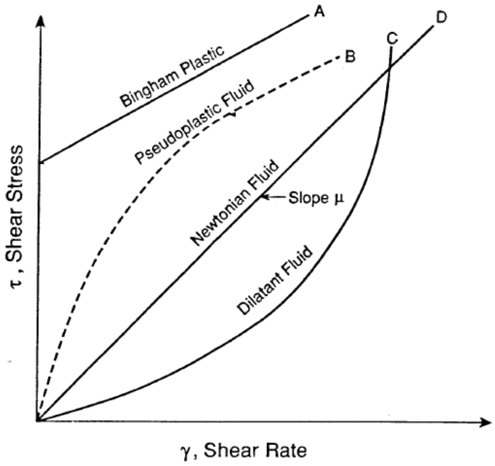
Non-Newtonian Fluids: The fluid which do not follow newton's law of viscosity is called Non- Newtonian fluids. Or A real fluid, in which the shear stress is not proportional to rate of shear strain (or velocity gradient), is known as a Non-Newtonian fluid. The behavior of these fluid can be described in one of four ways:

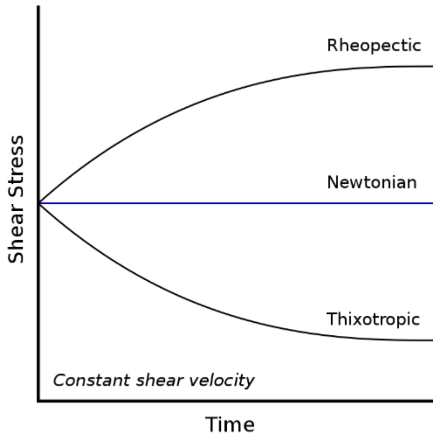
- **Dilatant -** Viscosity of the fluid increases when shear is applied. For example: Quicksand, Corn flour and water Silly putty.

- **Pseudoplastic -** Pseudoplastic is the opposite of dilatant; the more shear applied, the less viscous it becomes. For example: Ketchup

- **Rheopectic -** Rheopectic is very similar to dilatant in that when shear is applied, viscosity increases. The difference here is that viscosity increase is time-dependent. For example: Gypsum paste, Cream etc.

- **Thixotropic -** Fluids with thixotropic properties decrease in viscosity when shear is applied. This is a time-dependent property as well. For example: Paint, Cosmetics, Asphalt and Glue etc.





Pascal's Law:

It states that the pressure or intensity of pressure at a point in a static fluid is equal in all directions.

According to Pascal's law $P_1=P_2=P_3$

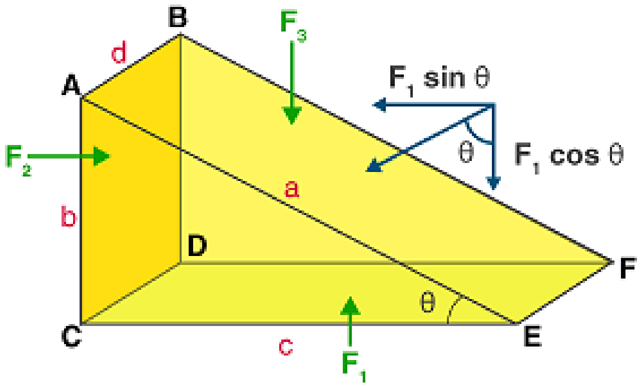
Where P_1, P_2, P_3 are intensity of pressure along z, y and x direction respectively. According to definition of **pressure or intensity of pressure**.

$$P = \frac{F}{A}$$

Where, F is the force applied, P is the pressure transmitted and A is the cross-sectional area.

Pascal's Law Derivation

Consider an arbitrary right-angled prismatic triangle in the liquid of density rho. Since the prismatic element is very small, every point is considered to be at the same depth from the liquid surface. The effect of gravity is also the same at all these points.



Let ad, bd, and cd be the area of the faces ABFE, ABDC, and CDFE respectively. Let P_1, P_2, and P_3 be the pressure on the faces ABFE, ABDC, and CDFE. Pressure exerts a force which is normal to the surface. Let P exert force F on the surface ABFE, P exert force F on the surface ABDC, and P exert force F on the surface CDFE.

Therefore, Force F_1, F_2 , and F_3 are given as:

$F_1 = P_1 \times$ area of ABFE = P ad ……………………………………………………………(1)

$F_2 = P_2 \times$ area of ABDC = P bd ……………………………………………………………(2)

F = P × area of CDFE = P cd…………………………………………………………………(3)

Also, $\sin\theta = b/a$, $\cos\theta = c/a$

The net force on the prism will be zero since the prism is in equilibrium.

$F_1 \sin\theta = F_2$……………………………………………(4)

$F_1 \cos\theta = F_3$…………………………………………………………………………(5)

Putting the value of F_1 , F_2 and sinϴ in equation (4), we get

P_1 ad x b/a = P_2 bd

$P_1 = P_2$…………………………………………………………………………………(6)

Putting the value of F_1 , F_3 and Cos ϴ in equation (5), we get

P_1 ad x c/a= P_3 cd

$P_1 = P_3$…………………………………………………………………………………(7)

From equation 6 and 7;

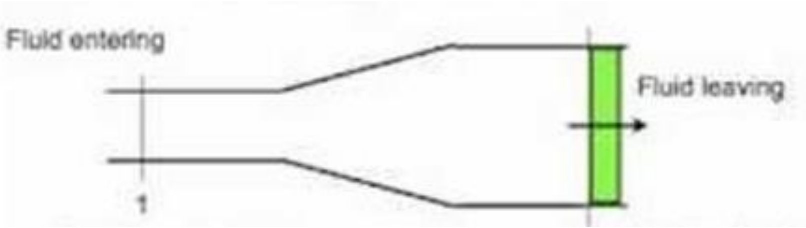
$P_1 = P_2 = P_3$

The above equation shows that the pressure at any point in z, y and x direction is equal.

Application of Pascal's law: Hydraulic Lift, It works based on the principle of equal pressure transmission throughout a fluid (Pascal's Law).

Continuity Equation

The equation based on the principle of conservation of mass is called continuity equation. Thus for a fluid through the pipe at all the cross-section, the quantity of fluid per second is constant. Consider two cross-section of pipe as shown in fig.



Let C_1 = Average velocity at cross-section 1-1,

ρ_1 = Density at section 1-1,

A_1 = Area of pipe at section 1-1,

And C_2, ρ_2, A_2 are corresponding value at section 2-2.

$\rho_1 A_1 C_1 = \rho_2 A_2 C_2$……………………………………………………………………(1)

Then rate of flow at section

1-1 = Rate of flow at section

2-2 = Rate of flow at section

According to law of conservation of mass

Rate of flow at section 1-1 = Rate of flow at section 2-2

Equation (1) is applicable to compressible as well as incompressible fluids and is called Continuity Equation. If the fluid is incompressible then and continuity equation (1) reduces to

$$\mathbf{A_1 C_1 = A_2 C_2}$$

Hydrostatic Law

The hydrostatic law, at a point in a static fluid system, states that the rate of increase of pressure equals the specific weight of the fluid. The pressure variation occurs vertically downwards and is a function of depth.

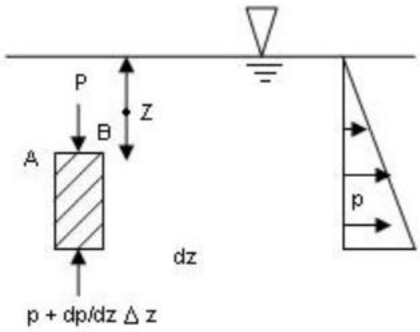
At depth z, if the pressure P acts on the surface, the equilibrium condition can be expressed with Newton’s second law of motion as:

$$\frac{dP}{dz} = -\rho g$$

This can alternately be written as:

$$P=pgh$$

Consider a small fluid element as shown in Fig.



Let A = cross sectional area of element

dz = height on fluid element

P_z= pressure on face AB

Z = distance of fluid element from free surface

The net upward pressure force:

$P_{(z+dz)}$ dA = P_z .dA+ d/dz(P_z.dZ) (as per Taylor series)……………………………………….(1)

Net downward force:

P_zdA + ρgdAdz………………………………………………………………………….(2)

Net upward force = Net downward force

P_z dA + d/dz(P_z.dz) = P_zdA + ρgdAdz

$$\frac{dPz}{dz} = \rho g = \omega$$

This is hydrostatic law which state, “The rate of increase of pressure in the vertically downward direction, at point in a static fluid, must be equal tot eh specific weight of the fluid.”

FLUID MECHANICS AND HYDRAULIC MACHINES

HYDRAULIC MACHINES

Hydraulic machines are defined as those machines which convert either hydraulic energy (energy possessed by water) into mechanical energy (which is further converted into electrical energy) or mechanical energy into hydraulic energy. The hydraulic machines, which convert the hydraulic energy into mechanical energy, are called turbines while the hydraulic machines which convert the mechanical energy into hydraulic energy are called pumps.

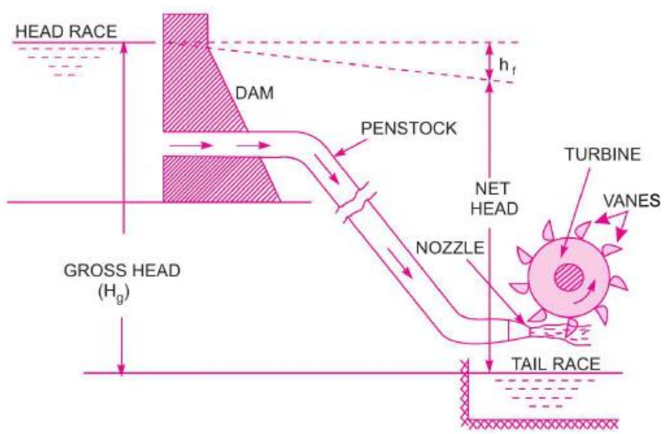
TURBINES

Turbines are defined as the hydraulic machines which convert hydraulic energy into mechanical energy. This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine. Thus, the mechanical energy is converted into electrical energy. The electric power which is obtained from the hydraulic energy (energy of water) is known as Hydroelectric power.

GENERAL LAYOUT OF A HYDROELECTRIC POWER PLANT

Figure shows a general layout of a hydroelectric power plant which consists of:

i. A dam constructed across a river to store water.
ii. Pipes of large diameters called penstocks, which carry water under pressure from the storage reservoir to the turbines. These pipes are made of steel or reinforced concrete.
iii. Turbines having different types of vanes fitted to the wheels.
iv. Tail race, which is a channel which carries water away from the turbines after the water has worked on the turbines. The surface of water in the tail race channel is also known as tail race.



Layout of a hydroelectric power plant.

DEFINITIONS OF HEADS AND EFFICIENCIES OF A TURBINE

1. **Gross Head**: The difference between the head race level and tail race level when no water is flowing is known as Gross Head. It is denoted by 'H_g' in above figure.
2. **Net Head:** It is also called effective head and is defined as the head available at the inlet of the turbine. When water is flowing from head race to the turbine, a loss of head due to friction between the water and penstocks occurs. Though there are other losses also such as loss due to bend, pipe fittings, loss at the entrance of penstock etc., yet they are having small magnitude as

compared to head loss due to friction. If "h_f" is the head loss due to friction between penstocks and water then net heat on turbine is given by

$$H_{net}=H_g- h_f$$

Efficiencies of a Turbine

The following are the important efficiencies of a turbine.

(a) Hydraulic Efficiency (η_h) (b) Mechanical Efficiency (η_m)

(c) Volumetric Efficiency (η_v) and (d) Overall Efficiency (η_o)

a) Hydraulic Efficiency: It is defined as the ratio of power given by water to the runner of a turbine (runner is a rotating part of a turbine and on the runner, vanes are fixed) to the power supplied by the water at the inlet of the turbine. The power at the inlet of the turbine is more and this power goes on decreasing as the water flows over the vanes of the turbine due to hydraulic losses as the vanes are not smooth. Hence, the power delivered to the runner of the turbine will be less than the power available at the inlet of the turbine. Thus, mathematically, the hydraulic efficiency of a turbine is written as

$$\text{Hydraulic Efficiency} = \frac{\text{Power deliveredtorunner}}{\text{Power supplied at inlet}}$$

b) Mechanical Efficiency: The power delivered by water to the runner of a turbine is transmitted to the shaft of the turbine. Due to mechanical losses, the power available at the shaft of the turbine is less than the power delivered to the runner of a turbine. **The ratio of the power available at the shaft of the turbine to the power delivered to the runner is defined as mechanical efficiency.**

$$\textbf{Mechanical Efficiency} = \frac{\text{Power at the shaft of the turbine}}{\text{Power delivered by water to the runner}}$$

c) Volumetric Efficiency: The volume of the water striking the runner of a turbine is slightly less than the volume of the water supplied to the turbine. Some of the volume of the water is discharged to the tail race without striking the runner of the turbine. Thus, ***the ratio of the volume of the water actually striking the runner to the volume of water supplied to the turbine is defined as volumetric efficiency.*** It is written as

$$\textbf{Volumetric Efficiency} = \frac{\text{Volume of water actually striking the runner}}{\text{Volume of water supplied to the turbine}}$$

d) Overall Efficiency: It is defined as the ratio of power available at the shaft of the turbine to the power supplied by the water at the inlet of the turbine. It is written as:

$$\textbf{Volumetric Efficiency} = \frac{\text{power available at the shaft of the turbine}}{\text{water at the inlet of the turbine}}$$

CLASSIFICATION OF HYDRAULIC TURBINES

The hydraulic turbines are classified according to the type of energy available at the inlet of the turbine, direction of flow through the vanes, head at the inlet of the turbine and specific speed of the turbines. Thus, the following are the important classifications of the turbines:

1. According to the type of energy at inlet:

(a) Impulse turbine, and (b) Reaction turbine.

2. According to the direction of flow through runner:

(a) Tangential flow turbine, (b) Radial flow turbine, (c) Axial flow turbine, and (d) Mixed flow turbine.

3. According to the head at the inlet of turbine:
(a) High head turbine, (b) Medium head turbine, and (c) Low head turbine.

4. 4. According to the specific speed of the turbine:
(a) Low specific speed turbine, (b) Medium specific speed turbine, and (c) High specific speed turbine.

PELTON WHEEL (OR TURBINE)

The Pelton wheel or Pelton turbine is a tangential flow impulse turbine. The water strikes the bucket along the tangent of the runner. The energy available at the inlet of the turbine is only kinetic energy. The pressure at the inlet and outlet of the turbine is atmospheric. This turbine is used for high heads and is named after L.A. Pelton, an American Engineer.

Working of Pelton (impulse) Turbine

The water stored at a high head is made to flow through the penstock and reaches the nozzle of the Pelton turbine. The nozzle increases the kinetic energy of the water and directs the water in the form of a jet which strikes on the buckets of the runner tangentially. The water jet exerts a force on the bucket called as Impulse force. This made the runner to rotate at very high speed. The quantity of water striking the buckets is controlled by the needle valve (spear) present inside the nozzle. The generator is attached to the shaft of the runner which converts the mechanical energy of the runner into electrical energy.

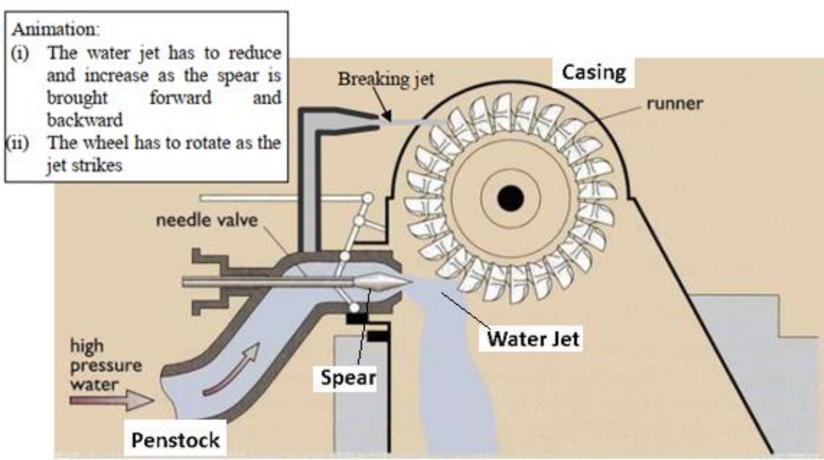
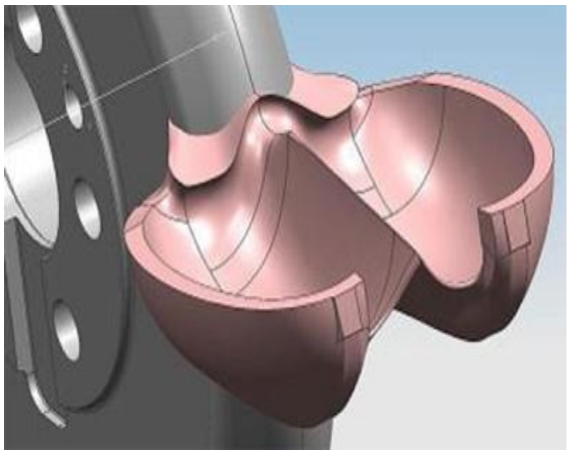


Figure shows the layout of a hydroelectric power plant in which the turbine is Pelton wheel. The water from the reservoir flows through the penstocks at the outlet of which a nozzle is fitted. The main parts of the Pelton turbine are:

1. Nozzle and flow regulating arrangement (spear),
2. Runner and buckets,
3. Casing, and
4. Breaking jet.

1. **Nozzle and Flow Regulating Arrangement:** The amount of water striking the buckets of the runner is controlled by providing a spear in the nozzle as shown in Figure. The spear is a conical needle which is operated either by a hand wheel or automatically in an axial direction depending upon the size of the unit. When the spear is pushed forward into the nozzle the amount of water striking the runner is reduced. On the other hand, if the spear is pushed back, the amount of water striking the runner increases.

2. **Runner with Buckets**: Figure shows the runner of a Pelton wheel. It consists of a circular disc on the periphery of which a number of buckets evenly spaced are fixed. The shape of the buckets is of a double hemispherical cup or bowl. Each bucket is divided into two symmetrical parts by a dividing wall which is known as splitter. The jet of water strikes on the splitter. The splitter divides the jet into two equal parts and the jet comes out at the outer edge of the bucket. The buckets are shaped in such a way that the jet gets deflected through 160° or 170°. The buckets are made of cast iron, cast steel bronze or stainless steel depending upon the head at the inlet of the turbine.



(do not try to draw this three dimensional diagram)

3. **Casing:** Figure shows a Pelton turbine with a casing. The function of the casing is to prevent the splashing of the water and to discharge water to tail race. It also acts as safeguard against accidents. It is made of cast iron or fabricated steel plates. The casing of the Pelton wheel does not perform any hydraulic function.
4. **Breaking Jet**: When the nozzle is completely closed by moving the spear in the forward direction, the amount of water striking the runner reduces to zero. But the runner due to inertia goes on revolving for a long time. To stop the runner in a short time, a small nozzle is provided which directs the jet of water on the back of the vanes. This jet of water is called breaking jet.

Advantage of Pelton turbine:

1. It has simple construction
2. It is easy to maintain
3. Intake and exhaust of water takes place at atmospheric pressure hence no draft tube is required
4. No cavitation problem
5. It can work on low discharge

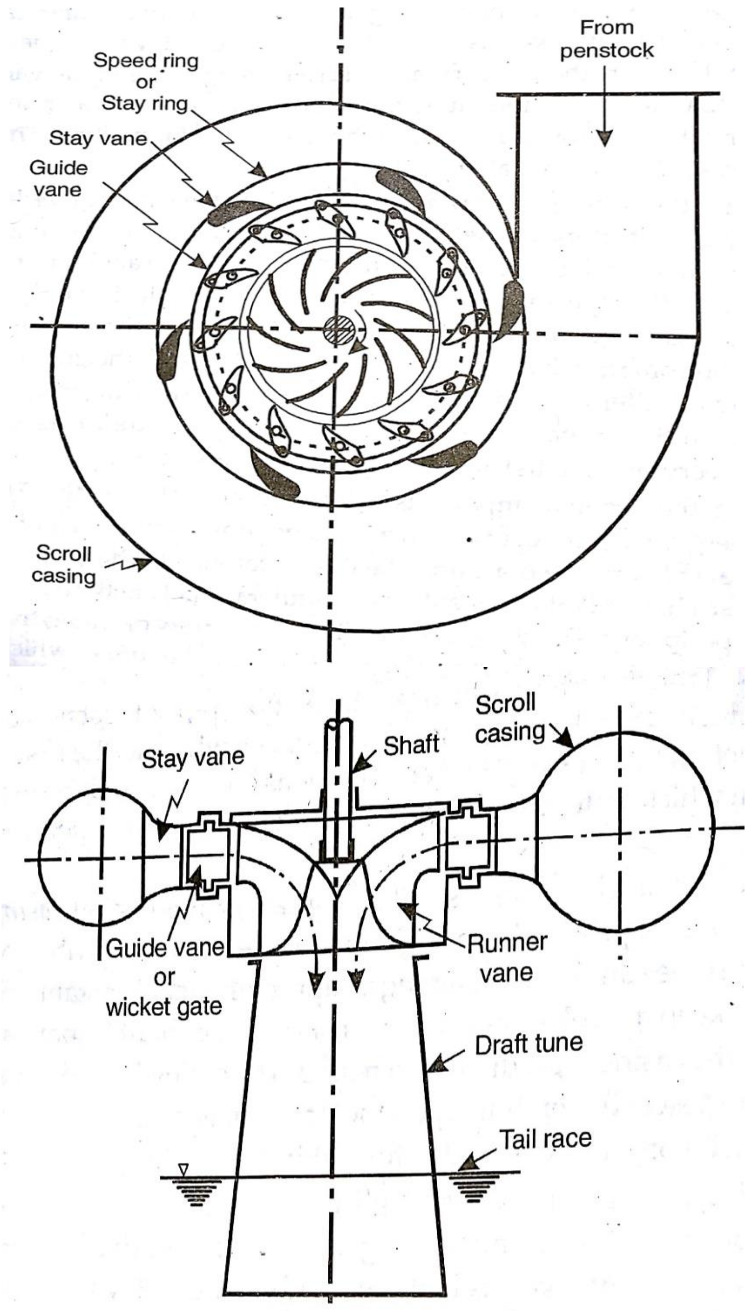
Disadvantage of Pelton turbine:

1. It requires high head for operation
2. Turbine size is generally large
3. Due to high head, it is very difficult to control variations in operating head

Francis turbine (reaction turbine)

Reaction turbine means that the water at the inlet of the turbine possesses kinetic energy as well as pressure energy. As the water flows through the runner, a part of pressure energy goes on changing into kinetic energy. Thus, the water through the runner is under pressure. The runner is completely enclosed in an air-tight casing and casing and the runner is always full of water.

Working of Francis turbine



The water is allowed to enter the spiral casing of the turbine, which lead the water through the stay vanes and guide vanes. The spiral case is kept in decreasing diameter so as to maintain the flow pressure. The stay vanes being stationary at their place. The angle of guide vanes decides the angle of attack of water at the runner blades thus make sure the maximum output of the turbine. The runner blades are stationary and can-not pitch or change their angle so it's all about the guide vanes which controls the power output of a turbine. The performance and efficiency of the turbine is dependent on the design of the runner blades. In a Francis turbine, runner blades are divided into two parts. The lower half is made in the shape of small bucket so that it uses the impulse action of water to rotate the turbine. The upper part of the blades uses the reaction force of water flowing through it. Thus, runner blades make use of both pressure energy and kinetic energy of water and rotates the runner in most efficient way. The water coming out of runner blades would lack both the kinetic energy and pressure energy, so we use the draft tube to recover the pressure as it advances towards tail race.

construction of Francis turbine

Main Parts of a Radial Flow Reaction Turbine. The main parts of a radial flow reaction turbine are:

1. Casing,
2. Guide mechanism,
3. Runner, and
4. Draft-tube.

1. **Casing:** As mentioned above that in case of reaction turbine, casing and runner are always full of water. The water from the penstocks enters the casing which is of spiral shape in which area of cross-section of the casing goes on decreasing gradually. The casing completely surrounds the runner of the turbine. The casing made of spiral shape, so that the water may enter the runner at constant velocity throughout the circumference of the runner. The casing is made of concrete, cast steel etc.
2. **Guide Mechanism:** It consists of a stationary circular wheel all-round the runner of the turbine. The stationary guide vanes are fixed on the guide mechanism. The guide vanes allow the water to strike the vanes fixed on the runner without shock at inlet. Also, by a suitable arrangement, the width between two adjacent vanes of guide mechanism can be altered so that the amount of water striking the runner can be varied.
3. **Runner:** It is a circular wheel on which a series of radial curved vanes are fixed. The surface of the vanes are made very smooth. The radial curved vanes are so shaped that the water enters and leaves the runner without shock. The runners are made of cast steel, cast iron or stainless steel. They are keyed to the shaft.
4. **Runner Blades:** The performance and efficiency of the turbine is dependent on the design of the runner blades. In a Francis turbine, runner blades are divided into 2 parts. The lower half is made in the shape of small bucket so that it uses the impulse action of water to rotate the turbine. The upper part of the blades uses the reaction force of water flowing through it. These two forces together make the runner to rotate.
5. **Draft tube:** The pressure at the exit of the runner of a reaction turbine is generally less than atmospheric pressure. The water at exit cannot be directly discharged to the tail race. A tube or pipe of gradually increasing area is used for discharging water from the exit of the turbine to the tail race. This tube of increasing area is called draft tube.

Advantages:

- Usually, there is no head failure, even if the water discharge level is lower.
- The mechanical efficiency rate is quite higher than any other turbine.
- The runner size is competitively smaller than other turbines.

Disadvantages

- Francis turbine always demands costly maintenance.
- The design of the Francis turbine is complex.
- The cost of the Francis turbine is higher.

HYDRAULIC PUMPS

Hydraulic pumps are devices designed to convert mechanical energy to hydraulic energy. They are used to move water from lower points to higher points with a required discharge and pressure head.

Classification of hydraulic pump

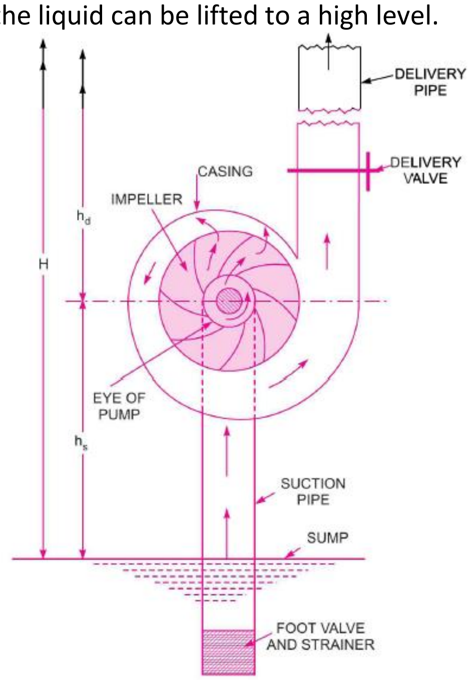
1. **Turbo-hydraulic (kinetic) pumps**
    a. Centrifugal pumps (radial-flow pumps)
    b. Propeller pumps (axial-flow pumps)
    c. Jet pumps (mixed-flow pumps)
2. **Positive-displacement pumps**
    a. Reciprocating pumps
    b. Screw pumps

Centrifugal pump:

If the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, the hydraulic machine is called centrifugal pump.

Working of Centrifugal pump

The centrifugal pump acts as a reverse of an inward radial flow reaction turbine. This means that the flow in centrifugal pumps is in the radial outward directions. **The centrifugal pump works on the principle of forced vortex flow which means that when a certain mass of liquid is rotated by an external torque, the rise in pressure head of the rotating liquid takes place.** The rise in pressure head at any point of the rotating liquid is proportional to the square of tangential velocity of the liquid at that point **(i.e.,** $\textbf{rise in pressure head} = \frac{V^2}{2g} \; or \; \frac{r^2\omega^2}{2g}$). Thus, at the outlet of the impeller, where radius is more, the rise in pressure head will be more and the liquid will be discharged at the outlet with a high-pressure head. Due to this high-pressure head, the liquid can be lifted to a high level.



Main parts of a centrifugal pump.

CONSTRUCTION OF CENTRIFUGAL PUMP

The following are the main parts of a centrifugal pump:

1. Impeller.
2. Casing.
3. Suction pipe with a foot valve and a strainer.
4. Delivery pipe.

1. **Impeller:** The rotating part of a centrifugal pump is called 'impeller'. It consists of a series of backward curved vanes. The impeller is mounted on a shaft which is connected to the shaft of an electric motor.
2. **Casing:** The casing of a centrifugal pump is similar to the casing of a reaction turbine. It is an airtight passage surrounding the impeller and is designed in such a way that the kinetic energy of the water discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing and enters the delivery pipe.
   Volute Casing: Figure shows the volute casing, which surrounds the impeller. It is of spiral type in which area of flow increases gradually. The increase in area of flow decreases the velocity of flow. The decrease in velocity increases the pressure of the water flowing through the casing.
3. **Suction Pipe with a Foot valve and a Strainer:** A pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump is known as suction pipe.
   A foot valve which is a non-return valve or one-way type of valve is fitted at the lower end of the suction pipe. The foot valves open only in the upward direction. A strainer is also fitted at the lower end of the suction pipe.
4. **Delivery Pipe:** A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.
5. **Suction Head (h_s):** It is the vertical height of the center line of the centrifugal pump above the water surface in the tank or pump from which water is to be lifted as shown in Figure. This height is also called suction lift and is denoted by 'h_s'.
6. **Delivery Head (h_d):** The vertical distance between the center line of the pump and the water surface in the tank to which water is delivered is known as delivery head. This is denoted by 'h_d'.
7. **Static Head (Hs):** The sum of suction head and delivery head is known as static head. This is represented by "H_s' and is written as $Hs=h_s + h_d$

Advantages of Centrifugal Pump

1. The most significant advantage of centrifugal pumps is their simplicity.
2. They are suitable for large discharge and smaller heads.
3. This pump allows them to run at high speeds with minimal maintenance.
4. Their output is very steady and consistent.
5. There are very less frictional losses.

Disadvantages of Centrifugal Pump

1. Centrifugal pumps always face cavitation problems.
2. Cannot be able to work with high head.
3. During pump operation, there may be a possibility of misalignment of the shaft.
4. These pumps are not built to operate with highly viscous liquids.

Application of Centrifugal Pump

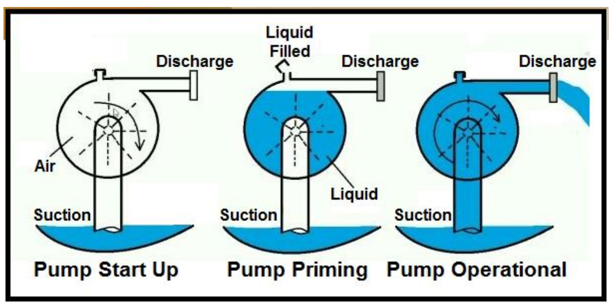
1. These pumps are popularly used in domestic applications like pumping water from one place to another.
2. They are also used in refrigerant and coolant recirculation.

3. This pump is also used for drainage, irrigation, and sprinkling.
4. Centrifugal pumps are widely used in gas and oil industries for pumping slurry, mud, and oil.
5. These pumps are also valuable for sewage systems.

Cavitation: It occurs in centrifugal pumps when the Net Positive Suction Head Available (NPSHa) is lower than the Net Positive Suction Head Required (NPSHr) causing the formation and accumulation of bubbles around the impeller eye that then collapse resulting in a series of mini-implosions and significant damage to both the impeller and the casing.

If we take water as an example, it vaporizes at atmospheric pressure at 100 degrees C. But the internal design of a pump means that fluids flow at high velocities and the pressure decreases (see Bernoulli's Law), consequently the liquid will vaporize at a much lower temperature.
Priming of centrifugal pumps:

Priming: It is the process of removing air from the pump and suction line. In this process the pump is been filled with the liquid being pumped and this liquid forces all the air, gas, or vapor contained in the passage ways of pump to escape out. Priming maybe done manually or automatically. Not all pumps require priming but mostly do.



Reciprocating Pumps:
If the mechanical energy is converted in to pressure energy by sucking the liquid in to a cylinder in which a piston is reciprocating backward and forward, which exerts the thrust on the liquid and increases its hydraulic energy or pressure energy, the hydraulic machine will be termed as reciprocating pump.

Working of Single acting reciprocating pump

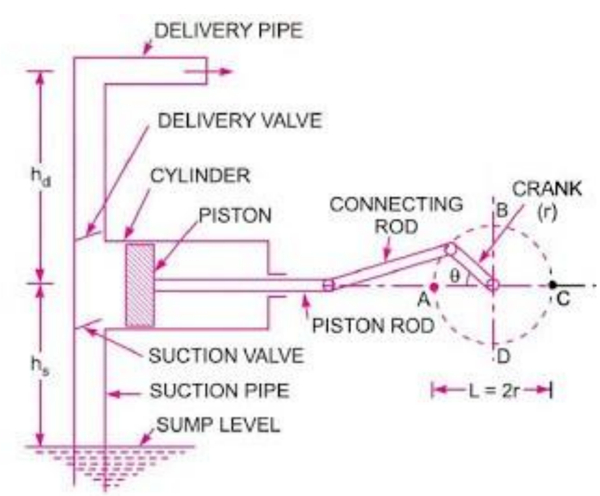


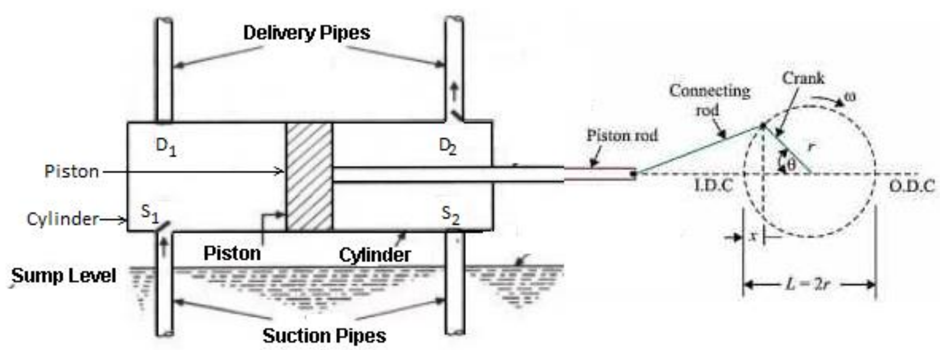
Figure shows a **single acting** reciprocating pump, which consists of a piston which moves forwards and backwards in a close-fitting cylinder. The movement of the piston is obtained by connecting the piston rod to crank by means of a connecting rod. The crank is rotated by means of an electric motor. Suction and delivery pipes with suction valve and delivery valve are connected to the cylinder. The suction and delivery valves are one-way valves or non-return valves, which allow the water to flow in one direction only. Suction valve allows water from suction pipe to the cylinder which delivery valve allows water from cylinder to delivery pipe only.

When crank starts rotating, the piston moves to and fro in the cylinder. When crank is at A., the piston is at the extreme left position in the cylinder. As the crank is rotating from A to C, (i.e., from $\Theta = 0°$ to $\Theta = 180°$), the piston is moving towards right in the cylinder. The movement of the piston towards right creates a partial vacuum in the cylinder. But on the surface of the liquid in the sump atmospheric pressure is acting, which is more than the pressure inside the cylinder. Thus, the liquid is forced in the suction pipe from the sump. This liquid opens the suction valve and enters the cylinder. When crank is rotating from C to A (i.e., from $\Theta = 180°$ to $\Theta = 360°$), the piston from its extreme right position starts moving towards left in the cylinder. The movement of the piston towards left increases the pressure of the liquid inside the cylinder more than atmospheric pressure. Hence suction valve closes and delivery valve opens. The liquid is forced into the delivery pipe and is raised to a required height.

Working of double acting reciprocating pump

In a double acting reciprocating pump, the suction and delivery strokes occur simultaneously. When the crank rotates from **IDC** to **ODC**, a vacuum is created on the left side of the piston and the liquid is sucked from the sump through suction valve **S_1**. At the same time, the liquid on the right side of the piston is pressed and a high pressure causes the delivery valve **D_2** to open and the liquid is passed to the discharge tank. This operation continuous till the crank reaches **ODC**.

With further rotation of the crank, the liquid is sucked from the sump through suction valve **S_2** and delivered to the discharge tank through valve **D_1**. When the crank reaches **IDC**, the piston is in the extreme left position. Thus, one cycle is completed. Double acting reciprocating pump gives more uniform discharge because of continuous of delivery strokes.



Construction of reciprocating pump

The basic components of a single-acting reciprocating pump are:

Plunger/piston: the reciprocating pump has a piston or plunger and it reciprocates in the cylinder due to which suction and increase in pressure takes place.

Piston rod: The piston rod connects the connecting rod to the piston and transfers reciprocating motion to the piston from the connecting rod. As shown in the figure below.

Connecting rod: The connecting rod is used to connect the piston rod to the Crank.

Crank: The crank is connected to a prime mover which may be an electric motor an engine. This crank is then connected to the connecting rod as shown in the figure below. Thus, the rotary motion of the crank is converted into the reciprocating motion of the piston rod.

Suction pipe: It is the pipe that connects the reservoir to the inlet cylinder of the pump as shown in the figure.

Delivery pipe: The delivery pipe is used for delivering the pressurized liquid coming out from the pump to its destination.

Suction and delivery valve: These are non-return valves and allow the liquid to enter from one direction only. One valve is fitted at the inlet of the cylinder whereas the other is fitted at the outlet of the cylinder as shown in the figure. This ensures that the water or the liquid doesn't flow backward.

Strainer: A Strainer is attached at the beginning of the suction pipe so as to prevent the entering of any foreign material or particles.

Advantages of reciprocating pump

- The reciprocating pump requires no priming.
- It can be used to deliver liquid at higher pressure.
- It has higher efficiency as compared to a centrifugal pump.
- It can work in a wide pressure range.

Disadvantages of reciprocating pump

- The reciprocating pump has a high maintenance cost due to more wear and tear of the parts.
- As compared to centrifugal pumps, it is heavy and bigger in size.
- The initial cost is high.
- The flow rate of the liquid delivered is low.

Applications of reciprocating pump

- Reciprocating pumps are used as a feed pump for boilers.
- For pumping industrial fluids.
- Hydraulic jack.
- Firefighting application.
- Fuel injection in automobile engines.

Difference Between Centrifugal Pump and Reciprocating Pump

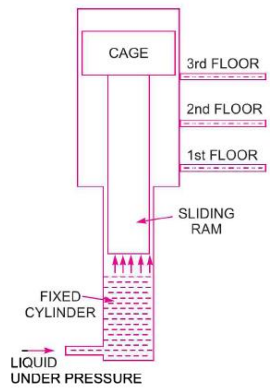
Centrifugal Pump	Reciprocating Pump
Centrifugal pump is simple in construction due to lesser number of parts.	Reciprocating pump is complicated in construction due to a greater number of parts.
Centrifugal pumps are suitable for large discharge with a small head.	Whereas reciprocating pumps are suitable for less discharge with a high head.
Centrifugal pump requires more floor space and heavy foundation.	The reciprocating pump requires less floor space with a simple foundation.
Centrifugal pump has less wear and tear and can handle dirty water.	The reciprocating pump has more wear and tear and cannot handle dirty water.
Centrifugal pump delivery is continuous and needs priming.	Whereas reciprocating pump delivery is pulsating and does not need priming.
Centrifugal pump has low efficiency and can run higher speed.	Whereas the reciprocating pump has high efficiency and cannot run at a higher speed.
Centrifugal pump has less maintenance cost.	Reciprocating pump has more maintenance cost.
It cannot require air vessels, and operation is quite.	It requires air vessels, and operation is complicated.
In this, the thrust on the crankshaft is uniform.	In this, thrust on the crankshaft is not uniform.

THE HYDRAULIC LIFT

A hydraulic lift is a device for moving objects or passenger using force created by the pressure on a liquid inside a cylinder that moves a piston upward. Incompressible oil is pumped into the cylinder, which forces the piston upward. When a valve opens to release the oil, the piston lowers by gravitational force.
The principle for hydraulic lifts is based on Pascal's law for generating force or motion, which states that pressure change on an incompressible liquid in a confined space is passed equally throughout the liquid in all directions. The hydraulic lifts are of two types, namely,

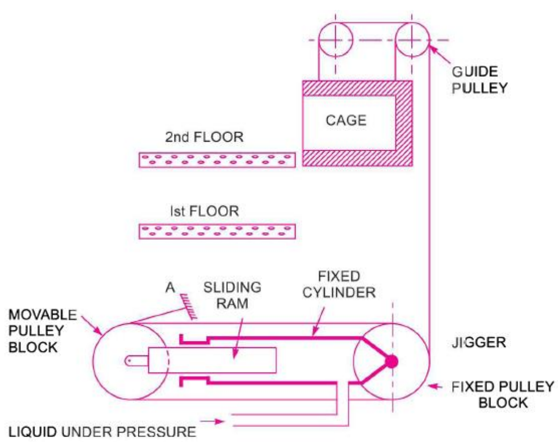
1. Direct acting hydraulic lift, and
2. Suspended hydraulic lift.

Direct Acting Hydraulic Lift



It consists of a ram, sliding in fixed cylinder as shown in Fig. 21.8. At the top of the sliding ram, a cage (on which the persons may stand or goods may be placed) is fitted. The liquid under pressure flows into the fixed cylinder. This liquid exerts force on the sliding ram, which moves vertically up and thus raises the cage to the required height. The cage is moved in the downward direction, by removing the liquid from the fixed cylinder.

Suspended Hydraulic Lift



Suspended hydraulic lift.

Figure shows the suspended hydraulic lift. It is a modified form of the direct acting hydraulic lift. It consists of a cage (on which persons may stand or goods may be placed) which is suspended from a wire rope. A jigger, consisting of a fixed cylinder, a sliding ram and a set of two pulley blocks, is provided at the foot of the hole of the cage. One of the pulley blocks is movable and the other is a fixed one. The end of the sliding ram is connected to the movable pulley block. A wire rope, one end of which is fixed at A and the other end is taken round all the pulleys of the movable and fixed blocks and finally over the guide pulleys as shown in Figure. The cage is suspended from the other end of the rope. The raising or lowering of the cage of the lift is done by the jigger as explained below.

When water under high pressure is admitted into the fixed cylinder of the jigger, the sliding ram is forced to move towards left. As one end of the sliding ram is connected to the movable pulley block and hence the movable pulley block moves towards the left, thus increasing the distance between two pulley blocks. The wire rope connected to the cage is pulled and the cage is lifted. For lowering the cage, water from the fixed cylinder is taken out. The sliding ram moves towards right and hence movable pulley blocks also moves towards right. This decreases the distance between two pulley blocks and the cage is lowered due to increased length of the rope.

Applications of hydraulic lift: They can be found in automotive, shipping, construction, waste removal, mining, and retail industries as they are an effective means of raising and lowering people, goods, and equipment.