CMR Engineering college
Department of Mechanical Engineering

HYDRAULIC MACHINES

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HYDRALIC TURBINES

What is Hydraulic Machines?

Hydraulic machines are defined as those machines which convert either hydraulic energy (energy possessed by water) into mechanical energy (P.E+K.E) or mechanical energy into hydraulic energy.

Ex.

- Turbines
- Pumps

What is Turbine?

- The hydraulic machines, which converts the hydraulic energy into mechanical energy, are called turbines.
- This mechanical energy is used to in running an electric generator which is directly coupled to the shaft of the turbine.

What is a pump?

Pump is defined as a mechanical device that rotates or reciprocates to move fluid from one place to another.

Types of turbines

1. Steam Turbines
2. Gas Turbines (Combustion Turbines)
3. Hydraulic Turbines (Water Turbines)

Hydraulic Turbine

- The hydraulic machines, which converts hydro power (energy of water) into mechanical energy, are called Hydraulic Turbines.
- Mechanical energy is used in running an electric generator which is coupled to the turbine shaft.

Classification of Water 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, (b) Radial flow,

   (c) Axial flow, and (d) mixed flow.

3. According to the head at the inlet of turbine:

   (a) High head, (b) Medium head, and

   (c) Low head.

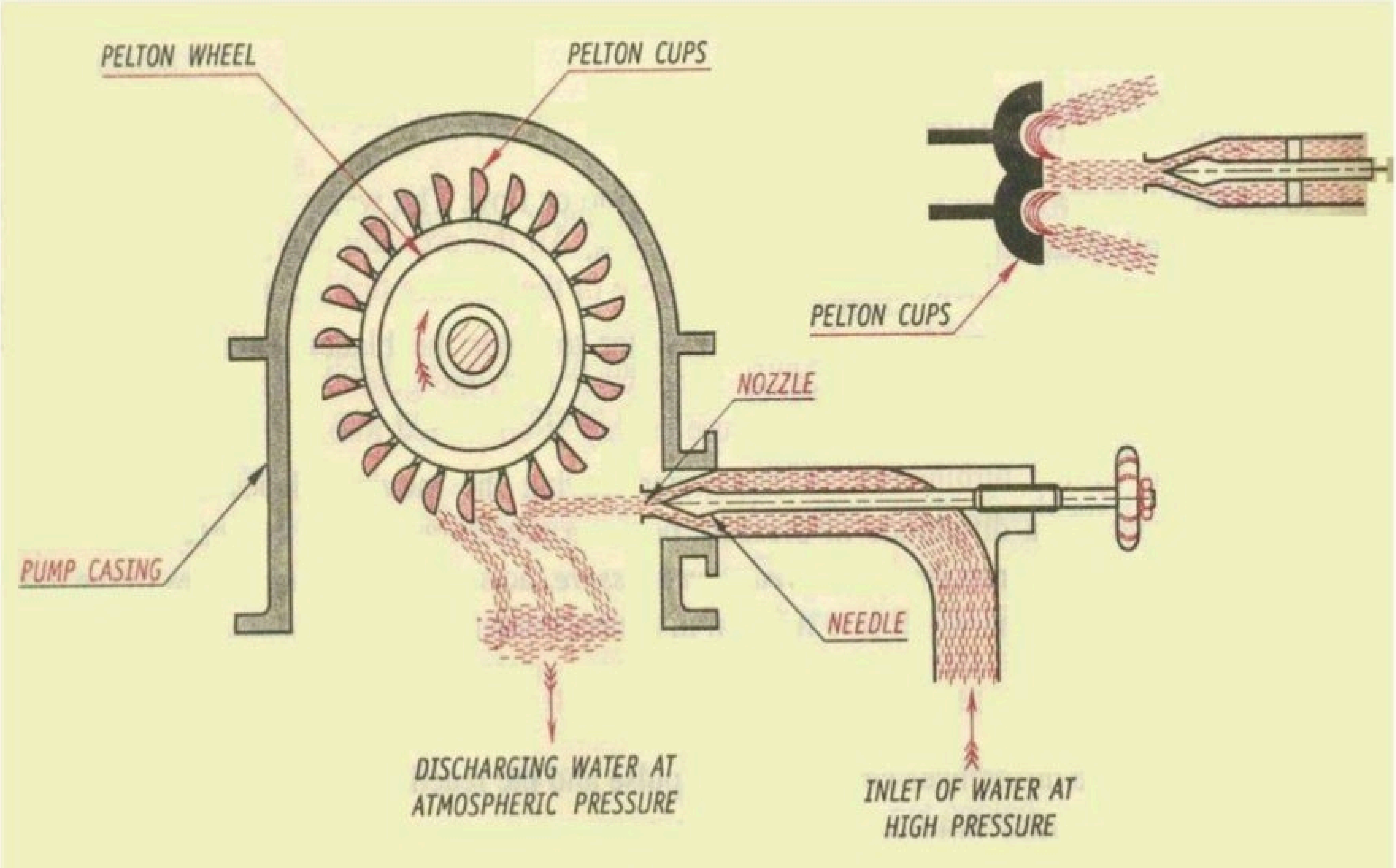
4. According to the specific speed of the turbine:

   (a) Low specific speed, (b) Medium Specific Speed,

   (c) High specific speed.

IMPULSE TURBINES

Pelton Turbine



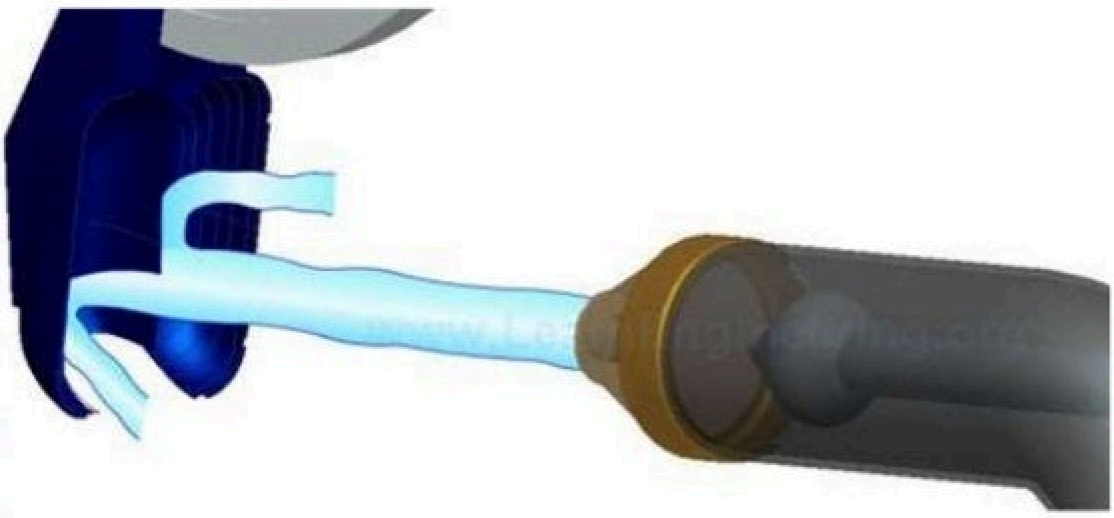
PELTON WHEEL

Pelton Turbine (Pelton Wheel or Free Jet Turbine)

- High head, Tangential flow, Impulse turbine, Horizontal shaft.
- This turbine is named after L.A Pelton, an American engineer.
- The water strikes the bucket along the tangent of the runner.
- Head= 50m to1300m
- Specific speed= 8.5 to 30 (single jet)
- Specific speed= 30 to 51 (two or more jets)

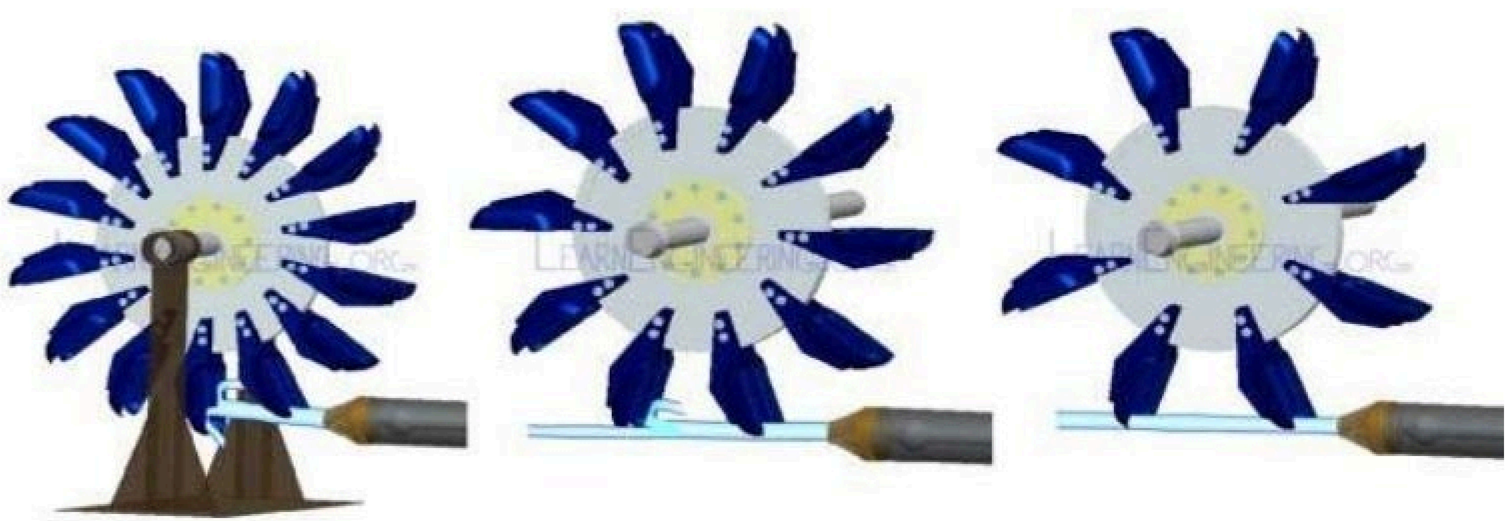
Pelton Turbine
The Basic Working Principle

Working principle of Pelton turbine is simple. When a high speed water jet injected through a nozzle hits buckets of Pelton wheel; it induces an impulsive force. This force makes the turbine rotate.



Number of Buckets in Pelton Wheel

One of the most important parameter of Pelton turbine design is number of buckets on the disk. If number of buckets is inadequate, this will result in loss in water jet. So there should be an appropriate number of buckets, which will make sure that no water is lost.



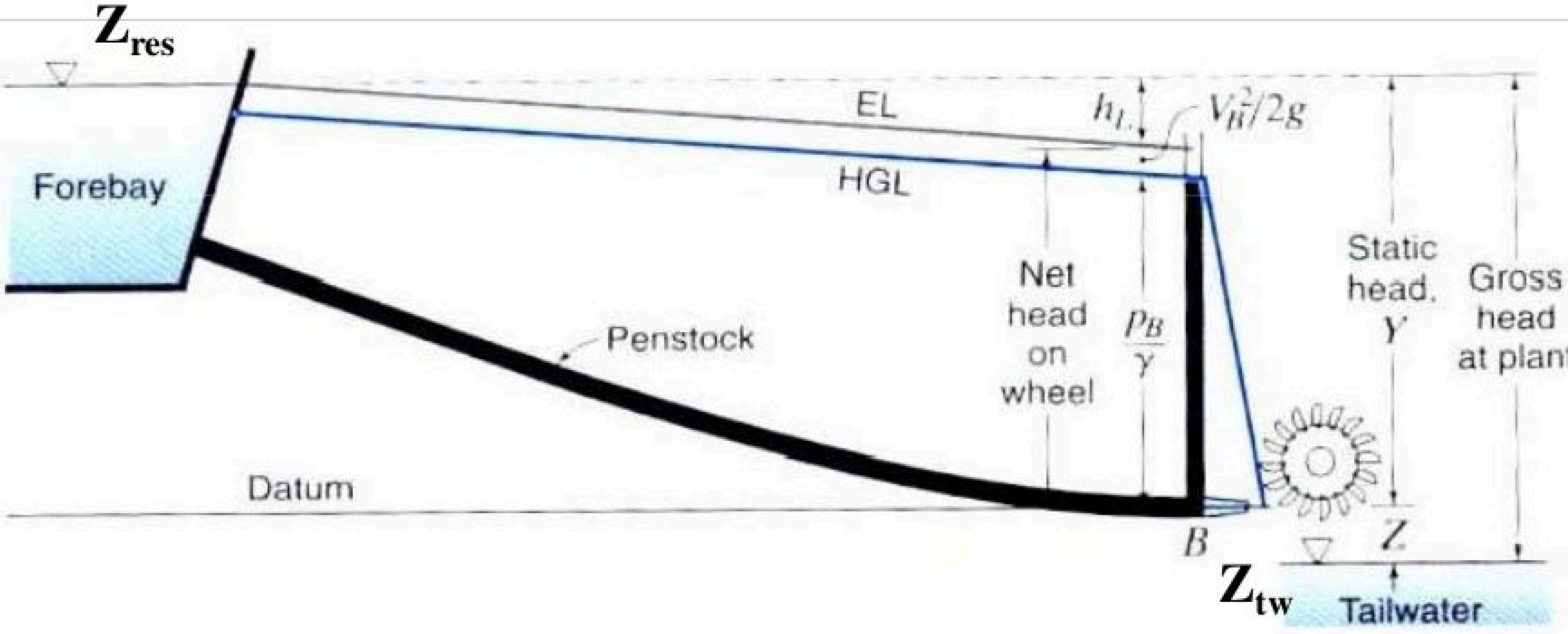
CATCHING COMPLETE JET

MISSING COMPLETE JET

Pelton Runner with Buckets

- Fig. Shows the runner of a Pelton wheel.
- The shape of buckets is of a double hemispherical cup or Bowl.
- Water jet is split into 2 equal components with help of a splitter. The special shape of bucket makes the jet turn almost 180 degree. This produces an impulsive force on bucket.

Impulse Turbine - Head



Gross head: It is the difference between the head race and tail race level when there is no flow. As such it is termed as static head and is denoted as H_s or H_g

Effective head: It is the head available at the inlet of the turbine. It is obtained by considering all losses. If h_f is the total loss then the effective head above the turbine is $H = H_g - H_f$

Specific Energy of Hydraulic Turbine

The specific energy of a hydro power plant is the quantity of potential and kinetic energy which 1 kilogram of the water delivers when passing through the plant from an upper to a lower reservoir. The expression of the specific energy is *Nm/kg* or *J/kg* and is designated as [m^2/s^2].

In a hydro power plant as outlined in the figure, the difference between the level of the upper reservoir z_{res} and the level of the tail water z_{tw} is defined as the gross head

$$H_g = z_{res} - z_{tw} \quad \text{(a)}$$

The corresponding gross specific hydraulic energy

$$E_g = gH_g \quad \text{(b)}$$

where g is the acceleration of gravity.

When a water discharge Q [m^3/s] passes through the plant, the delivered power is

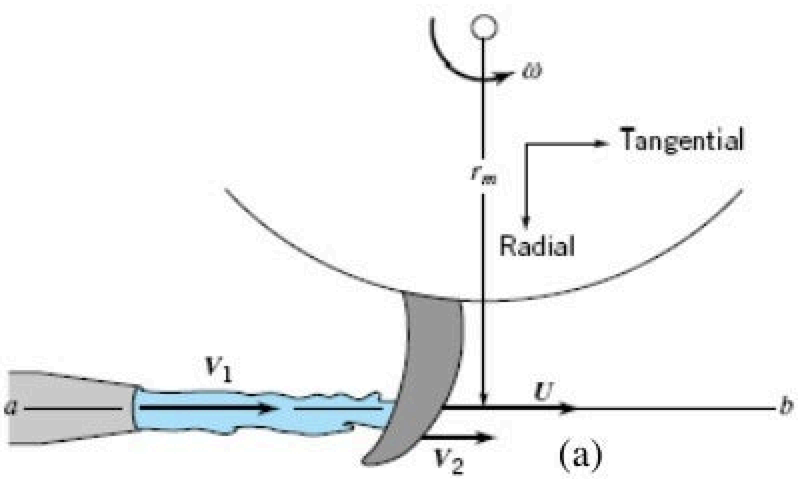
$$P_{gr} = \rho Q_g H_g \quad \text{(c)}$$

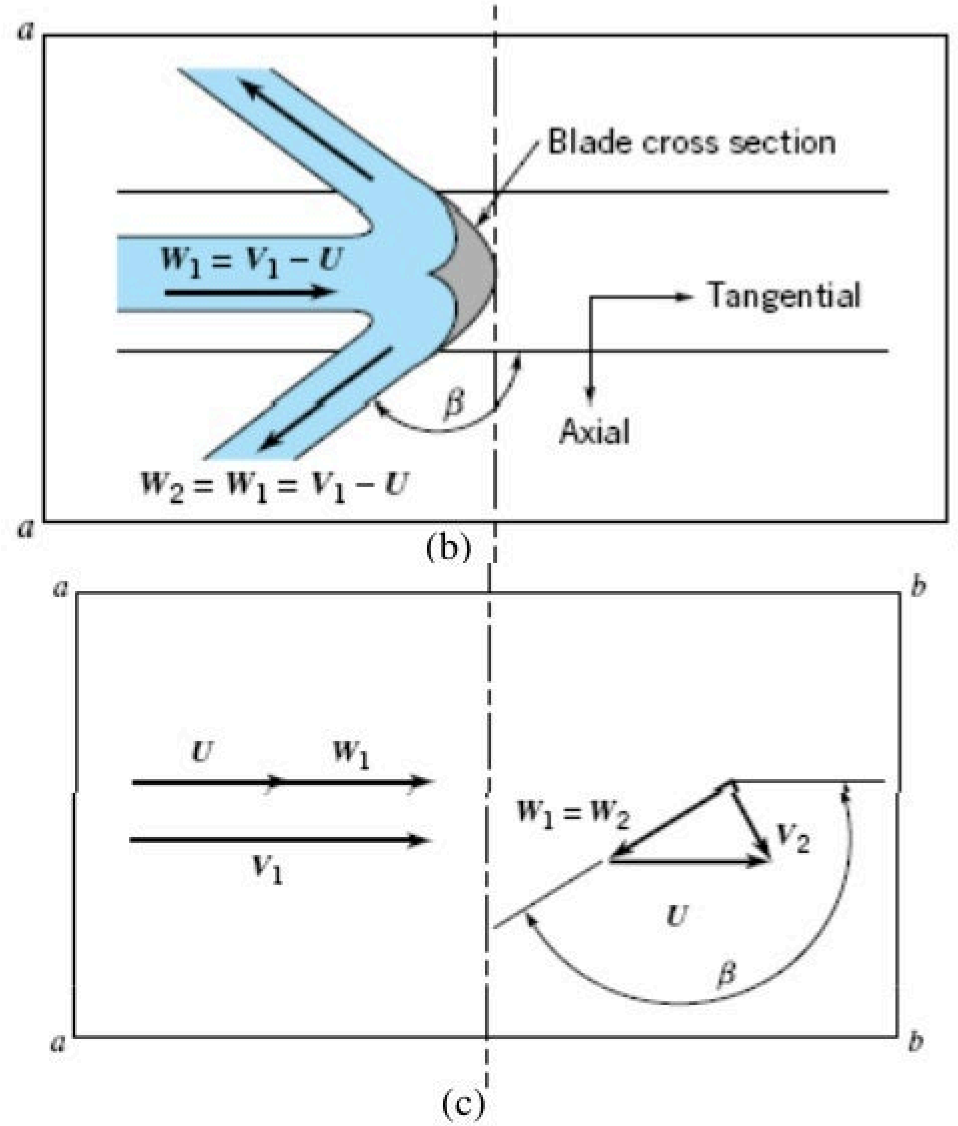
where P_g is the gross power of the plant

ρ is the density of the water

Q is the discharge

Velocity Triangle for Pelton Turbine





(a) Ideal fluid velocities for Pelton wheel turbine

(b) Relative velocities for Pelton wheel turbine

(c) Inlet and exit velocity triangles for Pelton wheel turbine

Work Done for Pelton Turbine

Tangential velocity at inlet of Pelton wheel

$$V_{\theta 1} = V_1 = W_1 + U \qquad (1)$$

Tangential velocity at outlet of Pelton wheel

$$V_{\theta 2} = W_2 \cos \beta + U \qquad (2)$$

Assuming $W_1 = W_2$ (i.e., the relative speed of the fluid does not change as it is deflected by the buckets, we can combine equation (1) and (2) to obtain

$$V_{\theta 2} - V_{\theta 1} = (U - V_1)(1 - \cos \beta) \qquad (3)$$

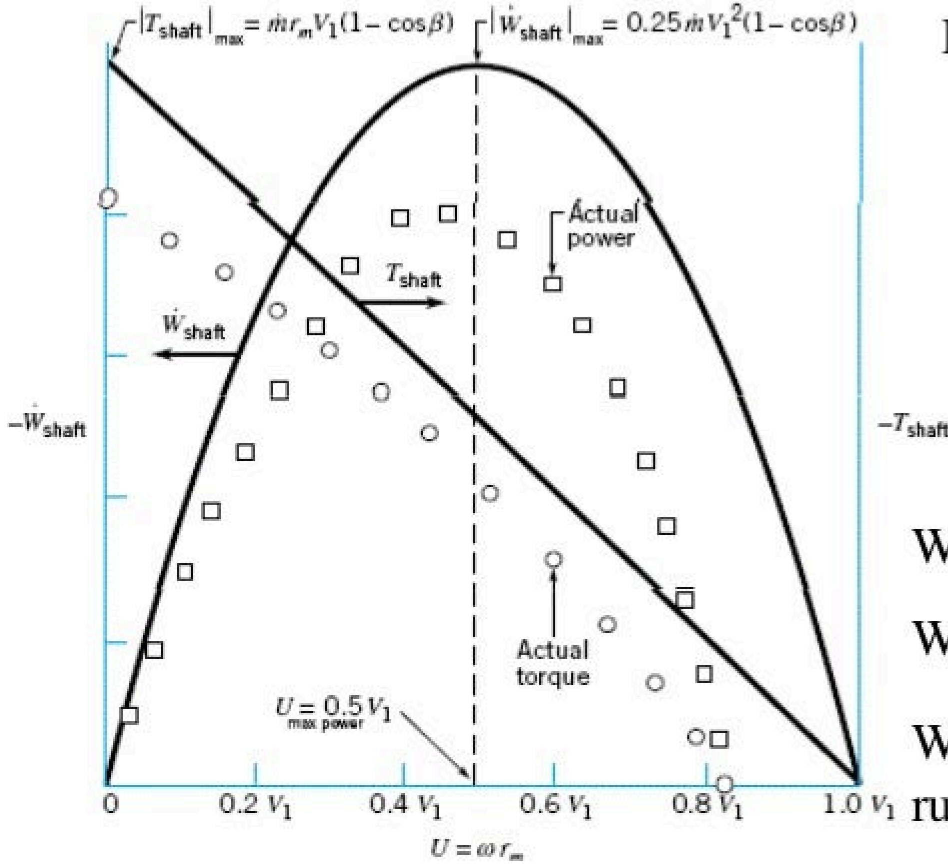
This change in tangential component of velocity combined with torque and power equation gives

$$T_{shaft} = \dot{m}\, r_m (U - V_1)(1 - \cos \beta) \qquad (4)$$

and since $U = \omega r_m$

$$W_{shaft} = T_{shaft} \quad = \dot{m}\, U (U - V_1)(1 - \cos \quad) \qquad (5)$$

Power and Torque for Pelton Turbine



Typical theoretical and experimental power and torque relation for a Pelton turbine as a function of bucket speed

Power,

$$P = \rho Q (U_1 V_{u1} - U_2 V_{u2})$$

Since $U_1 = U_2$,

$$P = \quad Q (V_{u1} - V_{u2})$$

When runner is at standstill ($U = 0$), $P = 0$

When $U = 0.5V_1$, power is maximum

When $U = V_1$, power = 0 (corresponds to run away speed)

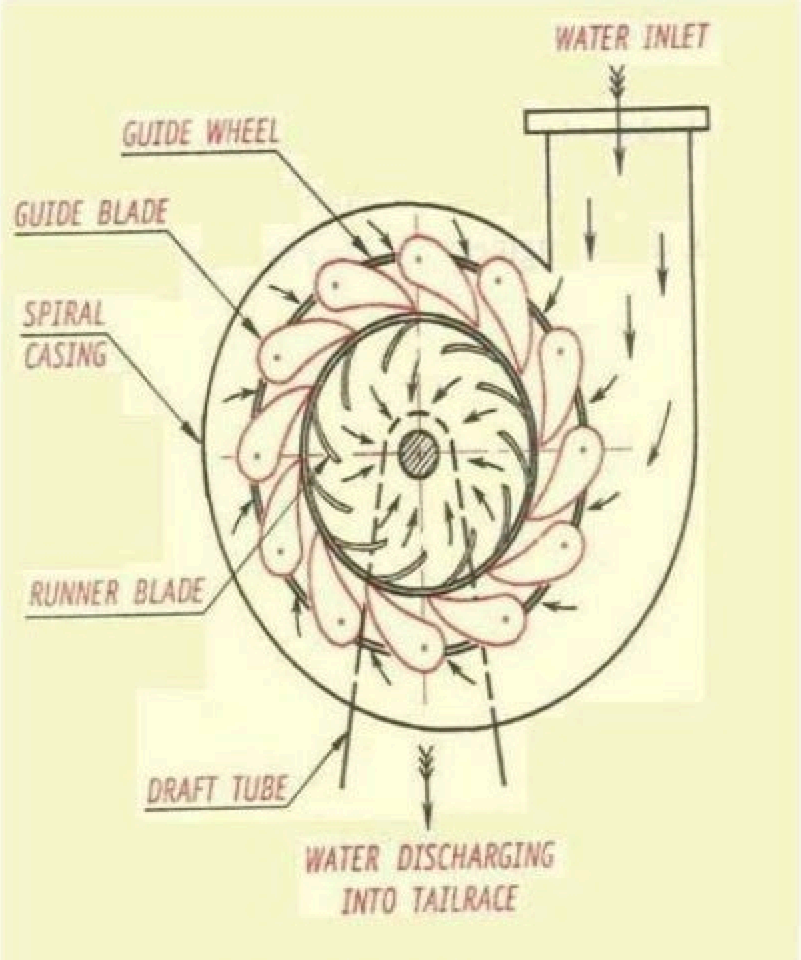
REACTION TURBINES

Francis Turbine

- The inward flow reaction turbine having radial discharge at outlet.
- This turbine is named after an American scientist J.B. Francis.
- Mixed flow, medium head reaction turbine.
  - ❖Head = 40-600 m.
  - ❖Flow rate = 10-700 m^3/s.
- Specific Speed = 51 to 255.

Francis Turbine

- In modern Francis Turbine, the water enters the runner of the turbine in the radial direction at outlet and leaves in the axial direction at the inlet of the runner. Thus the modern Francis Turbine is a mixed flow type turbine.



FRANCIS TURBINE

Francis Turbine - Runner

Most important part of Francis turbine is its runner. It is fitted with a collection of complex shaped blades as shown in Fig.

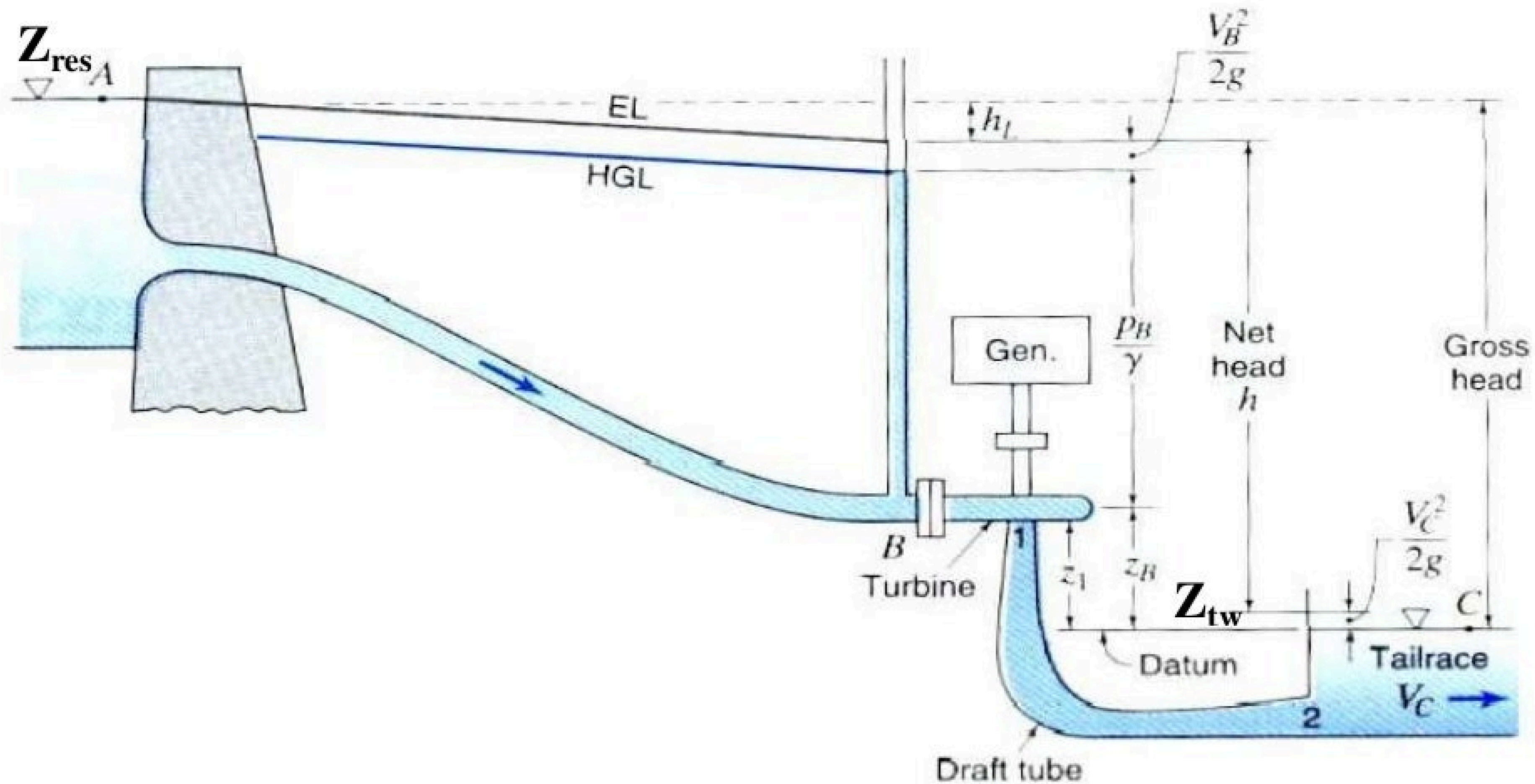
Francis Turbine - Runner

In runner water enters radially, and leaves axially. During the course of flow, water glides over runner blades as shown in figure below.

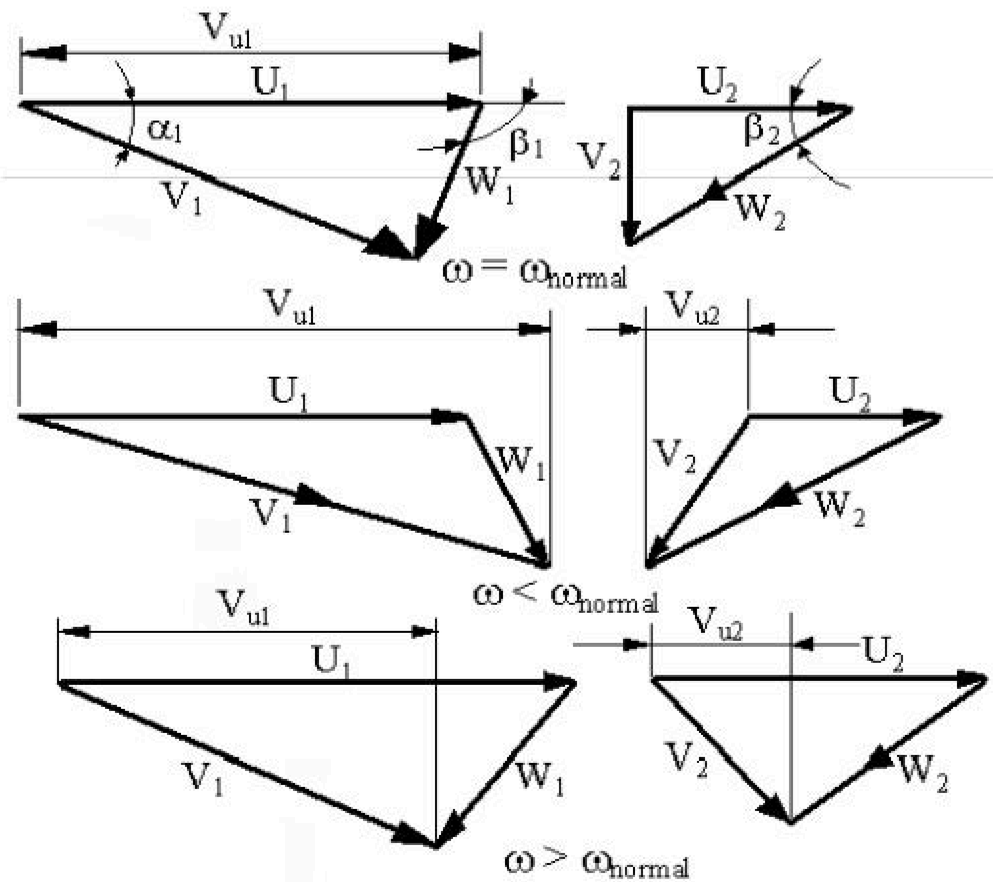
Francis Turbine - Runner

Blades of Francis turbine are specially shaped. So when water flows over it, a low pressure will be induced on one side, and high pressure on the other side. This will result in a lift force.

Reaction Turbine- Head



Velocity Triangle for Francis Turbine



Velocity triangle for three angular velocities

The absolute velocity at exit of the runner is such that there is no whirl at the outlet i.e., $V_{u2} = 0$.

Work done per kg of water

$$W_{shaft} = (U_1 - V_{\theta 1} - U_2 \quad - V_{\theta 2})$$

Power,

$$P = \rho Q \left(U_1 V_{u1} - U_2 V_{u2} \right)$$

$\omega = \omega_{\text{normal}}$ means the rotational speed for which the turbine gives the lowest energy loss at outlet represented mainly by $V_2^2/2$ and highest hydraulic efficiency for the given angle α_o of the guide vane canal.

Guide Vane Setting for Francis Turbine

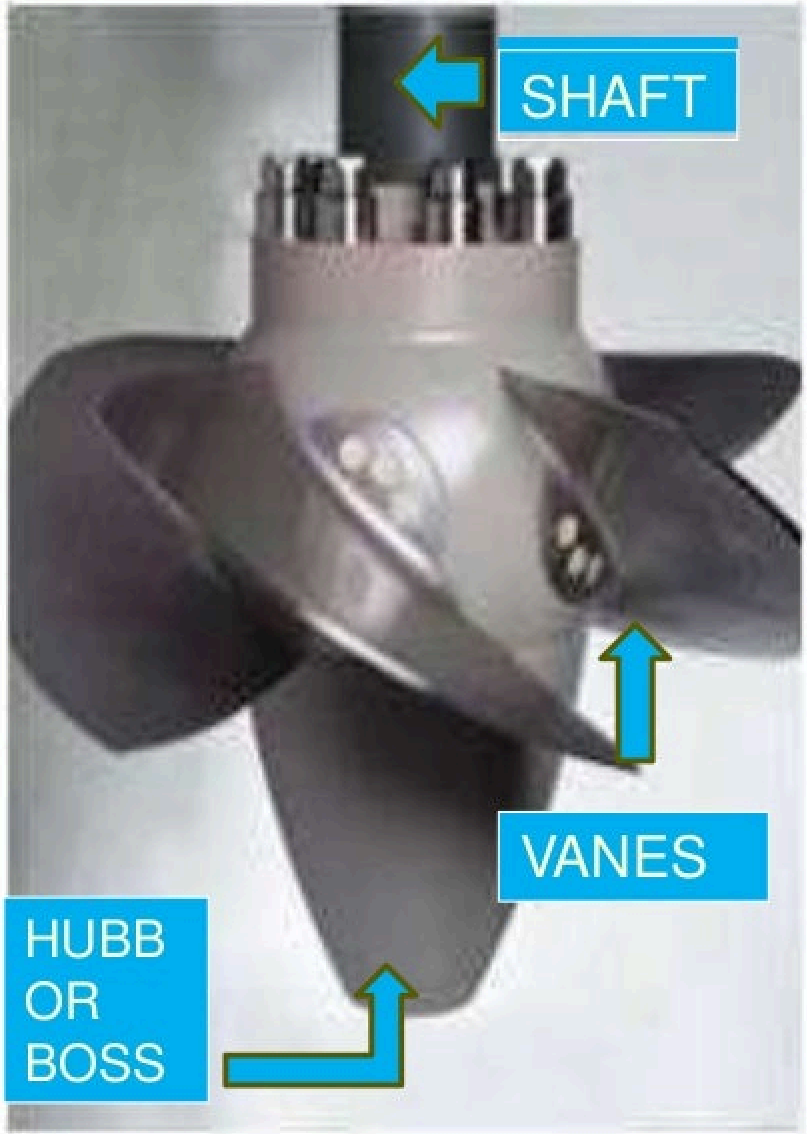
- ✓ For regulating discharge Q of the turbine, the width of the guide vane canals must be varied.
- ✓ An increase in Q requires adjusting the guide vanes to a larger angle α_o and a decrease of Q requires an adjustment in the opposite direction. This regulation causes corresponding changes in the direction of the absolute velocity V_1. Accordingly, the velocity diagrams change.
- ✓ Both, the variation of the angular velocity ω and the regulation of the discharge Q, involve changes in the direction and magnitude of the relative velocity W_1. The relative velocity W_2 varies accordingly in magnitude with the regulation of Q. Moreover the difference (U_1V_{u1} - U_2V_{u2}), and thereby the power transfer, is entirely dependent on these changes.
- ✓ The most efficient power transfer, however, is obtained for the operating condition when the relative velocity W_1 coincides with blade angle β_1 at the runner inlet and simultaneously the rotational component $V_{u2} \approx 0$.
- ✓ Therefore, the hydraulic layouts of all reaction turbine runners are based on the data of rotational speed n, discharge Q and net head H_n, at which the optimal efficiency is desired.

Kaplan Turbine

- This turbine is named after an Austrian Engineer, V. Kaplan.
- Axial flow, low head reaction turbine.
- Kaplan turbines are suitable for power extraction when water energy is available at low head and high flow rate. Following are the operating conditions Kaplan turbine is best suitable for
  - Head = 2-25 m
  - Flow rate = 70-800 m^3/s
  - Specific speed = 255 to 860

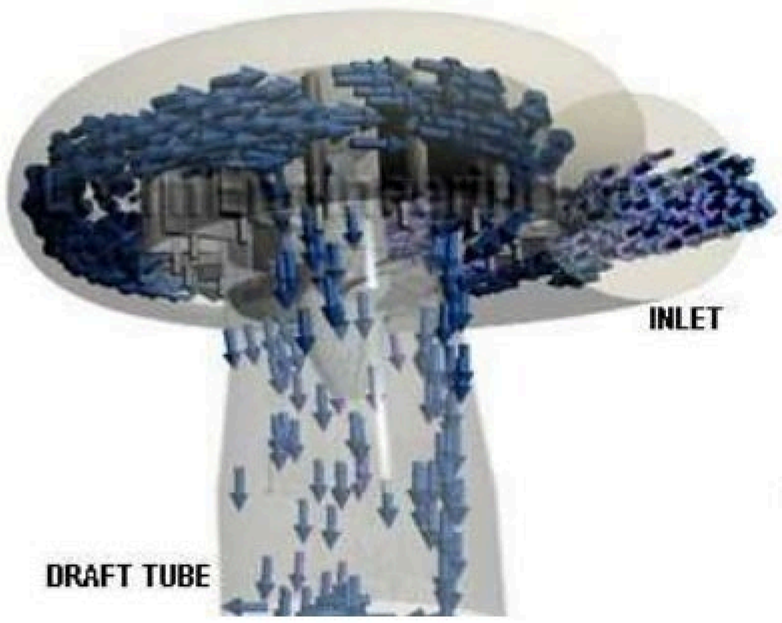
Continuous…….

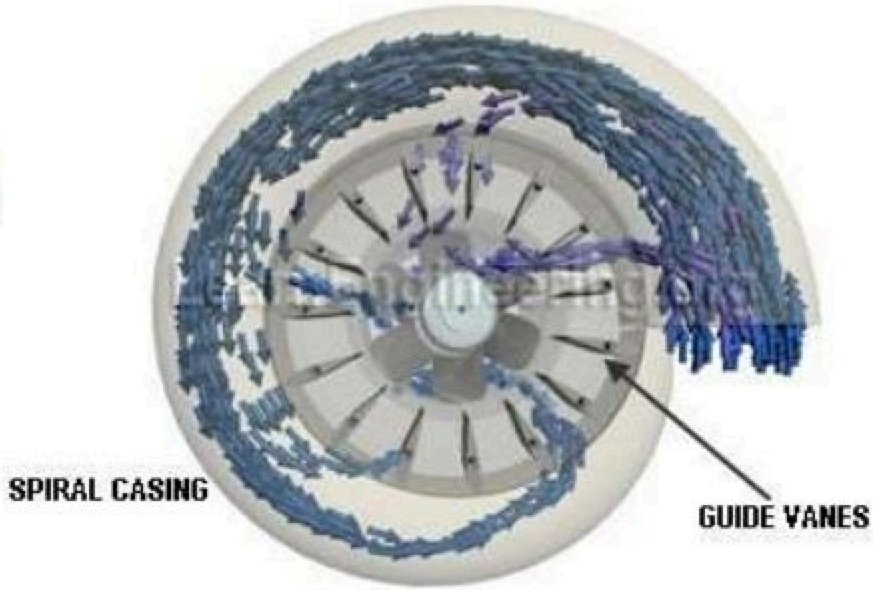
- In an axial flow reaction turbine the shaft is vertical. The lower end of the shaft is larger and is known as ‘hub’ or ‘boss’. It is on this
- hub that the vanes are attached. If the vanes are adjustable then it is known as **Kaplan Turbine** and if the vanes are non adjustable then it is known as **Propeller Turbine**.



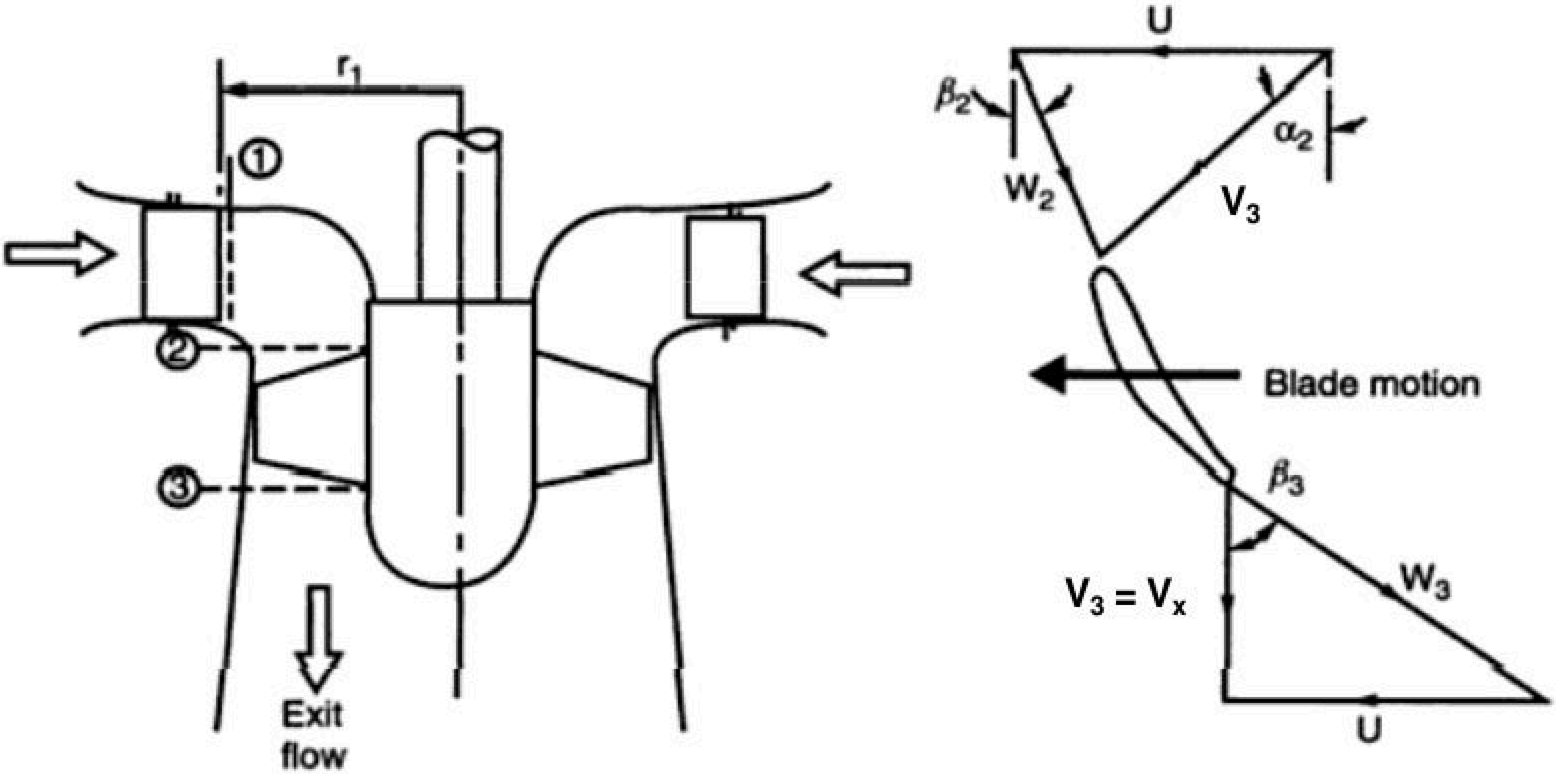
Flow in Kaplan Turbine

Kaplan turbine flow is entered through a spiral casing. Decreasing area of casing makes sure that flow is entered to the central portion almost at uniform velocity throughout the perimeter. Water after crossing the guide vanes passes over the runner. Finally it leaves through a draft tube.

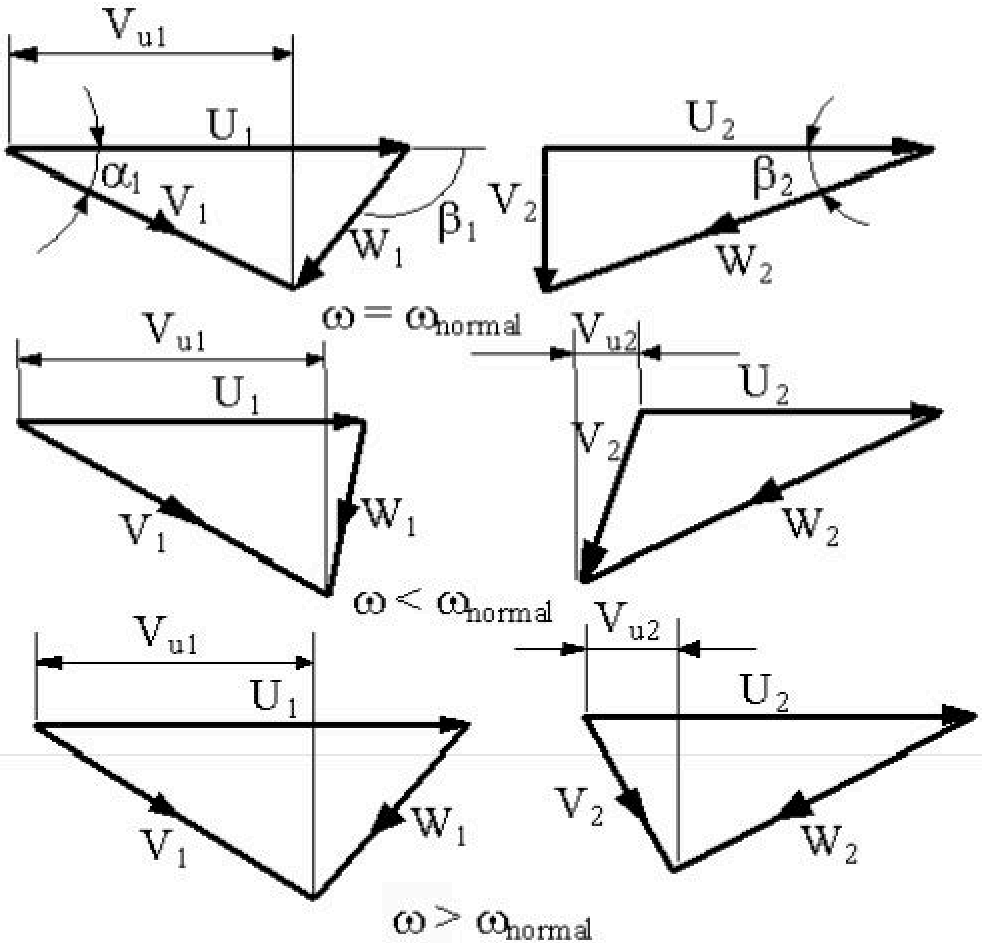




Velocity Triangle for Kaplan Turbine



Velocity Triangle for Kaplan Turbine



Velocity triangle for three angular velocities

The absolute velocity at exit leaves the runner such that there is no whirl at the outlet i.e., $V_{u2} = 0$.

Work done per kg of water

$$W_{shaft} = (U_1 - V_{\theta 1} - U_2 \quad - V_{\theta 12})$$

Power,

$$P = \rho Q\left(U_1 V_{u1} - U_2 V_{u2}\right)$$

$\omega = \omega_{normal}$ means the rotational speed for which the turbine gives the lowest energy loss at outlet represented mainly by $V_2^2/2$ and highest hydraulic efficiency for the given angle α_o of the guide vane canal.

Efficiencies of Hydraulic Turbines

Efficiencies:

Various efficiencies of hydraulic turbines are:

- Hydraulic efficiency
- Volumetric efficiency
- Mechanical Efficiency
- Overall Efficiency

Efficiency in general is defined as the ratio of power delivered to the shaft (brake Power) to the power taken from water.

Hydraulic efficiency :

It is the ratio of the power developed by the runner to the water power available at the inlet of turbine.

Total available power of a plant is given by

$$P_{available} = \rho Q g H_n$$

Power transfer from the fluid to the turbine runner is given by

$$P_{shaft} = \rho Q \left(U_1 V_{u1} - U_2 V_{u2} \right)$$

Efficiencies of Hydraulic Turbines

The ratio of these two powers is given by

$$_{hydraulic} - \frac{Power_{shaft}}{Power_{available}}$$

$$\eta_{hydraulic} = \frac{Q\ U_1 V_{u1} - U_2 V_{u2}}{\rho Q g H_n}$$

$$_{hydraulic} = \frac{\left(U_1 V_{u1} - U_2 V_{u2}\right)}{g H_n}$$

The rearrangement of this equation gives the main turbine equation

$$\eta_{hydraulic} H_n = \frac{\left(U_1 V_{u1} - U_2 V_{u2}\right)}{g}$$

Specific Energy of Hydraulic Turbine

The specific hydraulic energy between section *B* and *C* is available for the turbine.

This specific energy is defined as net specific energy and is expressed by

$E_n = gH_n$

And the net head of the turbine $H_n = E_n/g$

$H_n = h_p + V^2/2g$

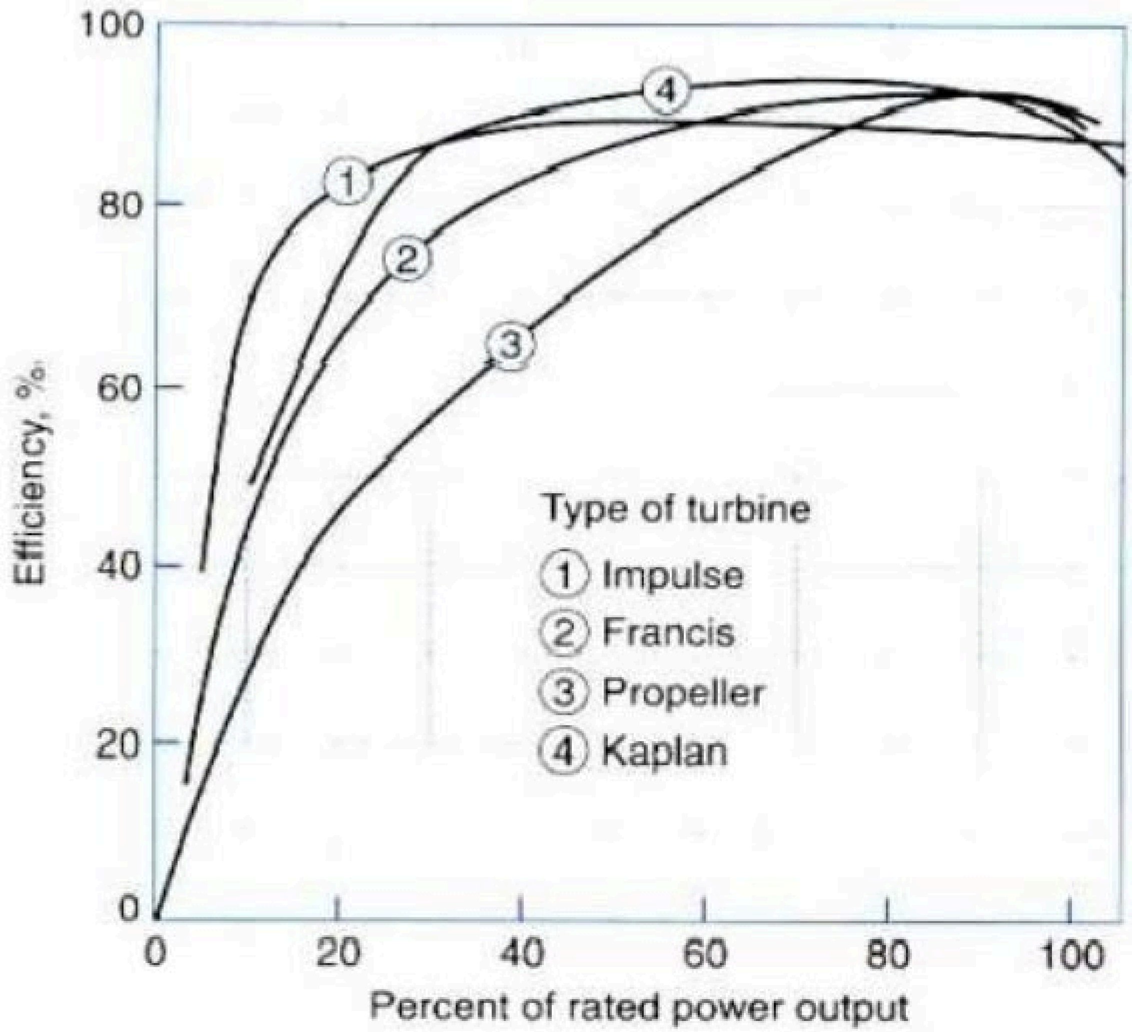
$H_n = H_g - E_L/g = H_g - H_L$

where h_p is the piezometric head above tail water level (P_B/γ)

$V^2/2g$ is the velocity head

E_L/g is specific hydraulic energy loss H_L

Efficiency vs Load for Turbines



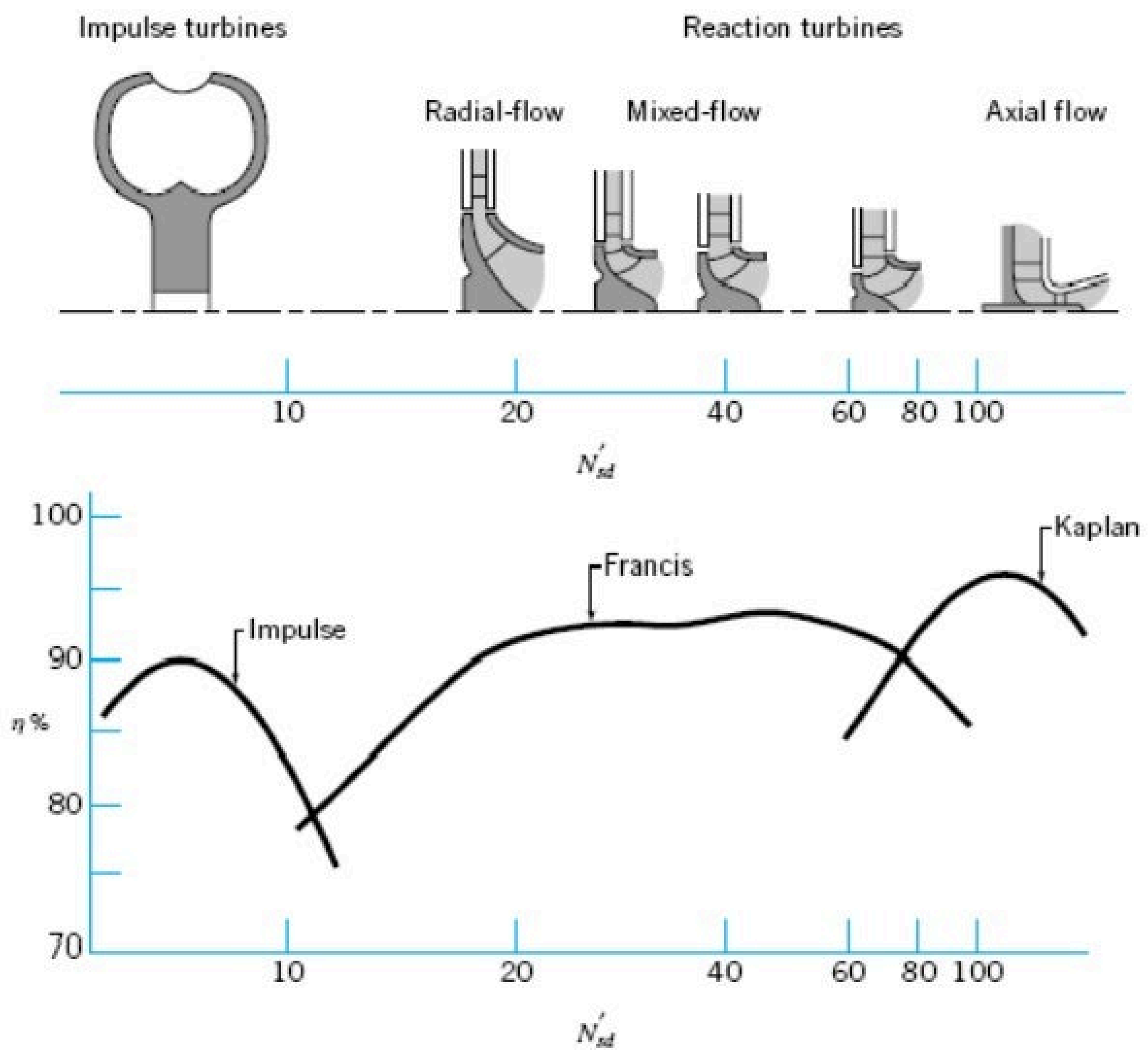
Specific Speed

- It is defined as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles, gate opening etc., with the actual turbine but of such a size that it will develop unit power when working under unit head
- This is the speed at which the runner of a particular diameter will develop 1 kW (1 hp) power under 1 m (1 ft) head.

$$N_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$$

- The specific speed is an important factor governing the selection of the type of runner best suited for a given operating range. The impulse (Pelton) turbines have very low specific speeds relative to Kaplan turbines. The specific speed of a Francis turbine lies between the impulse and Kaplan turbine.

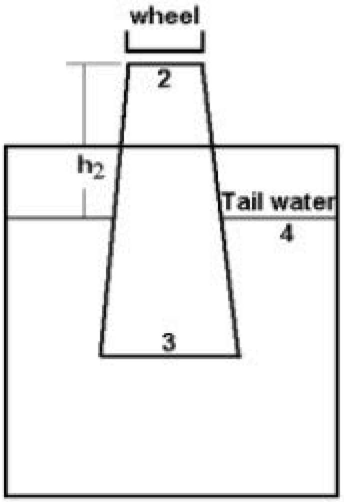
Efficiency vs Specific Speed



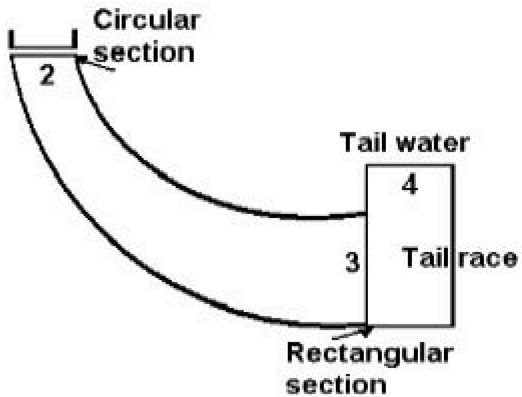
Draft Tube

1. In a reaction turbine, water leaves the runner with remaining kinetic energy. To recover as much of this energy as possible, the runner outlet is connected to a diffuser, called draft tube. The draft tube *converts* the dynamic pressure (kinetic energy) into static pressure.
2. Draft tube permits a suction head to be established at the runner exit, thus making it possible for placing the wheel and connecting machinery at a level above that of water in the tail race under high water flow conditions of river, without loss of head.
3. To operate properly, reaction turbines must have a submerged discharge.
4. The water after passing through the runner enters the draft tube, which directs the water to the point of discharge.
5. The aim of the draft tube is also to convert the main part of the kinetic energy at the runner outlet to pressure energy at the draft tube outlet.
6. This is achieved by increasing the cross section area of the draft tube in the flow direction.
7. In an intermediate part of the bend, however, the draft tube cross sections are decreased in the flow direction to prevent separation and loss of efficiency.

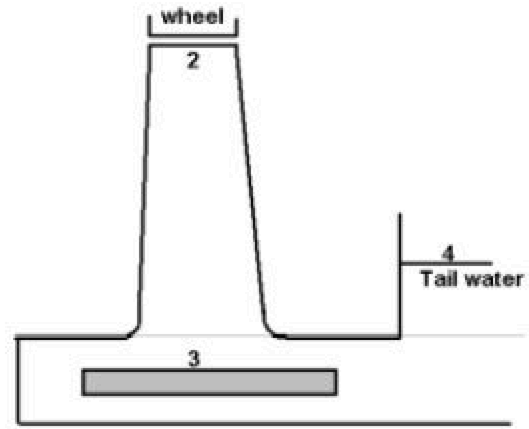
Types of Draft Tube



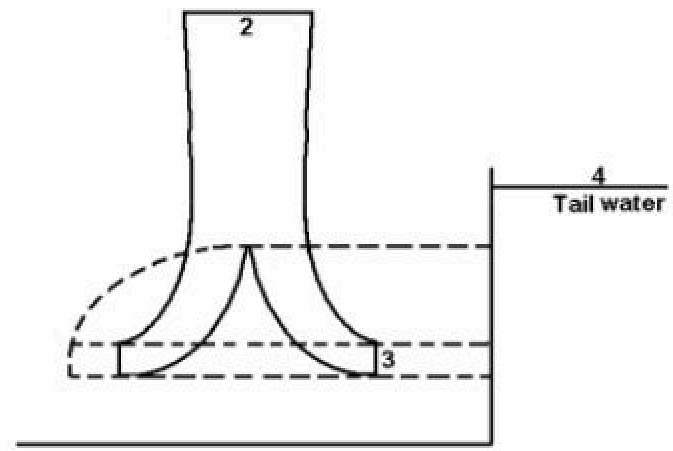
(a)



(b)



(c)



(d)

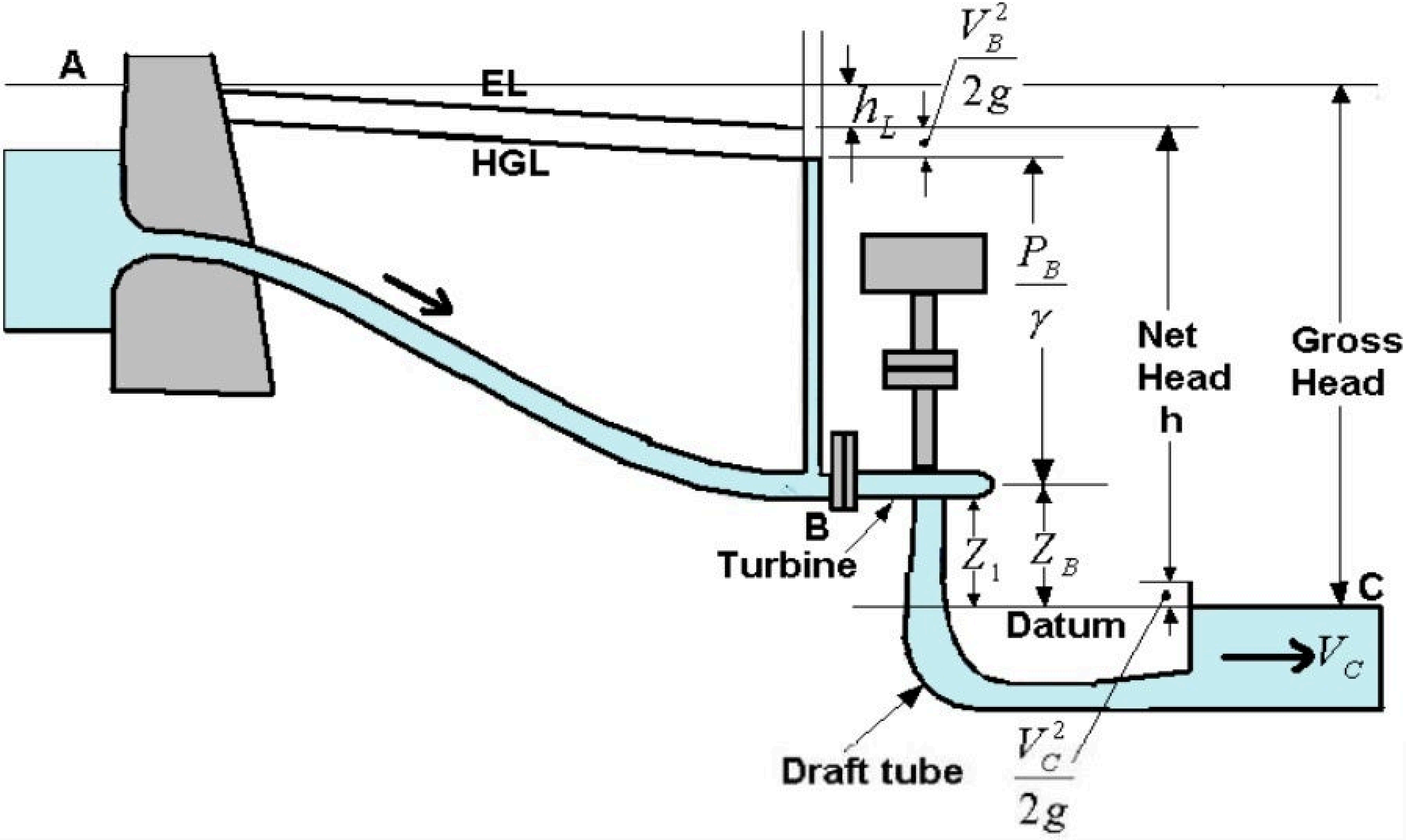
(a) Conical type
(b) Elbow type
(c) Hydraucone type
(d) Moody spreading type

Energy Equation Applied to Draft Tube

$$\frac{P_B}{\gamma} + Z_B \quad + \frac{V_B^2}{2g} + h_L$$

- The velocity V_2 can be reduced by having a diverging passage.
- To prevent cavitation, the vertical distance z_1 from the tail water to the draft tube inlet should be limited so that at no point within the draft tube or turbine will the absolute pressure drop to the vapour pressure of water.

Draft Tube



A
EL
HGL
h_L
$\frac{V_B^2}{2g}$
$\frac{P_B}{\gamma}$
Net Head h
Gross Head
B
Turbine
Z_1
Z_B
C
Datum
V_C
Draft tube
$\frac{V_C^2}{2g}$

PERFORMANCE CHARACTERISTIC CURVES OF TURBINES

INTRODUCTION

- Designed conditions of turbine -
- Hydraulic Turbines gives their best performance when they are operated at certain conditions of head, discharge, speed and output power.
- Model turbines are tested under different conditions of head, discharge, speed, power, efficiency. Results are plotted in the form of curves and are known as **performance characteristic curves**.
- For convenience, curves are plotted in terms of unit quantities.

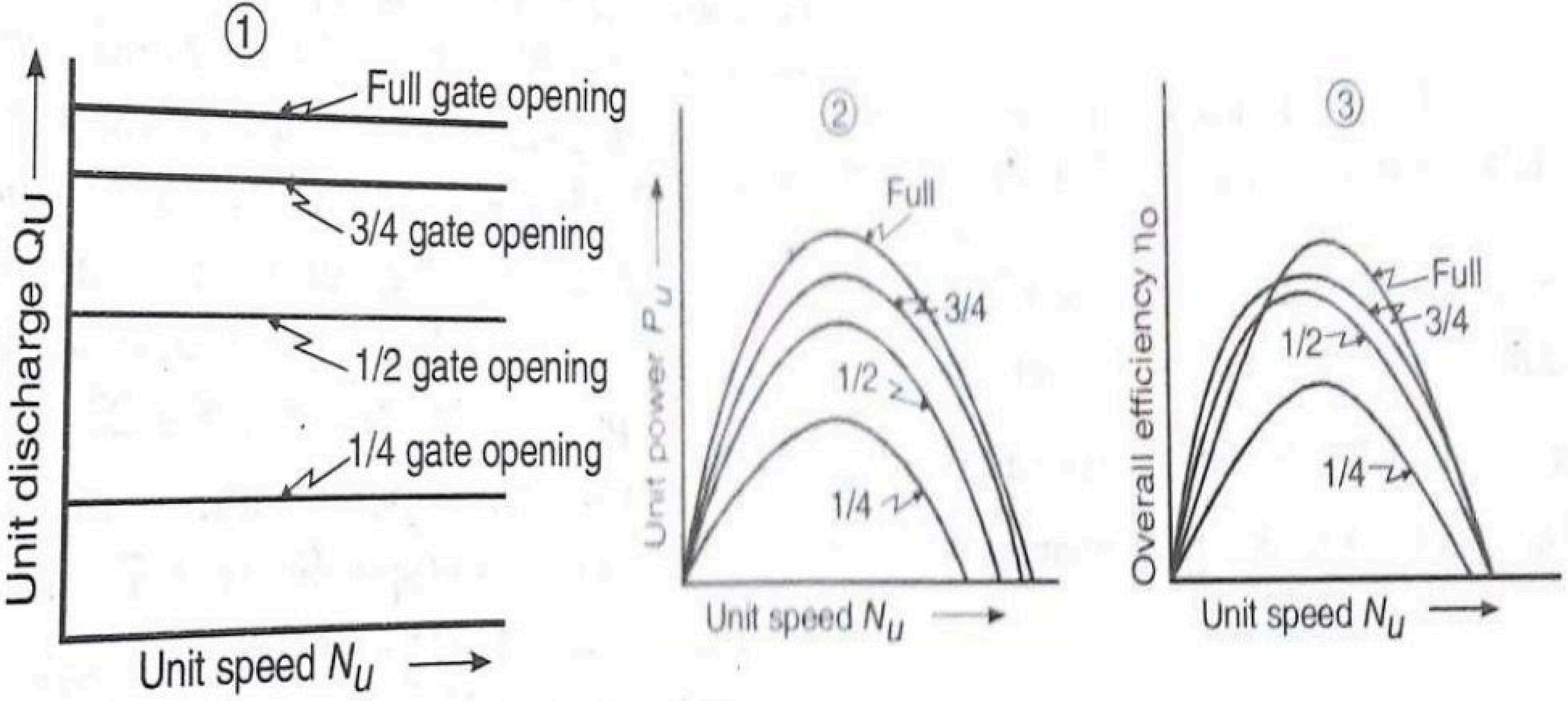
Types of PC curves

- Main Characteristic curves / Constant head curves
- Operating characteristic curves / Constant Speed curves
- Constant efficiency curves (Muschel Curves)

Main Characteristic curves/ Constant head curves

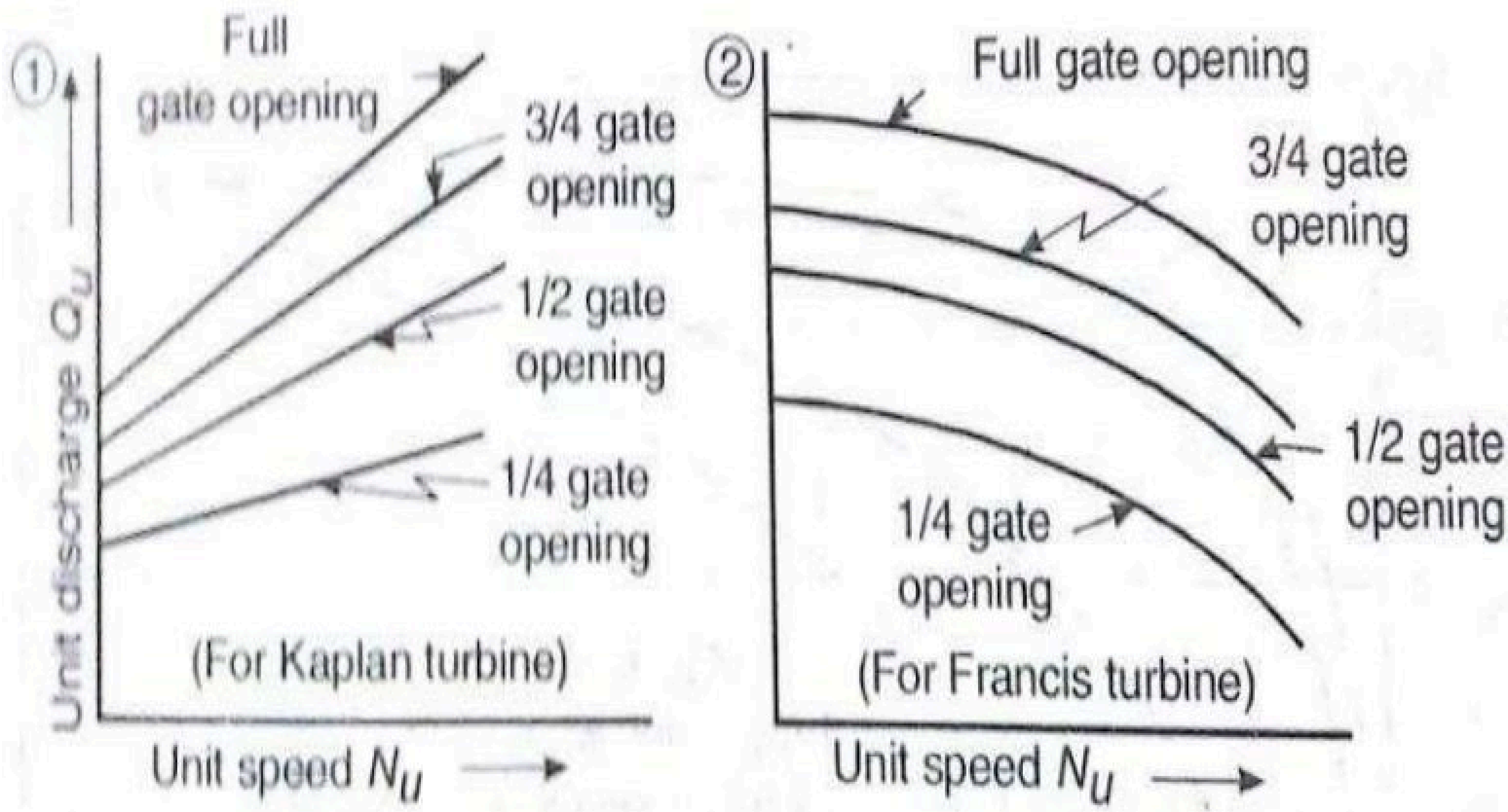
- Curves are drawn by conducting experiment at constant head.
- Head and gate openings are kept constant and speed is varied by varying load on the turbine.
- For each value of speed, corresponding values of power and discharge are obtained.

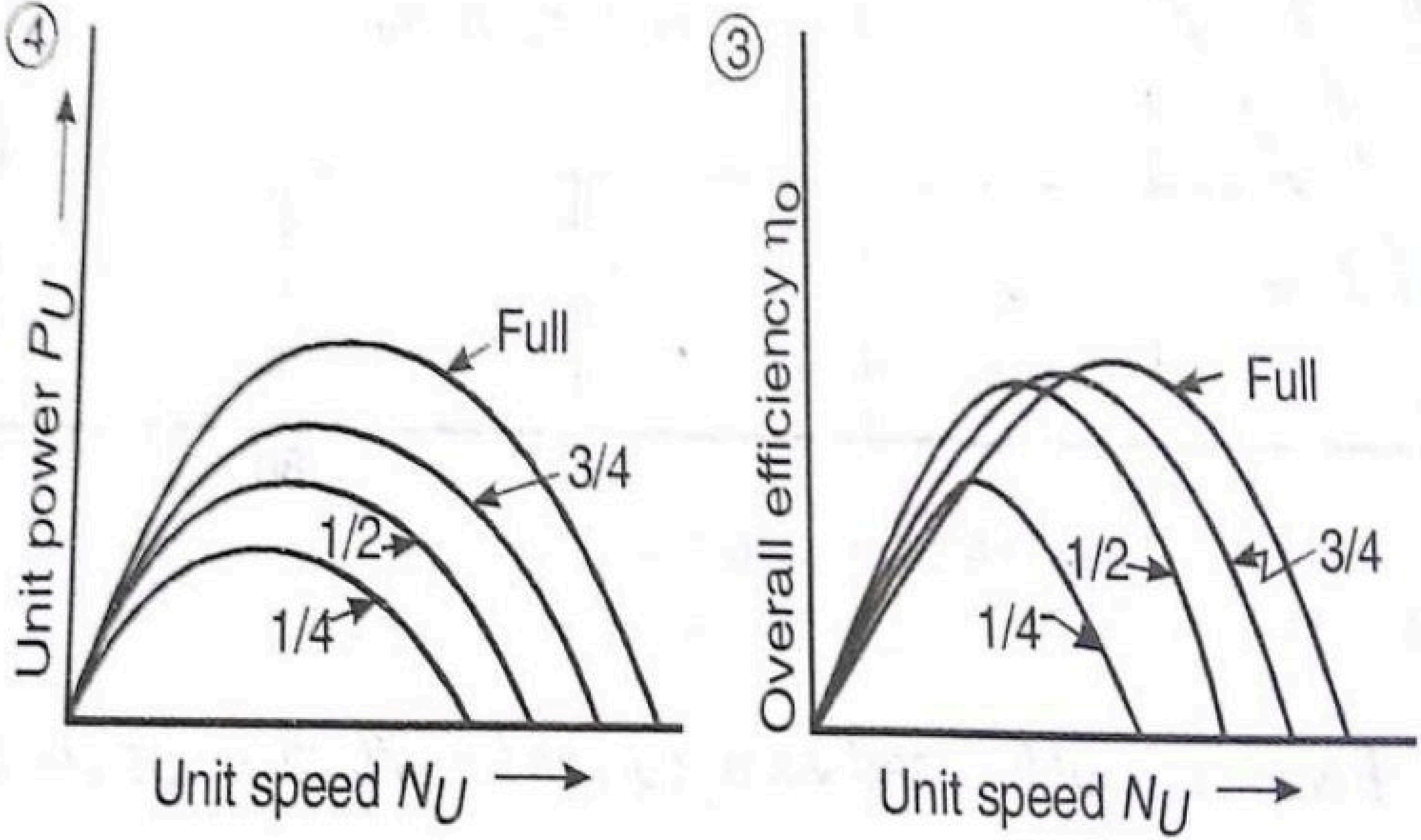
For Pelton wheel



(a) For pelton wheel

For Reaction turbines

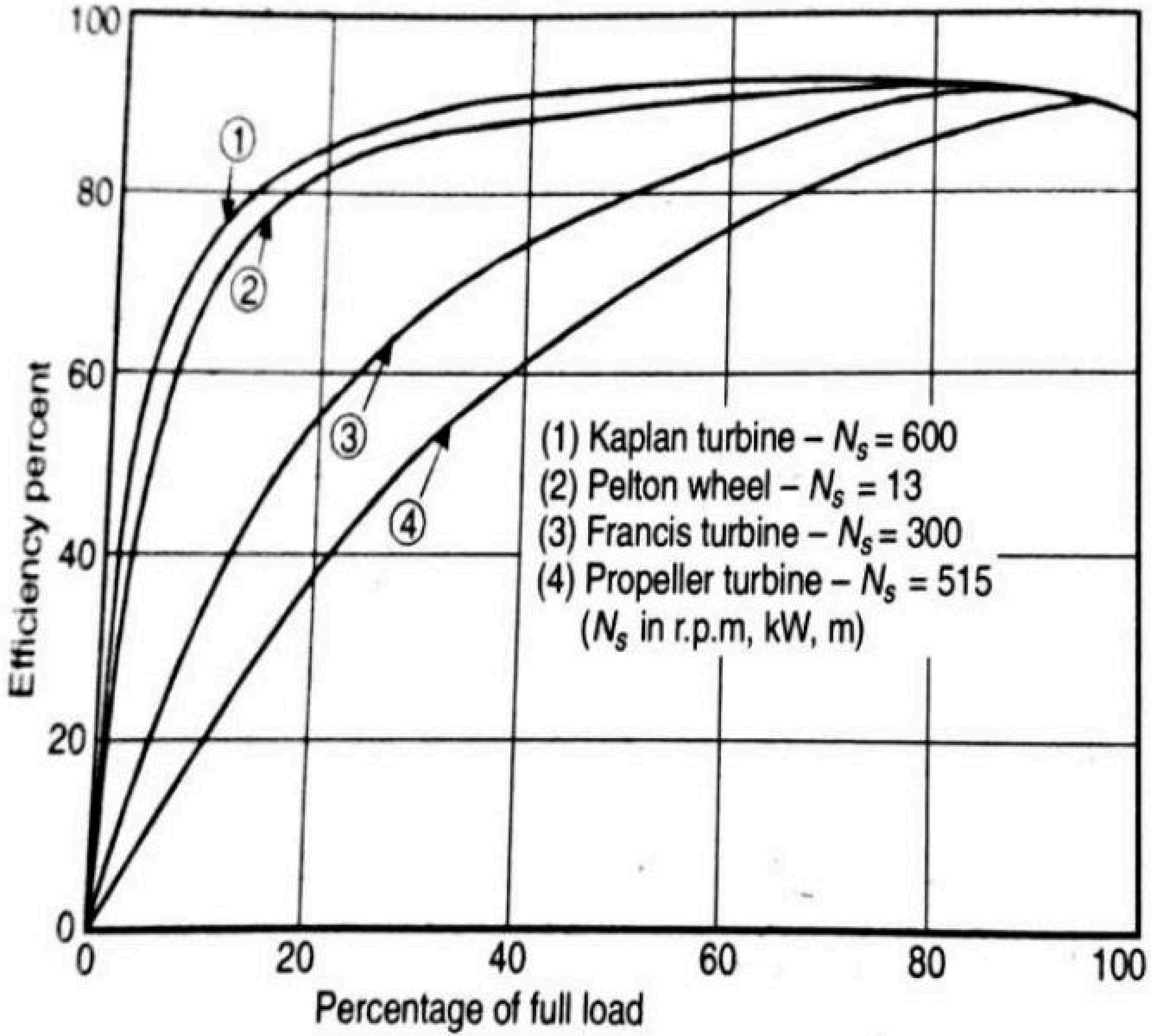




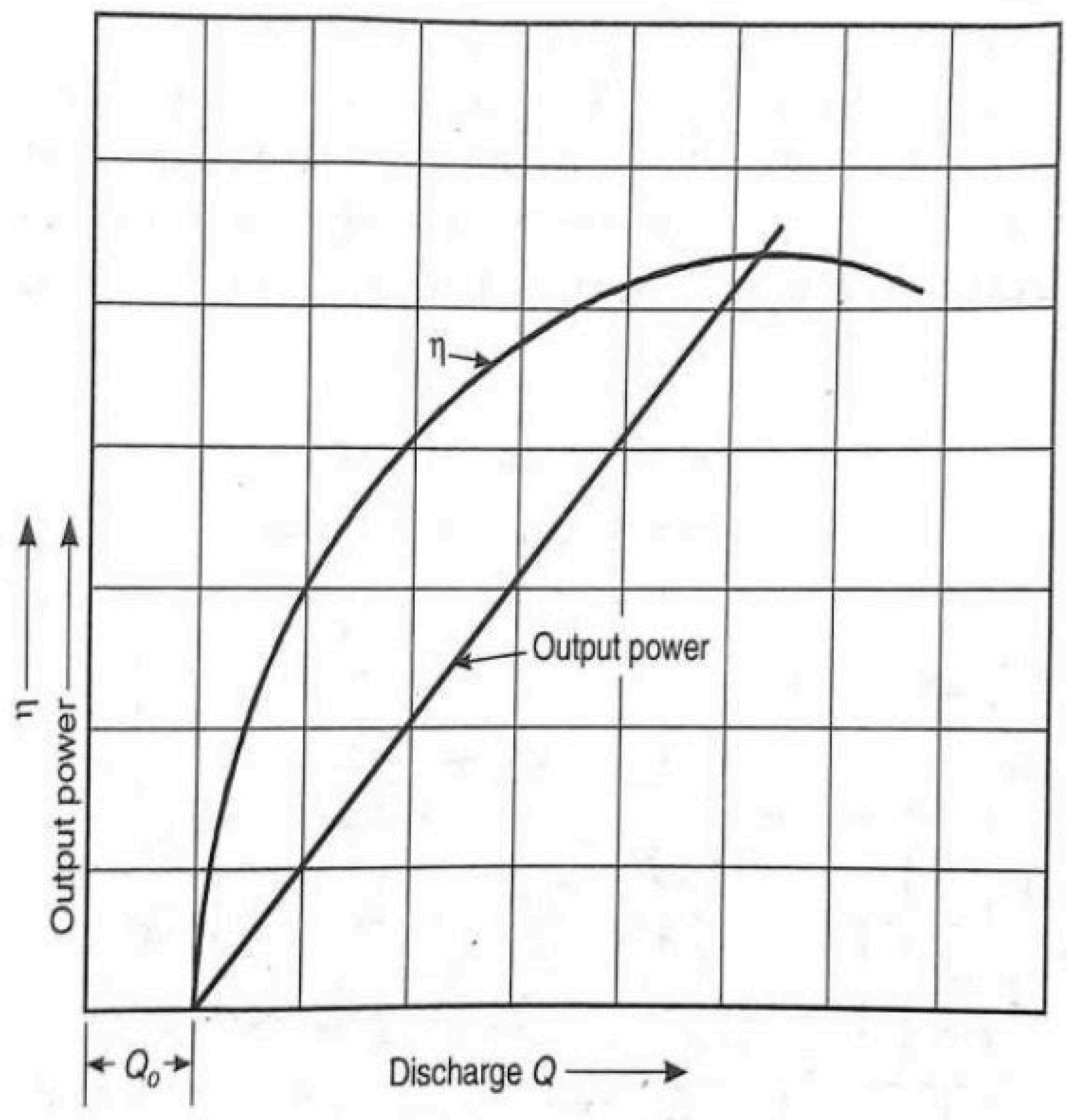
(b) For reaction turbine

OPERATING CHARACTERISTIC CURVES / Const. Speed curves

- Tests are performed at constant speed.
- Const. speed is attained by regulating the gate opening thereby varying the discharge flowing through the turbine as the load varies.
- Head may or may not kept constant.



100
80
60
40
20
0
0
20
40
60
80
100
Efficiency percent
Percentage of full load
1
2
3
4
(1) Kaplan turbine – $N_s = 600$
(2) Pelton wheel – $N_s = 13$
(3) Francis turbine – $N_s = 300$
(4) Propeller turbine – $N_s = 515$
(N_s in r.p.m, kW, m)



η
Output power
η
Output power
Q₀
Discharge Q

Constant Efficiency

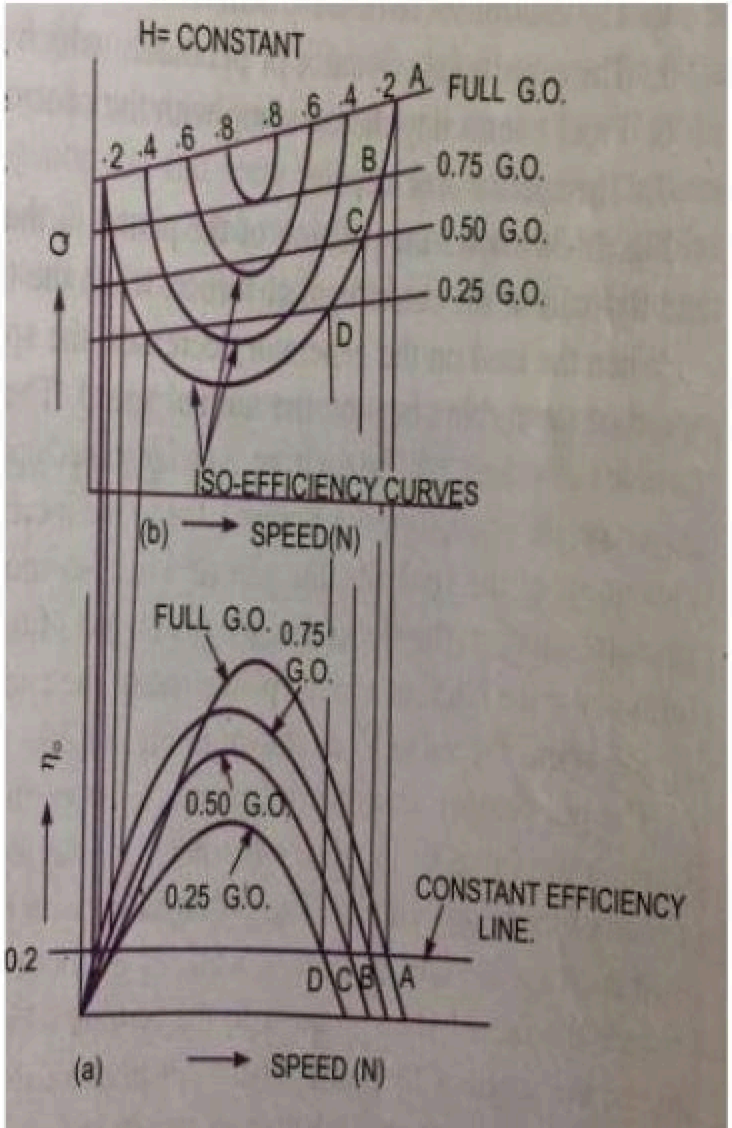
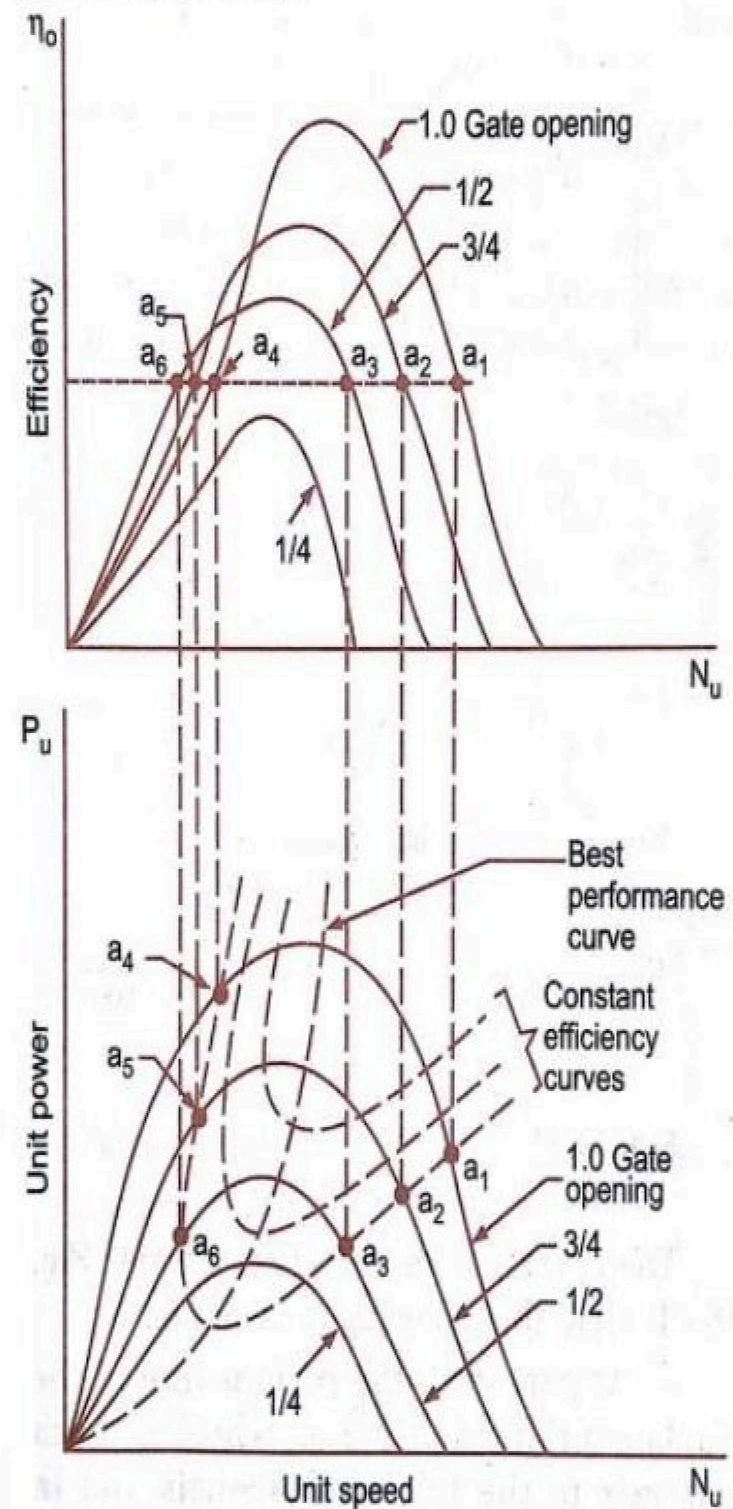


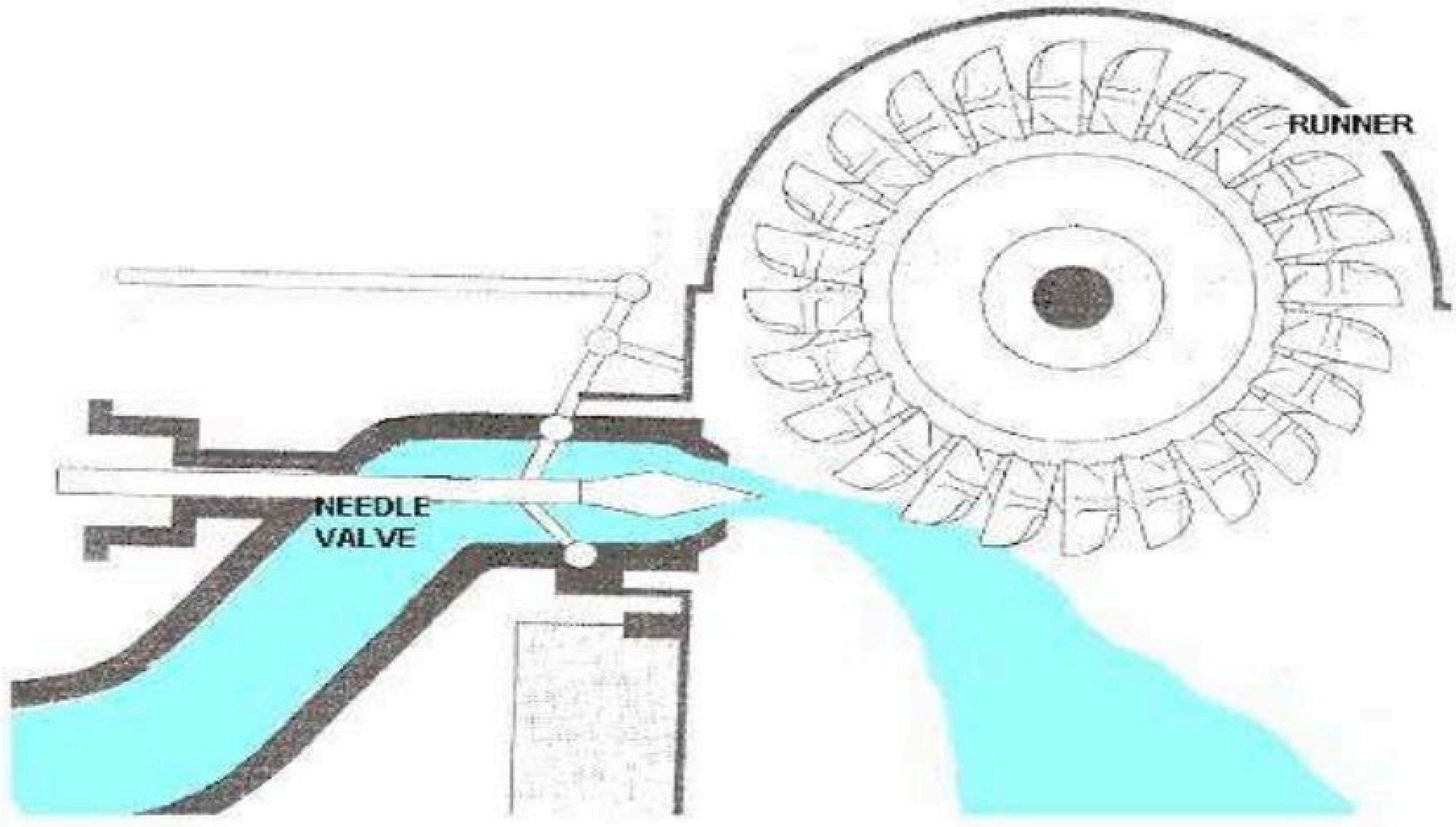
Fig. 18.38 *Constant efficiency curve.*



GOVERNING OF HYDRAULIC TURBINES

Types of governing mechanisum for impulse turbine

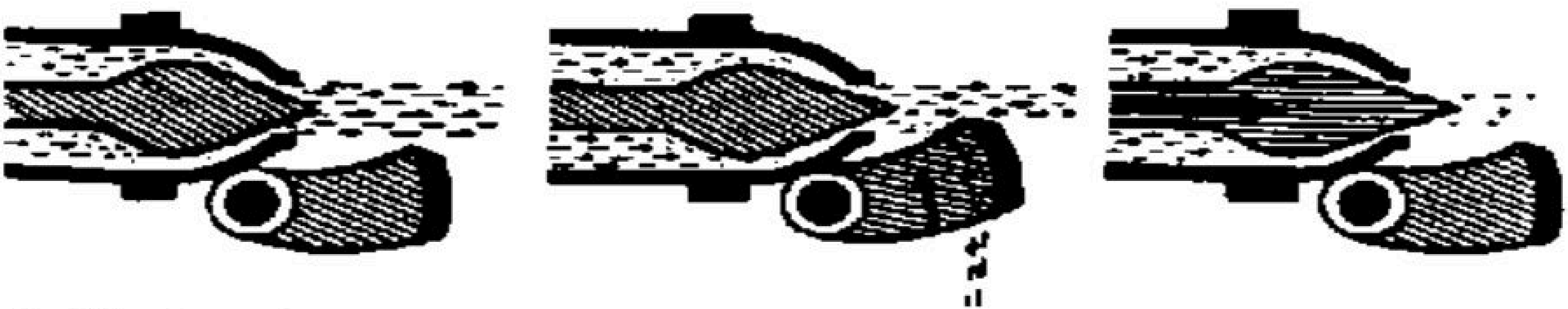
Needle wheel rod mechanism



Neddle wheel rod mechanisum

- This mechanisum is useful when capacity of pelton wheel turbine is very less.
- It is simplest type of mechanisum its maintenance cost is very less.
- In this mechanisum needle wheel rod is used to control flow of water .
- One wheel is provided end of the rod ,when move that forward and backward the needle valve the water flowing rate increases or decreases.

Deflector pin mechanisum and wheel rod mechanisum for pelton turbine



full load

partial deflection of jet

needle reduces water flow

Fig. 10: Operation of Jet Deflector and Needle

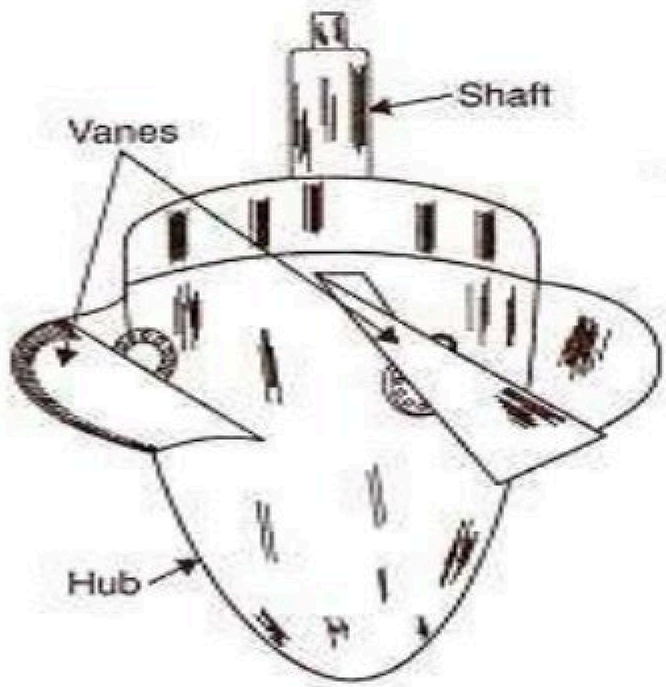
Deflector pin mechanisum

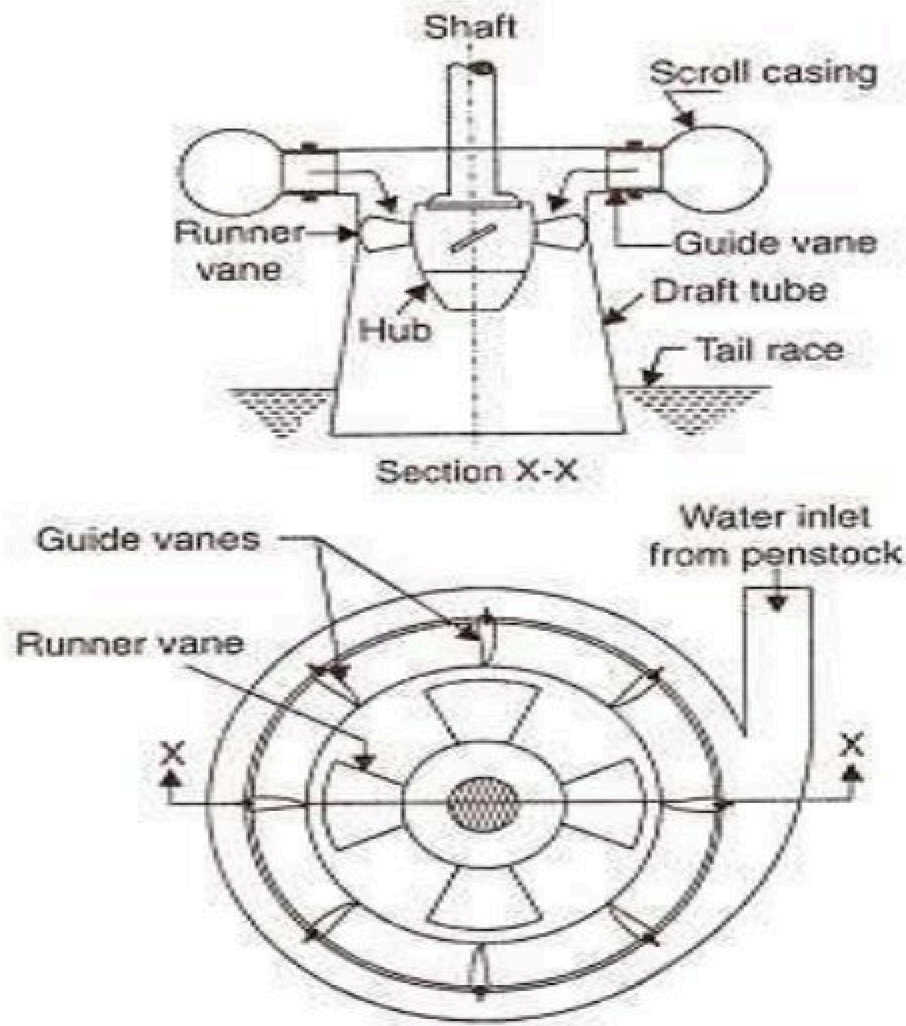
- In this type of mechanisum deflector pin is used to control amount of water flow.
- Deflector pin is actuated by servo mechanisum by sensors.
- If the pin is get contact with jet of water some water get deflected and less amount of water get contact with blades.

A Francis turbine consists of the following main parts:

- **Spiral casing:** The spiral casing around the runner of the turbine is known as the volute casing or scroll case. Throughout its length, it has numerous openings at regular intervals to allow the working fluid to impinge on the blades of the runner. These openings convert the pressure energy of the fluid into momentum energy just before the fluid impinges on the blades. This maintains a constant flow rate despite the fact that numerous openings have been provided for the fluid to enter the blades, as the cross-sectional area of this casing decreases uniformly along the circumference.
- **Guide or stay vanes**: The primary function of the guide or stay vanes is to convert the pressure energy of the fluid into the momentum energy. It also serves to direct the flow at design angles to the runner blades.
- **Runner blades**:Runner blades are the heart of any turbine. These are the centers where the fluid strikes and the tangential force of the impact causes the shaft of the turbine to rotate, producing torque. Close attention in design of blade angles at inlet and outlet is necessary, as these are major parameters affecting power production.
- **Draft tube**: The draft tube is a conduit which connects the runner exit to the tail race where the water is discharged from the turbine. Its primary function is to reduce the velocity of discharged water to minimize the loss of kinetic energy at the outlet. This permits the turbine to be set above the tail water without appreciable drop of available head.

REATION (FRANSIS) TURBINE





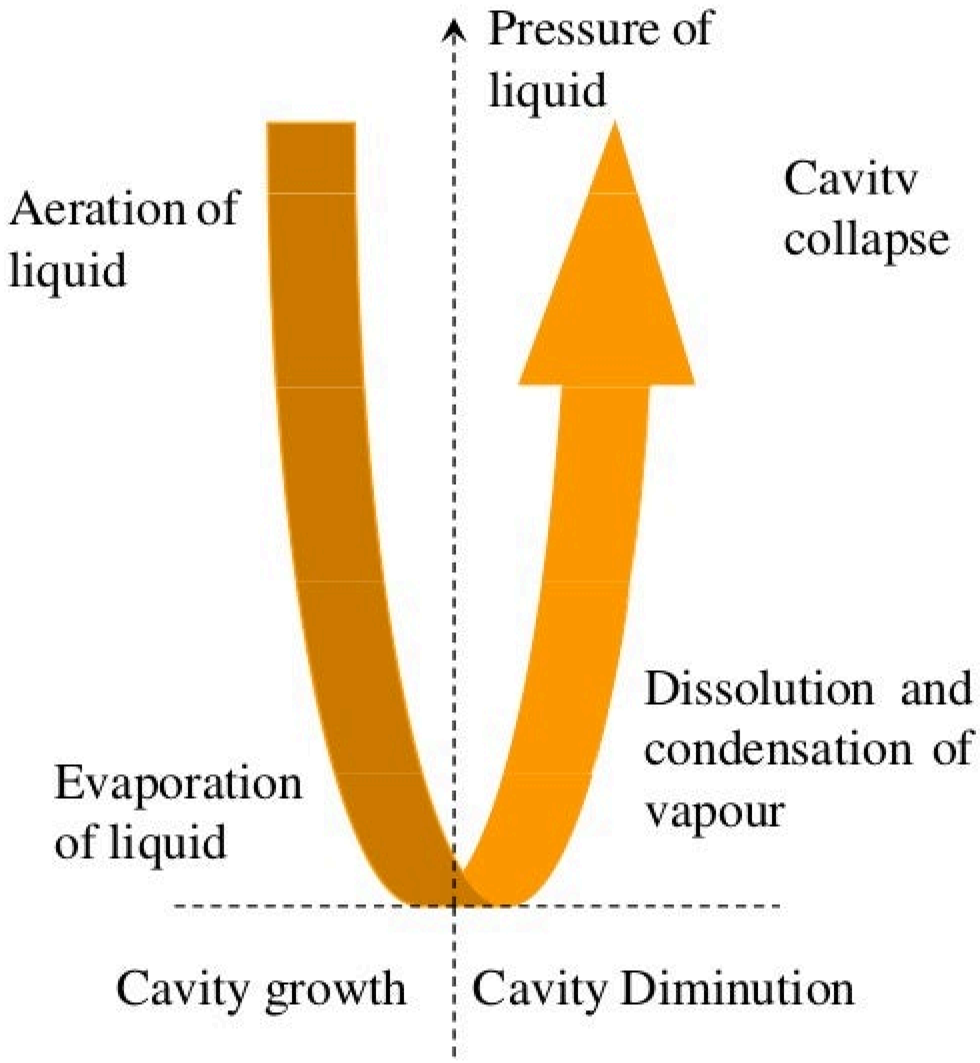
SPECIFICATION

- Medium head turbine.
- Specific speed and discharge is medium.
- Efficency is about 88 %.
- Combine of radial and axial flow turbine.

Cavitation in Turbines

- **Cavitation** is a term used to describe a process, which includes nucleation, growth and implosion of vapour or gas filled cavities. These cavities are formed into a liquid when the static pressure of the liquid for one reason or another is reduced below its vapour pressure at the prevailing temperature. When cavities are carried to high-pressure region, they implode violently.
- Cavitation is an undesirable effect that results in pitting, mechanical vibration and loss of efficiency.
- If the nozzle and buckets are not properly shaped in impulse turbines, flow separation from the boundaries may occur at some operating conditions that may cause regions of low pressure and result in cavitation.
- The turbine parts exposed to cavitation are the runners, draft tube cones for the Francis and Kaplan turbines and the needles, nozzles and the runner buckets of the Pelton turbines.
- Measures for combating erosion and damage under cavitation conditions include improvements in hydraulic design and production of components with erosion resistant materials and arrangement of the turbines for operations within good range of acceptable cavitation conditions.

Cavitation Process



Cavitation in Turbines

Traveling bubble cavitation in Francis turbine

Leading edge cavitation damage in Francis turbine

Inlet edge cavitation in Francis turbine

Surge Tank

a tank connected to a pipe carrying a liquid and intended to neutralize sudden changes of pressure in the flow by filling when the pressure increases and emptying when it drops.

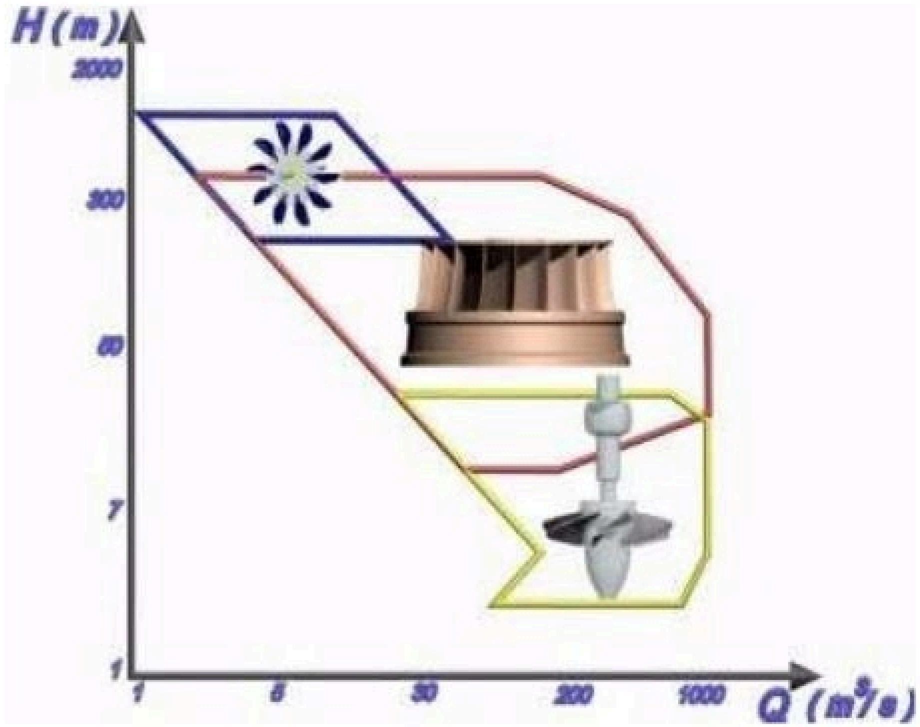
Surge Tank

Selection of Turbines

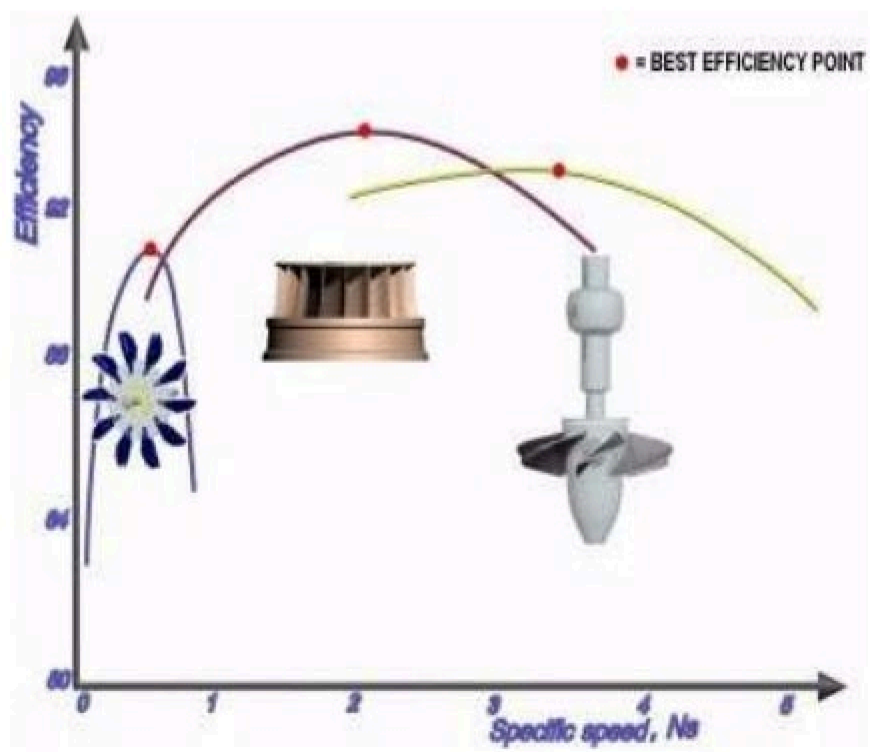
Turbine	**Head**	**Specific Speed (SI)**
Pelton Wheel	>300 m	8.5-30 (Single Jet) 30-51 (2 or More)
Francis Turbine	50-450 m	51-255
Kaplan Turbine	Up to 60 m	255-860

Turbine Selection Graph

Head verses Flow graph



Turbines Efficiency graph



HYDRAULIC PUMPS

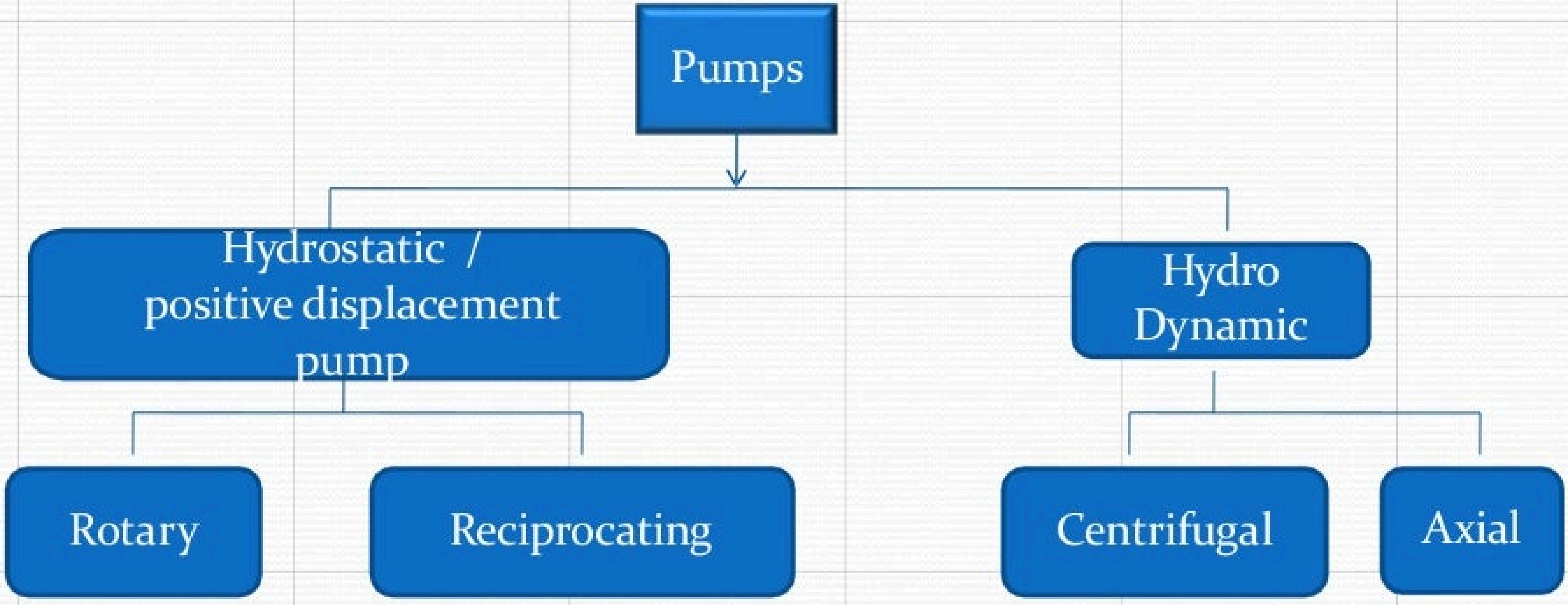
What is a pump?

- Pump is defined as a mechanical device that rotates or reciprocatesto move fluid from one place to another.
- It converts Prime mover energy in to mechanical energy , then mechanical energy into hydraulic energy(flow, pressure).

Need Of a Pump

- Used to pump a liquid from lower pressure area to a High pressure area.
- To increase Flow rate.
- To move liquid from lower elevation to higher elevation.

Different types of pump



Hydrostatic or Positive Displacement Pump

Working Principle:

- A positive displacement pump makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe.

- Some positive displacement pumps use an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses

Positive Displacement Pump

- For each pump revolution
  - Fixed amount of liquid taken from one end
  - Positively discharged at other end
  - a specific amount of fluid passes through the pump for each rotation
- If pipe blocked
  - Pressure rises
  - Can damage pump
  - In order to avoid this happening, Relief valve is required
- Used for pumping fluids other than water

Positive Displacement Pump

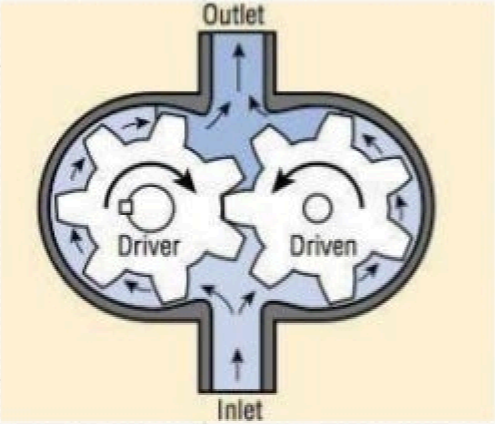
Positive Displacement pumps apply pressure directly to the liquid by a reciprocating piston, or by rotating members.

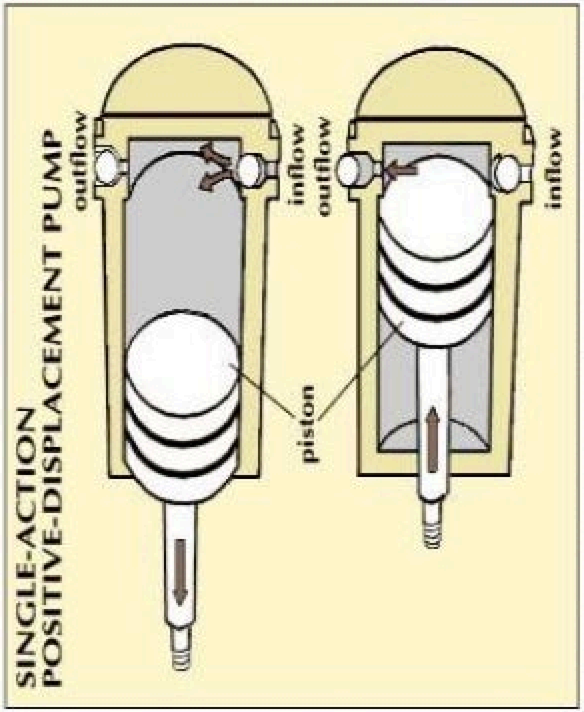
Uses:

- can handle shear sensitive liquid.
- Use for high pressure application
- Use for variable viscosity applications.

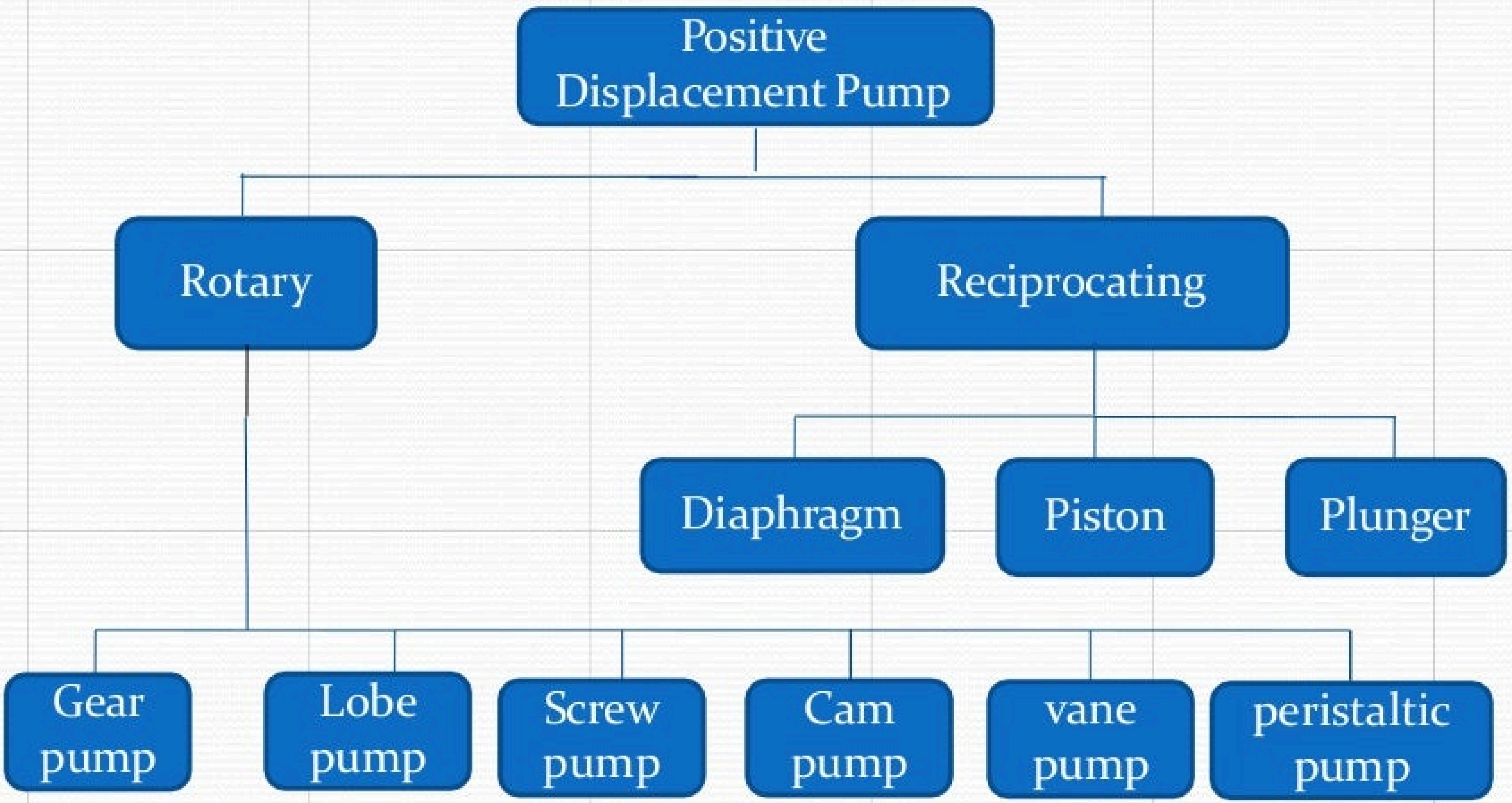
Different Types

1. Reciprocating pump
2. Rotary pump





Different Types of Positive Displacement Pump



Reciprocating Positive Displacement Pumps

- Reciprocating pumps move the fluid using one or more oscillating pistons, plungers, or membranes (diaphragms), while valves restrict fluid motion to the desired direction.
- Pumps in this category range from *simplex*, with one cylinder, to in some cases *quad* (four) cylinders, or more. Many reciprocating-type pumps are *duplex* (two) or *triplex* (three) cylinder. They can be either *single-acting* with suction during one direction of piston motion and discharge on the other, or *double-acting* with suction and discharge in both directions. The pumps can be powered manually, by air or steam, or by a belt driven by an engine.

1. Piston pump

A piston pump is a type of positive displacement pump where the high-pressure seal reciprocates with the piston. Piston pumps can be used to move liquids or compress gases.

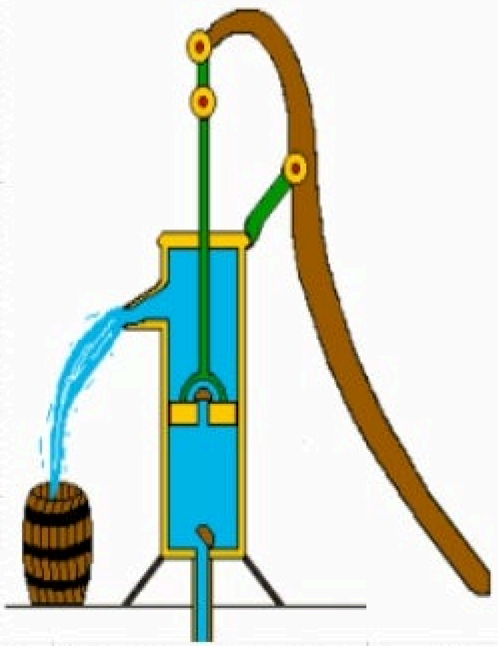
Types

1. Lift pump
2. Force pump
3. Axial piston pump
4. Radial piston pump

Reciprocating Positive Displacement Pumps

Lift pump

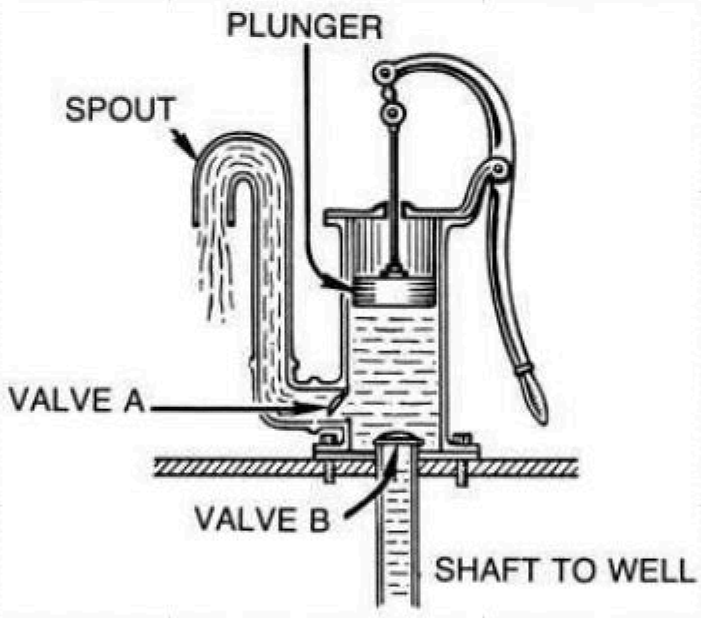
In a lift pump, the upstroke of the piston draws water, through a valve, into the lower part of the cylinder. On the down stroke, water passes through valves, set in the piston, into the upper part of the cylinder. On the next upstroke, water is discharged from the upper part of the cylinder via a spout.



Reciprocating Positive Displacement Pumps

Force pump

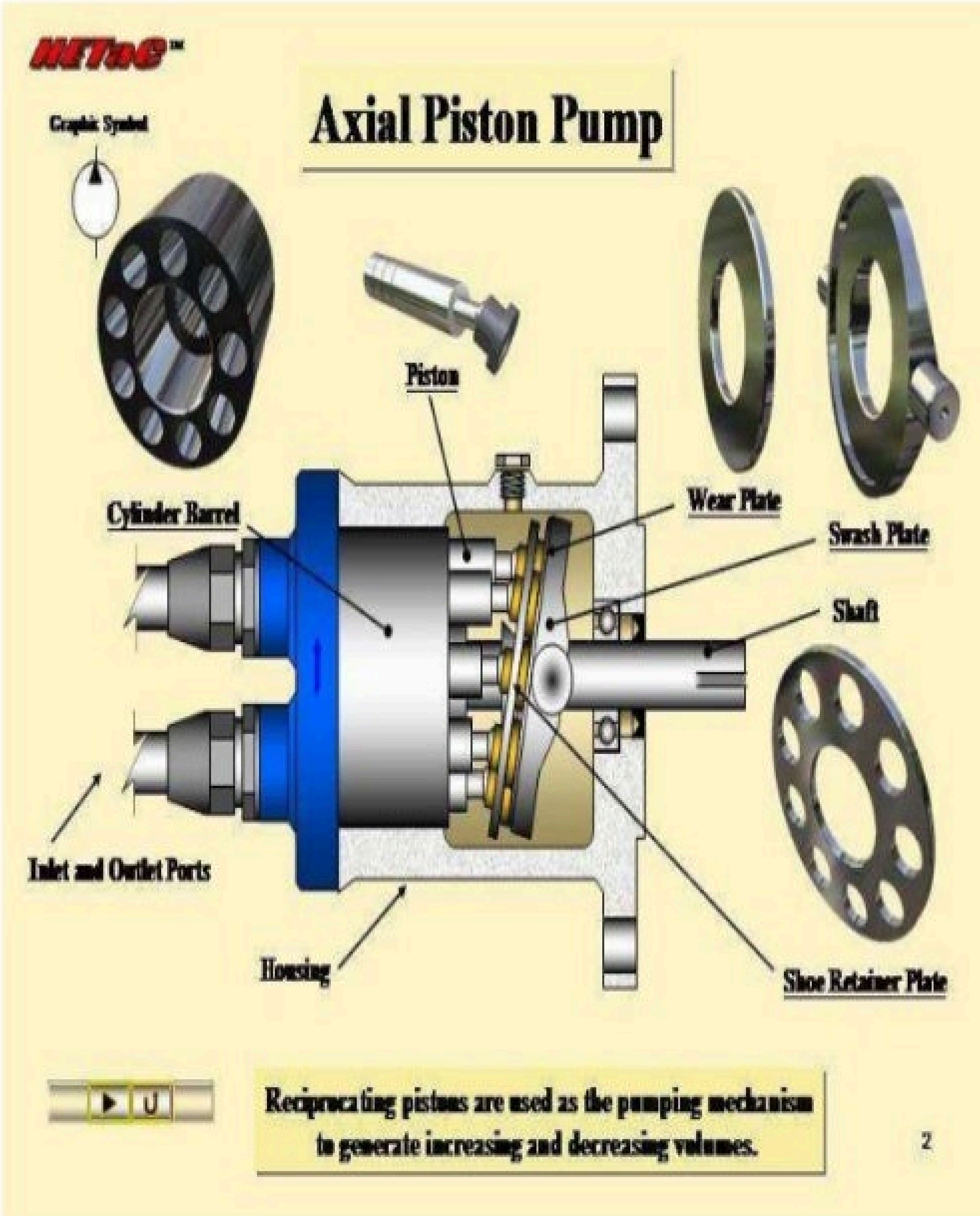
In a force pump, the upstroke of the piston draws water, through a valve, into the cylinder. On the down stroke, the water is discharged, through a valve, into the outlet pipe. And this has the same mode of application as a lift pump.



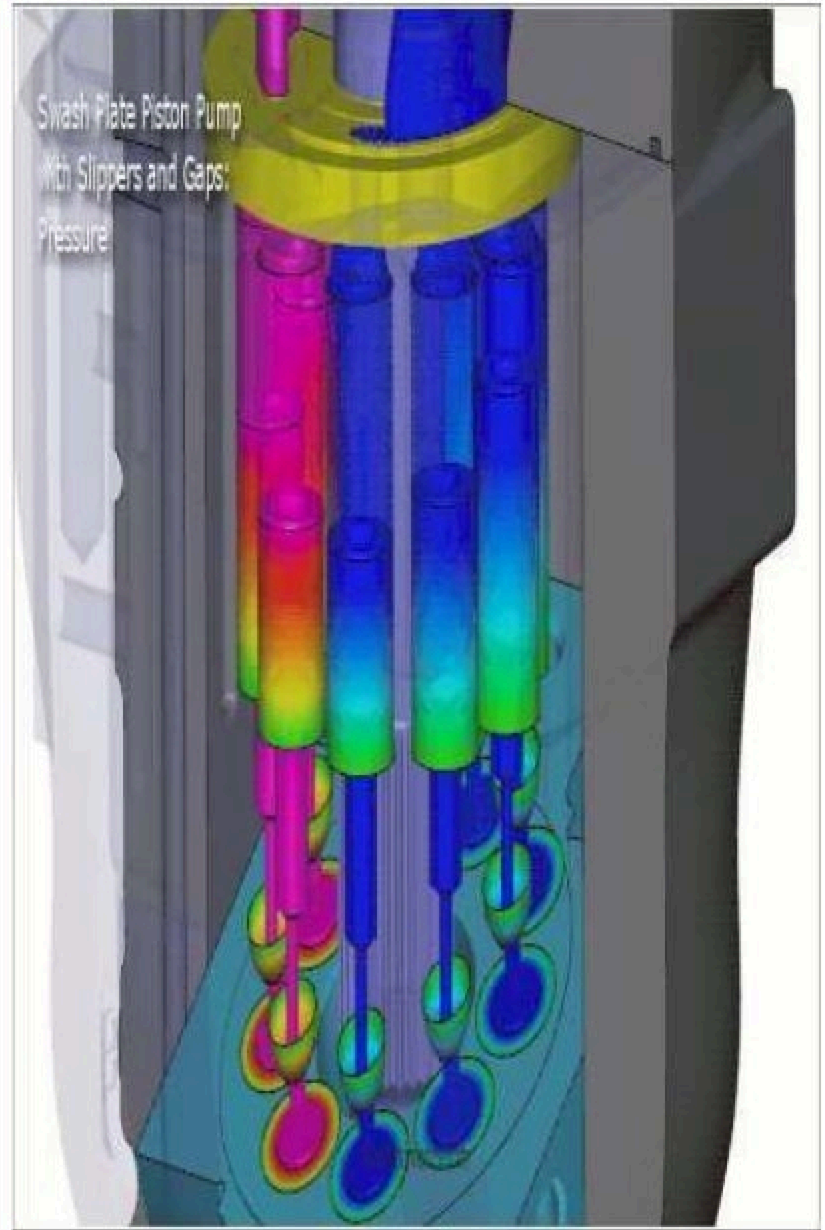
Reciprocating Positive Displacement Pumps

Axial Piston Pump

An axial piston pump is a positive displacement pump that has a number of pistons arranged in a circular array within a *housing* which is commonly referred to as a *cylinder block*, *rotor* or *barrel*. This cylinder block is driven to rotate about its axis of symmetry by an integral shaft that is, more or less, aligned with the pumping pistons (usually parallel but not necessarily).



Axial Piston Pump
Graphic Symbol
Piston
Cylinder Barrel
Wear Plate
Swash Plate
Shaft
Inlet and Outlet Ports
Housing
Shoe Retainer Plate
Reciprocating pistons are used as the pumping mechanism to generate increasing and decreasing volumes.
2



Swash Plate Piston Pump
With Slippers and Gaps:
Pressure

ADVANTAGES

- high efficiency
- high pressure
- low noise level
- very high load at lowest speed due to the hydrostatically balanced parts possible
- high reliability

DISADVANTAGES

- Piston pumps cost more per unit to run compared to centrifugal and roller pumps.
- The mechanical parts are prone to wear , so the maintenance costs can be high.
- Piston pumps are heavy due to their large

COMPATIBILITY

Due to the hydrostatically balanced parts it is possible to use the pump with various hydraulic fluids like

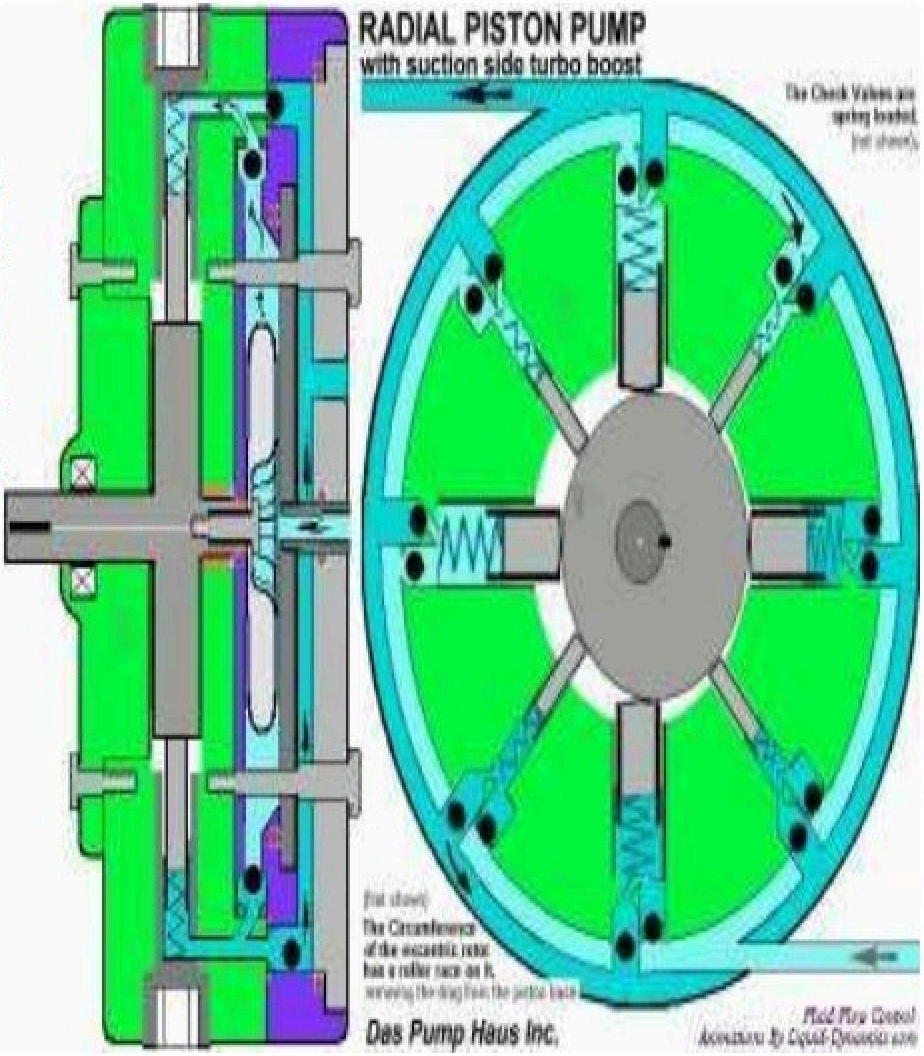
- Mineral oil
- Biodegradable oil
- HFA (oil in water)
- HFC (water-glycol)
- HFD (synthetic ester) or cutting emulsion

APPLICATION

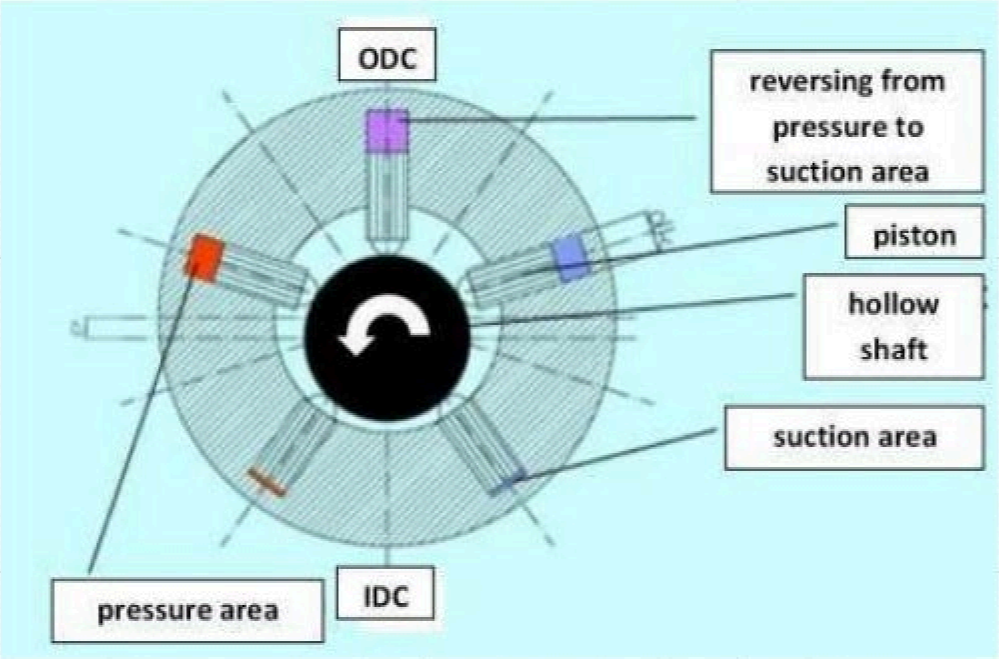
- automotive sector (e.g., automatic transmission, hydraulic suspension control in upper-class cars)
- hydraulic systems of jet aircraft, being gear-driven off of the turbine engine's main shaft

Radial piston pump

A radial piston pump is a form of hydraulic pump. The working pistons extend in a radial direction symmetrically around the drive shaft, in contrast to the axial piston pump.



- The stroke of each piston is caused by an eccentric drive shaft or an external eccentric tappet.
- When filling the workspace of the pumping pistons from "inside" (e.g., over a hollow shaft) it is called an *inside impinged* radial piston pump. If the workspace is filled from "outside" it's called an *outside impinged* radial piston pump.

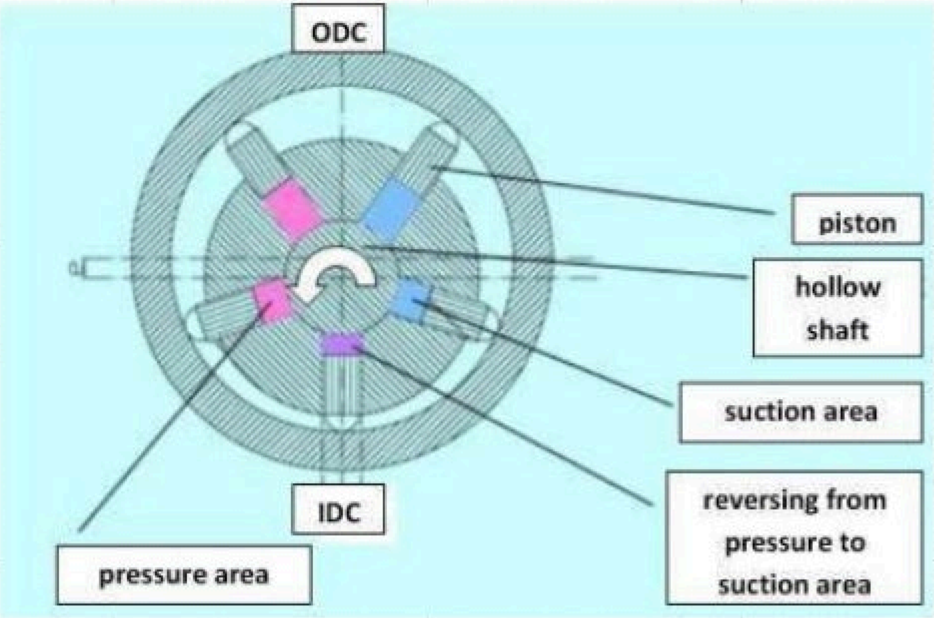


Outside impinged radial piston pump

ADVANTAGES

- high efficiency
- high pressure (up to 1,000 bar)
- low flow and pressure ripple (due to the small dead volume in the workspace of the pumping piston)
- low noise level
- very high load at lowest speed due to the hydrostatically balanced parts possible
- no axial internal forces at the drive shaft bearing.

high reliability



Inside impinged radial piston pump

DISADVANTAGES

- A disadvantage are the bigger radial dimensions in comparison to the axial piston pump, but it could be compensated with the shorter construction in axial direction.

COMPATIBILITY

Due to the hydrostatically balanced parts it is possible to use the pump with various hydraulic fluids like

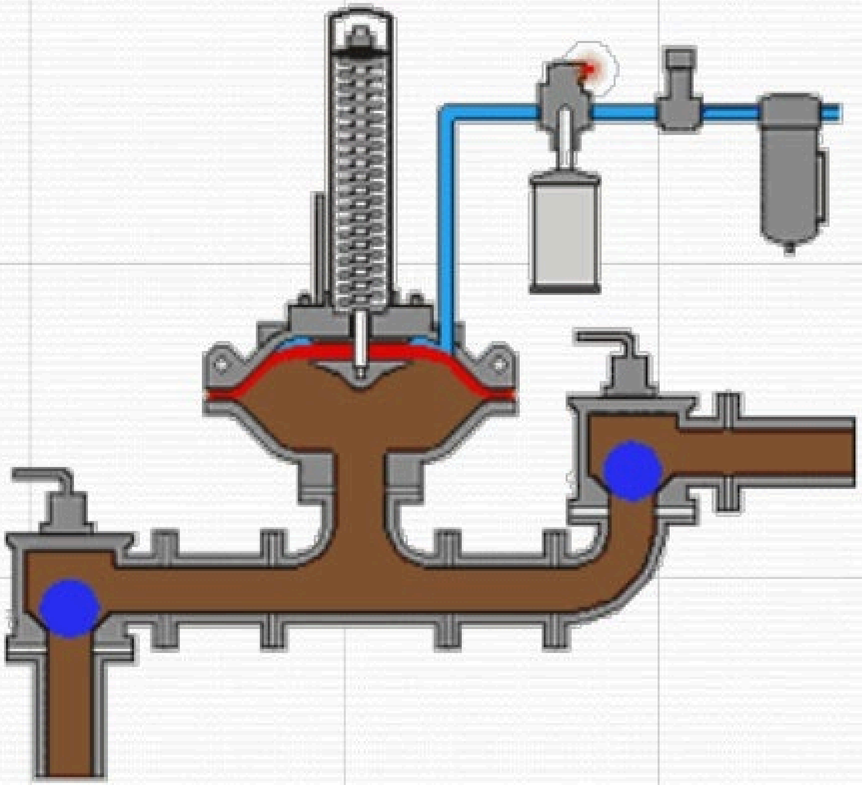
- Mineral oil
- Biodegradable oil
- HFA (oil in water)
- HFC (water-glycol)
- HFD (synthetic ester) or cutting emulsion.

APPLICATIONS

- Radial piston pumps are used in applications that involve high pressures (operating pressures above 400 bar and up to 700 bar), such as presses, machines for processing plastic and machine tools that clamp hydraulics. Radial piston pumps are the only pumps capable of working satisfactorily at such high pressures, even under continuous operation
- machine tools (e.g., displace of cutting emulsion, supply for hydraulic equipment like cylinders)
- high pressure units (HPU) (e.g., for overload protection of presses)
- test rigs
- automotive sector (e.g., automatic transmission, hydraulic suspension control in upper-class cars)
- plastic- and powder injection molding
- wind energy
- Oil industry

Diaphragm Pump

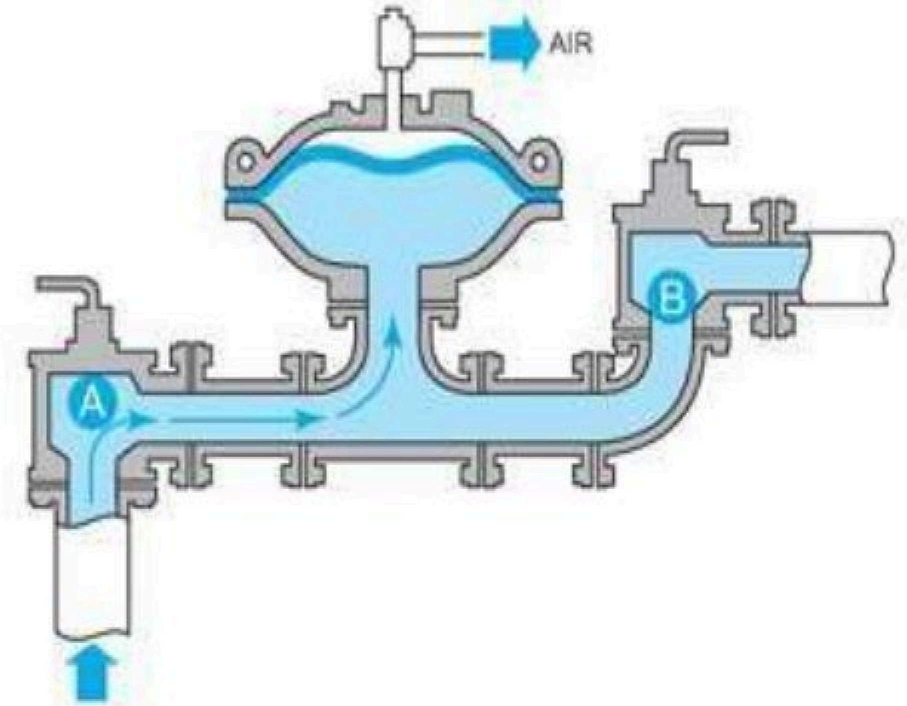
A diaphragm pump (also known as a Membrane pump, Air Operated Double Diaphragm Pump (AODD) or Pneumatic Diaphragm Pump) is a positive displacement pump that uses a combination of the reciprocating action of a rubber, thermoplastic or Teflon diaphragm and suitable valves on either side of the diaphragm (check valve, butterfly valves, flap valves, or any other form of shut-off valves) to pump a fluid.



<u>WORKING</u>

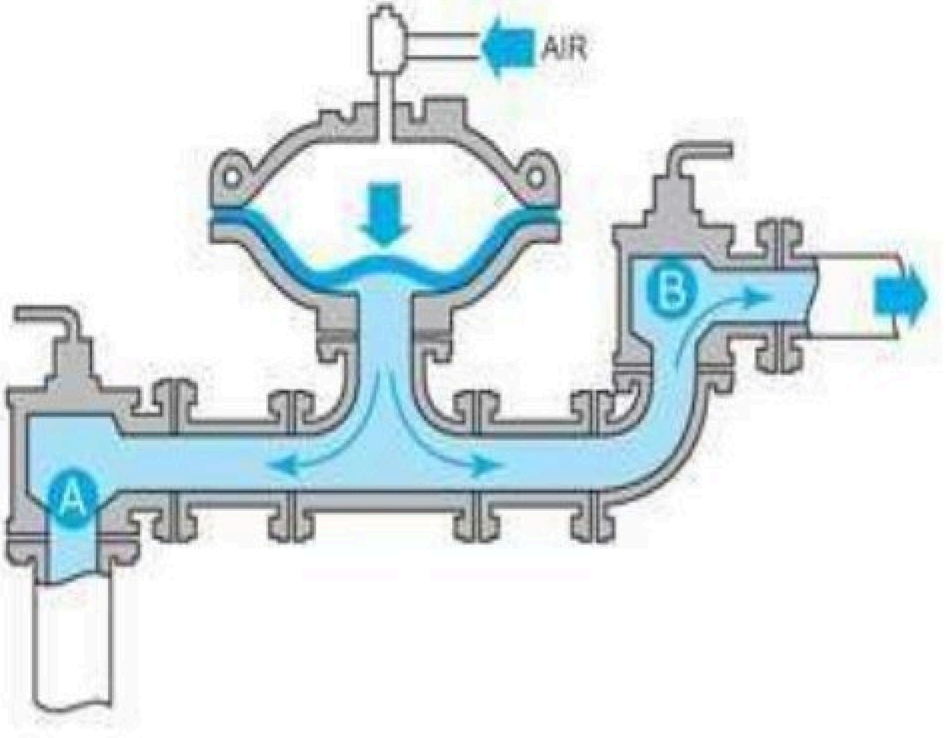
Suction stroke

To fill the pump cavity, positive suction head (inlet pressure) is required. When inlet valve **A** is lifted by the pressure of the suction head, the slurry completely fills the pump cavity. The diaphragm returns to its normal convex position and the air exhausts. Discharge valve **B**, seated by line pressure, prevents slurry from returning to the pump cavity.



Discharge stroke

Compressed air is admitted to the chamber above the diaphragm. The diaphragm descends, gradually increasing the pressure in the pump cavity. This in turn closes inlet valve **A** and causes discharge valve **B** to open when the line pressure is exceeded. Further movement of the diaphragm displaces the slurry from the pump cavity.



ADVANTAGES

- have good suction lift characteristics. They can handle sludge and slurries with a relatively high amount of grit and solid content.
- Used for low pressure application like removing water from trenches
- have good dry running characteristics.
- can be used to make artificial hearts.
- are used to make air pumps for the filters on small fish tanks.
- can be up to 97% efficient.
- have good self priming capabilities.
- can handle highly viscous liquids.
- Can handle tough corrosives, abrasives, temperatures to 200°F and slurries containing up to 75% solids.

DISADVANTAGES

- Most air diaphragm pumps require around 20 standard cubic-feet per minute and 100 psi of air intake to operate efficiently.

- Also, these types of pumps tend not to pump very accurately at their bottom end. A functioning air diaphragm pump pulsates, and a dampener must be fitted onto the pump to reduce pulsing.

COMPATIBILITY

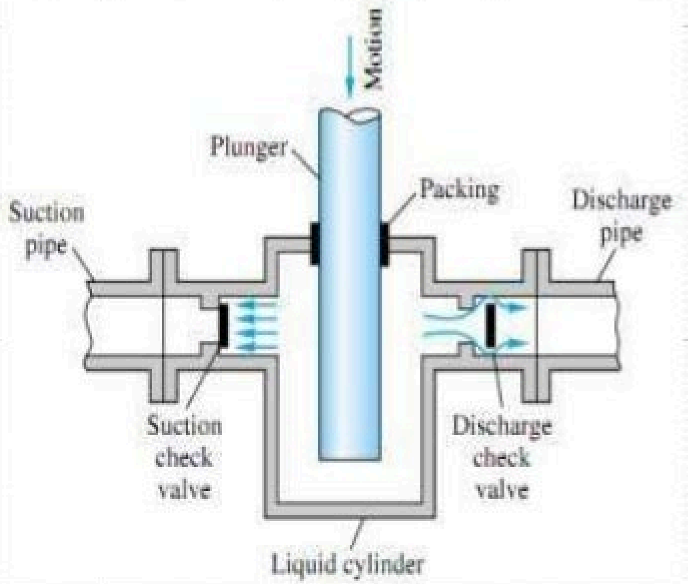
- Delicate crystal slurries
- Highly concentrated and unusually viscous slurries
- Highly abrasive slurries
- Highly corrosive slurries
- Very large solids in slurries
- Extremely volatile slurries
- Delicate and unstable slurries
- Air-entrained slurries
- Shear-sensitive slurries

APPLICATIONS

- For drum and small tank transfer, pickling solutions, chemical feed.
- Filter press, tank cleaning systems, pigments and resins.
- Paints, latex, ceramic slip, slurries, polymers, tank car fill and empty, foods.
- Handling optical lens grinding rouges, waste glass slurries and cutting slurries.
- Ship cleaning, dewatering holds, bilges, coffer dams, fire-fighting, sewage from holding tanks, offshore drilling, sand blast slurries.
- Mill scale, pickling tank chemicals, foundry sand slurries, palm oils, cutting oils. Dewatering mines and construction sites, caissons, tunnels.
- Transfer of frits, enamels, solvents, latex, pigments, additives, inhibitors, resins, dryers.
- Decanting and emptying of acid and alkaline bath solutions, pumping of heavy contaminated sewage and slurries.

Plunger pump

A plunger pump is a type of positive displacement pump where the high-pressure seal is stationary and a smooth cylindrical plunger slides through the seal. This makes them different from piston pumps and allows them to be used at higher pressures. This type of pump is often used to transfer municipal and industrial sewage.



ADVANTAGES

- Plunger pumps are used in applications that could range from 70 to 2,070 bar (1,000 to 30,000 psi)
- Pressure and flow rate changes have little effect on performance.
- Pressure can be controlled without affecting flow rate.
- Wide pressure range - can achieve very high pressures
- Have high efficiency
- Capable of developing very high pressures.
- Low and easy maintenance

DISADVANTAGES

- Pulsating flow
- Typically only handles lower flow rates
- Typically heavy and bulky
- High operating and maintenance costs.
- not be compatible for use with highly acidic fluids

APPLICATIONS

- Raw and Digested sewage sludge
- Industrial and chemical waste and slurries
- Lime putty and slurries
- Pulp and paper stock
- Settled oil solids

Rotary PositiveDisplacement Pumps

The working of all the rotary type positive displacement pumps are based on the same principle, i.e pumping of the liquid with the help of rotating elements. The rotating elements can be gears, screws, vanes or cam, etc.

The different types are

1. Gear pump
2. Lobe pump
3. Screw pump
4. Cam pump
5. Vane pump
6. Peristaltic pump

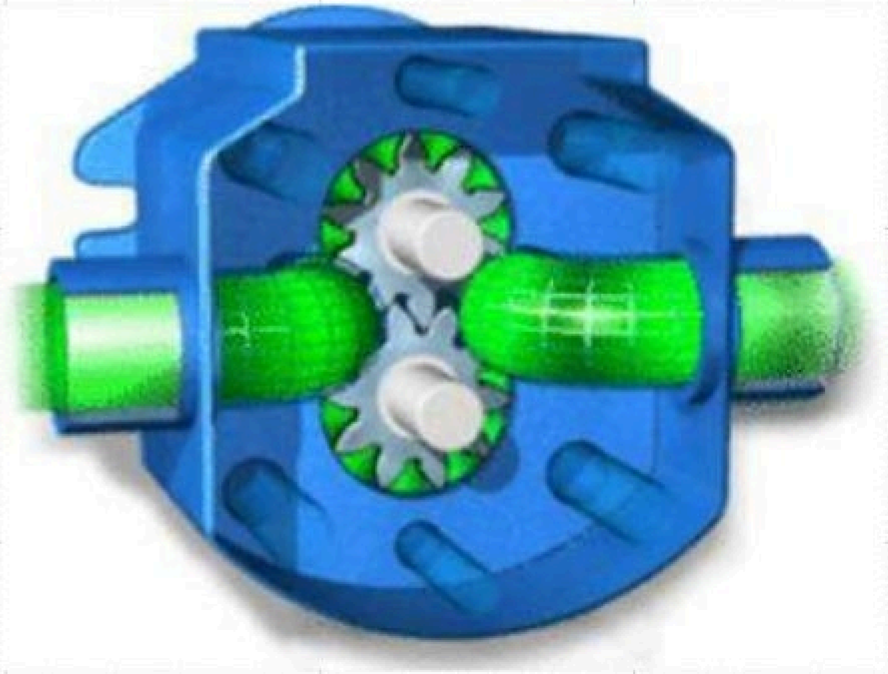
Gear pump

A gear pump uses the meshing and De-meshing of gears to pump fluid by displacement. They are one of the most common types of pump for hydraulic fluid power applications. There are two types of gear pumps, they are

1. External gear pump
2. Internal gear pump

External Gear pump

External gear pump uses two identical gears rotating against each other. one gear is driven by a motor and it in turn drives the other gear. Each gear is supported by a shaft with bearings on both sides of the gear.



External Gear pump

- As the gears come out of mesh, they create expanding volume on the inlet side of the pump. Liquid flows into the cavity and is trapped by the gear teeth as they rotate.
- Liquid travels around the interior of the casing in the pockets between the teeth and the casing -- it does not pass between the gears.
- Finally, the meshing of the gears forces liquid through the outlet port under pressure.

ADVANTAGES

- High speed
- High pressure
- No overhung bearing loads
- Relatively quiet operation
- Design accommodates wide variety of material
- Low weight
- Relatively high working pressures
- Wide range of speeds
- Wide temperature and viscosity range (i.e. flexibility)
- Low cost

DISADVANTAGES

- Four bushings in liquid area
- No solids allowed
- Fixed End Clearances

APPLICATIONS

- Various fuel oils and lube oils
- Chemical additive and polymer metering
- Chemical mixing and blending (double pump)
- Industrial and mobile hydraulic applications (log splitters, lifts, etc.)
- Acids and caustic (stainless steel or composite construction)
- Low volume transfer or application
- Lubrication pumps in machine tools
- Fluid power transfer units and oil pumps in engines

Rotary Positive Displacement Pumps

1.2 Internal gear pump

Internal gear pumps are primarily used in non-mobile hydraulics (e.g. machines for plastics and machine tools, presses, etc.) and in vehicles that operate in an enclosed space (electric fork-lifts, etc.). The internal gear pump is exceptionally versatile and also capable of handling thick fluids.

Internal gear pump

- Liquid enters the suction port between the rotor (large exterior gear) and idler (small interior gear) teeth. The arrows indicate the direction of the pump and liquid.
- Liquid travels through the pump between the teeth of the "gear- within-a-gear" principle. The crescent shape divides the liquid and acts as a seal between the suction and discharge ports.
- The pump head is now nearly flooded, just prior to forcing the liquid out of the discharge port. Intermeshing gears of the idler and rotor form locked pockets for the liquid which assures volume control.
- Rotor and idler teeth mesh completely to form a seal equidistant from the discharge and suction ports. This seal forces the liquid out of the discharge port

ADVANTAGES

- This pump can transport liquids of any viscosity
- Can work at even high and low temperatures.
- Only two moving parts
- Can create strong vacuum
- Can be used as self vacuum pump for air and gases
- Non-pulsating discharge
- Excellent for high-viscosity liquids
- Good suction and NPSH
- Constant and even discharge regardless of pressure
- conditions
- Operates well in either direction
- Single adjustable end clearance
- Easy to maintain
- Flexible design offers application customization

DISADVANTAGES

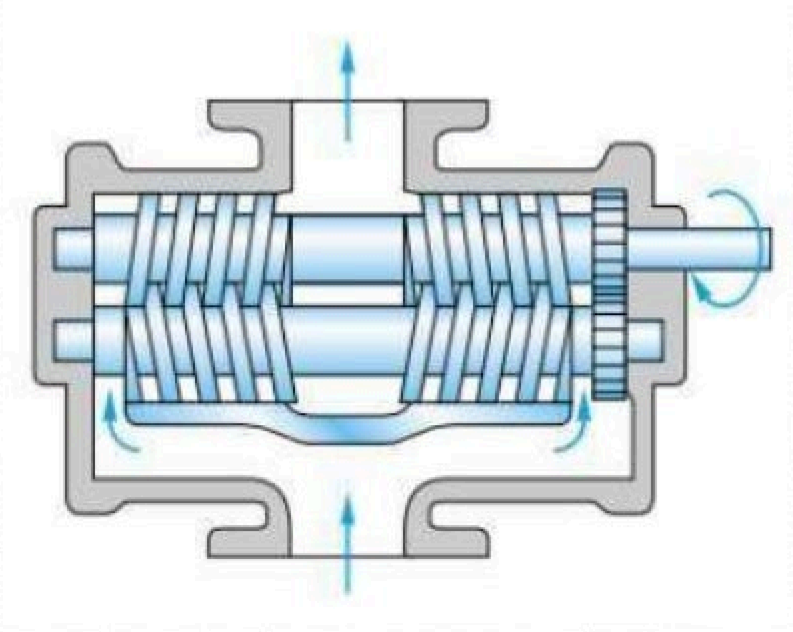
- Usually requires moderate speeds
- Medium pressure limitations
- One bearing runs in the product pumped
- Overhung load on shaft bearing

APPLICATIONS

- All varieties of fuel oil, Cooking oil and lube oil
- Resins and Polymers
- Alcohols and solvents
- Asphalt, Bitumen, and Tar
- Polyurethane foam (Isocyanate and polyol)
- Food products such as corn syrup, chocolate, and peanut butter
- Paint, inks, and pigments
- Soaps and surfactants
- Glycol
- Plastics, oil soap liquid, phenol resin, formalin, polycarbonate resin, acrylics, liquid calcium, inks, latex compounds, high viscosity adhesives, cleansers, hot melt, epoxy resin.
- LPG, benzene, gasoline, alcohol, liquid Freon, heavy oils, coal tar, pitches, greases, asphalt, Bitumen acid pitch.

Screw pump

A screw pump is a positive-displacement pump that use one or several screws to move fluids or solids along the screw(s) axis. In its simplest form the (Archimedes' screw pump), a single screw rotates in a cylindrical cavity, thereby moving the material along the screw's spindle. This ancient construction is still used in many low-tech applications, such as irrigation systems and in agricultural machinery for transporting grain and other solids.



ADVANTAGES

- Slow Speed, Simple and Rugged design
- Pumps raw water with heavy solids and floating debris
- No collection sump required = minimum head
- 'Gentle handling' of biological flock
- Long lifetime (> 20-40 years)
- Pump capacity is self-regulating with incoming level
- Easy maintenance (no 'high skilled' staff required)
- Constant high efficiency with variable capacity
- Can run without water
- Screw pumps allow a wide range of flows and pressures
- They can also accommodate a wide range of liquids and viscosities
- Screw pumps have high speed capability and this allows the freedom of driver selection
- All the screw pumps are Self-priming which allows them to have good suction characteristics

DISADVANTAGES

- Cost of manufacturing is high because of close tolerances and running clearances
- Any changes in the viscosity of the fluid results in high fluctuations in the performance.
- A screw pump with high pressure capability will require high pumping elements which increases the overall size of the pump.

APPLICATIONS

- chemical-processing
- liquid delivery
- marine
- biotechnology
- pharmaceutical
- food, dairy, and beverage processing.
- fuel-injection
- oil burners
- lubrication

Lobe pump

Lobe pumps are similar to external gear pumps in operation in that fluid flows around the interior of the casing. Unlike external gear pumps, however, the lobes do not make contact. Lobe contact is prevented by external timing gears located in the gearbox.

ADVANTAGES

- Pass medium solids
- No metal-to-metal contact
- Long term dry run (with lubrication to seals)
- Non-pulsating discharge

DISADVANTAGES

- Requires timing gears
- Requires two seals
- Reduced lift with thin liquids

APPLICATIONS

- Polymers
- Paper coatings
- Soaps and surfactants
- Paints and dyes
- Rubber and adhesives
- Pharmaceuticals
- Food applications

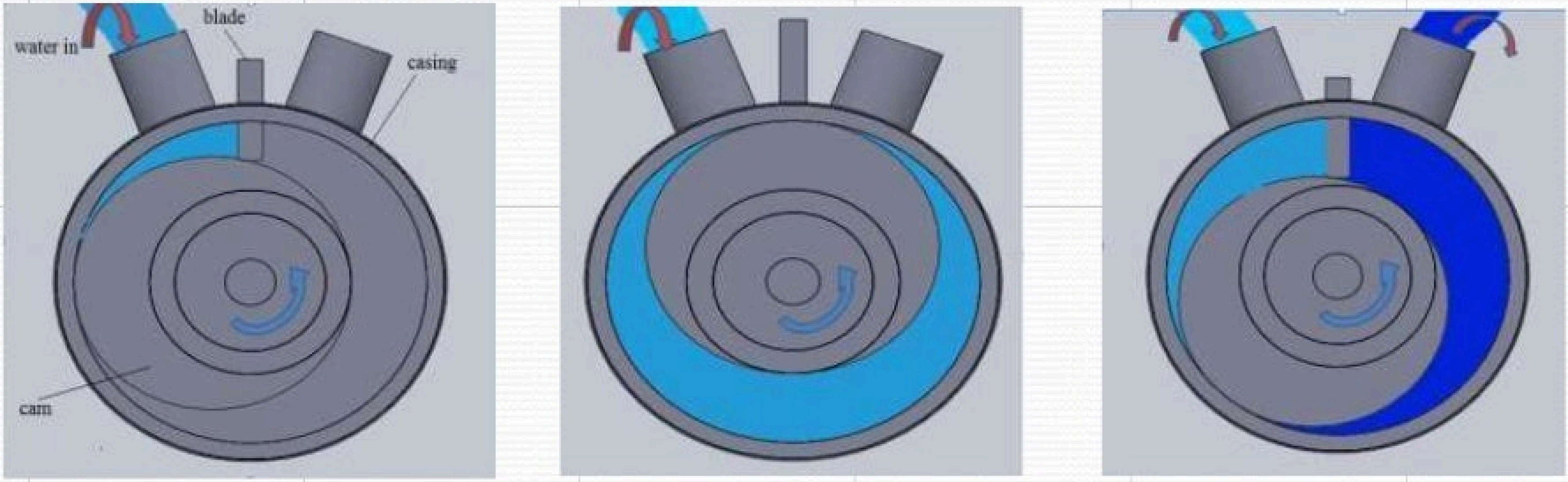
Cam pump

The main part of the pump is a cam which is mounted on a rotating shaft that rotates in a cylindrical casing. The cam is designed in such a way that it always maintains contact with the walls of the casing as it rotates. A spring loaded blade acts as the cam follower and moves in an accurately machined slot in the casing. This blade separates suction and delivery sides of the pump. Inlet and outlet ports are placed on either sides of this blade. The discharge from the pump is continuous. It also eliminates the crank and connecting rod mechanisms and delivers a smooth operation.

(a) The water is sucked in during the counter clockwise rotation of the cam.

(b) The apex of the cam is at top, displacing the follower blade to maximum. At current position, the whole cavity is filled completely by water. Now suction process is complete.

(c) further advancement of the cam pushes the water out via the outlet port, which is connected to the delivery pipe.



(a) (b) (c)

ADVANTAGES

- The pump operates smoothly.
- It has less noise and vibration.
- The delivery is at a constant rate.
- The suction and discharge happens simultaneously.
- The absence of unidirectional valves and other linkages like crank and connecting rods reduce the complexity and floor space required.

DISADVANTAGES

- The discharge was found to be decreasing with increase of head due to the increase of leakage around the cam with increase in pressure.
- The tolerances are not close enough to seal the leakages.
- There is excessive leakage through the rectangular groove provided for the movement of the follower blade, at high pressures.
- The volumetric efficiency was also found to be decreasing with increase of head.

Vane pump

A rotary vane pump is a positive-displacement pump that consists of vanes mounted to a rotor that rotates inside of a cavity. In some cases these vanes can be variable length and/or tensioned to maintain contact with the walls as the pump rotates.

- ADVANTAGES

- Handles thin liquids at relatively higher pressures
- Compensates for wear
- through vane extension
- Sometimes preferred for solvents, LPG
- Can run dry for short periods
- Can have one seal or stuffing
- box
- Develops good vacuum

DISADVANTAGES

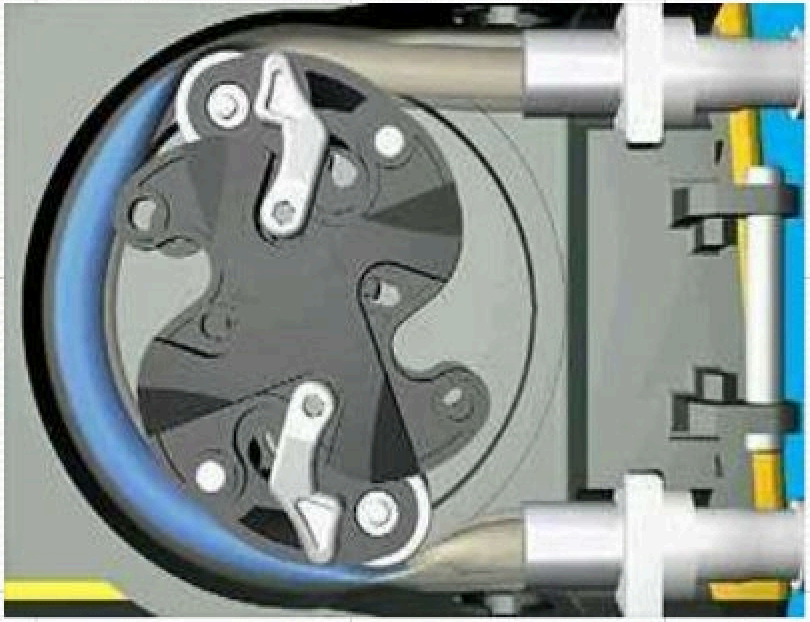
- Can have two stuffing boxes
- Complex housing and many parts
- Not suitable for high pressures
- Not suitable for high viscosity
- Not good with abrasives

APPLICATIONS

- Aerosol and Propellants
- Aviation Service - Fuel Transfer, Deicing
- Auto Industry - Fuels, Lubes, Refrigeration Coolants
- Bulk Transfer of LPG and NH_3
- LPG Cylinder Filling
- Alcohols
- Refrigeration – Freons, Ammonia
- Solvents
- Aqueous solutions

Peristaltic pump

A peristaltic pump is a type of positive displacement pump used for pumping a variety of fluids. The fluid is contained within a flexible tube fitted inside a circular pump casing. A rotor with a number of "rollers", "shoes", "wipers", or "lobes" attached to the external circumference of the rotor compresses the flexible tube. As the rotor turns, the part of the tube under compression is pinched closed (or "occludes") thus forcing the fluid to be pumped to move through the tube.



ADVANTAGES

- No contamination. Because the only part of the pump in contact with the fluid being pumped is the interior of the tube, it is easy to sterilize and clean the inside surfaces of the pump.
- Low maintenance needs. Their lack of valves, seals and glands makes them comparatively inexpensive to maintain.
- They are able to handle slurries, viscous, shear-sensitive and aggressive fluids. Pump design prevents backflow and syphoning without valves

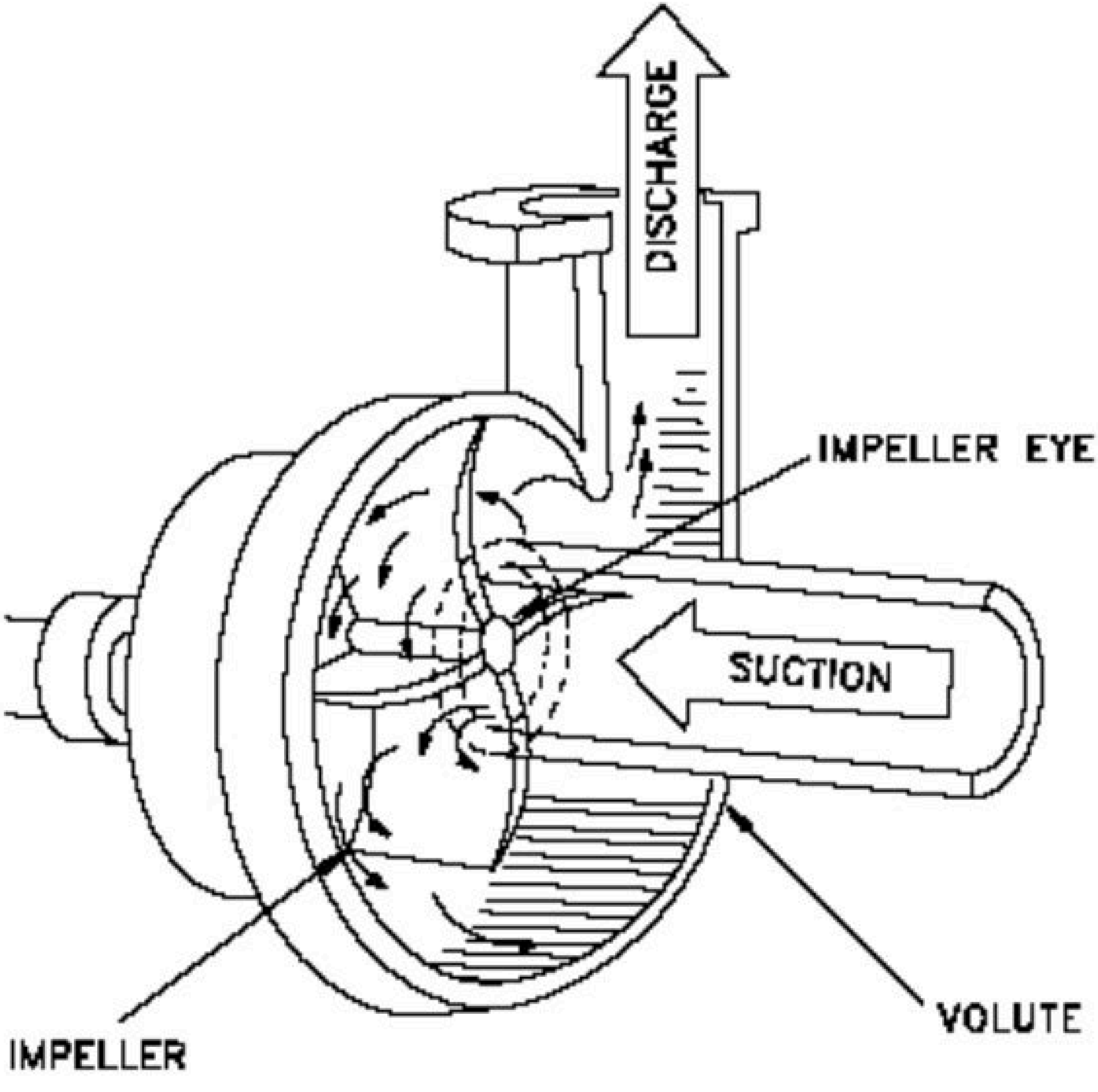
DISADVANTAGES

- The flexible tubing will tend to degrade with time and require periodic replacement.
- The flow is pulsed, particularly at low rotational speeds. Therefore, these pumps are less suitable where a smooth consistent flow is required

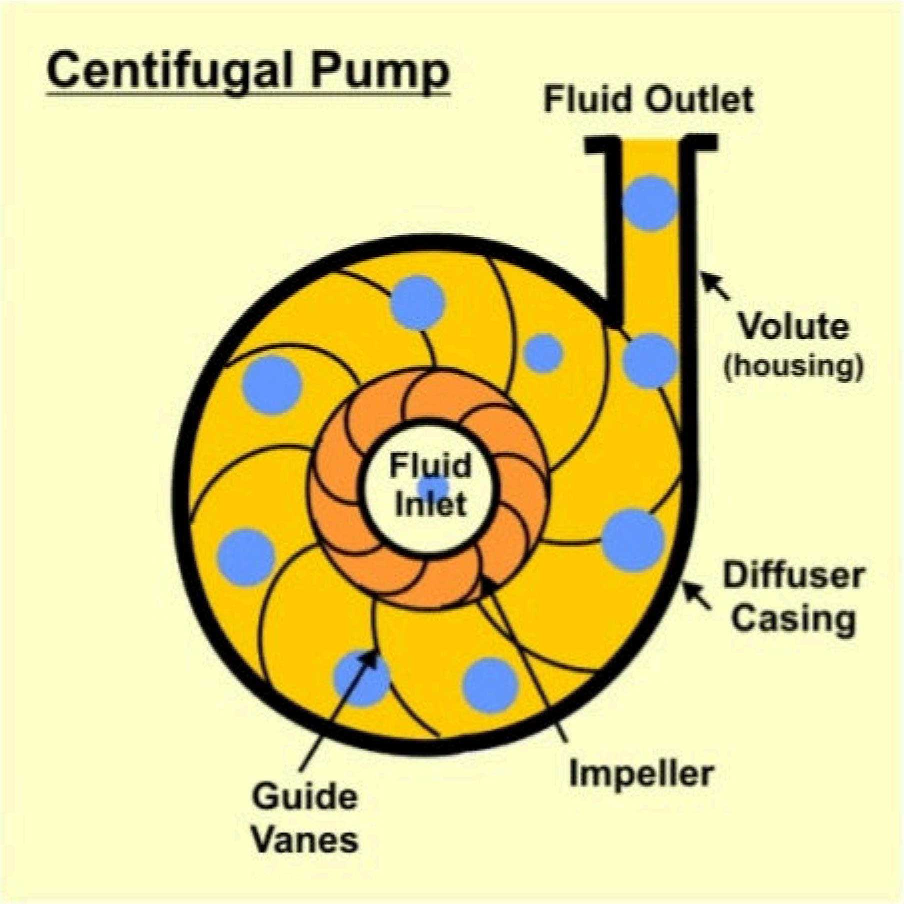
APPLICATIONS

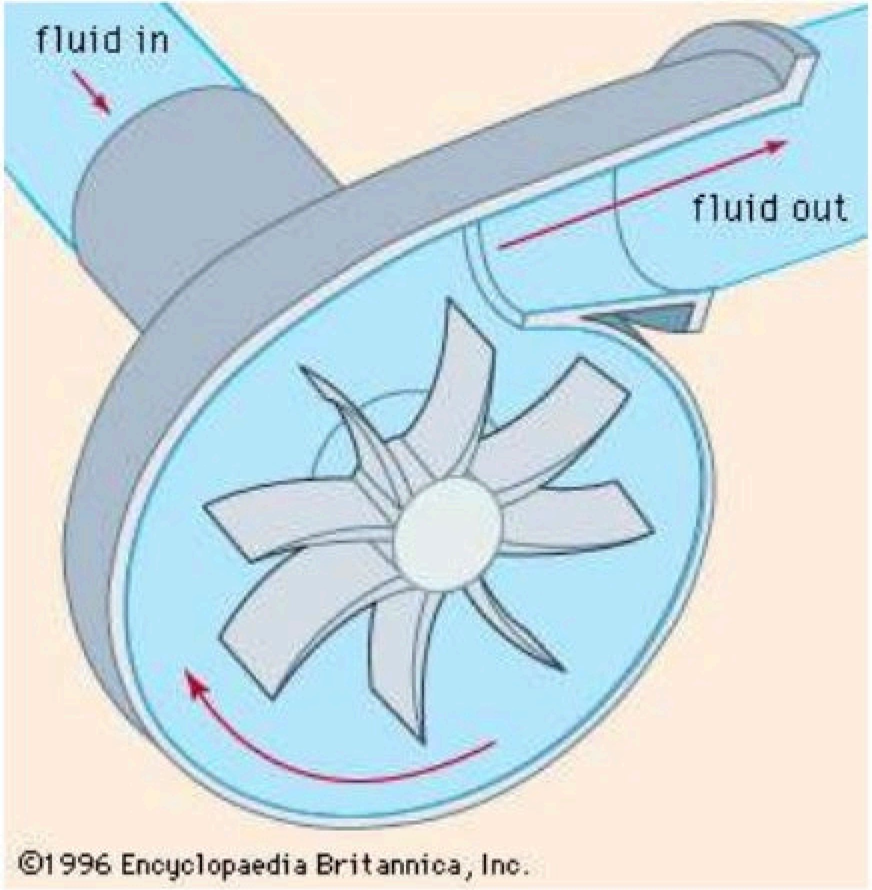
- Medicine
  - Dialysis machines
  - Open-heart bypass pump machines
  - Medical infusion pumps
- Testing and research
  - Auto Analyzer
  - Analytical chemistry experiments
  - Carbon monoxide monitors
  - Media dispensers
- Agriculture
- 'Sapsucker' pumps to extract maple tree sap Food manufacturing and sales
  - Liquid food fountains
  - Beverage dispensing
  - Food-service Washing Machine fluid pump
- Chemical handling
  - Printing, paint and pigments
  - Pharmaceutical production
- Dosing systems for dishwasher and laundry chemicalsEngineering and manufacturing
  - Concrete pump
  - Pulp and paper plants
  - Minimum quantity lubrication
- Water and Waste
  - Chemical treatment in water purification plant
  - Sewage sludge
  - Aquariums, particularly calcium reactors

Centrifugal Pumps



Centrifugal Pump - Working





Components of Centrifugal pump

- A rotating component comprising of an impeller and a shaft.
- A stationery component comprising a volute (casing), suction and delivery pipe.

Working Principle of Centrifugal pump

Principle: When a certain mass of fluid is rotated by an external source, it is thrown away from the central axis of rotation and a centrifugal head is impressed which enables it to rise to a higher level.

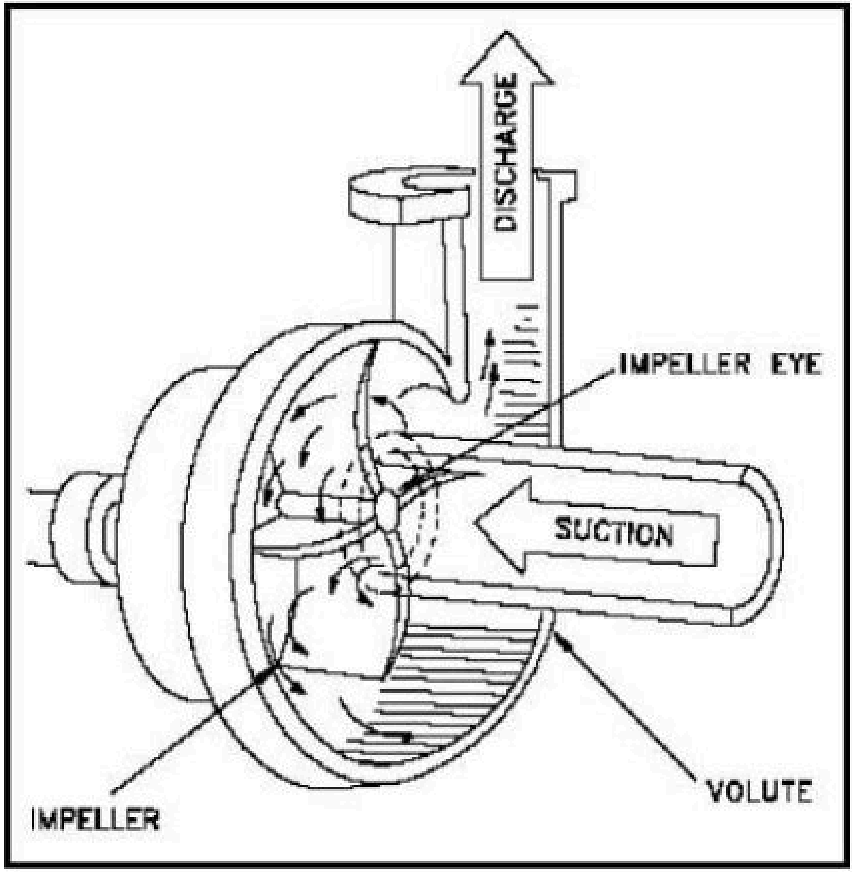
Working:

- The delivery valve is closed and the pump is primed, so that no air pocket is left.
- Keeping the delivery valve still closed the electric motor is started to rotate the impeller.
- The rotation of the impeller is gradually increased till the impeller rotates at its normal speed.
- After the impeller attains the normal speed the delivery valve is opened when the liquid is sucked
- continuously upto the suction pipe.

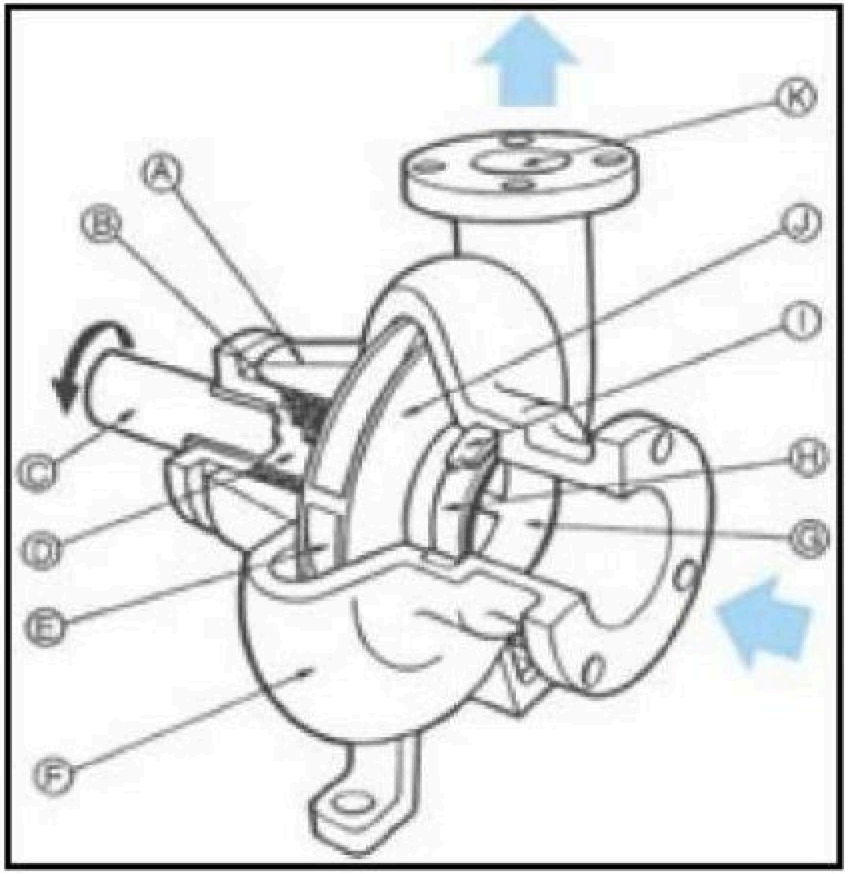
Working Principle of Centrifugal pump

- It passes through the eye of the casing and enters the impeller at its centre.
- The liquid is impelled out by the rotating vanes and it comes out at the outlet tips of the vanes into the casing.
- Due to the impeller action the pressure head as well as the velocity heads are increased.
- From the casing the liquid passes into the pipe and lifted to the required height.
- When pump is to be stopped the delivery valve is to be first closed, other wise there may be some backflow of water into the reservoir.

Volute and Vortex Casing



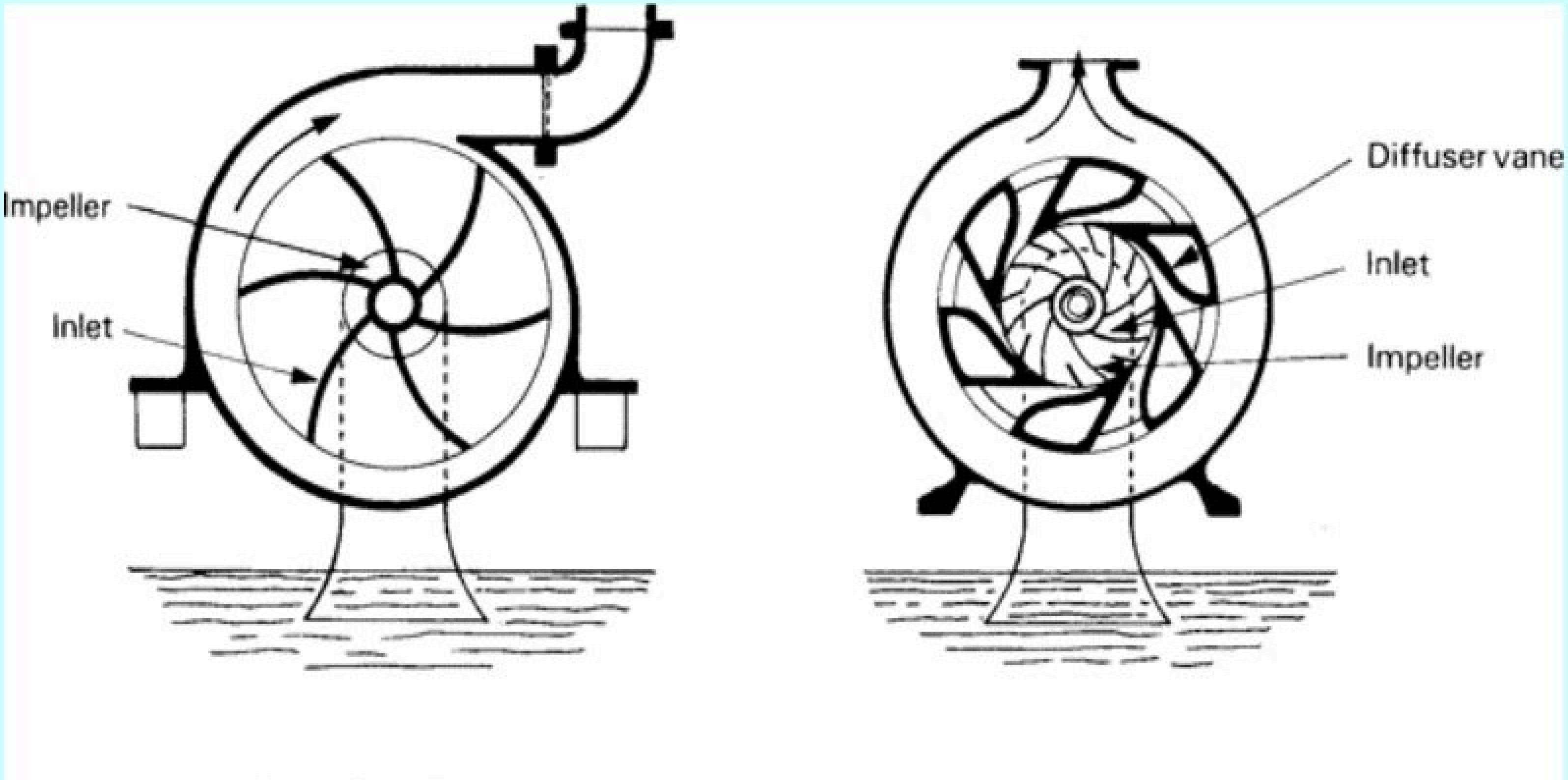
Volute Casing



Vortex Casing

Volute and Diffuser casing

Volute Diffuser (*guide Vane*)



A. - Volute Centrifugal Pump.

B. – Turbine Centrifugal Pump.

Volute and Diffuser casing

Volute Casing: In this type of casing the area of flow gradually increases from the impeller outlet to the delivery pipe.

Vortex Casing: If a circular chamber is provided between the impeller and volute chamber the casing is known as Vortex Chamber.

Diffuser C :

- The impeller is surrounded by a diffuser.
- The guide vanes are designed in such a way that the water from the impeller enters the guide vanes without shock.
- It reduces the vibration of the pump.
- Diffuser casing, the diffuser and the outer casing are
- stationery parts.

Priming of a centrifugal Pump

- The operation of filling the suction pipe, casing and a portion of delivery pipe with the liquid to be raised, before starting the pump is known as **Priming**
- It is done to remove any air, gas or vapour from these parts of pump.
- If a Centrifugal pump is not primed before starting air pockets inside impeller may give rise to vortices and causes discontinuity of flow

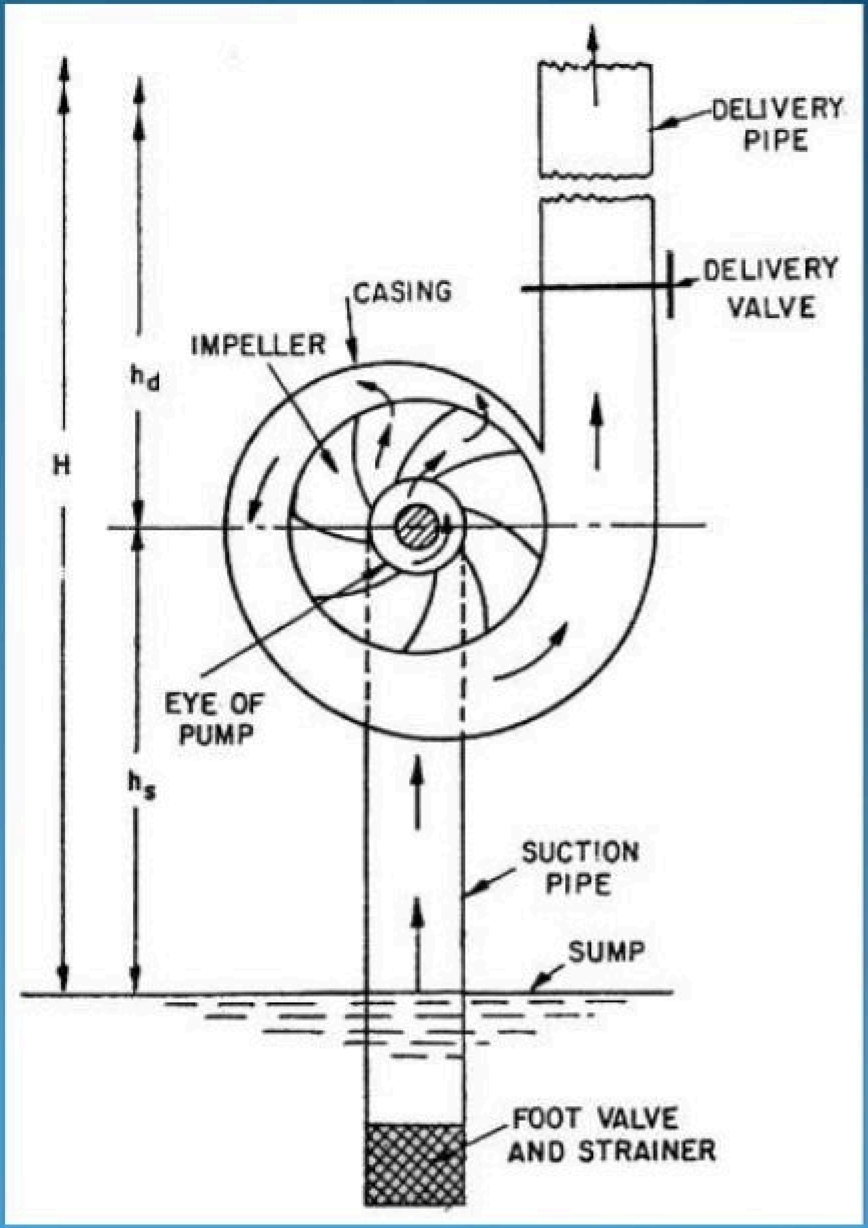
Main Parts of Centrifugal Pumps

Impeller:

which is the rotating part of the centrifugal pump.

It consists of a series of backwards curved vanes (blades).

The impeller is driven by a shaft which is connected to the shaft of an electric motor.

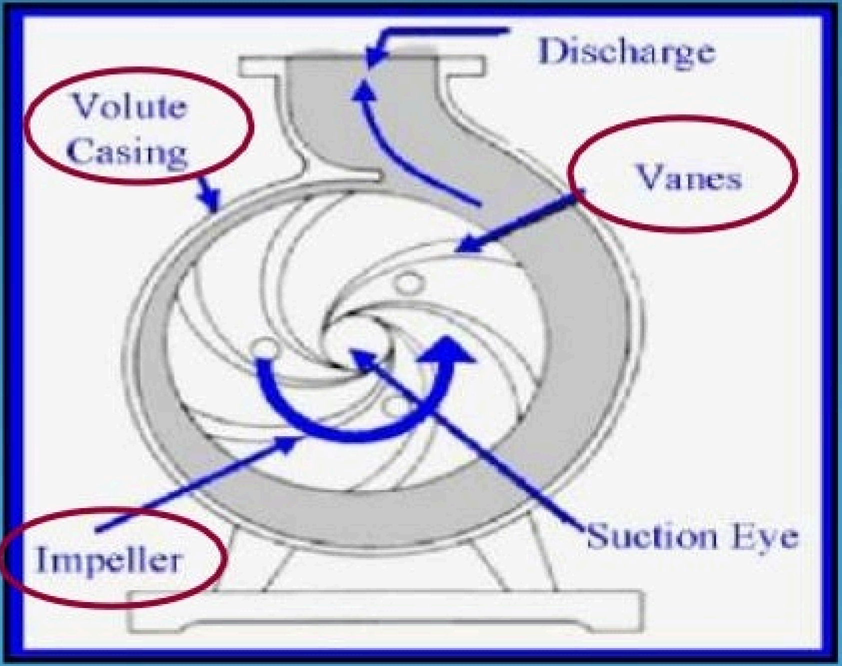


3. **Suction Pipe.**
4. **Delivery Pipe.**
5. **The Shaft**: which is the bar by which the power is transmitted from the motor drive to the impeller.
6. **The driving motor**: which is responsible for rotating the shaft. It can be mounted directly on the pump, above it, or adjacent to it.

Type of Pumps

Centrifugal Pumps

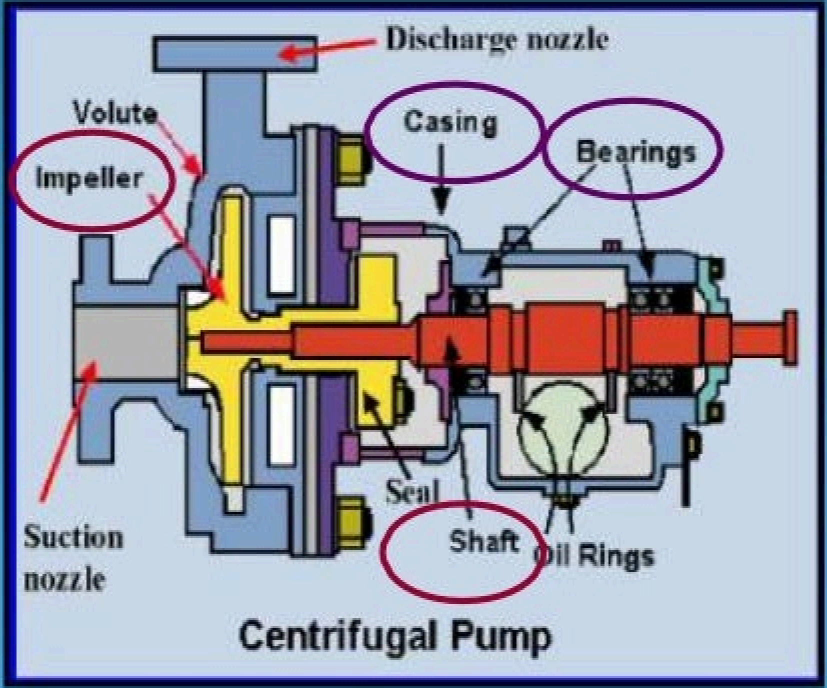
How do they work?



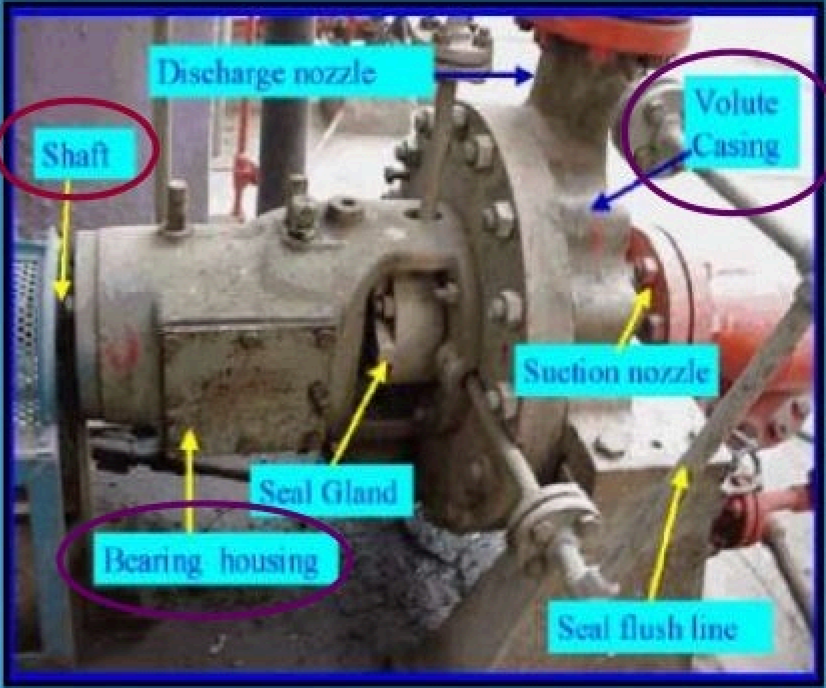
- **Liquid forced into impeller**
- **Vanes pass kinetic energy to liquid: liquid rotates and leaves impeller**
- **Volute casing converts kinetic energy into pressure energy**

Centrifugal Pumps

Rotating and stationary components



Centrifugal Pump



Shaft

Transfers torque from motor to impeller during pump start up and operation

Impellers

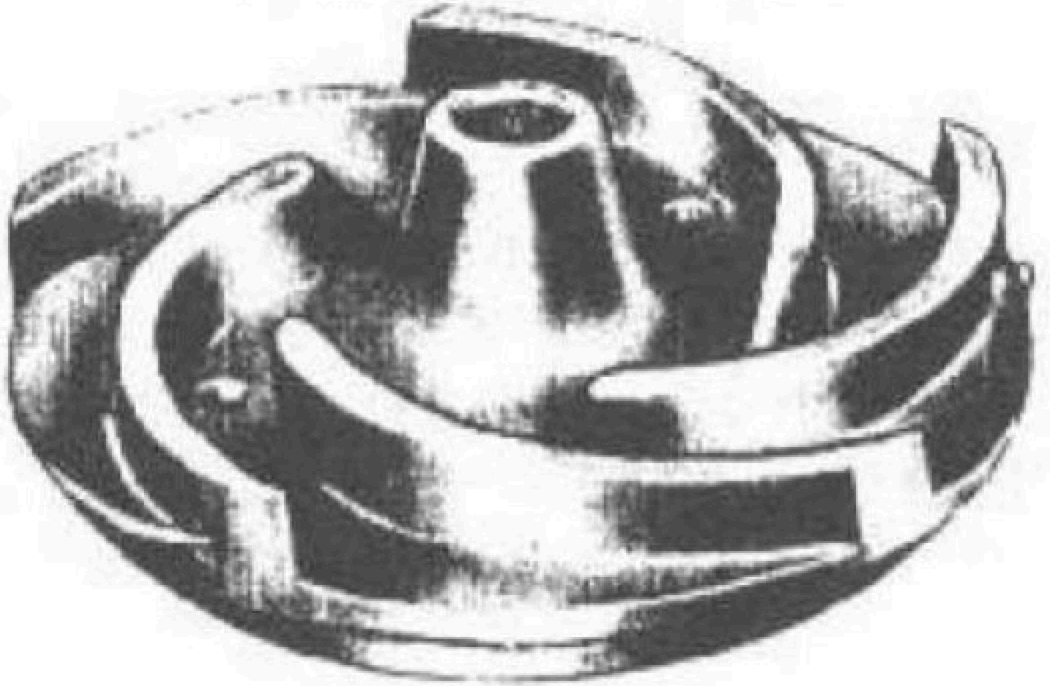
The impeller generates the centrifugal force that moves the liquid. Variations in the impeller are based on whether a particular application calls for large quantities of water, high pressure, or both. The design of the impeller is important to the development of pressure and flow.

Impellers in centrifugal pumps can be classified by size, type, and speed. There are three types of impellers for centrifugal pumps:

<u>Open Impeller</u>

An open impeller has its vanes exposed on the bottom side, a design that allows the pump to move liquids that contain large solids. Open impellers are used in propeller pumps in which the head is low (usually less than 20 feet) and the volume of water pumped is high. The rate of flow can easily be set by adjusting the clearance of the bottom of the impeller to the pump casing. The larger the clearance is, the less will be pumped.

Semi-Open Impeller



This design contains many of the same characteristics of the open impeller. The semi-open impeller has a shroud, or cover, on one side. It is used to pump liquids that contain medium-size solids.

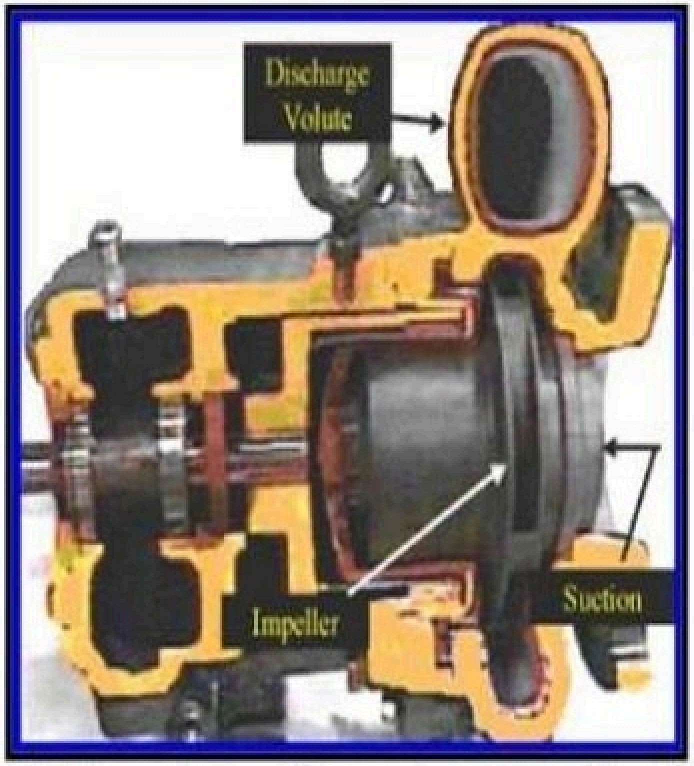
Closed Impeller

This is the impeller of choice in most pump designs and is used in cases where the liquid being pumped has few solids since it will pump the liquid with less wasted energy. With this design, there is a cover on both sides of the impeller with the vanes completely enclosed. The eye of the impeller is surrounded by a skirt, which fits into a recess in the pump casing and ensures that the water from the discharge side of the impeller does not recirculate back to the suction side. The impeller is set in the center of the pump casing.

c) Casing

The main function of casing is to enclose the impeller at suction and delivery ends and thereby form a pressure vessel. The pressure at suction end may be as little as one-tenth of atmospheric pressure and at delivery end may be twenty times the atmospheric pressure in a single-stage pump. For multi-stage pumps the pressure difference is much higher. The casing is designed to withstand at least twice this pressure to ensure a large enough safety margin.

Volute casing



(Figure 11) has impellers that are fitted inside the casings. One of the main purposes is to help balance the hydraulic pressure on the shaft of the pump. However, operating pumps with volute casings at a lower capacity than the manufacturer's recommended capacity, can result in lateral stress on the shaft of the pump. This can cause increased wearing of the seals, bearings, and the shaft itself. Double-volute casings are used when the radial force becomes significant at reduced capacities.

Types of Casing

Volute Pump with Vortex

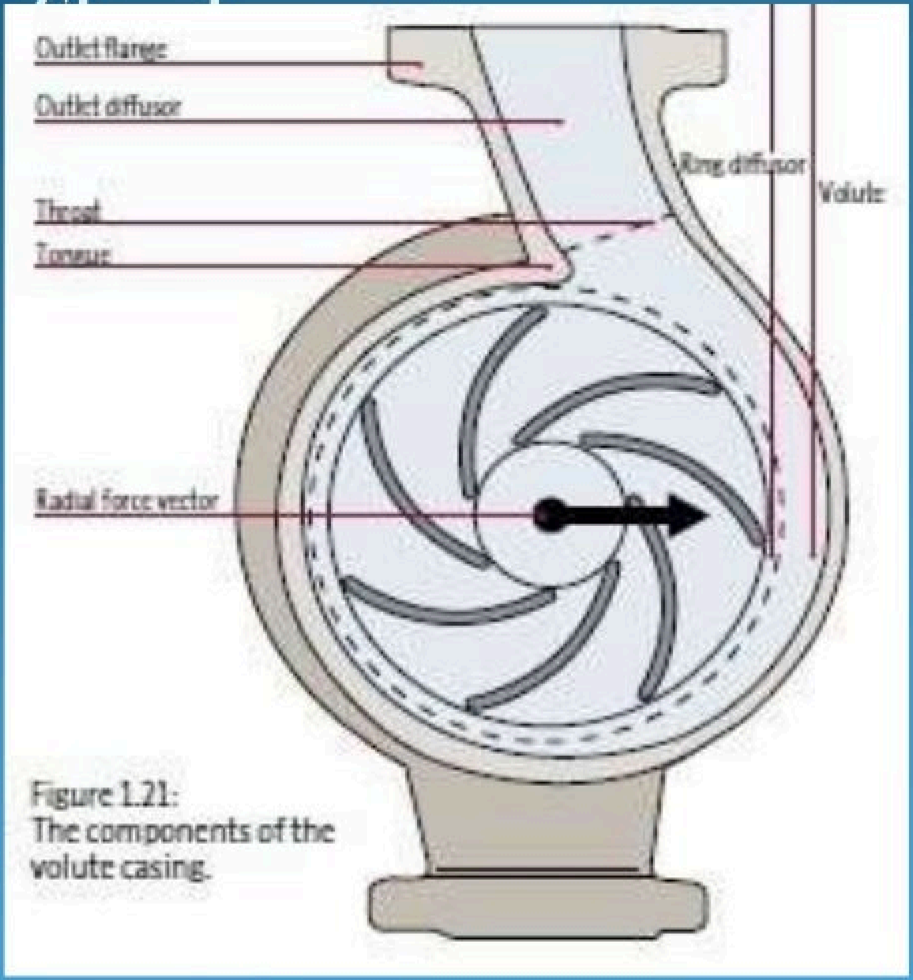
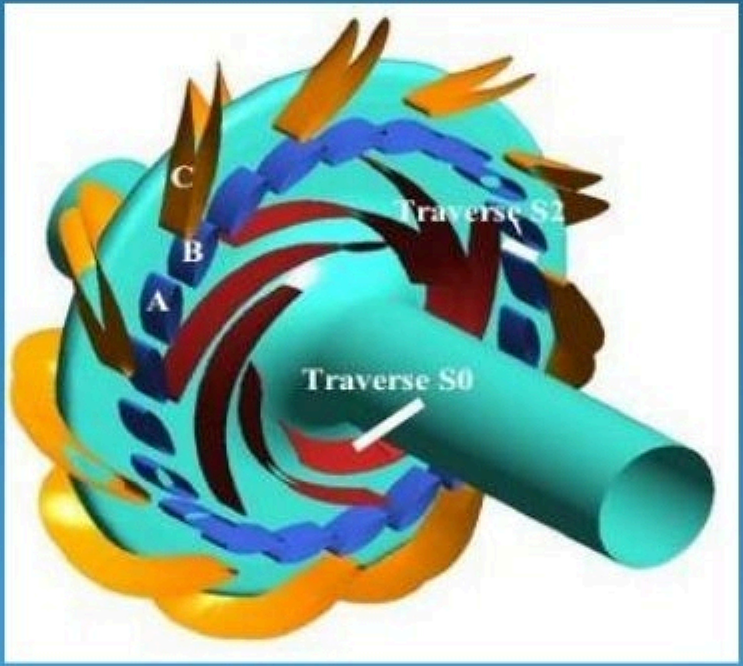


Figure 1.21:
The components of the volute casing.

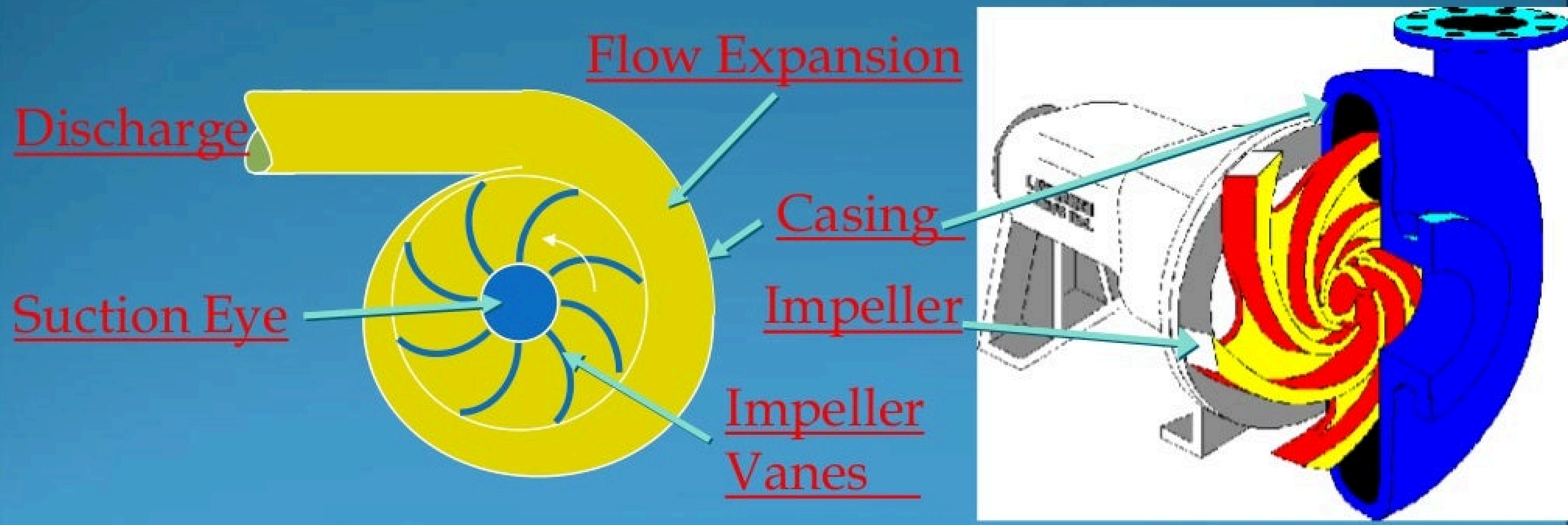
Diffuser Pump



Centrifugal Pumps

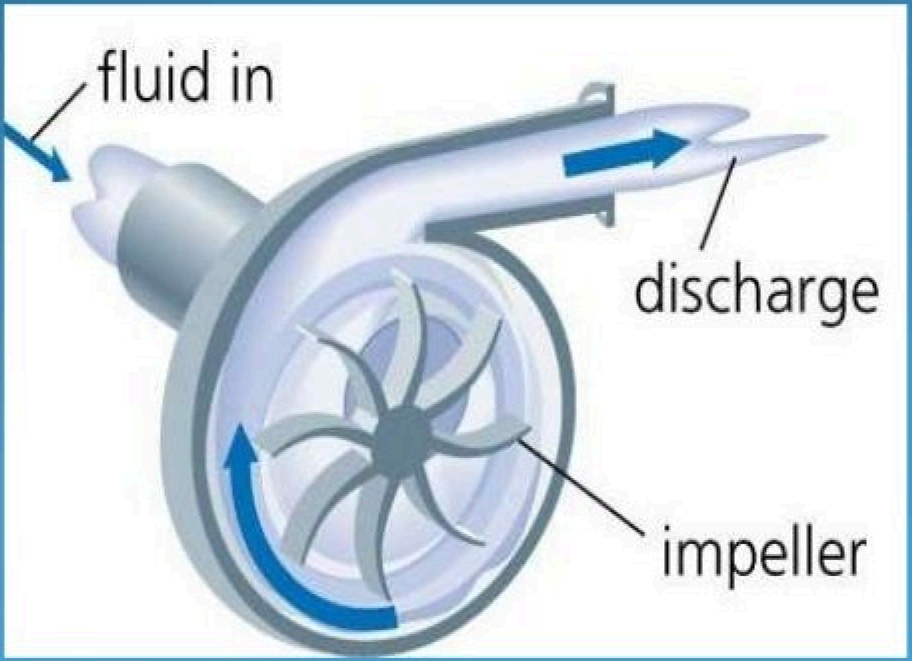
Broad range of applicable flows and heads

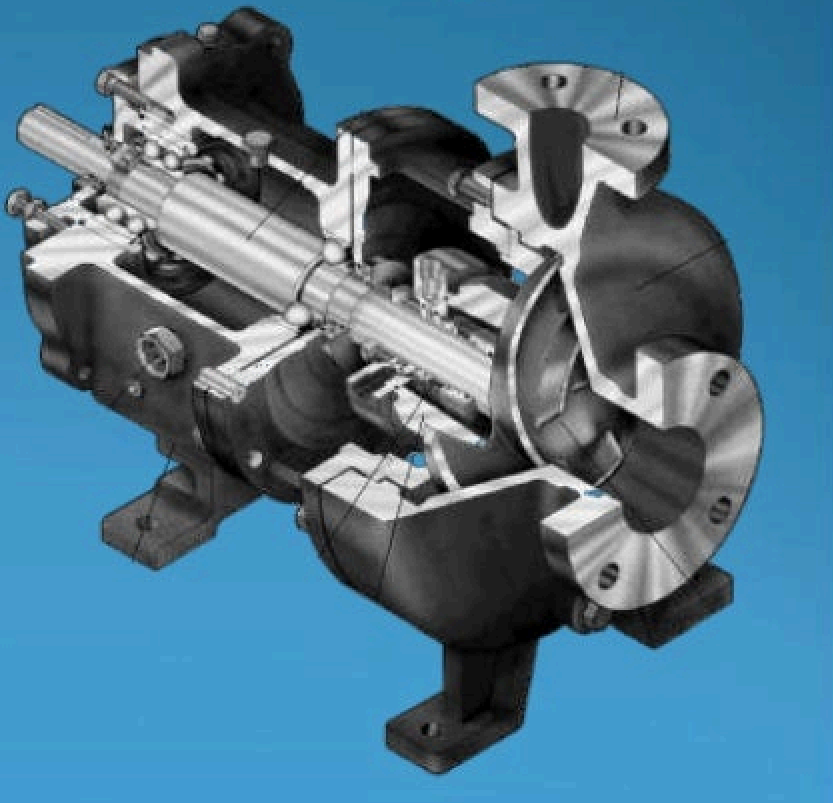
Higher heads can be achieved by increasing the diameter or the rotational speed of the impeller



Centrifugal Pump:

- Centrifugal pumps (radial-flow pumps) are the most used pumps for hydraulic purposes. For this reason, their hydraulics will be studied in the following sections.





(iv) Heads of a pump :

The heads of centrifugal pump are described by following ways.

(1) Suction Head (h_s)

(2) Delivery Head (h_d)

(3) Static Head (H_s)

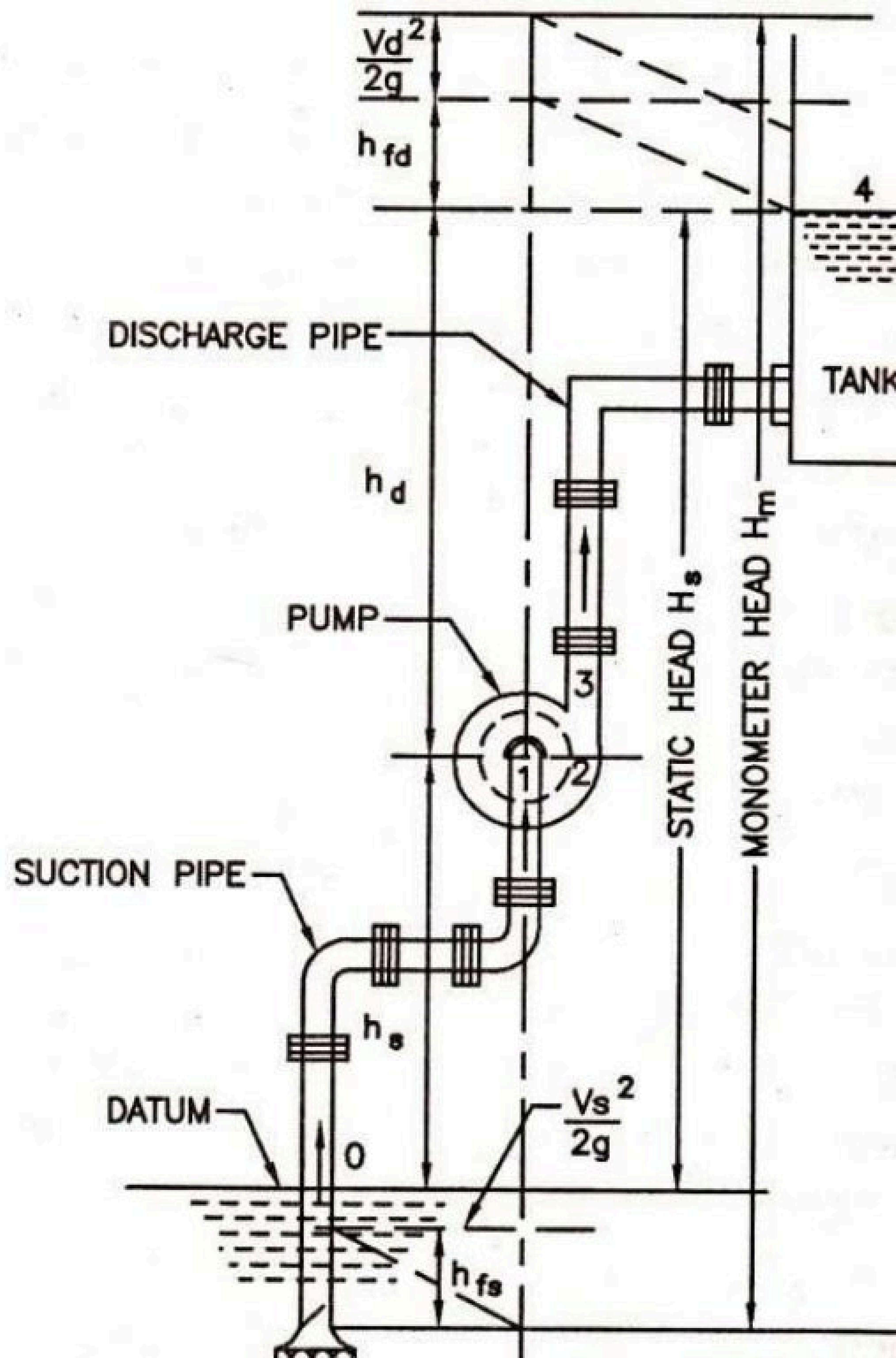
(4) Manometric Head (H_m)

(1) Suction Head (h_s) :

The suction head of centrifugal pump as shown in fig. 9.4. is a vertical height from water surface of sump to the centre line of centrifugal pump. It is denoted by 'hs'. This height is also known as suction lift.

(2) Delivery Head (h_d) :

The delivery head of centrifugal pump is vertical height from the centre of the pump to the water surface in the tank to which water



(3) Static Head :

The static head of centrifugal pump is sum of suction head and delivery head. It is denoted by 'H_s'.

Mathematically, written as

$$H_s = h_s + h_d$$

Where h_s = Suction head

and h_d = Delivery head

(4) Manometric Head (H_m) :

It is a head against which a centrifugal pump has to work, called as manometric Head. It is denoted by 'H_m'.

It is written as,

Hm = (Head imparted by the rotation of impeller to the water) – (Loss of head in the pump)

$$\therefore \quad H_m = H_s + \text{Losses in pipes} + \frac{V_d^2}{2g}$$

$$= h_s + h_d + h_{fs} + h_{fd} + \frac{V_d^2}{2g}$$

or

$$H_m = (h_s + h_{fs}) + (h_d + h_{fd}) + \frac{V_d^2}{2g}$$

Where h_{fs} = Head losses due to friction in suction pipe.

h_{fd} = Head losses due to friction in delivery pipe

V_d = Velocity of liquid (water) in delivery pipe.

The manometric head of centrifugal pump is head against the pump has to work. So that it is also considered as total head (H) against the pump has to work. Total head is denoted by H.

– **Efficiencies of a centrifugal pump and power required to drive the pump :**

Power required to drive the pump :

Power input to the pump = Power supplied by the electric motor.

= Shaft power of pump

$$P = \frac{\rho g Q H_m}{\eta_o} = \frac{\text{Power output of pump}}{\text{Overall efficiency of C.F. pump}}$$

$$P = \frac{\rho g Q H}{\eta o}$$

Where, P = Input shaft power of C.F. pump

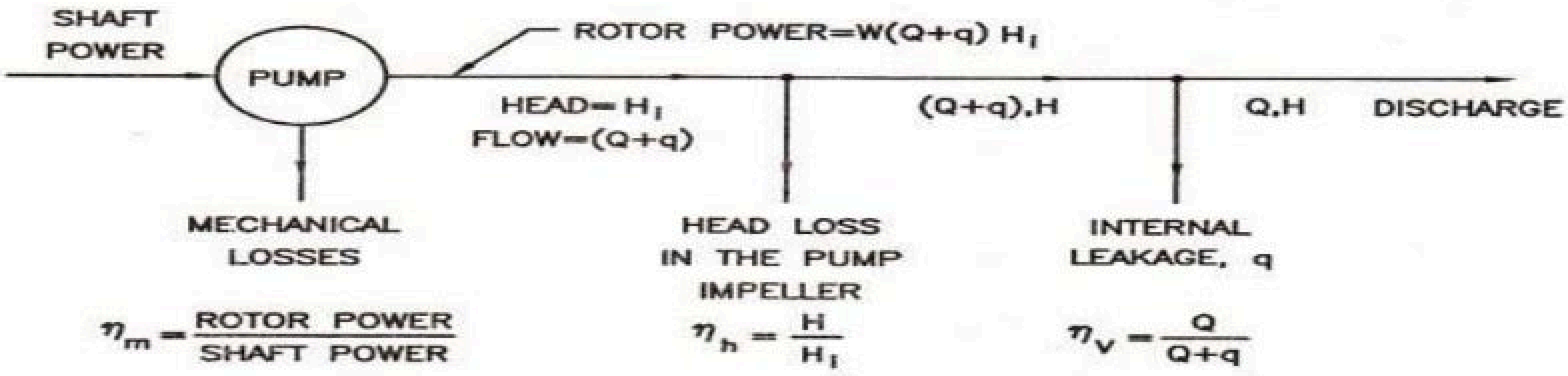
ϱ = Density of liquid, Kg/m^3

Q = Discharge, m^3/s

η_o = Overall efficiency of C.F. pump

H = Total head developed by the pump in m

Efficiencies of centrifugal pump :



(FIG. 9.5 SCHEMATIC REPRESENTATION OF LOSSES IN A PUMP)

Following are various losses and efficiencies of C.F. pump.

There are major two types of losses occur in centrifugal pump.

(a) Hydraulic losses :

Hydraulic losses occurs in pump due to friction in impeller, friction and eddy losses in guide vane, diffuser and casing and shock at the entrance and exit from pump also losses in friction in suction and dilivery pipe.

(b) Mechanical losses :

Mechanical losses are occur due to friction of the main bearing and glands and disc friction between the impeller and the liquid which fills the clearance space between the impeller and casing.

(1) Manometric efficiency (η_{mano}) :

It is defined as a ratio of manometric head developed by the pump to the head imparted by the impeller to the liquid is known as manometric efficiency.

$$\text{Hence, } \eta_{mano} = \frac{\text{Manometric head developed by pump}}{\text{Head imparted by impeller to liquid}}$$

(2) Volumetric efficiency :

It is defined as a ratio of quantity of liquid discharged per second from the pump to quantity of liquid passing per second through the impeller. It is denoted by 'η_v'.

$$\eta_v = \frac{\text{liquid discharged per second from the pump}}{\text{Quantity of liquid passing per second}}$$

$$= \frac{Q}{Q+q}, \text{ Where, } q = \text{leakage}$$

(3) Mechanical efficiency (η_m) :

It is defined as a ratio of the power delivered by the impeller to the liquid to the power input to the shaft of pump. It is denoted by "η_m'.

$$\eta_m = \frac{\text{Power delivered by impeller to the liquid}}{\text{Input power to the shaft of pump}} = \frac{\text{Rotor power}}{\text{Shaft power}}$$

(4) Overall efficiency (η_o) :

It is defined as a ratio of power output of the pump to the power input to the pump. It is denoted by 'η_o'.

Hence, $$\eta_o = \frac{\text{Power output of the pump}}{\text{Power input to the pump shaft}}$$

$$= \frac{\rho g Q H_m}{P} = \frac{\rho g Q H}{P}$$

EXAMPLE-1 :

A C.F. pump transmits 14.710 kW power against the total head of 15 m of water. Find the discharge of water in m^3/s. If efficiency of pump is 72%. (Oct./Nov. 2003)

Given data :

$$P = 14.710 \text{ kW} = 14710 \text{ W}$$

$$H = 15 \text{ m}$$

$$\eta_o = 72\% = 0.72$$

Now, $$\eta_o = \frac{\rho g Q H}{P}$$

$$Q = \frac{P \eta_o}{\rho g H}$$

$$= \frac{14710 \times 0.72}{1000 \times 9.81 \times 15}$$

$$= 0.0719 \text{ m}^3/\text{sec} = 71.9 \text{ lit/sec}$$

EXAMPLE-2 :

A C.F. pump, delivers water at the rate of 90 lits/sec against a total head of 30 m. Find out power of the pump. (May/June 2006)

Given data,

$H = 30\ m$

$Q = 90\ lit/s = 0.09\ m^3/s$

Assume, $\eta_o = 60\% = 0.6$

$$P = \frac{\rho g Q H}{\eta_o}$$

$$= \frac{1000 \times 9.81 \times 0.09 \times 30}{0.6}$$

$$= 44145\ W$$

$$= 44.145\ kW$$

EXAMPLE-3 :

A C.F. pump discharge 2000 liters of water with the head of water 17 meter. If overall efficiency of pump is 70%. find out power required for this pump. (Oct./Nov. 2006)

Given data :

$H = 17\ m$

$Q = 2000\ lit/sec = 2\ m^3/s$

$\eta_o = 70\% = 0.7$

Power required to drive the pump $P = \frac{\rho g Q H}{\eta_o}$

$$= \frac{1000 \times 9.81 \times 2 \times 17}{0.72}$$

$$= 463.250\ kW$$

ADVANTAGE OF CENTRIFUGAL PUMP

i. *Simple in construction and cheap*
ii. *Handle liquid with large amounts of solids*
iii. *No metal to metal fits*
iv. *No valves involved in pump operation*
v. *Maintenance costs are lower*

DISADVANTAGE OF CENTRIFUGAL PUMP

i. *Cannot handle highly viscous fluids efficiently*
ii. *Cannot be operated at high heads*
iii. *Maximum efficiency holds over a narrow range of conditions*

MULTISTAGE CENTRIFUGAL PUMP

¬***A centrifugal pump that consists of two or more impellers mounted on the same***

¬***shaft or on different shafts is called the MULTISTAGE centrifugal pump.***

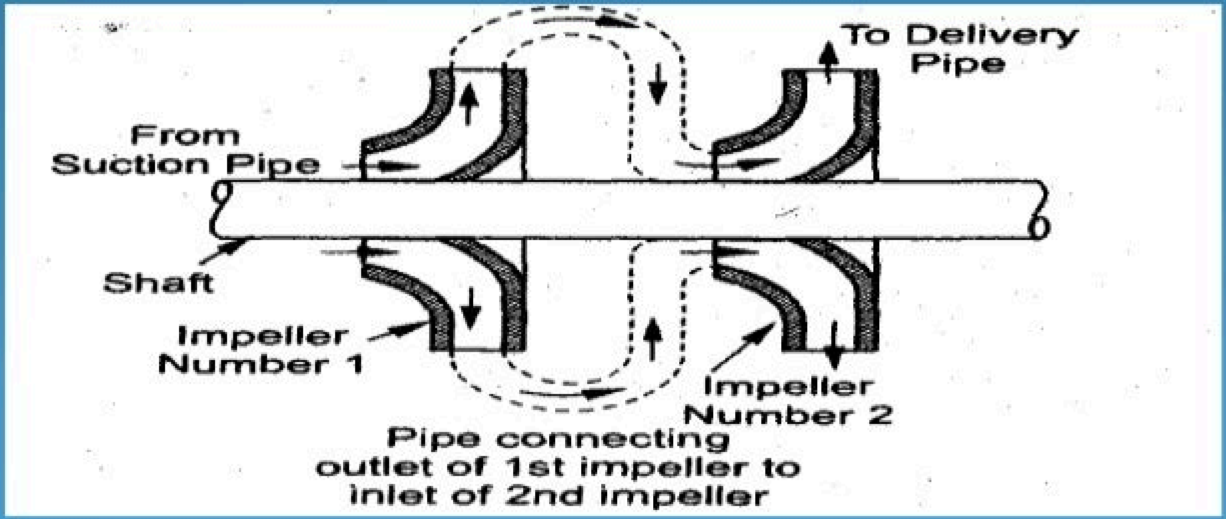
Multistage pumps are employed to accomplish the following two important
functions.

1. To produce a high head

2. To develop a high discharge

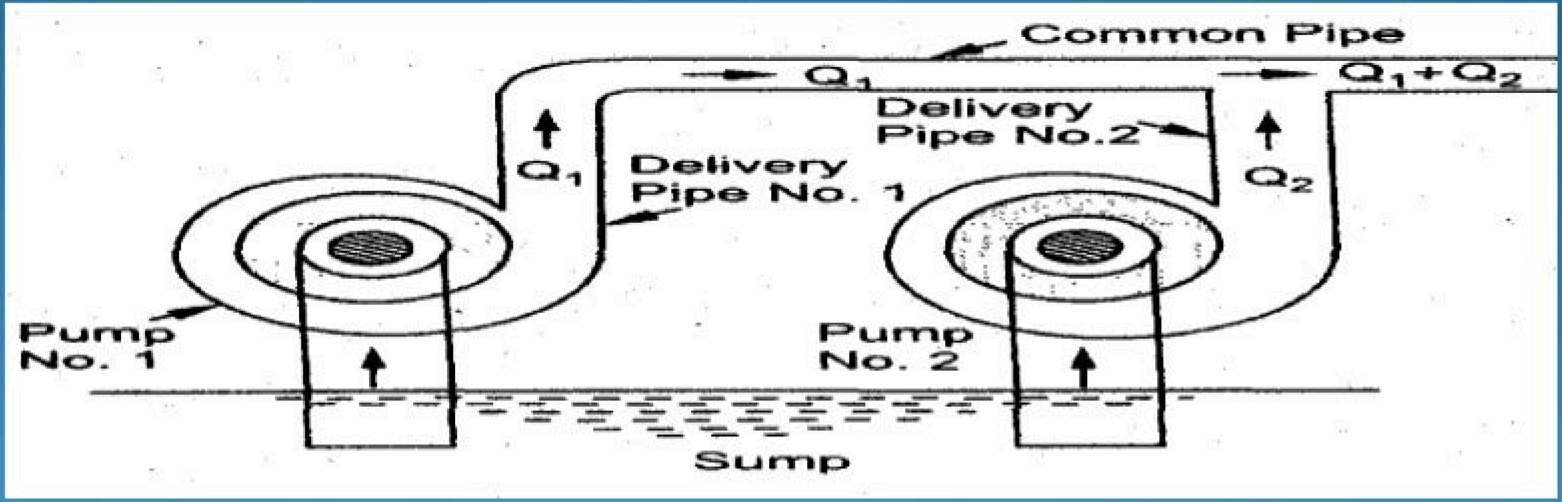
1. To produce a high head

if a high head is To be developed The impeller are connecTed in series or same shafT



2.TO DISCHARGE A LARGE QUANTITY OF LIQUID

if discharging large quanTiTy of liquid The impeller are connecTed in parallel



ToTal discharge = n q

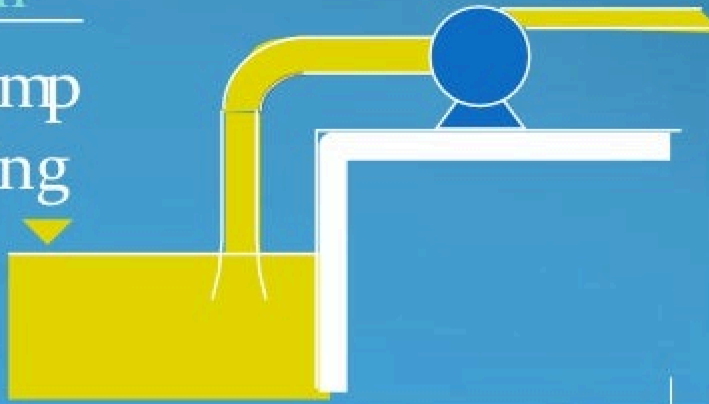
Priming

- The pressure increase created is proportional to the density of the fluid being pumped.
- A pump designed for water will be unable to produce much pressure increase when pumping air
  - Density of air at sea level Is. 225 kg/m^3
  - Change in pressure produced by pump is about 0.1% of design when pumping air rather than water!

$$C_H = \frac{\Delta H g}{\omega^2 D^2}$$

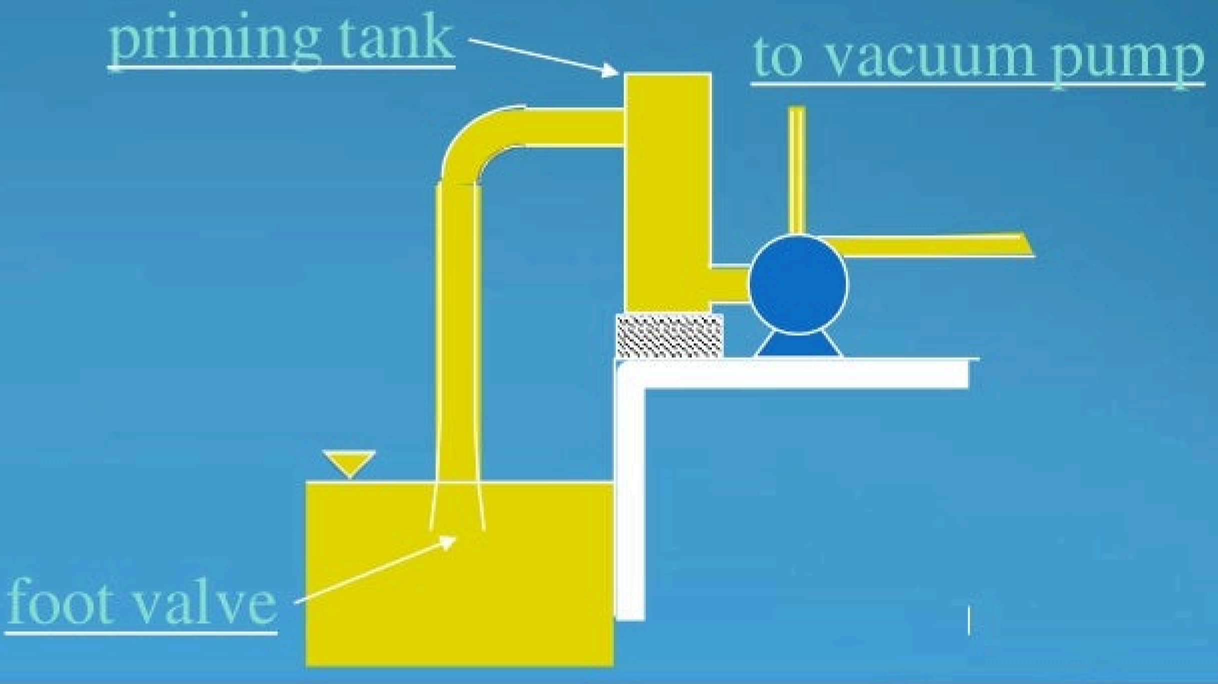
$$C_H = \frac{\Delta p}{\rho \omega^2 D^2}$$

$$\Delta p = C_H \rho \omega^2 D^2$$



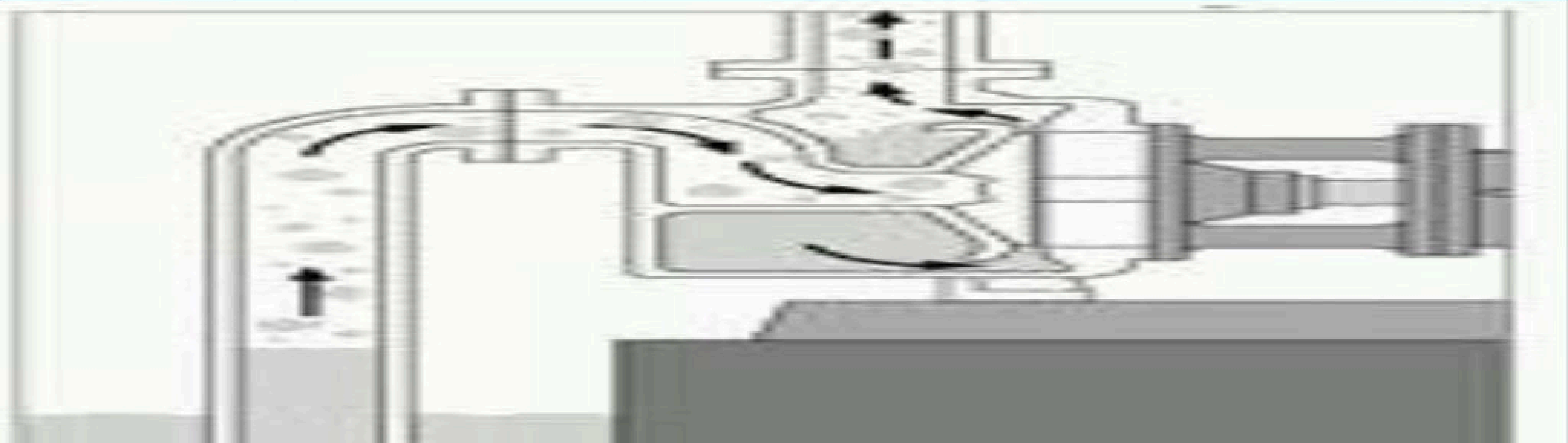
Priming Solutions

- Applications with water at less than atmospheric pressure on the suction side of the pump require a method to remove the air from the pump and the inlet piping
- Solutions
  - foot valve
  - priming tank
  - vacuum source
  - self priming

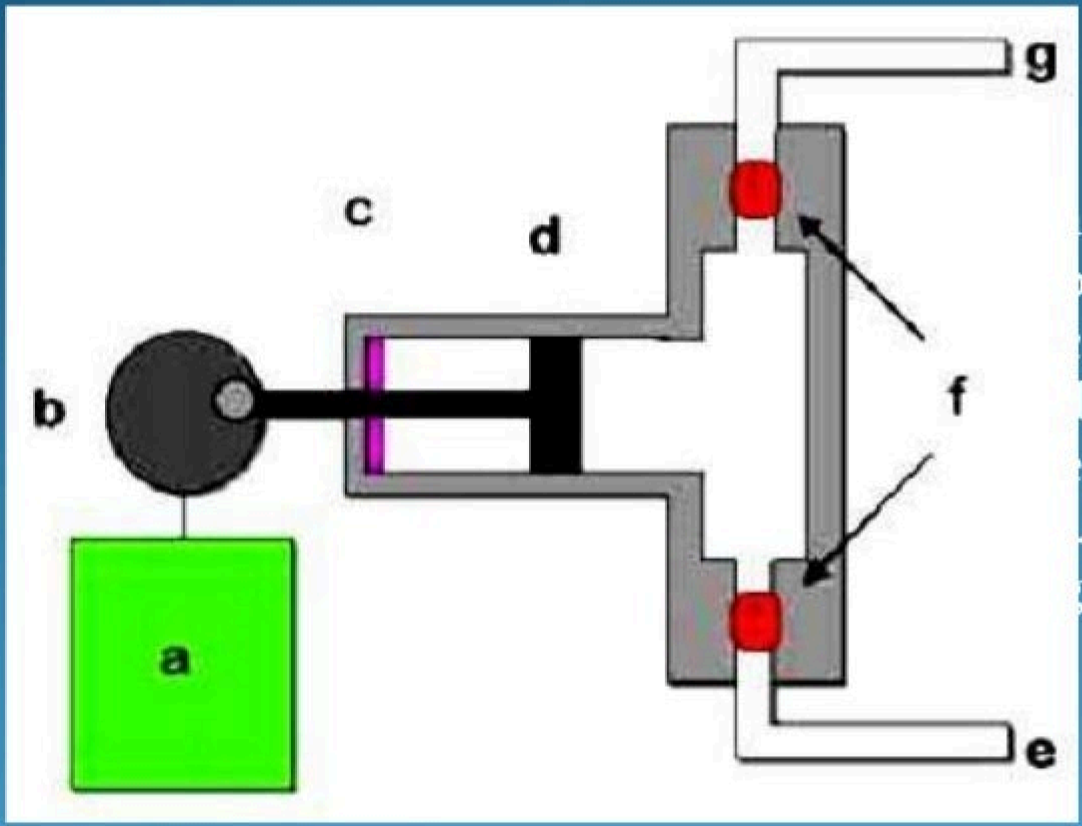


Self-Priming Centrifugal Pumps

- Require a small volume of liquid in the pump
- Recirculate this liquid and entrain air from the suction side of the pump
- The entrained air is separated from the liquid and discharged in the pressure side of the pump



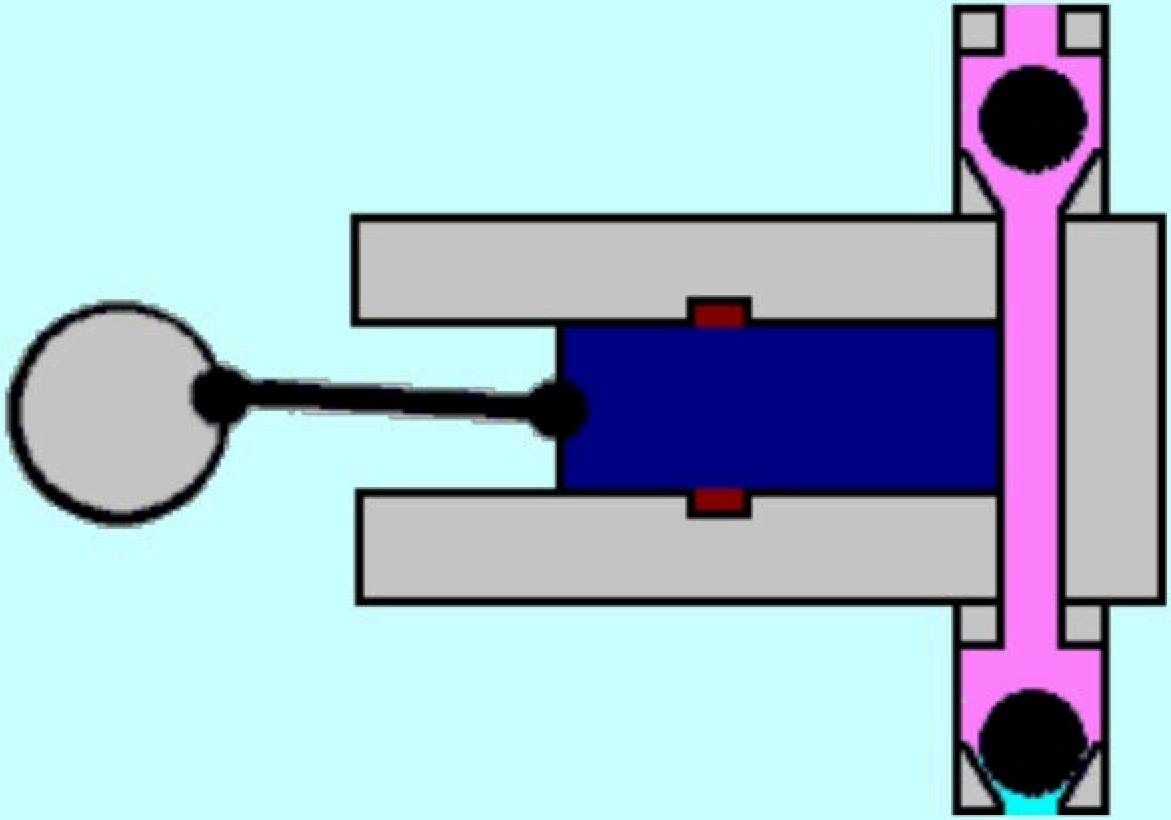
Reciprocating Pump



. Motor
. Gear
. Seal
. Piston
. Solvent in
. Check valves
. Solvent out

Working of single acting Reciprocating Pump

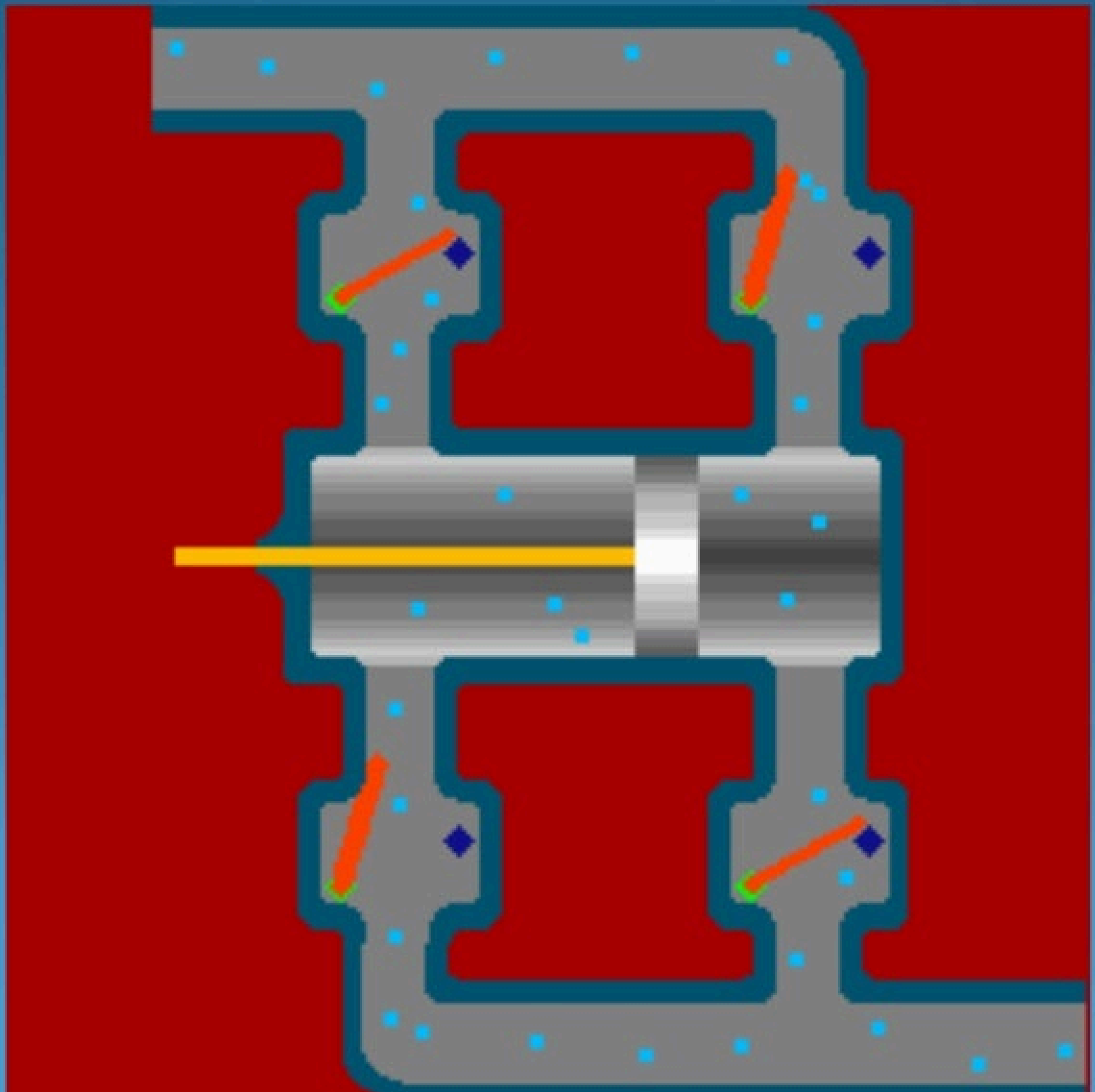
Single Acting Reciprocating Pump



Working of single acting Reciprocating Pump

- ✓ During suction stroke the piston moves to the left, causing the inlet valve to open.
- ✓ Water is admitted into the cylinder through the inlet valve.
- ✓ During the discharge stroke the piston moves to the right closes the suction valve and opens the out let valve.
- ✓ Through the outlet valve the volume of liquid moved out of the cylinder.

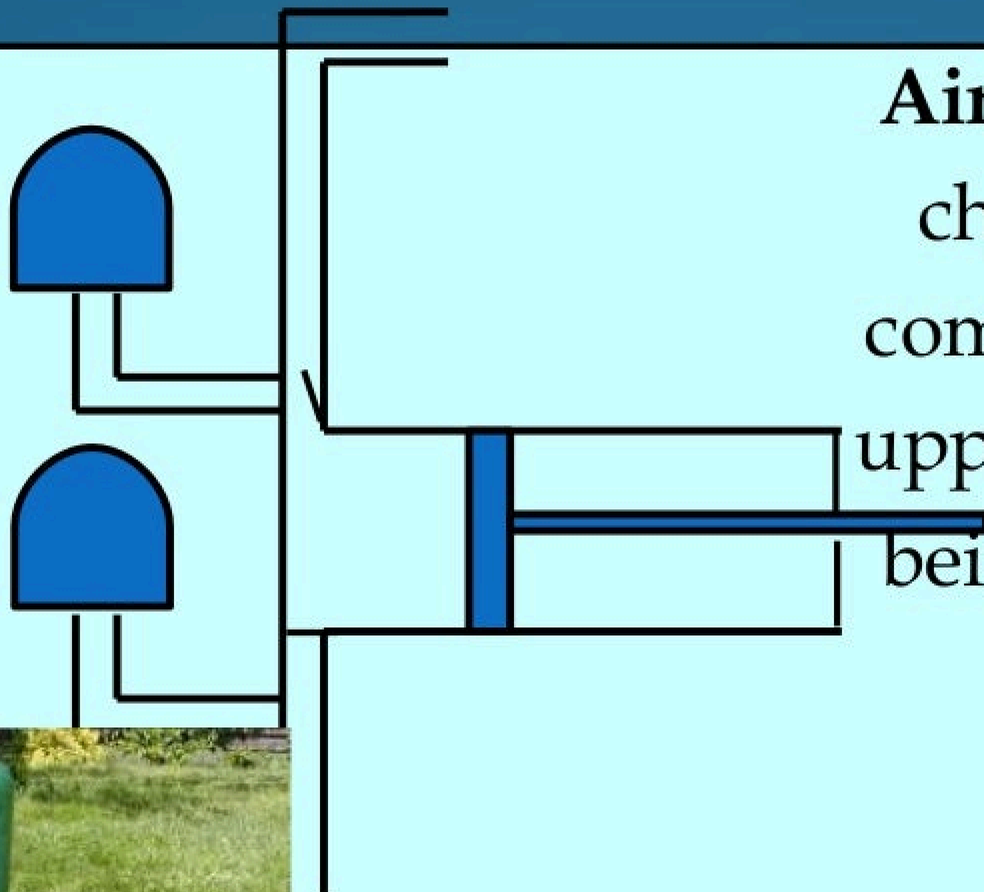
Double Acting Reciprocating pump



Double Acting Reciprocating Pump - Working

- Each cycle consists of two strokes.
- Both the strokes are effective, hence it is known as double acting pump
- Liquid is filled at one end and discharged at other end during forward stroke.
- During the return stroke, end of cylinder just emptied is filled and the end just filled is emptied.

Air Vessels



Air vessel is a closed chamber containing compressed air in the upper part and liquid being pumped in the lower part.

Advantages of reciprocating pump

- Relatively compact design
- High viscosity performance
- Ability to handle high differential pressure.

- **Purpose of Air Vessels fitted on reciprocating pump :**

  (1) To obtain liquid at uniform discharge.

  (2) Due to air Vessels, acceleration head and friction head decreases. The work required to overcoming the friction resistance in suction and delivery pipe considerably decreases. So it save considerable amount of work.

  (3) Reciprocating pump can run at high speed without flow separation.

- **Heads of reciprocating pump :**

  Suction Head (H_s) :

  It is a vertical height from the surface of liquid in sump to the centre of pump (centre of cylinder) as shown in fig. 9.7. So that it is a height to which the liquid to be is raised above the liquid surface in the sump. It is denoted by 'H_s'.

- **Delivery head (H_d) :**

  It is a height defference between centre of cylinder of the pump to the reservor, also it is defined as the height to which the liquid is lifted above the centre of cylinder.

* **Frictional Head (H_f) :** It is defined as the losses of head due to frictional resistancne. It is denoted by 'h_{fs}' for head losses due to friction in suction pipe and h_{fd}, head losses due to friction in delivery pipe.

Mathematically, Written by

$$h_f = \frac{4fl\,v^2}{2gd},$$

Where, f = friction factor

l = length of pipe

V = Velocity of liquid

d = Diameter of pipe

Suction pipe frictional head losses, $h_{fs} = \dfrac{4fl_sV_s^2}{2gd_s}$

Where l_s = length of suction pipe

V_s = Velocity of liquid in suction pipe

d_s = Diameter of suction pipe

Delivery pipe, friction head losses, $h_{fd} = \dfrac{4fl_dV_d^2}{2gd_d}$

Where, l_d = Length of delivery pipe

V_d^2 = Velocity of liquid in delivery pipe

d_d = Diameter of delivery pipe.

* **Total Head, (H) :**

Theoratically, total Head is sum of the suction and delivery heads, but in actual practice total head is sum of suction head, delivery head and frictional head losses in pipes.

∴ Total head, $H = H_s + H_d + h_{fs} + h_{fd}$

* **Theoretical power required to drive the pump :**

The discharge of reciprocating pump is the volume of liquid it handles in a unit time i.e., liquid flow rate, m^3/sec.

Let us crank of single acting reciprocating pump rotates N revolution per minute. Then N delivery stroke per minute i.e. $\frac{N}{60}$ delivery stroke per second.

If A = Cross – sectional area of the piston in m^2

L = Length of piston stroke

= Two times the crank radius.

= 2r, Where r = crank radius.

Then, Volume of liquid entres during the suction stroke = A × L

Theoretical discharg, Q = ALN/60

For Double acting reciprocating pump :

Theoretical discharge,

$$Q = \frac{ALN}{60} + \frac{(A - A_p)LN}{60}$$, Where A_p = Cross section area of piston r

N = Crank speed in rpm.

For double acting reciprocating pump, neglecting cross sectional ar of piston rod.

Theoretical discharg, $Q = \frac{2LAN}{60}$

Now, theoretical power required to drive the pump,

$P_{th} = \rho g Q\ (H_s+H_d)$ watts

Where, ρ = Density of liquid, Kg/m^3

Q = Discharge, m^3/s

H_s = Suction head, m

H_d = Delivery head, m

However, there are head losses due to frictional resistance and oth losses, the actual power required to drive the pump is more than t theoretical power P_{th}.

∴ The actual power P is related to the P_{th} (theoretical power) by t efficiency of pump 'η'.

∴ Mathematically, written as

$$\text{Actual power, } P = \frac{\text{Theoretical Power}}{\text{Efficiency of pump}}$$

$$P = \frac{\rho g Q(H_s + H_d)}{\eta}$$

Difference between centrifugal pump and reciprocating pump :

Sr No.	Centrifugal pump		Reciprocating pump
(1)	Centrifugal pump delivery is continuous and smooth.	(1)	Its delivery is fluctuating and pulseting in nature.
(2)	Centrifugal pump has less component than reciprocating pump and simple construction.	(2)	Reciprocating pump has more parts than the C.F. pump and complecated construction.
(3)	Low maintenance cost due to less parts.	(3)	High maintenance cost due to more parts.
(4)	Centrifugal pump unit is compact it required smaller space installation.	(4)	Reciprocating pump unit is large. due to large number of parts, it required more space for installation. 6 to 8 times more than C.F. pump.
(5)	Centrifugal pumps are prefered, when large liquid flow rate at low head required.	(5)	It is prefered at small discharge at high head.
(6)	It can handle highly viscous fluid. like, oils, sugar mollases, paper pulp, muddy and sewage water.	(6)	It can handle low viscous liquid and which is free from impurities other wise there will be a trouble in valves and glands.
(7)	Low wear of components.	(7)	High wear of parts due to reciprocating parts.
(8)	More number of parts are purely rotating type.	(8)	It consist of reciprocating parts.
(9)	C.F. pump can run at much higher speed.	(9)	Reciprocating pump is low speed machine, the speed limitation due to separation and cavitation.
(10)	Low initial cost	(10)	Inlitial cost is 4 times that of C.F. pump
(11)	For a small change in pressure, there will be a large change in discharge.	(11)	For a pressure fluctuation almost constant discharge.

(12) Low efficiency	(12) High efficiency.
(13) It required priming before starting the C.F. pump.	(13) It does not require priming
(14) Air vessels are not required.	(14) Air vessels are fitted on the pump for uniform flow rate.
(15) It is a rotodynamic type pump	(15) It is a positive displacement type pump.

EXAMPLES OF RECIPROCATING PUMP :

EXAMPLE-1 :

Compute the theoretical discharge of double acting reciprocating pump of 0.2 m stroke, 200 mm piston diameter, 50 mm piston rod diameter and 60 RPM crank speed. (April/May 2005)

Given data :

Diameter of piston rod, dp = 50 mm = 0.05 m

Diameter of piston d = 200 mm = 0.2 m

Cross sectional area of piston, $A = \frac{\pi}{4}(0.2)^2 = 0.0314\ m^2$

Cross sectional area of piston rod, $A_p = \frac{\pi}{4}(0.05)^2 = 1.962 \times 10^{-3}\ m^2$.

Stroke length, L = 0.2 m

Speed, N = 60 rpm

Theoretical discharge for double acting pump considering cross sectional area of piston rod.

$$Q = \frac{LAN}{60} + \frac{(A - A_P)\,LN}{60}$$

$$= \frac{0.2 \times 0.0314 \times 60}{60} + \frac{(0.0314 - 0.001962) \times 0.2 \times 60}{60}$$

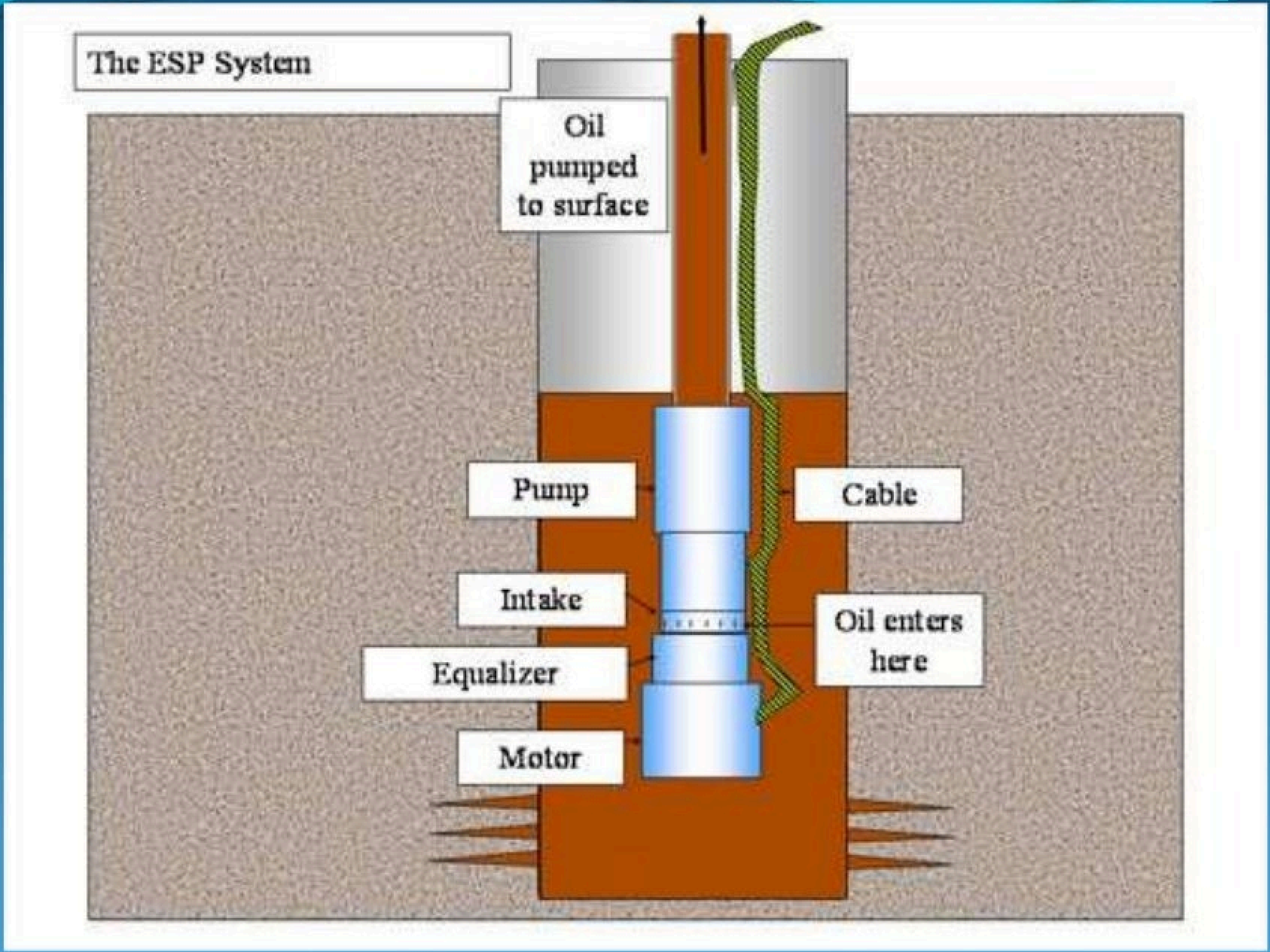
$$= 6.28 + 5.88760 \times 10^{-3}$$

$$= 0.01216\ m^3/s$$

$$= 12.16\ lit/sec.$$

Submersible pump

- A **submersible pump** (or **electric submersible pump** (ESP) is a device which has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped.
- A submersible pump is a pump that is able to be placed underwater and still carry out its intended purpose. Some pumps may be designed to work while being fully submerged, whereas others may be submerged or placed in a dry area.
- A submersible water pump pushes water to the surface, instead of sucking the water out of the ground like above ground water pumps.


The ESP System
Oil pumped to surface
Pump
Cable
Intake
Oil enters here
Equalizer
Motor

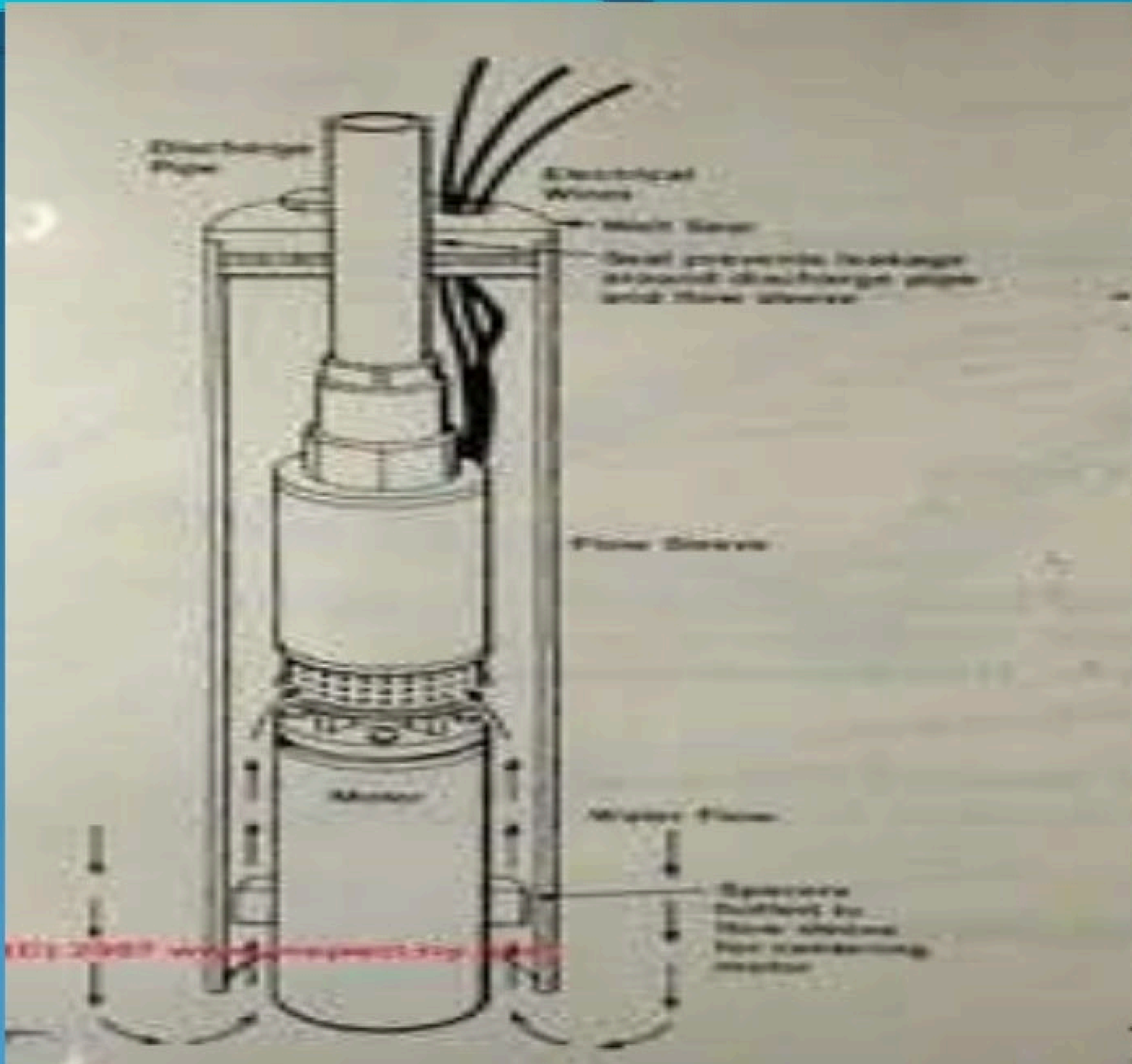
Working principle

- The submersible pumps used in ESP installations are multistage centrifugal pumps operating in a vertical position. Although their constructional and operational features underwent a continuous evolution over the years, their basic operational principle remained the same.
- Produced liquids, after being subjected to great centrifugal forces caused by the high rotational speed of the impeller, lose their kinetic energy in the diffuser where a conversion of kinetic to pressure energy takes place.

•The pump shaft is connected to the pr otector by a mechanical coupling at the bottom of the pump. Well fluids enter the pump through an intake screen and are lifted by the pump stages.

•Other parts include the radial bearings (bushings) distributed along the length of the shaft providing radial support to the pump shaft turning at high rotational speeds.

•An optional thrust bearing takes up part of the axial forces arising in the pump but most of those forces are absorbed by the protector's thrust bearing.


Discharge Pipe
Electrical Wires
Well Seal
Flow Sleeve
Motor
Water Flow

Applications

Submersible pumps are found in many applications:

- Single stage pumps are used for drainage, sewage pumping, general industrial pumping and slurry pumping.
- They are also popular with aquarium filters.
- Multiple stage submersible pumps are typically lowered down a borehole and used for water abstraction, water wells and in oil wells.

ADVANTAGE

- **Efficiency:** Compared to the ordinary pumps, the submersible pumps are more efficient as it pumps liquid which is close to the pump. It therefore functions less than the ordinary pumps. As these pumps are placed inside the sumps, it can detect the level of water quite easily.

DISADVANTAGE

- The largest disadvantage of thesepumps is that you put it in the water. This means it will have a shorter life because it is sitting in and sucking up muck from your pond. It is also harder to clean and maintenance because it is sitting on the bottom of the pond.
- There is the chance the pump will become corroded and lose its seals, thus allowing liquid to penetrate into the motor housing and causing substantial damage to the unit.