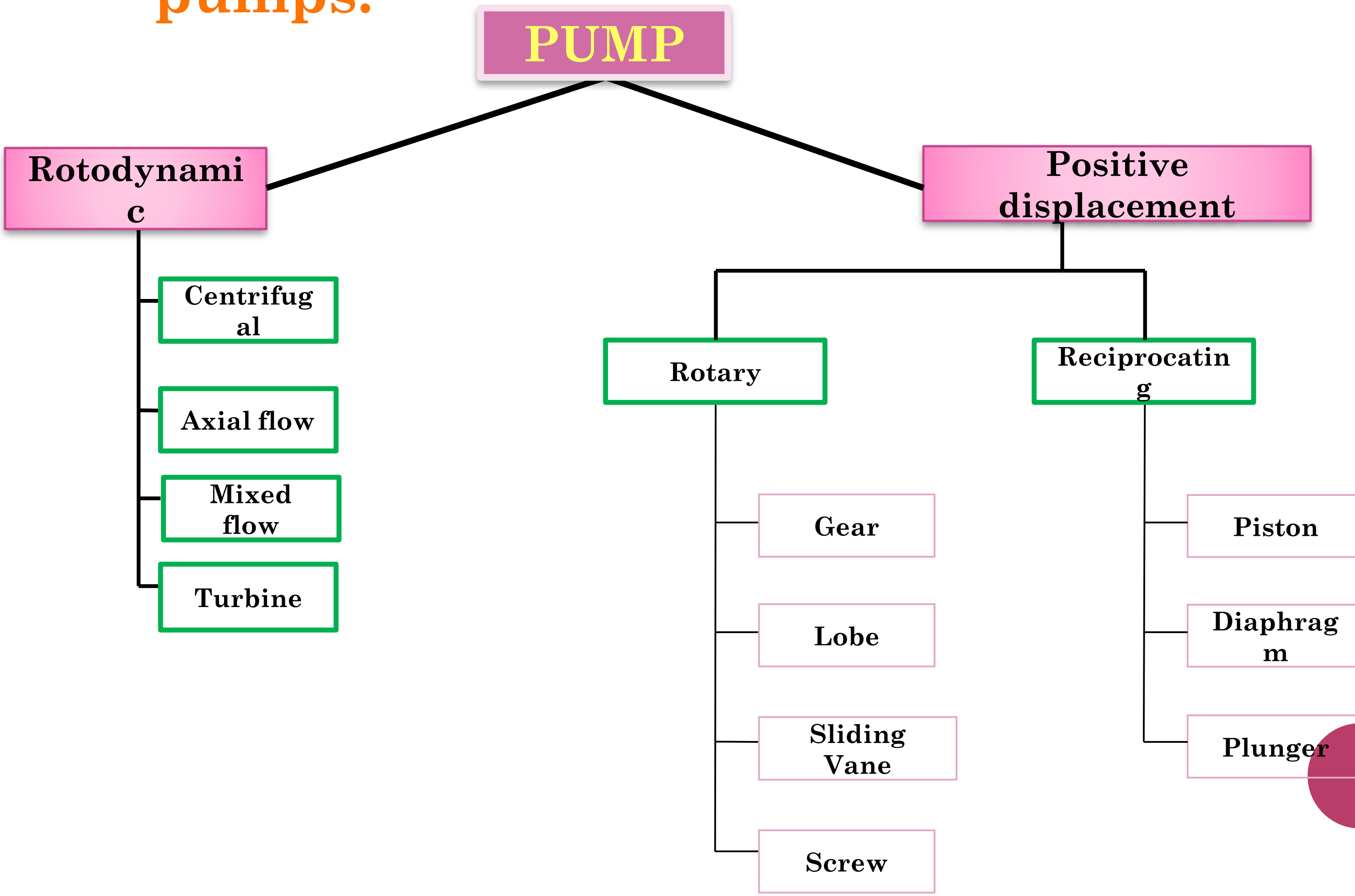
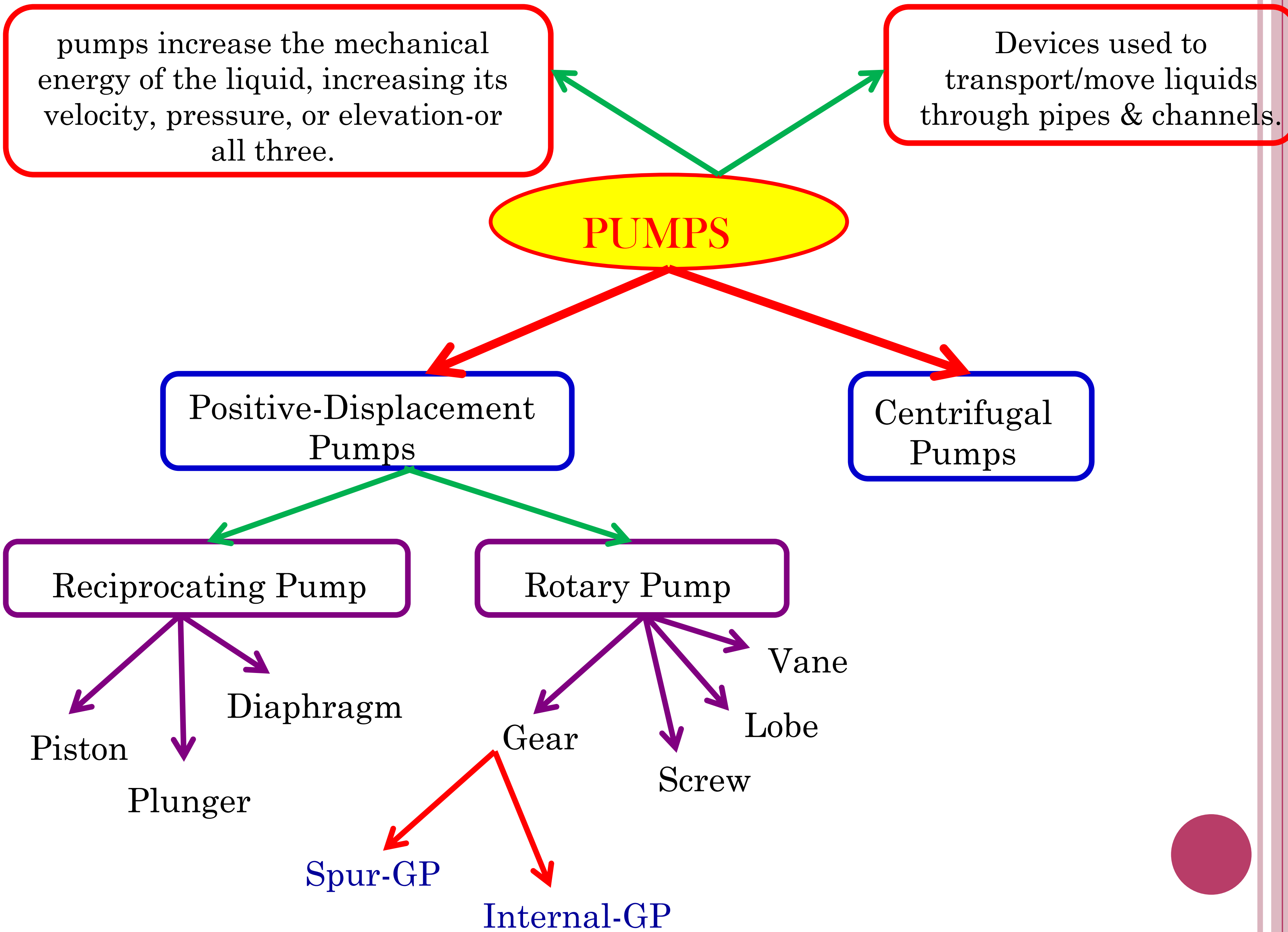
INTRODUCTION TO PUMPS, COMPRESSORS, FANS & BLOWERS

There are two main categories of pump:

- Rotodynamic pumps.
- Positive displacement pumps.




pumps increase the mechanical energy of the liquid, increasing its velocity, pressure, or elevation-or all three.
Devices used to transport/move liquids through pipes & channels.
PUMPS
Positive-Displacement Pumps
Centrifugal Pumps
Reciprocating Pump
Rotary Pump
Piston
Plunger
Diaphragm
Gear
Screw
Lobe
Vane
Spur-GP
Internal-GP

Centrifugal Pumps:

centrifugal pumps have a rotating impeller, also known as a blade, that is immersed in the liquid. Liquid enters the pump near the axis of the impeller, and the rotating impeller sweeps the liquid out toward the ends of the impeller blades at high pressure.

For low flows and high pressures, the action of the impeller is largely radial.

Positive-displacement Pumps:

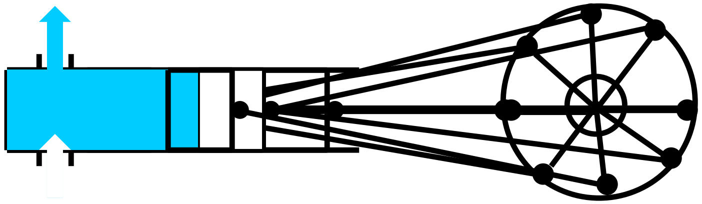
A variety of positive-displacement pumps are also available, generally consisting of a rotating member with a number of lobes that move in a close-fitting casing. The liquid is trapped in the spaces between the lobes and then discharged into a region of higher pressure. A common device of this type is the gear pump, which consists of a pair of meshing gears. The lobes in this case are the gear teeth

What is the main difference between kinetic and positive displacement pumps ?

The main difference between kinetic and positive displacement pumps lies in the method of fluid transfer.

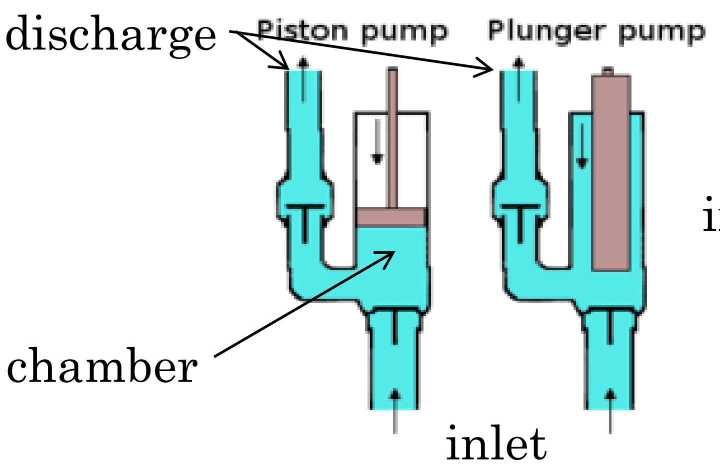
- **A kinetic pump imparts velocity energy to the fluid, which is converted to pressure energy upon exiting the pump casing**

- **A positive displacement pump moves a fixed volume of fluid within the pump casing by applying a force to moveable boundaries containing the fluid volume.**

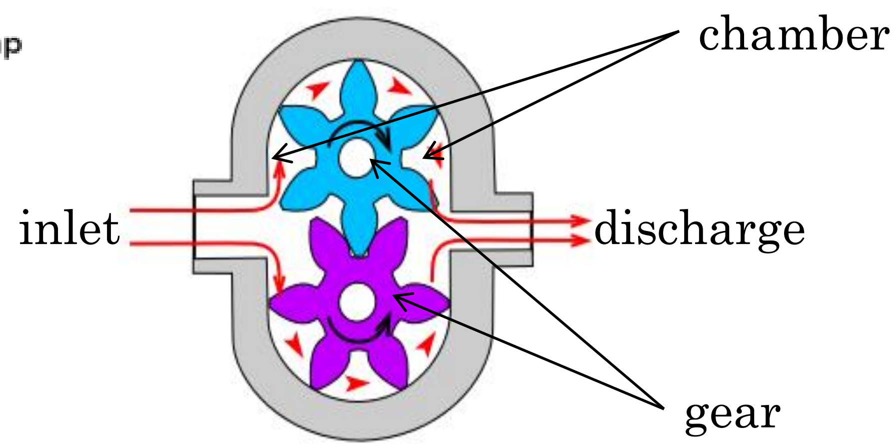


Positive-Displacement Pumps

- 2 subclasses: reciprocating pumps & rotary pumps.
- Reciprocating pumps: the chamber is stationary cylinder that contains a piston or plunger.
- Rotary pumps: the chambers moves from inlet to discharge and back to the inlet.



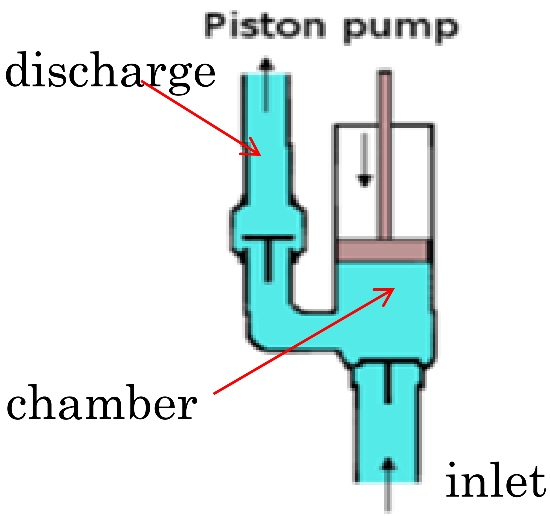
Reciprocating pumps

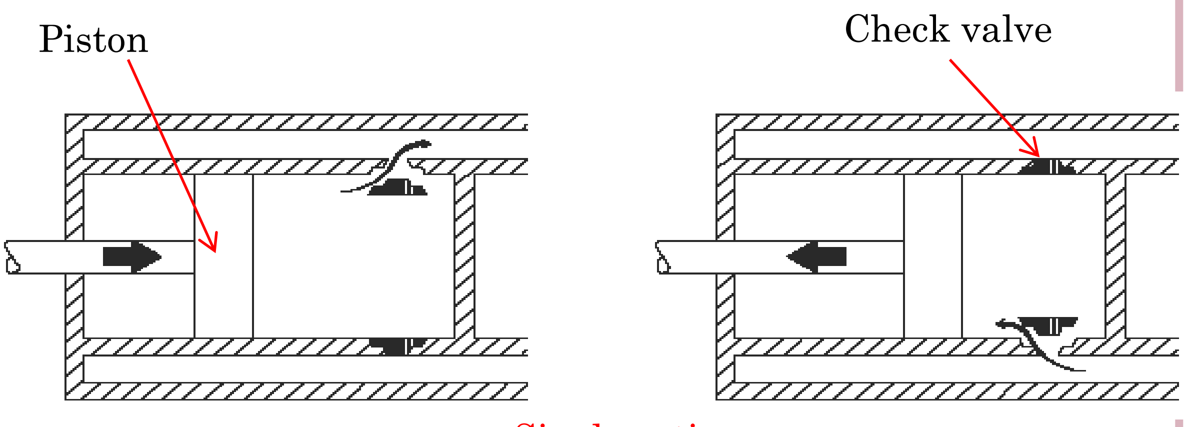


Rotary pump

Positive-Displacement Pumps:
Reciprocating Pumps

- Piston pump:
  - liquid is drawn through an inlet check valve into the cylinder by the withdrawal of a piston.
  - then the liquid is forced out through a discharge on the return stroke.



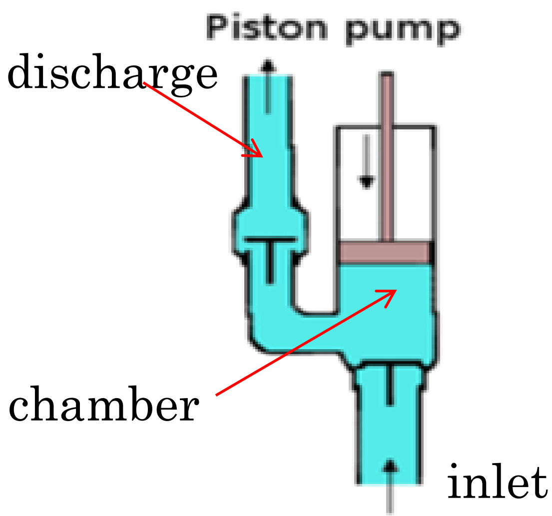


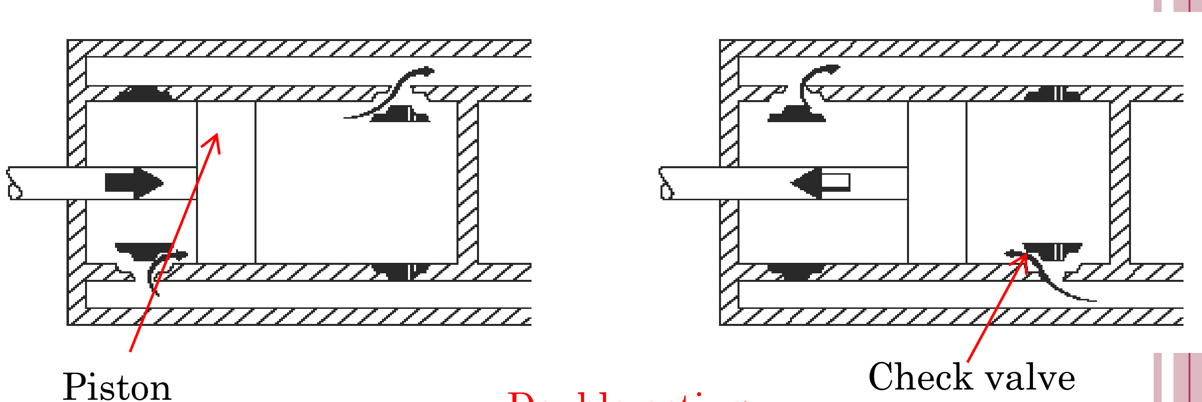
Single-acting

Piston pump:

Positive-Displacement Pumps: Reciprocating Pumps

- most piston pumps are double-acting with liquid admitted alternately on each side of the piston so that one part of the cylinder is being filled while the other is being emptied.
- the piston may be motor-driven through reducing gear or a steam cylinder may be used to drive the piston rod directly.
- max. discharge pressure for commercial piston pumps is about 50 atm.

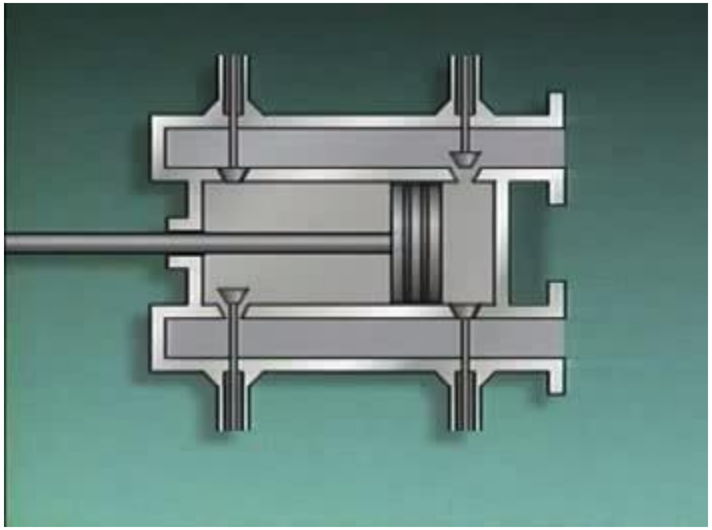




Double-acting

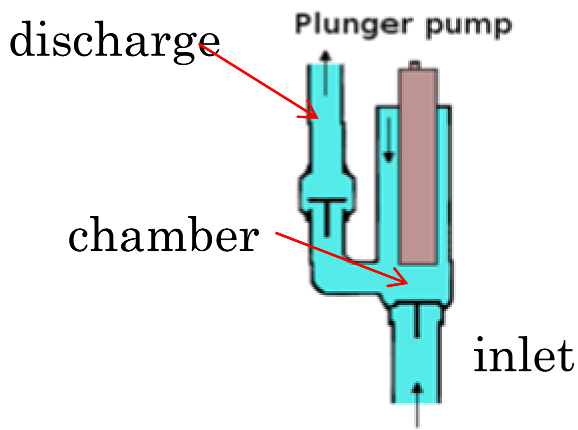
Positive-Displacement Pumps:
Reciprocating Pumps

Double Acting Piston Pump:



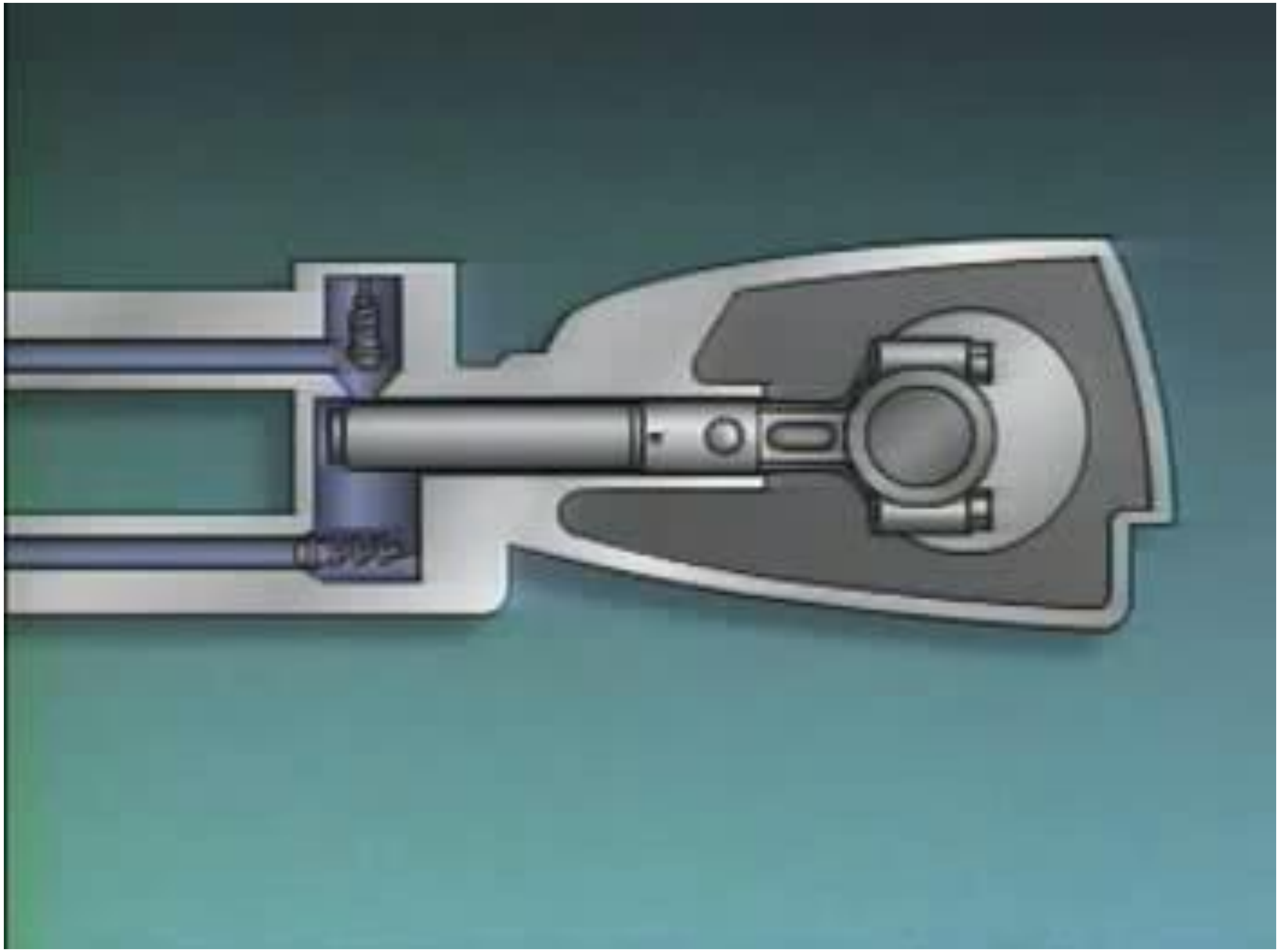
Positive-Displacement Pumps: Reciprocating Pumps

- Plunger pump:
  - are used for higher pressures.
  - instead of using pistons and piston rings, they make use of finely machined plungers of very small clearances in order to seal the liquid to be pumped.
  - the plungers are highly polished and made relatively long so that only very little liquid can escape through the clearances.
  - at the limit of its stroke, the plunger fills nearly all the space in the cylinder.
  - are single-acting and usually are motor driven.
  - they can discharge against a pressure of 1500 atm or more.



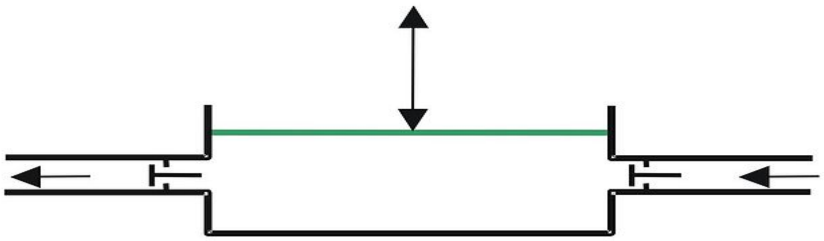
Positive-Displacement Pumps:
Reciprocating Pumps

Plunger pump:



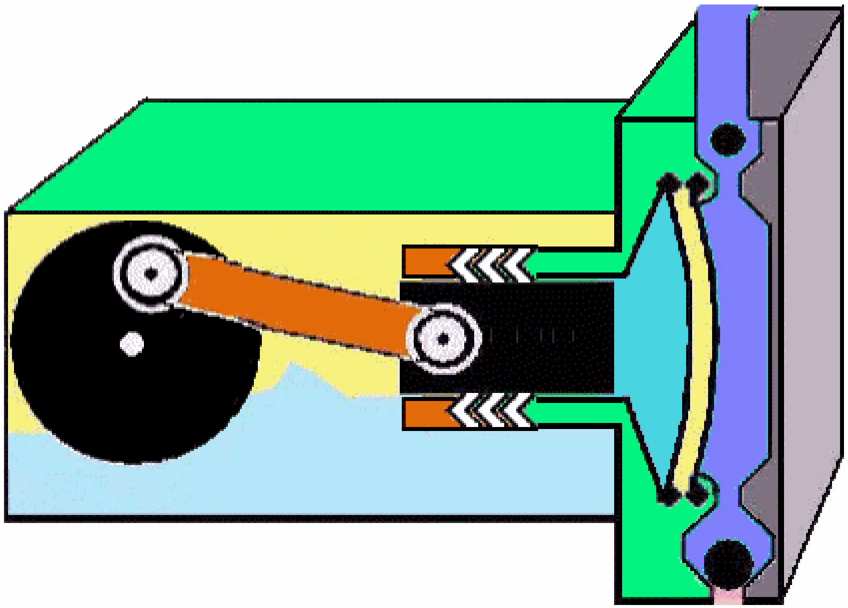
Positive-Displacement Pumps: Reciprocating Pumps

- Diaphragm pump:
  - the reciprocating member is a flexible diaphragm of metal, plastic & rubber.
  - diaphragm pumps handle small to moderate amounts of liquid, up to about 100 gal/min, can develop pressures in excess of 100 atm.



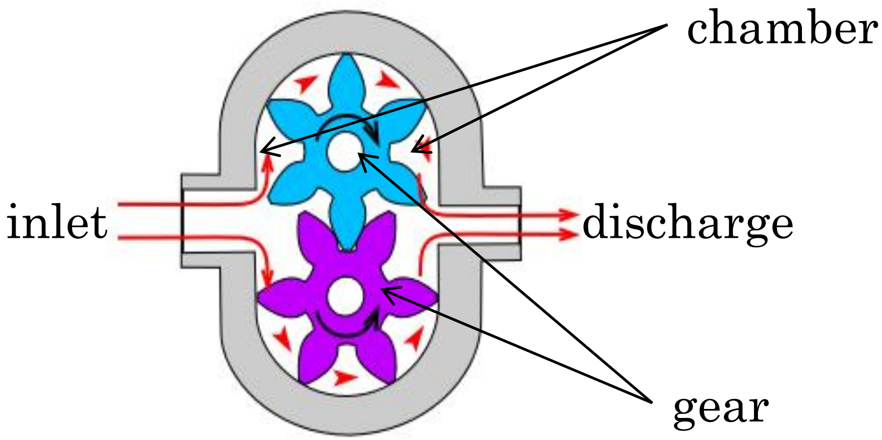
Positive-Displacement Pumps: Reciprocating Pumps

Diaphragm pump:

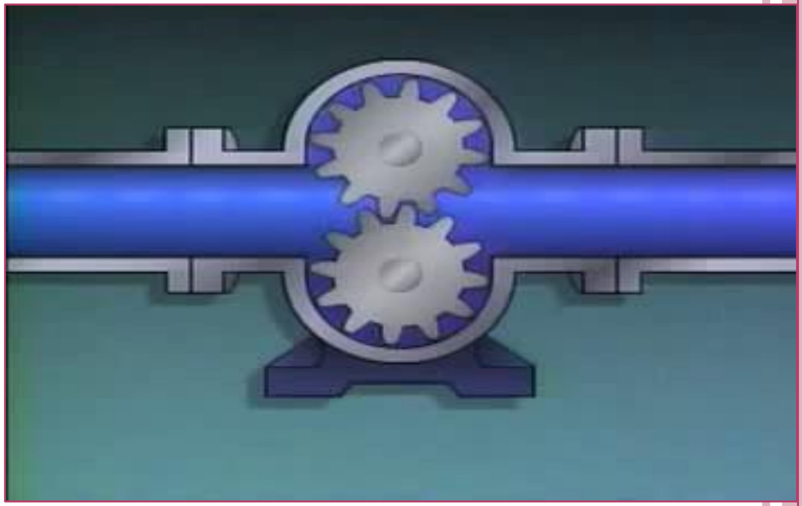


Positive-Displacement Pumps:
Rotary Pumps

- Unlike reciprocating pumps, rotary pumps **contain no check valves**.
- Minimize leakage from the discharge space back to the suction space; they also limit the operating speed.
- Rotary pumps operate best on clean, **moderately viscous fluids** such as light lubricating oil.
- Discharge pressures up to 200 atm or more can be attained.

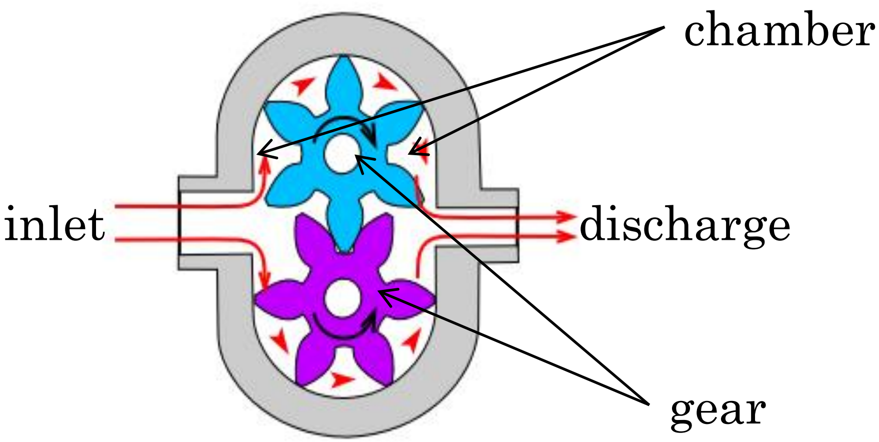


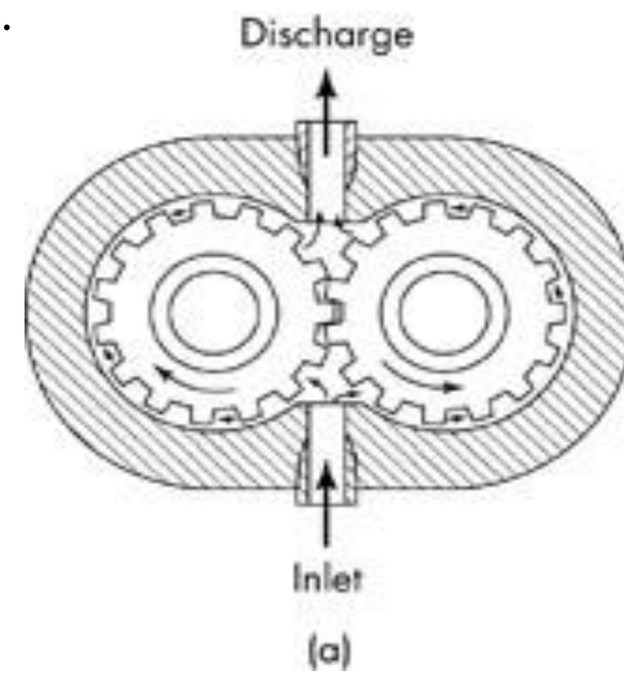
Rotary pump



Positive-Displacement Pumps:
Rotary Pumps

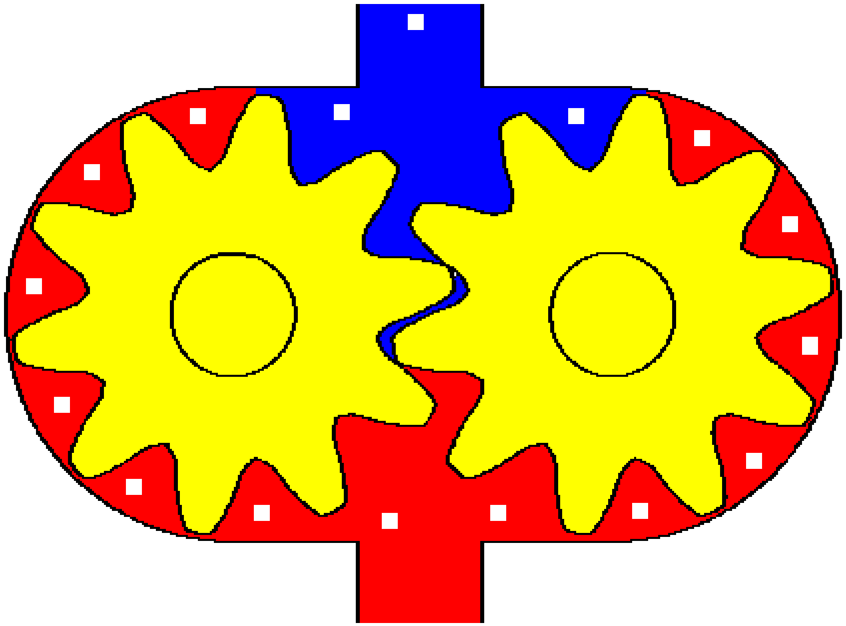
- <u>Spur-gear pump</u>
- **Intermeshing gears** rotate with close clearance inside the casing.
- Liquid entering the suction line at the bottom of the casing is caught in the spaces between the teeth & the casing & is carried around to the top of the casing & forced out the discharge.
- liquid cannot short-circuit back to the suction because of the close meshing of the gears in the center of the pump.





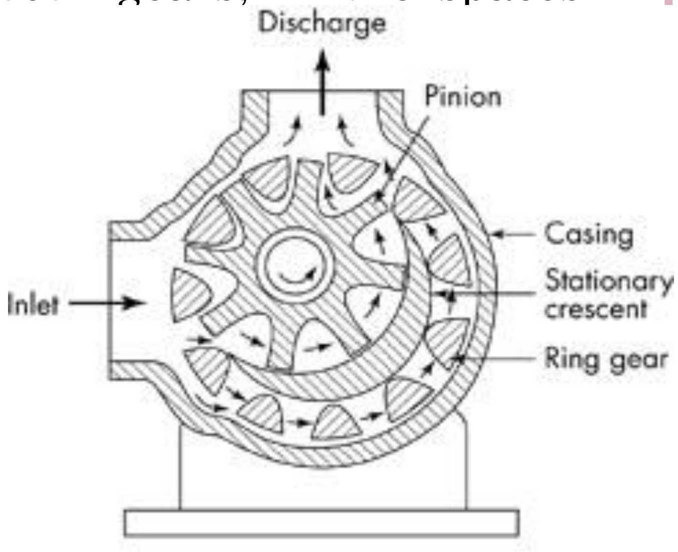
Spur-gear pump

- Spur-gear pump



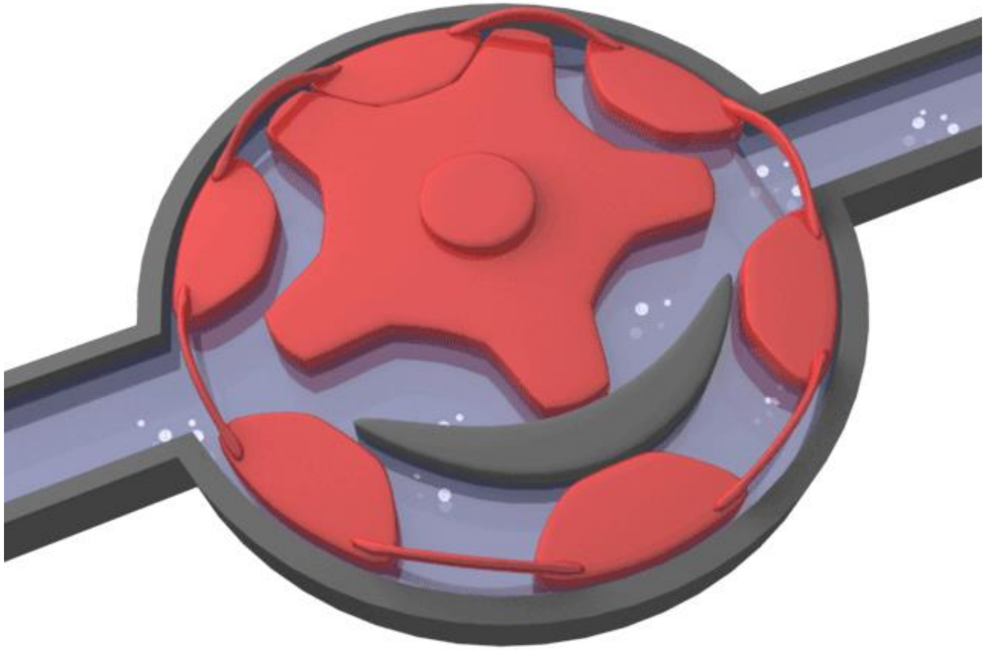
Positive-Displacement Pumps: Rotary Pumps

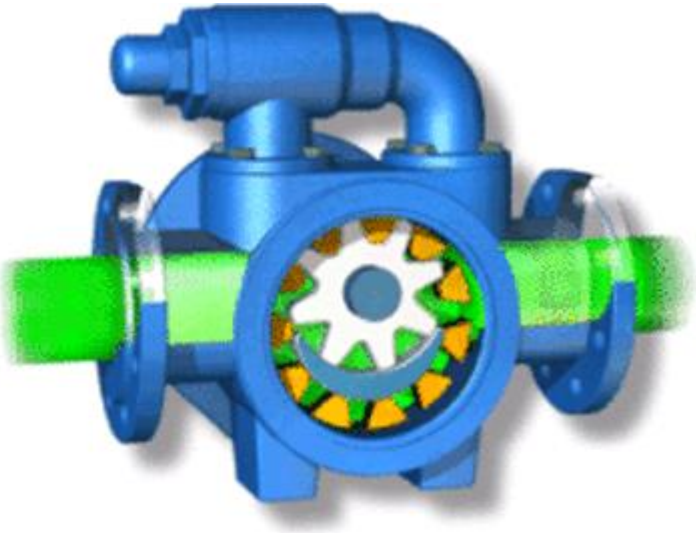
- Internal-gear pump
  - A **spur gear or pinion** meshes with a ring gear with internal teeth.
  - Both gears are inside the casing.
  - The **ring gear** is coaxial with the inside of the casing, but the pinion, which is externally driven, is mounted eccentrically with respect to the center of the casing.
  - A **stationary metal crescent** fills the space **between the two gears**.
  - Liquid is carried from inlet to discharge by both gears, in the spaces between the gear teeth and the crescent.



Internal-gear pump

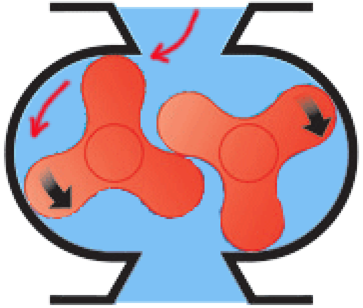
- Internal-gear pump

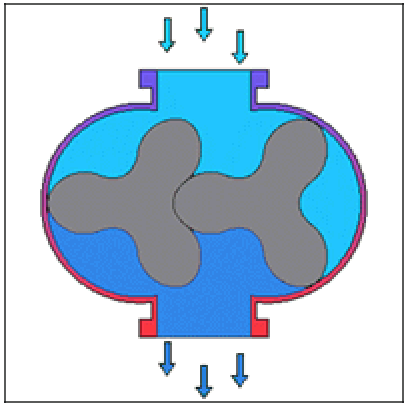


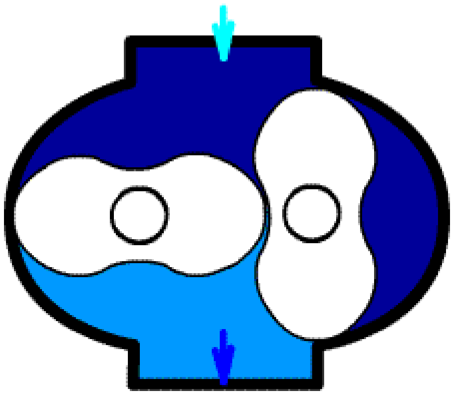


Positive-Displacement Pumps:
Rotary Pumps

Lobe pump

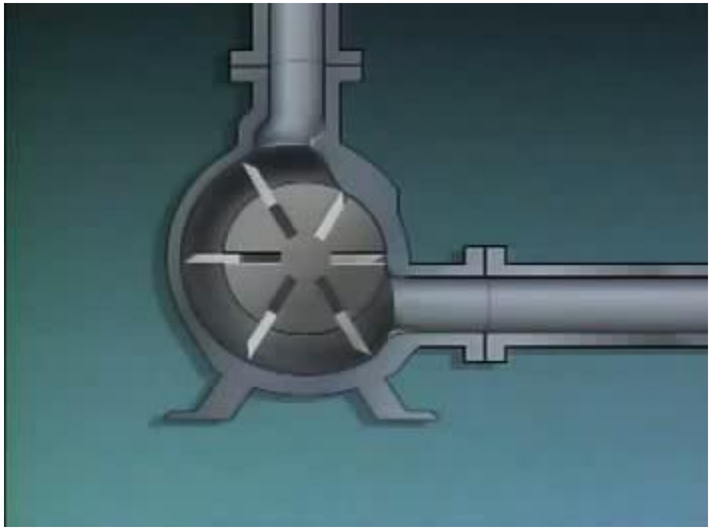


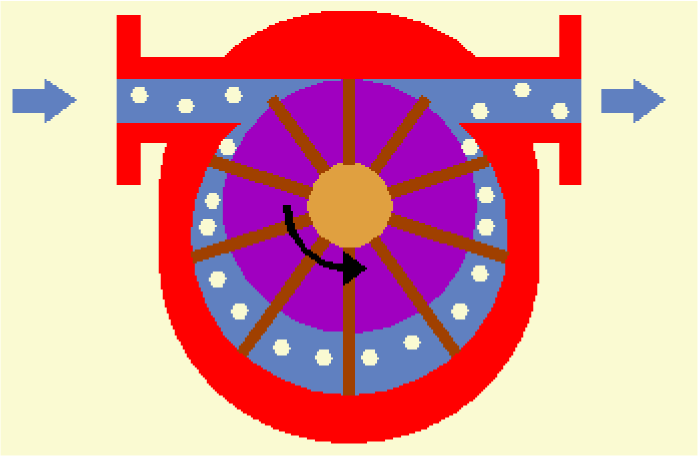




Positive-Displacement Pumps:
Rotary Pumps

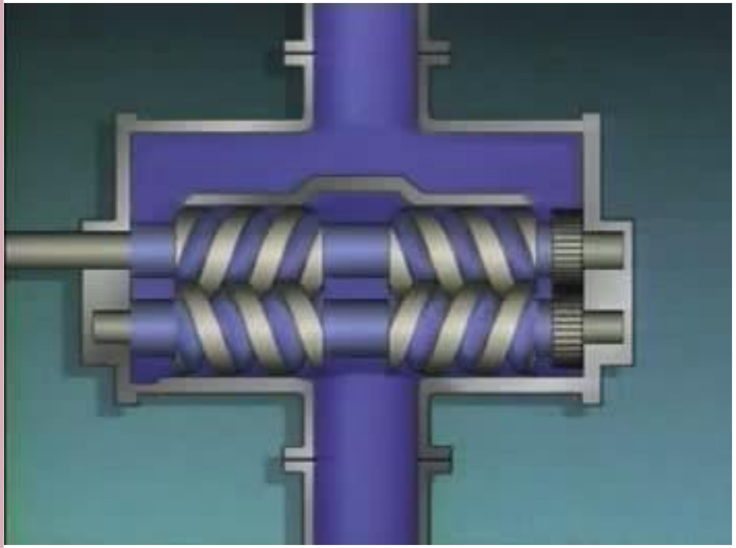
Vane pump

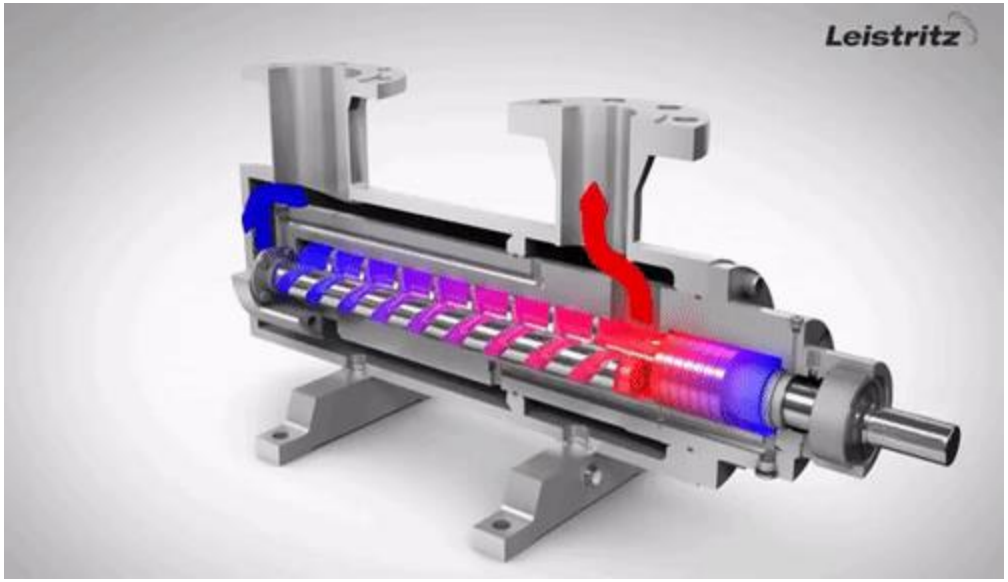




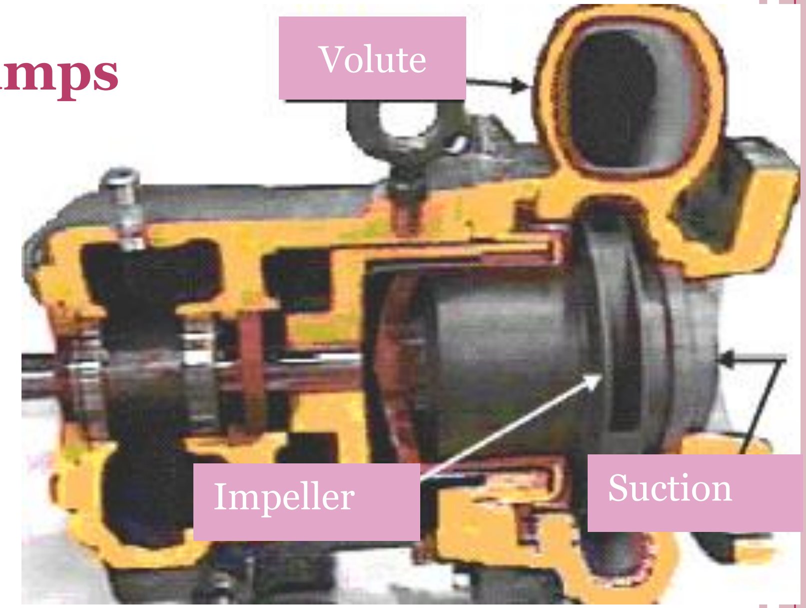
Positive-Displacement Pumps:
Rotary Pumps

Screw pump





Construction of Centrifugal Pumps



1- Casing:-

Casing generally are two types:

I. Volute casings for a higher head.

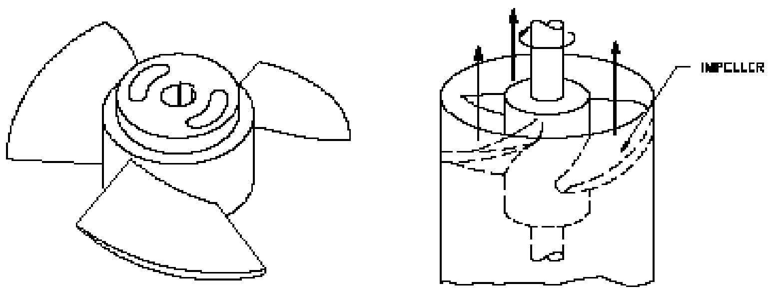
A *volute* is a curved funnel increasing in area to the discharge port.

II. Circular casings for low head and high capacity.

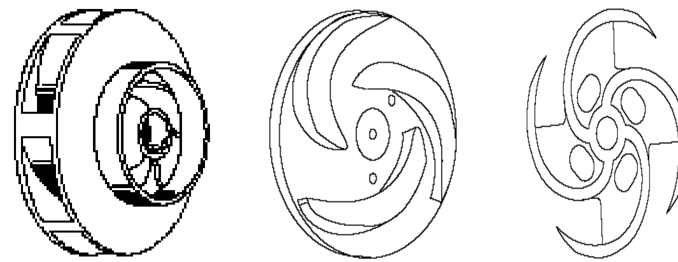
have stationary diffusion vanes surrounding the impeller periphery that convert velocity energy to pressure energy.

2-Impeller

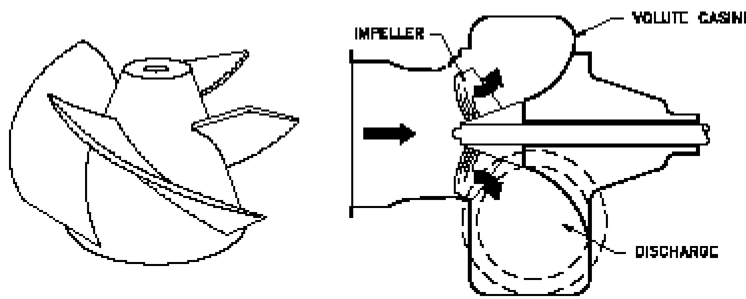
Three main categories of centrifugal pumps exist



Axial flow



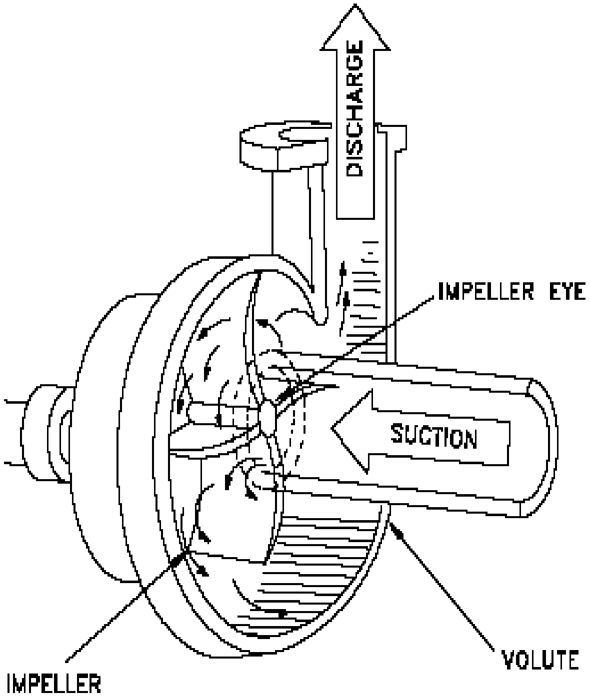
Radial flow



Mixed flow

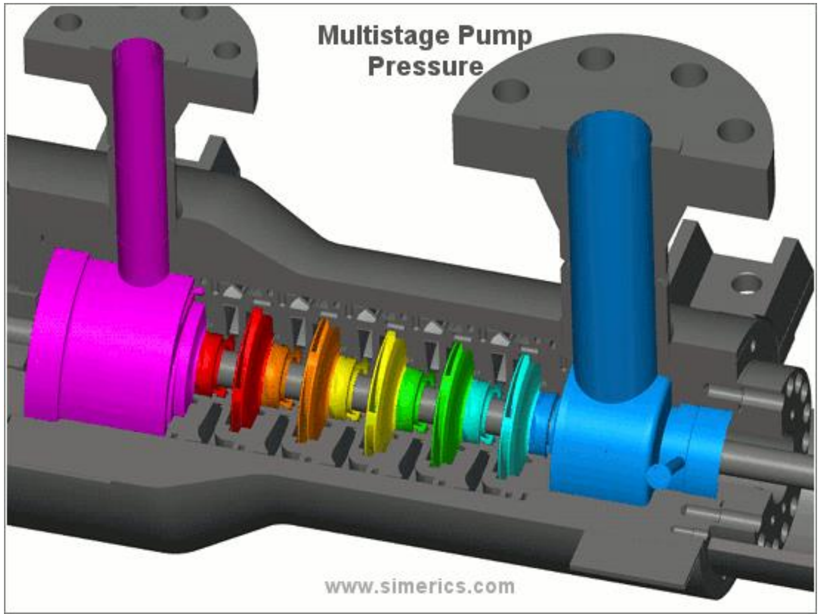
CENTRIFUGAL PUMPS

- The second major class of pumps, where mechanical energy of the liquid is increased **by centrifugal action**.
- The liquid enters through a suction connection concentric with the axis of a high-speed rotary element called the **impeller** which carries radial vanes integrally cast in it.
- Liquid flows outward in the spaces between the vanes and leaves the impeller in greater velocity with respect to the ground than at the entrance to the impeller.
  - In a properly functioning pump, the space between the vanes is completely filled with liquid flowing without cavitation.
  - The liquid leaving the outer periphery of the impeller is collected in a **spiral casing** called the **volute** and leaves the pump through a tangential discharge connection.
  - In the volute, the velocity head of the liquid from the impeller is converted to pressure head.

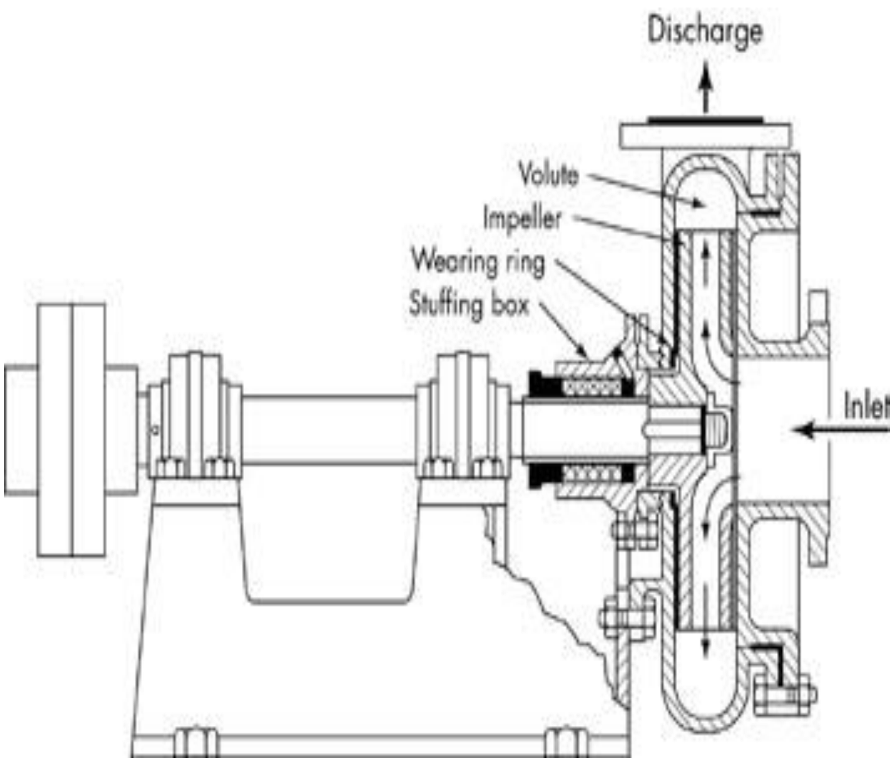


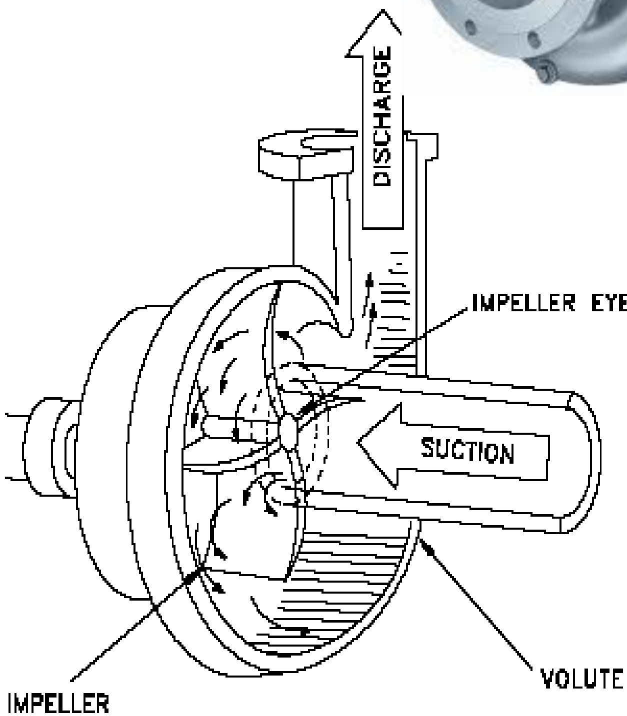
Centrifugal pumps

- The power is applied to the fluid by the impeller and is transmitted to the impeller by the torque of the driveshaft, which usually is driven by direct-connected motor at constant speed, commonly at 1750 or 3450 r/min.
- Centrifugal pumps constitute the most common type of pumping machinery in ordinary plant practice.
- A common type uses a double-suction impeller, which accepts liquid from both sides.



Centrifugal pumps

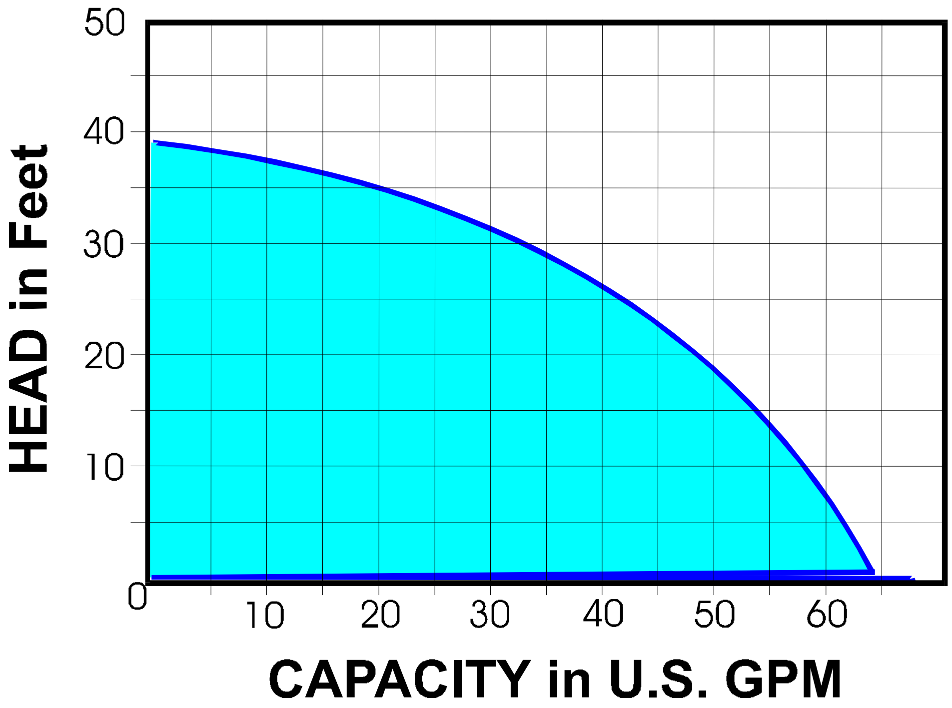




Single-suction centrifugal pump

Pump Performance Curve

- **A mapping or graphing of the pump's ability to produce head and flow**



Pump Performance Curve
Step #1, Horizontal Axis

- The pump's flow rate is plotted on the horizontal axis (X axis)
- Usually expressed in Gallons per Minute

Pump Flow Rate

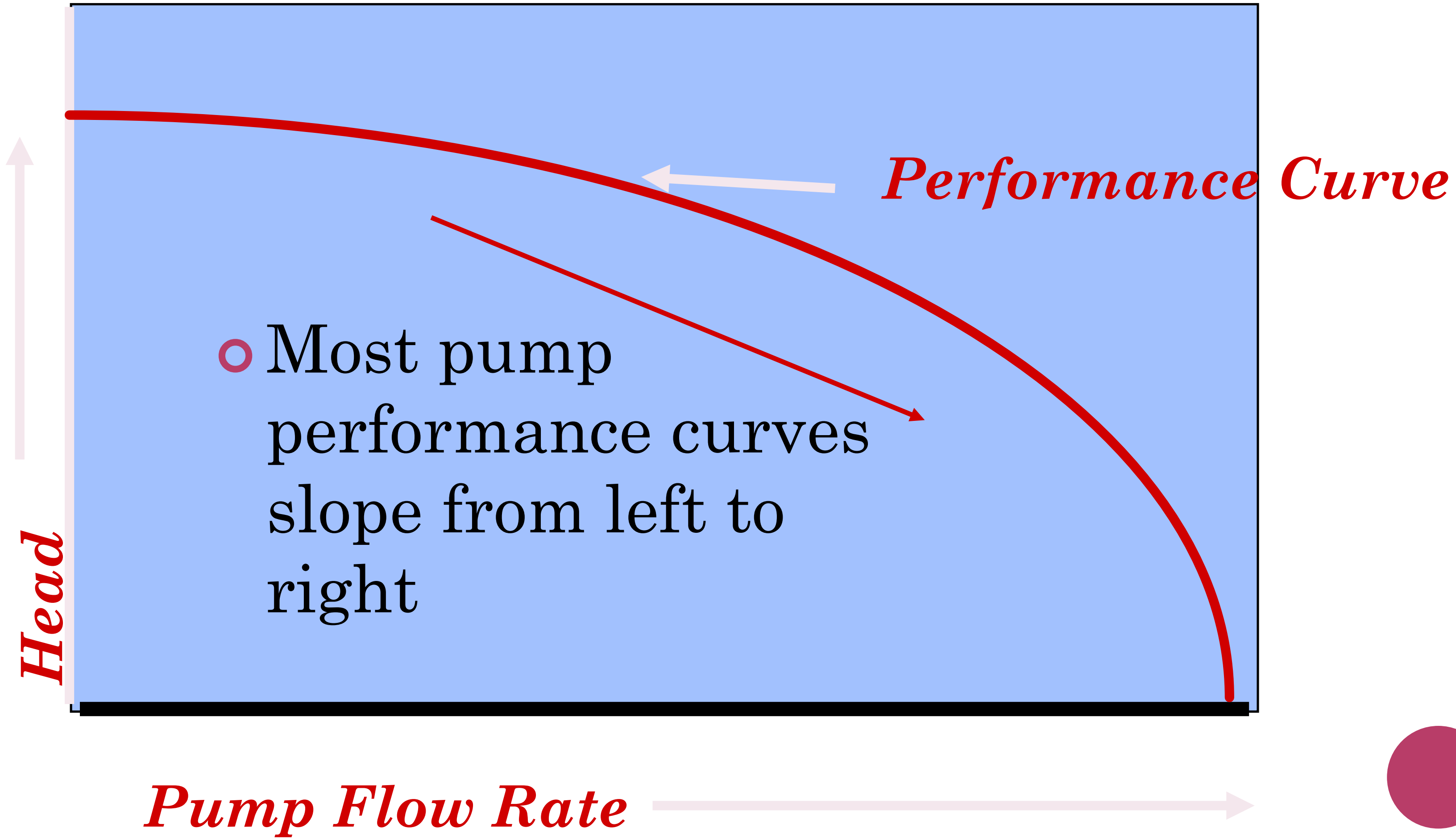
Pump Performance Curve
Step #2, Vertical Axis

- The head the pump produces is plotted on the vertical axis (Y axis)
- Usually express in Feet of Water

Head

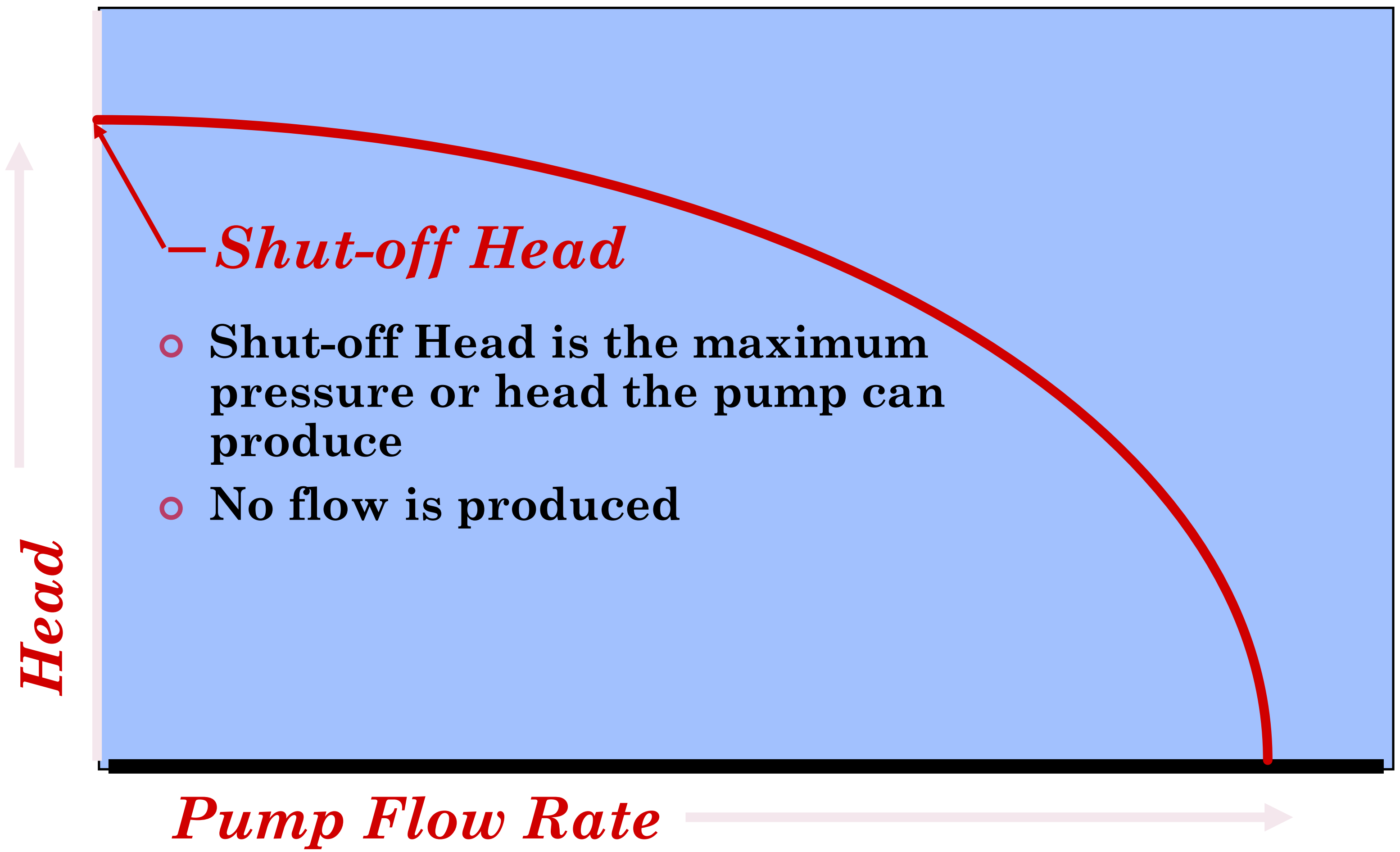
Pump Flow Rate

Pump Performance Curve
Step #3, Mapping the Flow and the Head



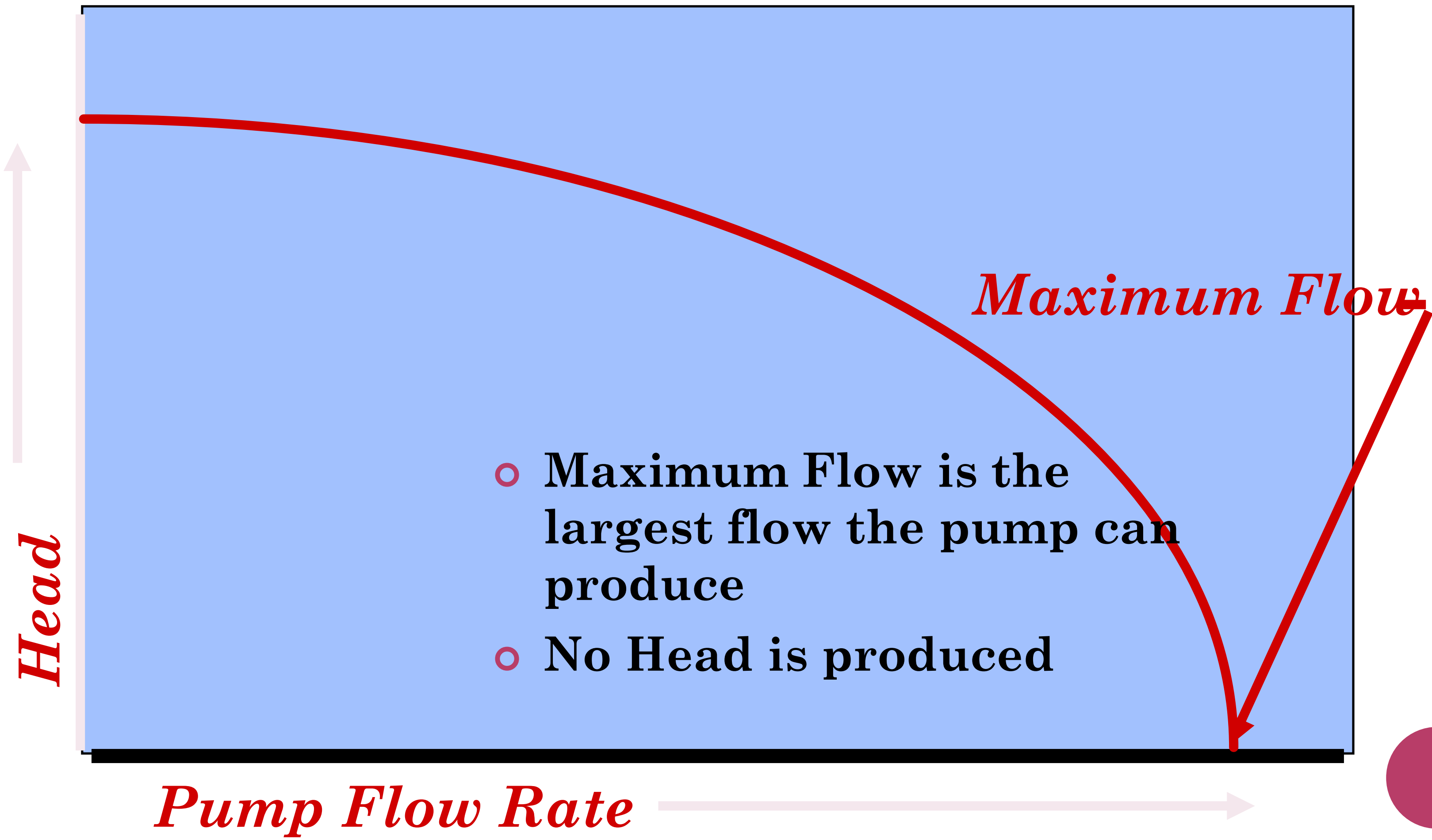
- Most pump performance curves slope from left to right

Pump Performance Curve Important Points



- Shut-off Head is the maximum pressure or head the pump can produce
- No flow is produced

Pump Performance Curve Important Points



- Maximum Flow is the largest flow the pump can produce
- No Head is produced

System Performance Curves

- System Performance Curve is a mapping of the head required to produce flow in a given system
- A system includes all the pipe, fittings and devices the fluid must flow through, and represents the friction loss the fluid experiences

System Performance Curve
Step #1, Horizontal Axis

- The System's flow rate in plotted on the horizontal axis (X axis)
- Usually expressed in Gallons per Minute

System Flow Rate

System Performance Curve Step #2, Vertical Axis

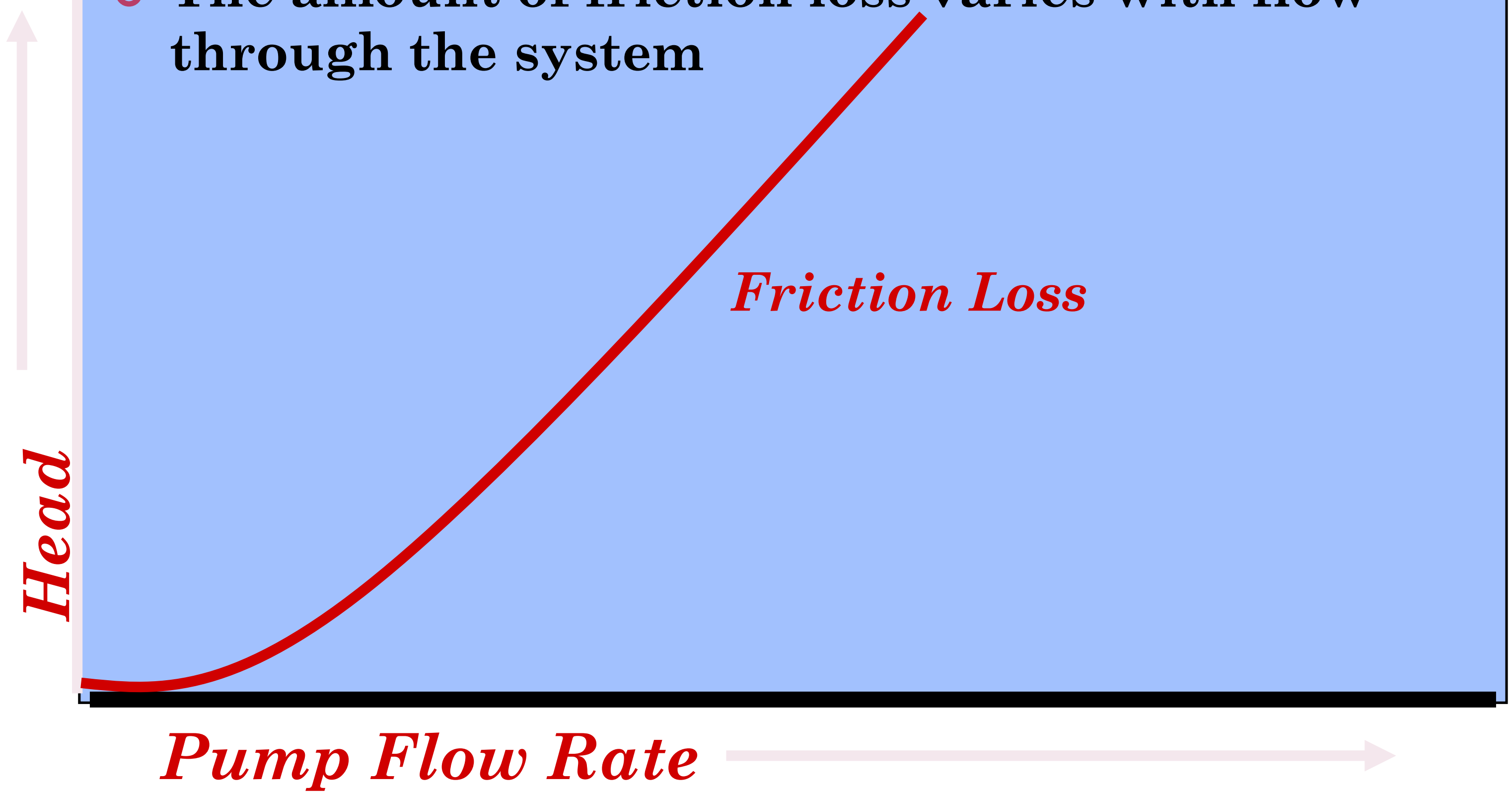
- **The head the system requires is plotted on the vertical axis (Y axis)**
- **Usually express in Feet of Water**

Head

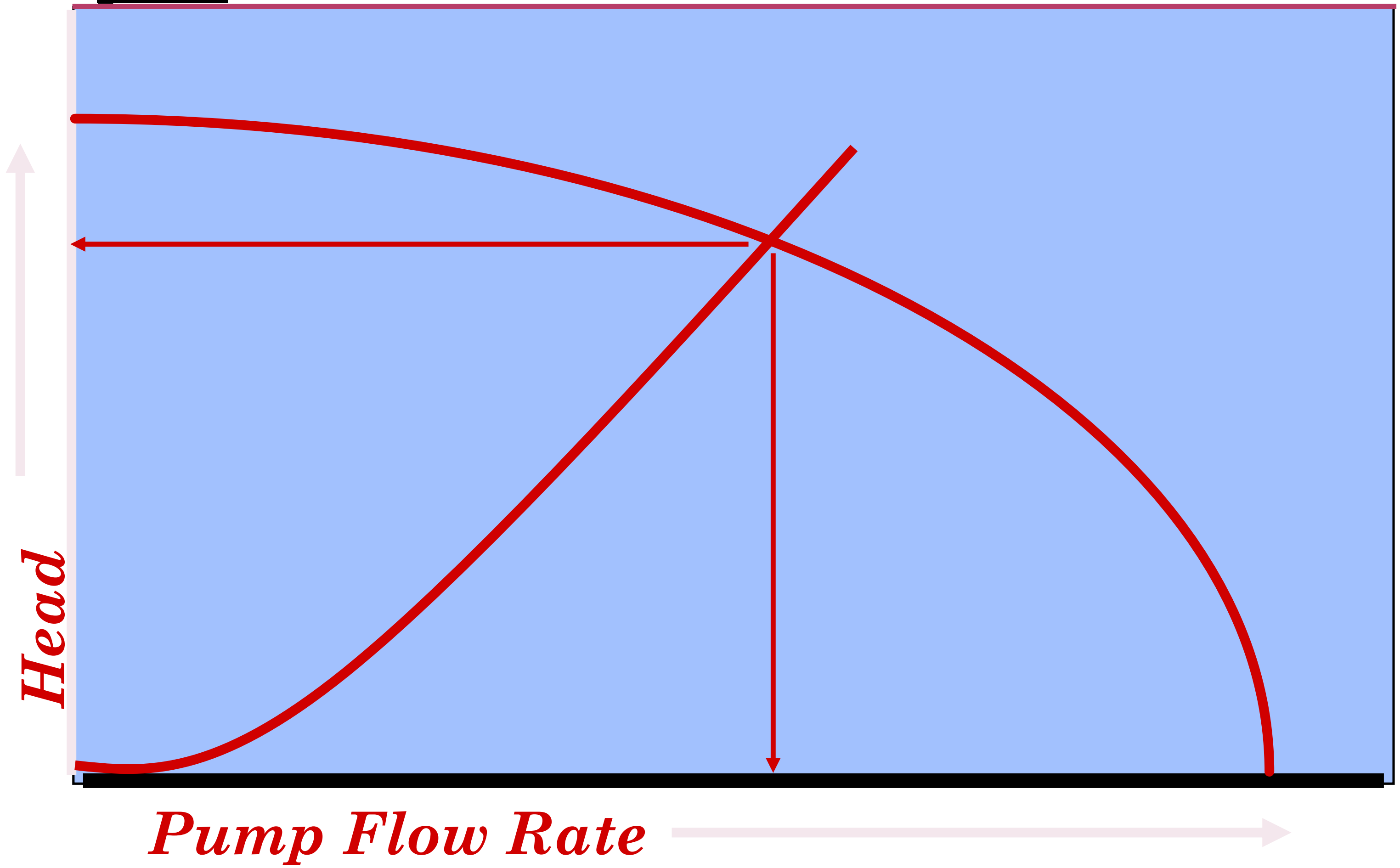
Pump Flow Rate

System Performance Curve
Step #3, Curve Mapping

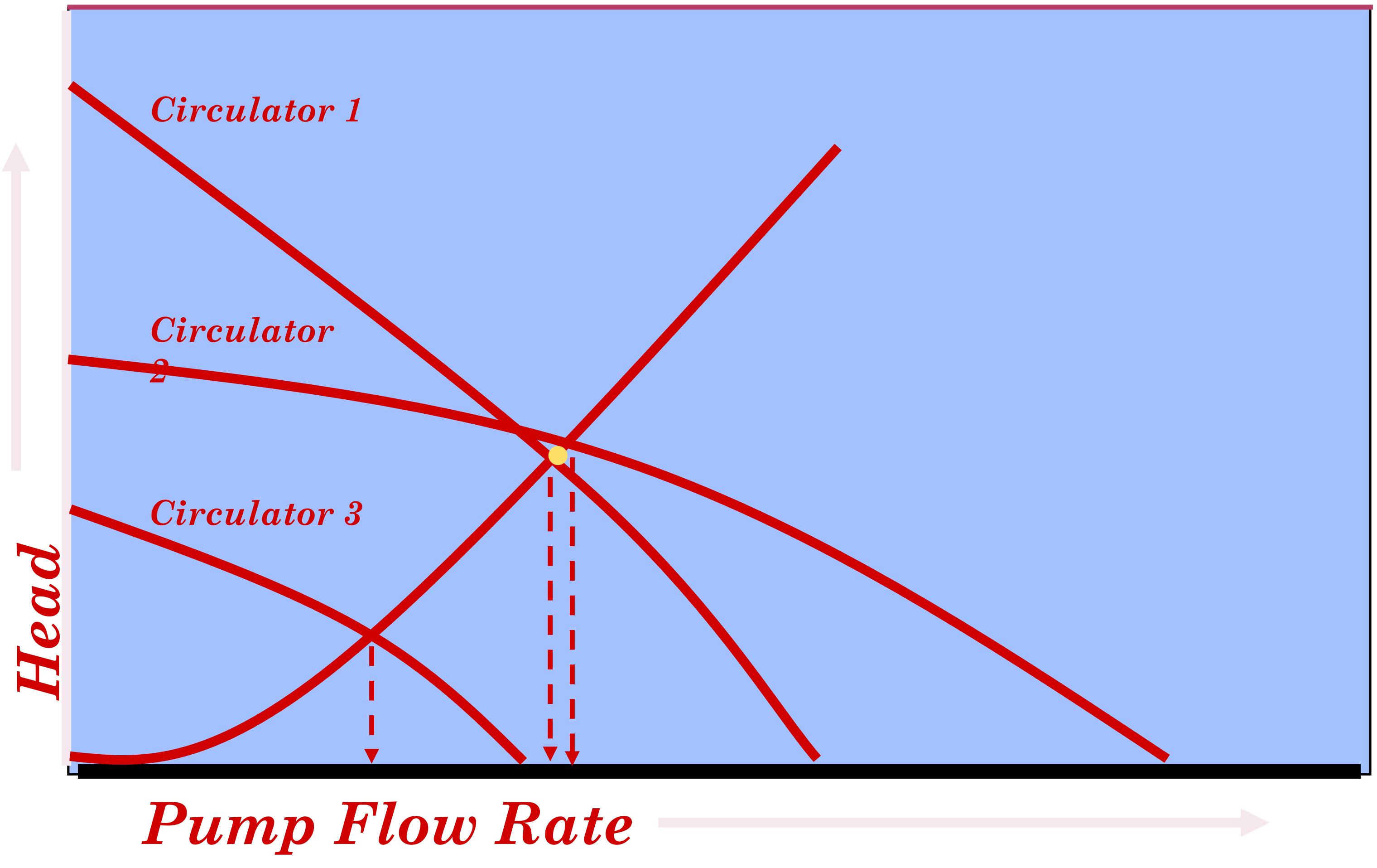
- The friction loss is mapped onto the graph
- The amount of friction loss varies with flow through the system



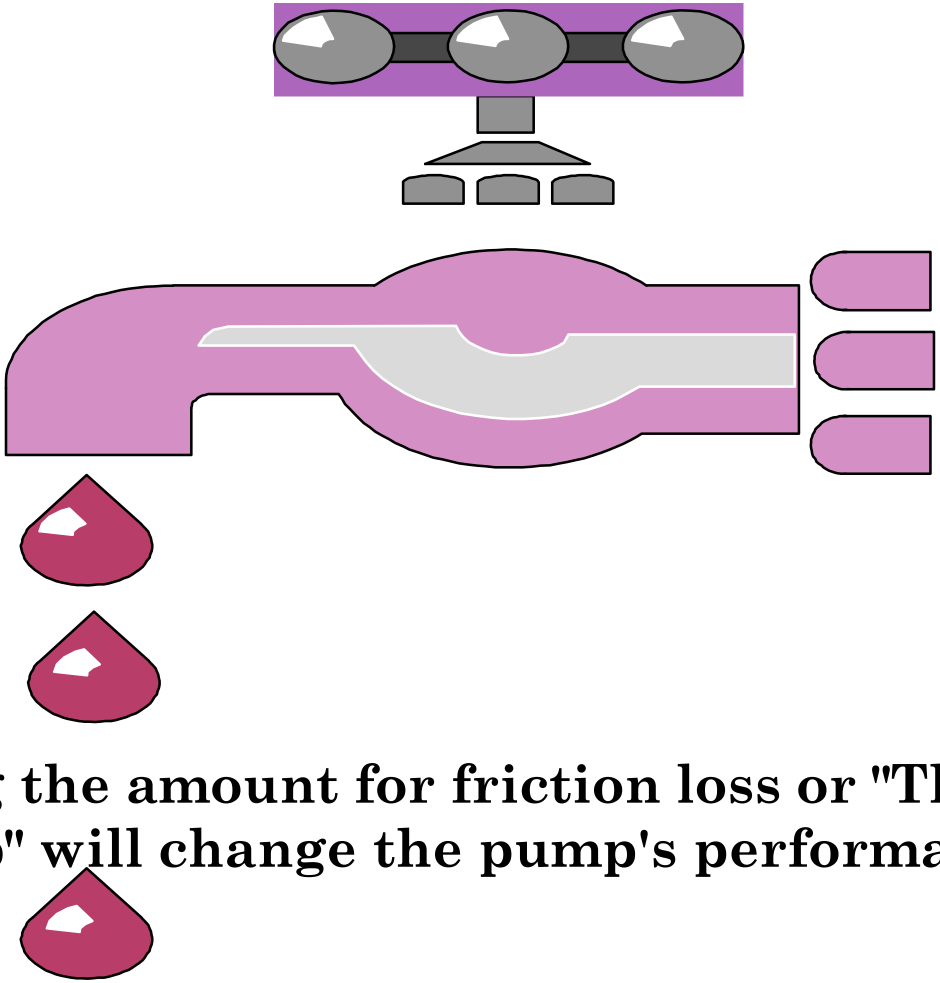
The point on the system curve that intersects the pump curve is known as the <u>operating point</u>.



PUMP SELECTION

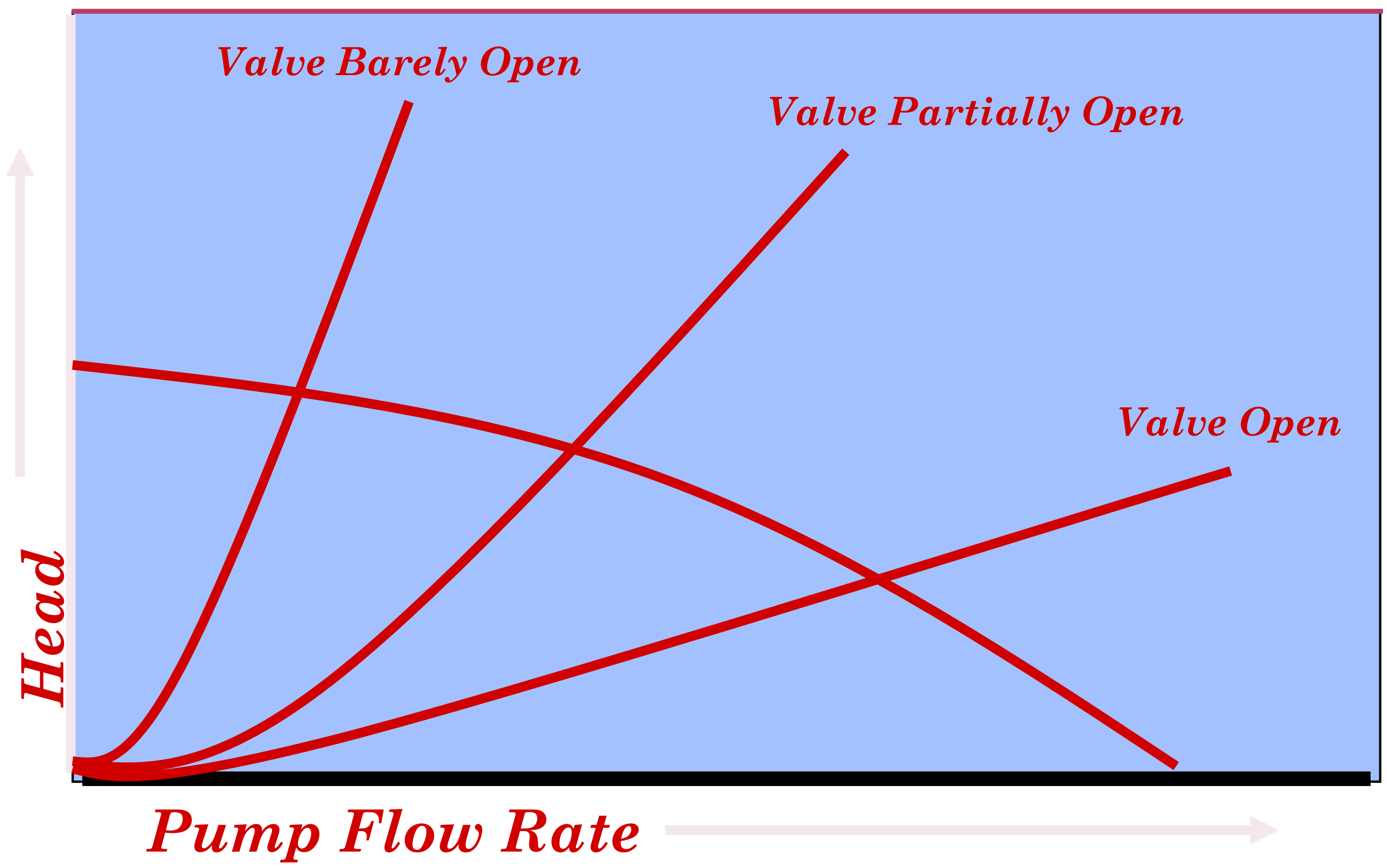


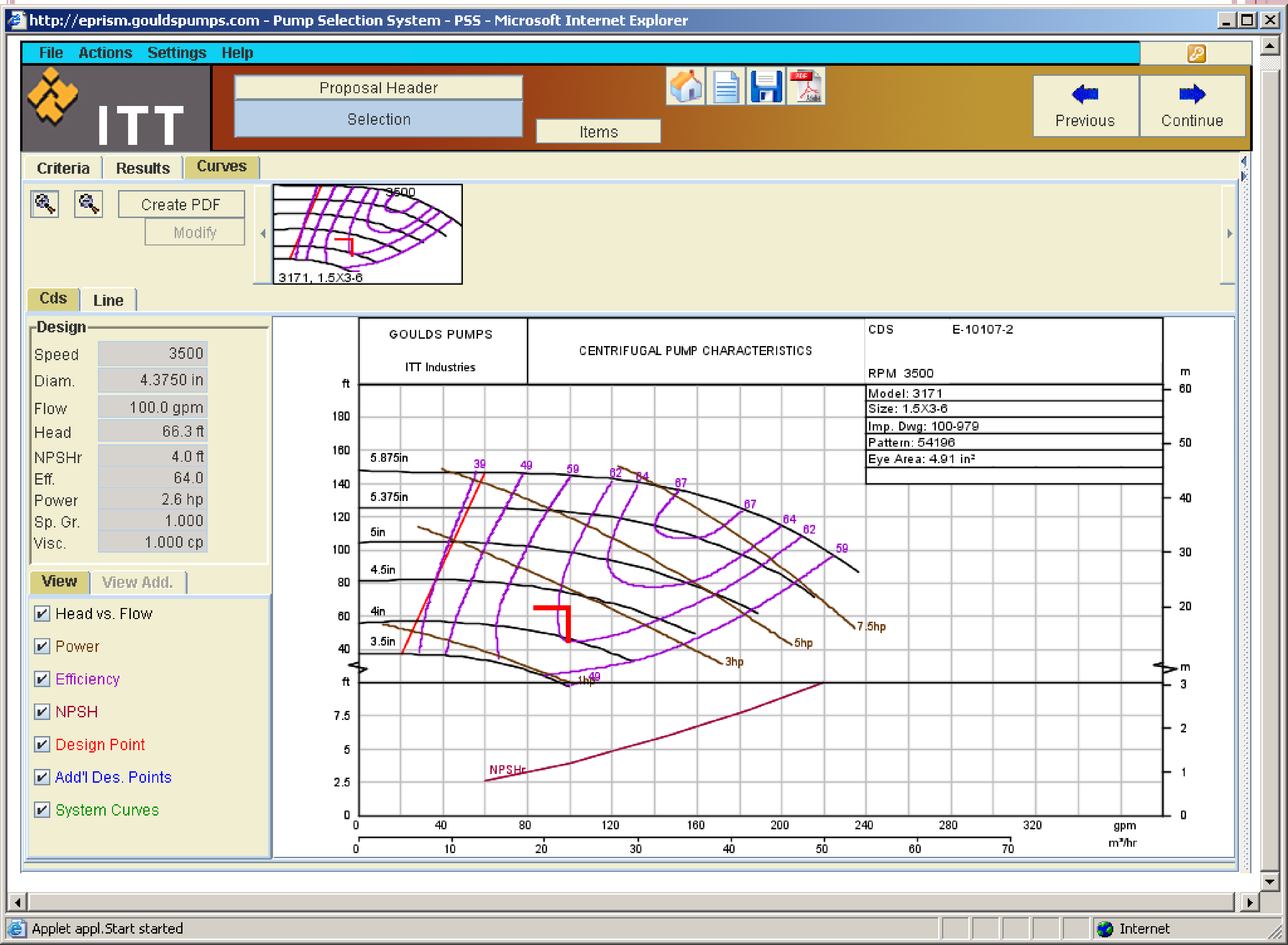
Controlling Pump Performance



- **Changing the amount for friction loss or "Throttling the Pump" will change the pump's performance**

PUMP SELECTION

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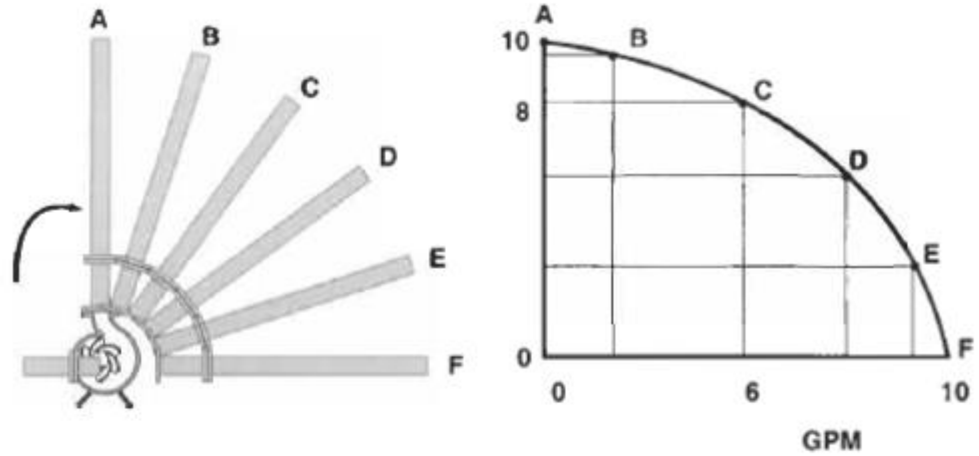
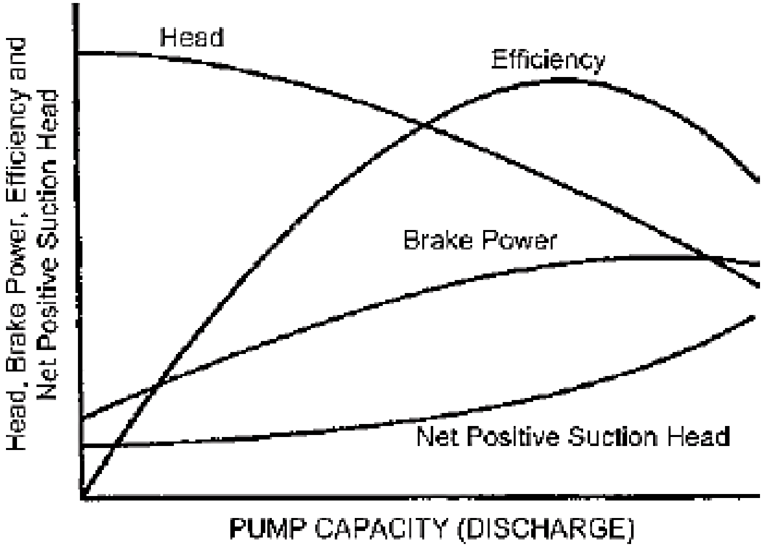
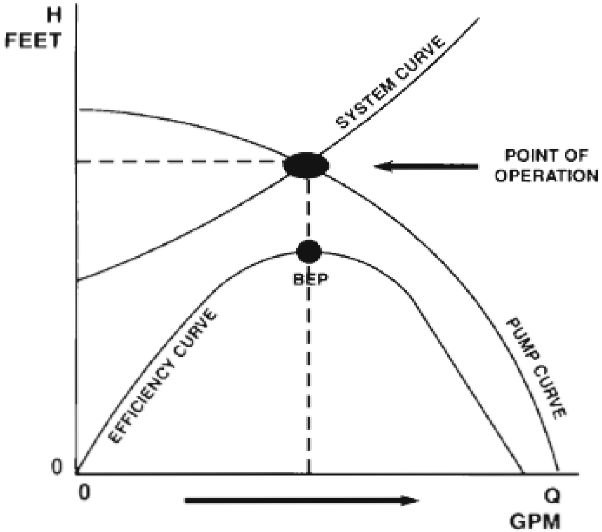
File Actions Settings Help
ITT
Proposal Header
Selection
Items
Previous
Continue
Criteria
Results
Curves
Create PDF
Modify
3500
3171, 1.5X3-6
Cds
Line
Design
Speed 3500
Diam. 4.3750 in
Flow 100.0 gpm
Head 66.3 ft
NPSHr 4.0 ft
Eff. 64.0
Power 2.6 hp
Sp. Gr. 1.000
Visc. 1.000 cp
View
View Add.
Head vs. Flow
Power
Efficiency
NPSH
Design Point
Add'l Des. Points
System Curves
GOULDS PUMPS
ITT Industries
CENTRIFUGAL PUMP CHARACTERISTICS
CDS E-10107-2
RPM 3500
Model: 3171
Size: 1.5X3-6
Imp. Dwg: 100-979
Pattern: 54196
Eye Area: 4.91 in²
5.875in
5.375in
5in
4.5in
4in
3.5in
7.5hp
5hp
3hp
1hp
NPSHr
ft
m
gpm
m³/hr
Applet appl.Start started
Internet

H-Q Carve

Once again, imagine starting a pump and raising the fluid in a vertical tube to the point of maximum elevation. On the curve this would be maximum head at zero flow. Now, rotate the running pump on its centerline *90°*, until the vertical tube is now in a horizontal position.

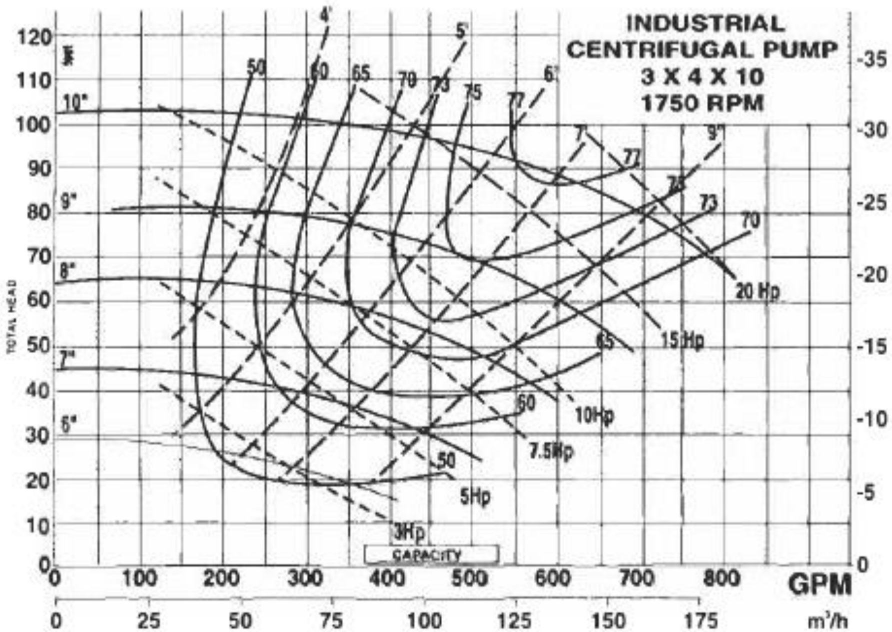


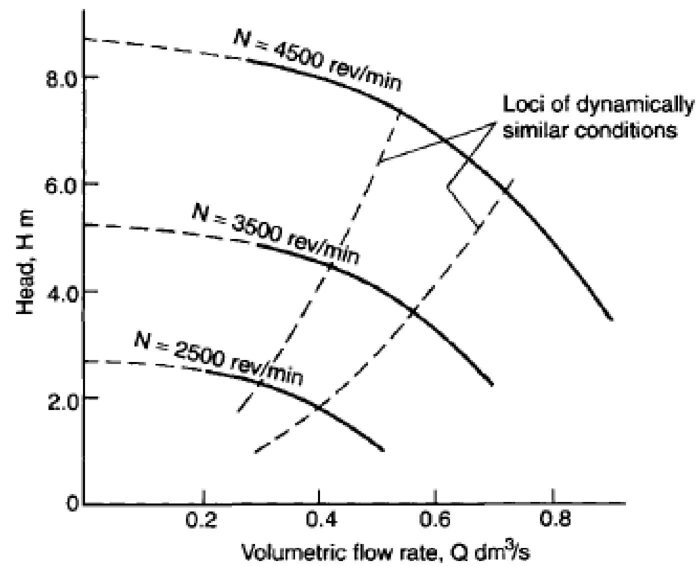




Family curves

At times you'll find that the information is the same, but the presentation of the curves is different. Almost all pump companies publish what are called the 'family of curves'. The pump family curves are probably the most useful for the maintenance engineer and mechanic, the design engineer and purchasing agent. The family curves present the entire performance picture of a pump.





Heads of Pump:

where :

V_s = Velocity of fluid in the suction pipe.

V_d = Velocity of fluid in the delivery pipe.

h_s = Suction head.

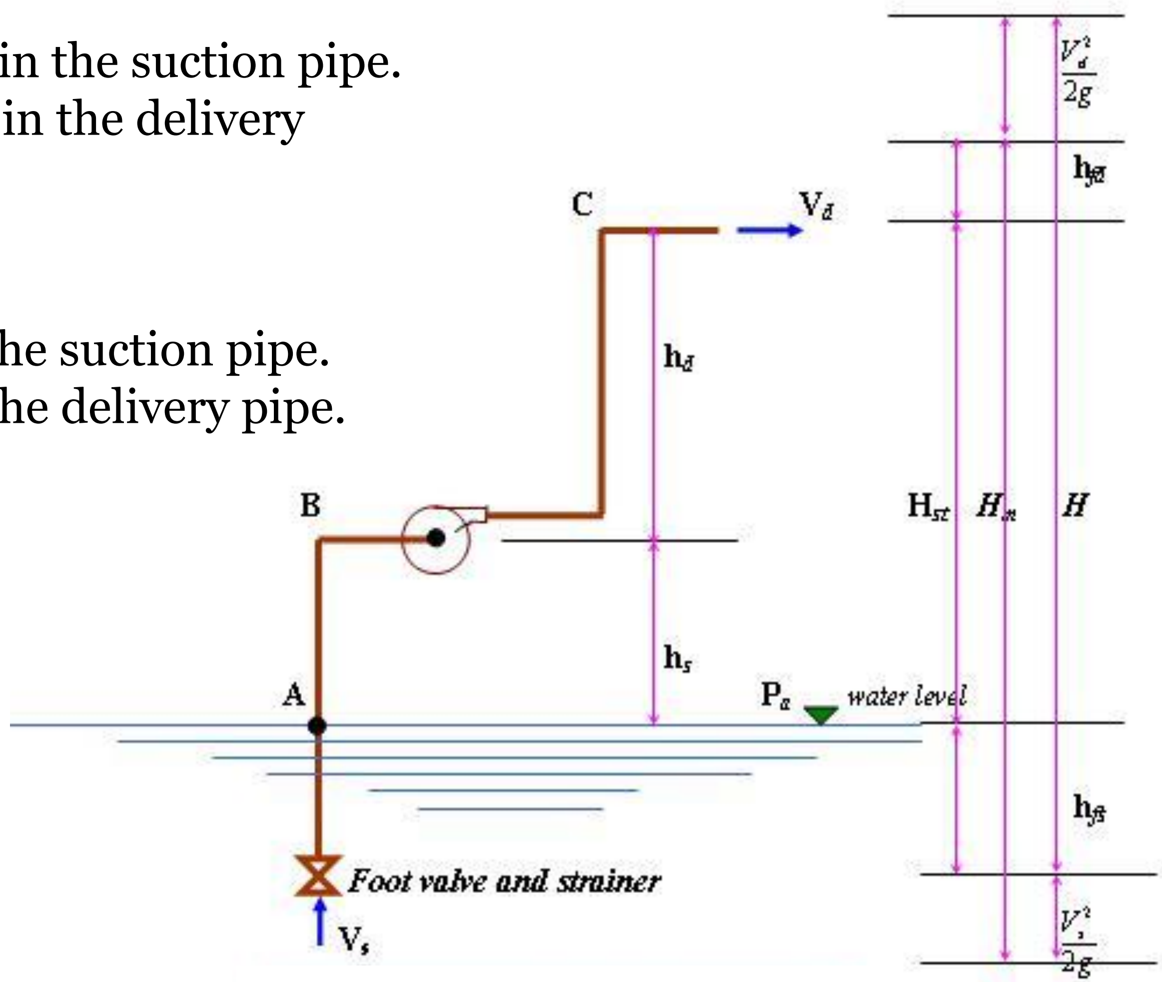
h_d = Delivery head.

h_{fs} = head losses in the suction pipe.

h_{fd} = head losses in the delivery pipe.

Static head (H_{st})

$$H_{st} = h_s + h_d$$



Manometric head (H_m) :

$$H_m = \frac{p_d - p_s}{\gamma} + (z_d - z_s)$$ but $$\frac{p_d}{\gamma} = h_d + h_{fd}$$ and $$\frac{p_s}{\gamma} = -(h_s + h_{fs})$$

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

$$= H_{st} + h_f + \frac{V_s^2}{2g}$$

(where $h_{fd} = f\frac{L}{D}(V_d^2/2g)$ **)**

where $h_f = h_{fs} + h_{fd}$

$$H_m = h' - H_L = \frac{V_{w2}U_2}{g} - H_L$$

(where H_L = impeller losses)

Total head (H)

$$H = \frac{p_d - p_s}{\gamma} + (z_d - z_s) + \frac{V_d^2 - V_s^2}{2g}$$

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

$$= H_{st} + h_f + \frac{V_d^2}{2g}$$

$$H_m = H + \frac{1}{2g}(V_s^2 - V_d^2)$$

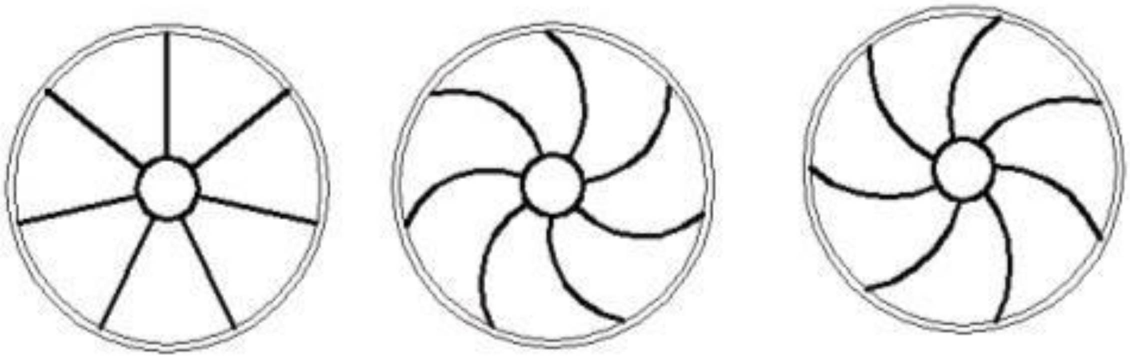
When $V_s = V_d$

Hence $H_m = H$

Type of Impeller

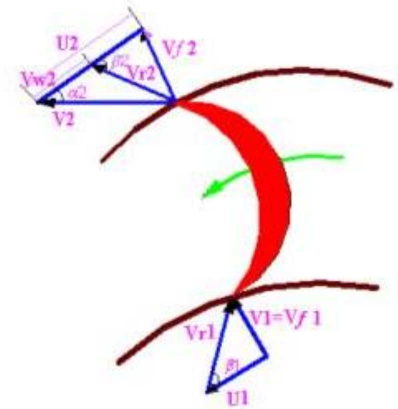
There are three main categories of impeller due type of impeller's vane, which are used in the centrifugal pumps as;

- **Radial vanes, Fig. (a).**
- **Backward vanes, Fig. (b).**
- **Forward vanes, Fig. (c).**

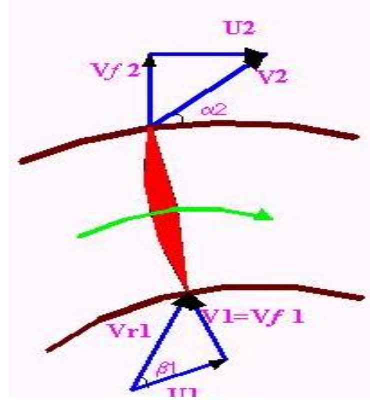


(a) (b) (c)

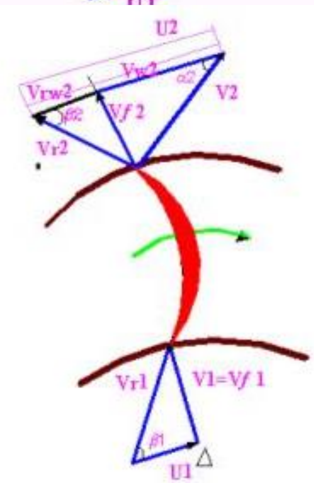
a) when $\beta_2 > 90^o$, the Forwards curved vanes of the impeller.



b) when $\beta_2 = 90^o$, the radial curved vanes of the impeller.



c) when $\beta_2 < 90^o$, the Backwards curved vanes of the impeller.



where :

V = absolute velocity of the water.

U = Tangential velocity of impeller (peripheral velocity).

$\boldsymbol{V_r}$ = relative velocity of water to the wheel.

$\boldsymbol{V_f}$ = velocity flow.

N = Speed of impeller in (rpm).

$\boldsymbol{\beta}$ = vane angle.

$\boldsymbol{\alpha}$ = angle at which water leaves.

Pump Efficiencies

1- *Hydraulic Efficiency (ζ_h)*

$$\zeta_h = \frac{Pump's\ Total\ \ Head\ (H)}{Euler\ Head\ (H_e)}$$

$$\zeta_h = \frac{gH}{V_{w2}U_2}$$

The normal value varies between 60% - 90%

2- *Manometric Efficiency(ζ_m)*

$$\zeta_m = \frac{Pump's\ \ Manometric\ \ \ Head\ (H_m)}{Euler\ Head\ (H_e)}$$

$$\zeta_m = \frac{gH_m}{V_{w2}U_2}$$

3 -*Volumetric Efficiency* (ζ_v)

$$\zeta_v = \frac{Q}{Q + \Delta Q}$$

The normal value lies between 97% to 98%

4- *Mechanical Efficiency* (ζ)

It is due to losses in the shaft, coupling, and other operation losses as vibration

$$\zeta = \frac{Power \quad into\ the\ impeller}{Power \quad at\ the\ shaft}$$

$$\zeta = \frac{\rho\,(Q + \Delta Q\,)\,V_{w2}\,U_2}{Power \quad Shaft}$$

The normal value is 95% - 98%

5 - *Overall Efficiency* (ζ_o)

$$\zeta_o = \frac{P_{out}}{P_{in}} = \frac{\gamma QH}{T.\omega}$$

$$\zeta_o = \frac{P_{out}}{P_t} \times \frac{P_t}{P_{in}} = \frac{P_t}{P_{in}} \times \frac{\gamma QH}{\gamma (Q + Q_l)h'}$$

$$\zeta_o = \zeta_m \times \zeta_v \times \zeta_h$$

The normal value is 71% - 86%

Discharge of a Centrifugal Pump

$$Q = \pi D_1 b_1 V_{f1} = \pi D_2 b_2 V_{f2}$$

6- *Power Required to Drive a Centrifugal Pump*

$$P = \frac{\gamma Q H}{750\zeta_o} \quad (hp) \qquad\qquad \boldsymbol{P = \frac{\gamma Q V_{w1} U_1}{g750}} \quad (hp)$$

7 -1 Cavitation

Cavitation is defined as the phenomenon of formation of vapor bubbles of flowing liquid in a region where the pressure of the liquid falls below its vapor pressure and the sudden collapsing of this vapor bubbles in a region of higher pressure. When the vapor bubbles collapse, a very high pressure is created. The formation and the collapse of a great number of bubbles on the surface produce intense local stresses that damage the surface by fatigue. It may occur at the entry to pumps or at the exit from hydraulic turbines in the vicinity of the moving blades

7 -2 Cavitation processes in centrifugal pump

The cavitation phenomenon develops in the impeller pump, when the pressure of liquid falls below the saturated vapor pressure at the prevailing temperature ($P_s < P_v$ of liquid), small vapor bubbles begin to form and the dissolved gases are evolved. The vapor bubbles are caught up by the following liquid and swept into a region of higher pressure, where they condense. Condensation takes place violently, accompanied by a tremendous increase in pressure, which has the character of water hammer blows. These impact follow each other in rapid succession, the vapor bubbles bursting both in the immediate vicinity of the surface attacked and in the pores causing cavitation pitting with many effecting.

The Table below outlines some of the main differences between centrifugal pumps, reciprocating pumps and rotary pumps. Note that "centrifugal", "reciprocating" and "rotary" pumps are all relatively broad categories

Parameter	Centrifugal Pumps	Reciprocating Pumps	Rotary Pumps
Optimum Flow and Pressure Applications	Medium/High Capacity, Low/Medium Pressure	Low Capacity, High Pressure	Low/Medium Capacity, Low/Medium Pressure
Maximum Flow Rate	100,000+ GPM	10,000+ GPM	10,000+ GPM
Low Flow Rate Capability	No	Yes	Yes
Maximum Pressure	6,000+ PSI	100,000+ PSI	4,000+ PSI
Requires Relief Valve	No	Yes	Yes
Smooth or Pulsating Flow	Smooth	Pulsating	Smooth
Variable or Constant Flow	Variable	Constant	Constant
Self-priming	No	Yes	Yes
Space Considerations	Requires Less Space	Requires More Space	Requires Less Space
Costs	Lower Initial Lower Maintenance Higher Power	Higher Initial Higher Maintenance Lower Power	Lower Initial Lower Maintenance Lower Power
Fluid Handling	Suitable for a wide range including clean, clear, non-abrasive fluids to fluids with abrasive, high-solid content. Not suitable for high viscosity fluids Lower tolerance for entrained gases	Suitable for clean, clear, non-abrasive fluids. Specially-fitted pumps suitable for abrasive-slurry service. Suitable for high viscosity fluids Higher tolerance for entrained gases	Requires clean, clear, non-abrasive fluid due to close tolerances Optimum performance with high viscosity fluids Higher tolerance for entrained gases

8- The Affinity Law

Formulas for Refiguring Pump Performance with Impeller Diameter or Speed Change		
Diameter Change Only	**Speed Change Only**	**Diameter and Speed Change**
$\mathbf{Q_2 = Q_1} \left(\frac{D_2}{D_1} \times \frac{N_2}{N_1}\right)$	$\mathbf{Q_2 = Q_1} \left(\frac{N_2}{N_1}\right)$	$\mathbf{Q_2 = Q_1} \left(\frac{D_2}{D_1}\right)$
$\mathbf{H_2 = H_1} \left(\frac{D_2}{D_1} \times \frac{N_2}{N_1}\right)^2$	$\mathbf{H_2 = H_1} \left(\frac{N_2}{N_1}\right)^2$	$\mathbf{H_2 = H_1} \left(\frac{D_2}{D_1}\right)^2$
$\mathbf{bhp_2 = bhp_1} \left(\frac{D_2}{D_1} \times \frac{N_2}{N_1}\right)^2$	$\mathbf{bhp_2 = bhp_1} \left(\frac{N_2}{N_1}\right)^2$	$\mathbf{bhp_2 = bhp_1} \left(\frac{D_2}{D_1}\right)^2$

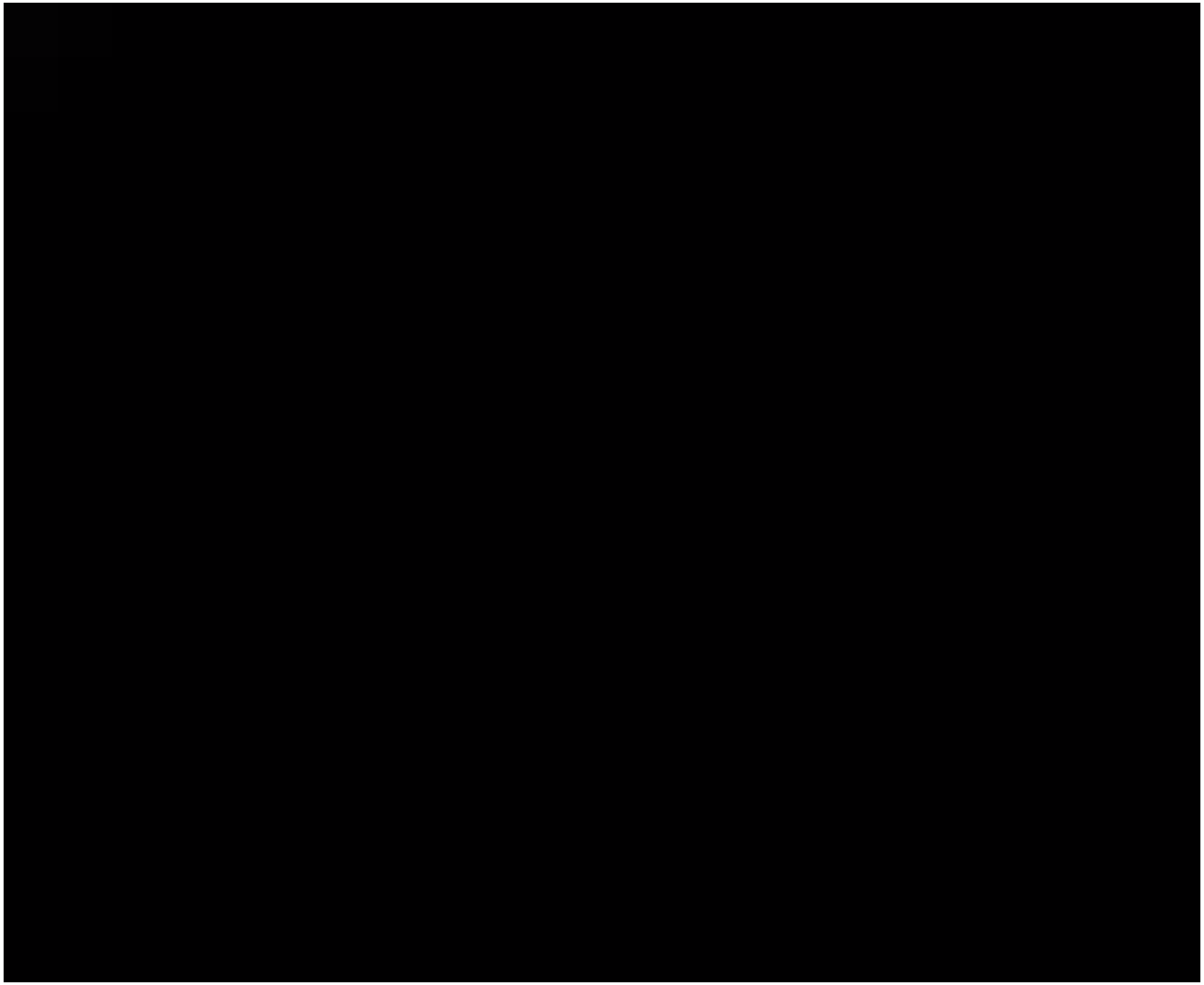
References:

1-Larry Bachus and Angel Custodio, (2003). Know and Understand Centrifugal Pumps.

2-Val S. Lobanoff Robert R. Ross, (1992). Centrifugal Pumps - Design and Application (2^{nd} ed.)

3-Igor J. Karassik ,oseph P. Messina,Paul Cooper and Charles C. Heald,2001. Pump Handbook(3^{rd} ed)

Centrifugal pumps



COMPRESSORS, BLOWERS & FANS

Compressors & Blowers, Fans

- are machines that **move & compress gases**.

1. **Fans** discharge **large volumes of gas** (usually air) into spaces or large ducts

   -are **low-speed machines** that generate **very low pressures**, on the order of **0.04 atm**.
2. **Blowers:** are **high-speed rotary devices** (using either positive displacement or centrifugal force) that **develop a max. pressure of about 2 atm.**
3. **Compressors:** are also positive-displacement or centrifugal machines, discharge at pressure from **2 atm to several thousand atmospheres.**

Differences between fans, blowers & compressors

Ratio of discharge pressure over suction pressure

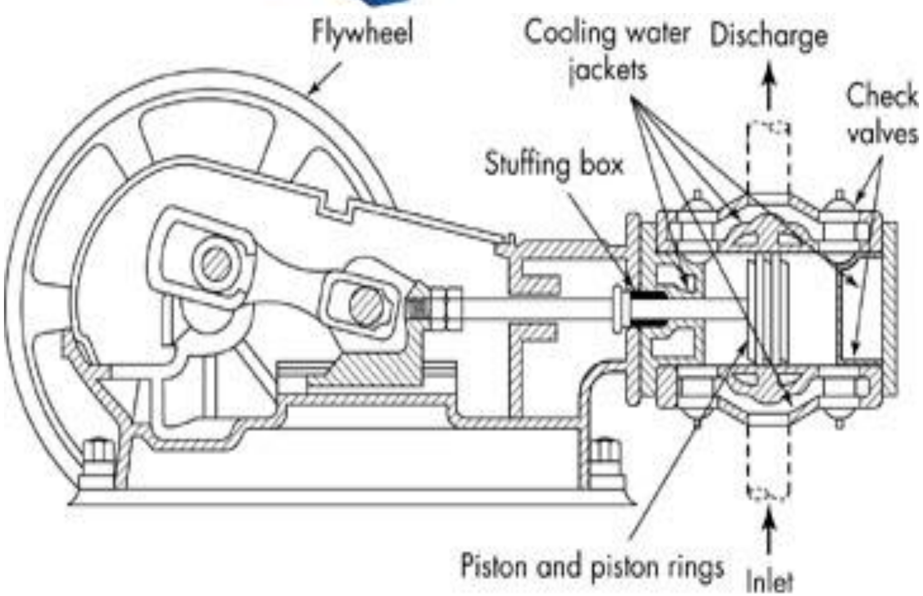
Equipment	Specific Ratio	Pressure rise (mmWg)
Fans	Up to 1.11	1136
Blowers	1.11-1.20	1136-2066
Compressors	More than 1.20	-

Compressors

Positive-displacement compressors

- Rotary positive-displacement compressors can be used for discharge pressures up to about 6 atm.
- These devices include **sliding-vane, screw-type, and liquid piston compressors.**
- For high to very high discharge pressures & modest flow rates, reciprocating compressor are the most common type.
- These machines operate mechanically in the same way as reciprocating pumps, with the differences that leak prevention is more difficult and temperature rise is important.
- The cylinder walls & cylinder heads are cored for cooling jackets using water refrigerant .
- Reciprocating compressors are usually motor-driven & nearly always double acting.

Compressors



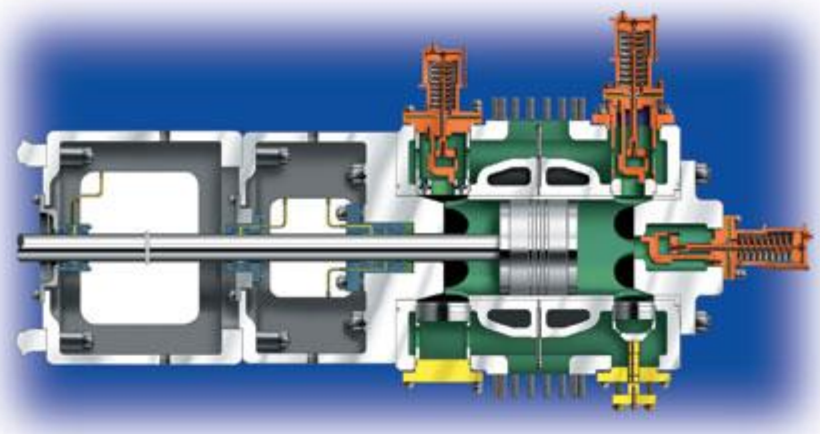


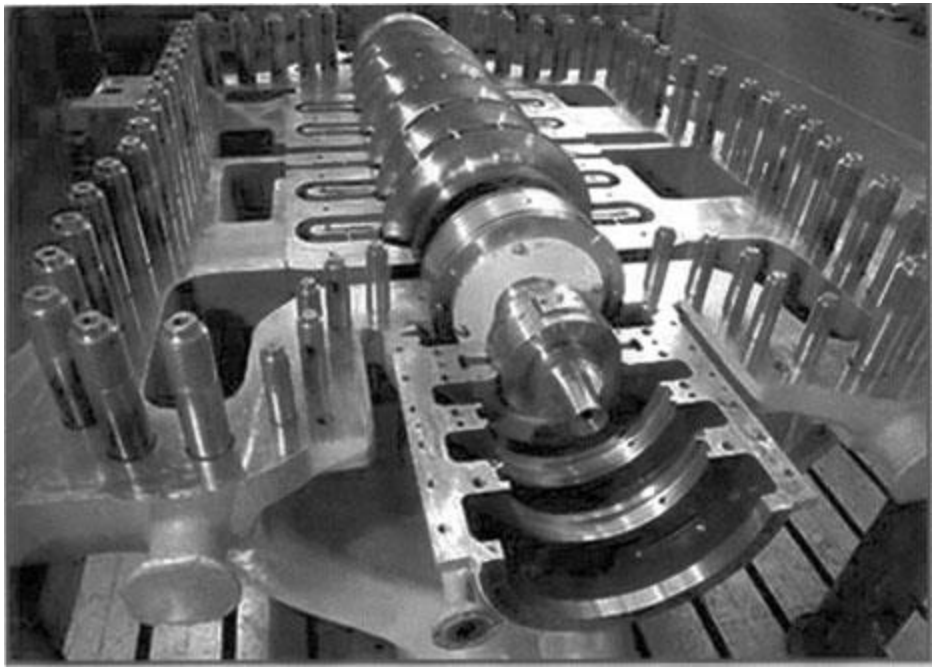
Figure 1. Reciprocating Compressor Cylinder Assembly

Reciprocating compressor

Compressors

- Centrifugal compressors
- are multistage units **containing a series of impellers** on a single shaft rotating at high speeds in massive casing.
- internal channels lead from the discharge of one impeller to the inlet of the next.
- these machines **compress enormous volumes of air or process gas-up to 200,000 ft^3/min (340,000 m^3/h) at the inlet-to outlet pressure of 20 atm.**
- smaller-capacity machines discharge at pressures up to several hundred atmospheres.
- interstage cooling is needed on the high-pressure units.
- axial-flow machines handle even larger volumes of gas up to 600,000 ft^3/min (1 x 10^6 m^3/h), but at lower discharge pressures of 2 to 12 atm.
- in these units the rotor vanes propel the gas axially from one set of vanes directly to the next. Interstage cooling is normally not required.

Compressors



Interior of centrifugal compressor

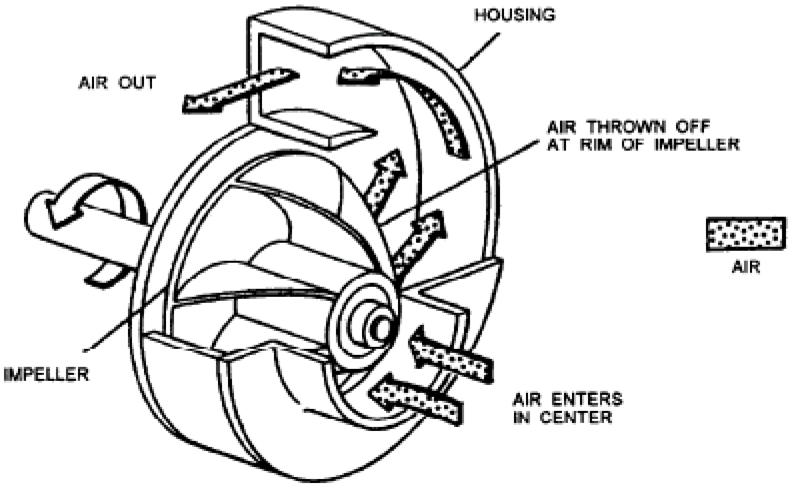
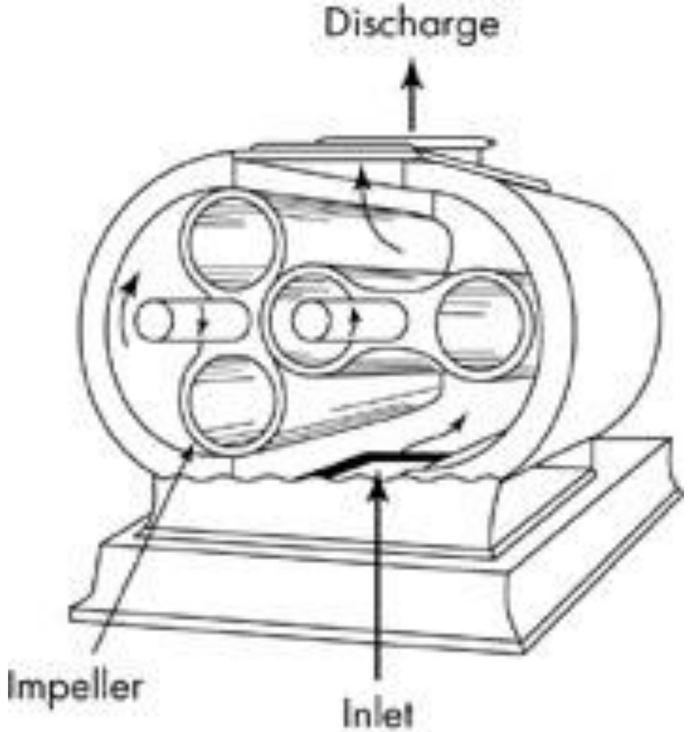
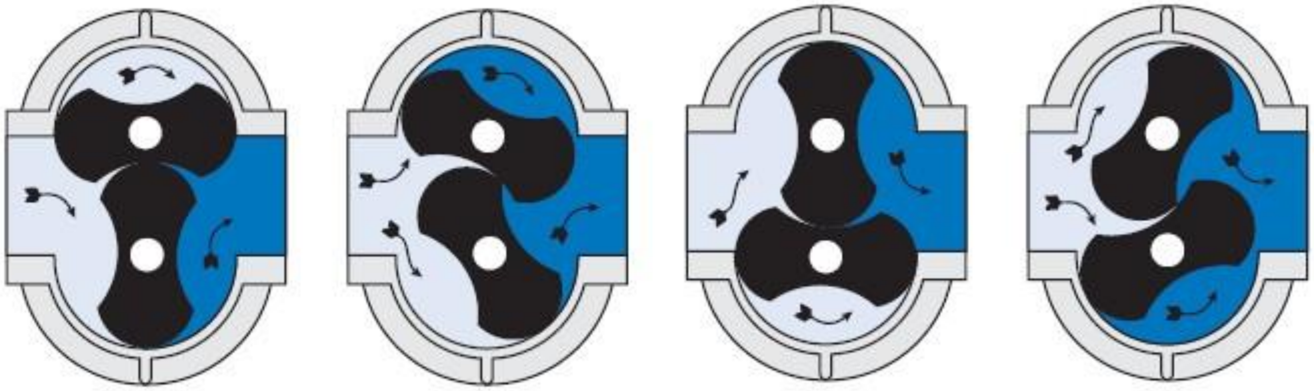


Figure 5-39.—Centrifugal supercharger.

Blowers

- Positive-displacement blower
- These machines operates as gear pumps do except that, because of the special design of the "teeth", the clearance is only a few thousandths of an inch.
- the relative position of the impellers is maintained precisely by heavy external gears.
- A single-stage blower can discharge gas at 0.4 to 1 atm gauge, a two-stage blower at 2 atm.
- Example: positive-displacement two-lobe blower.



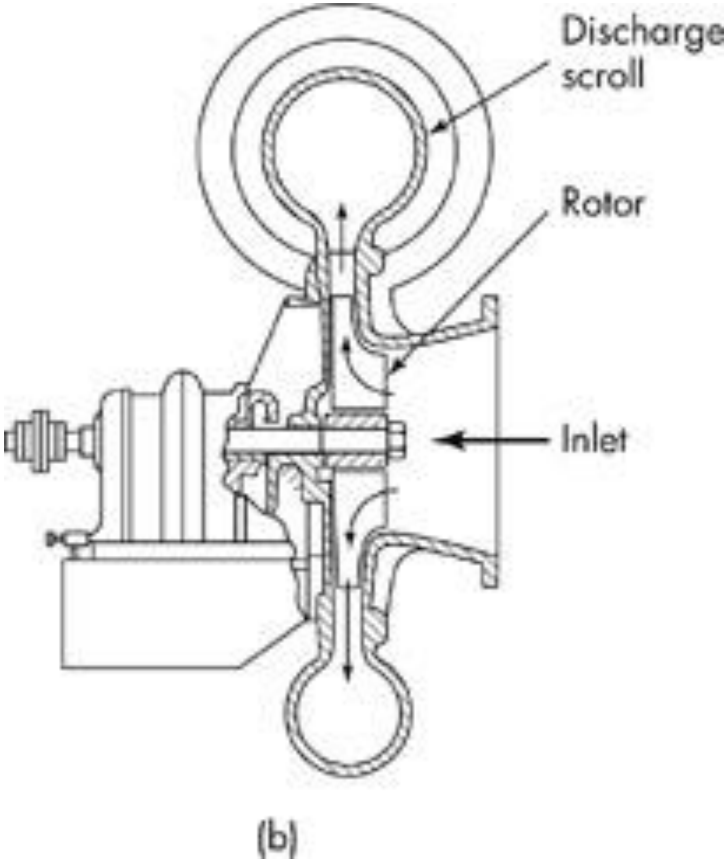


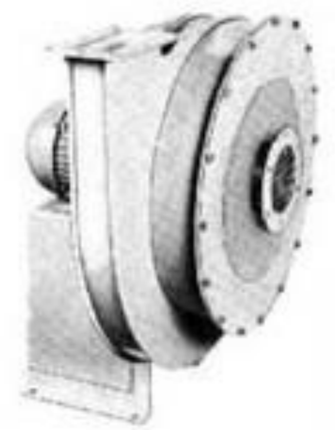
Positive-displacement two-lobe blower

Blowers

- Centrifugal blowers
- In appearance it **resembles a centrifugal pump**, except that casing is narrower and diameters of casing & discharge scroll are relatively larger than in centrifugal pump.
- The operating speed is high-3,600 r/min or more.
- High speed and large impeller diameters are required because very high heads of low-density fluids are needed to generate modest pressure ratios.
- Thus, the **velocity approximately 10 times those in centrifugal pump.**
- Example: single-suction centrifugal blower

BLOWERS



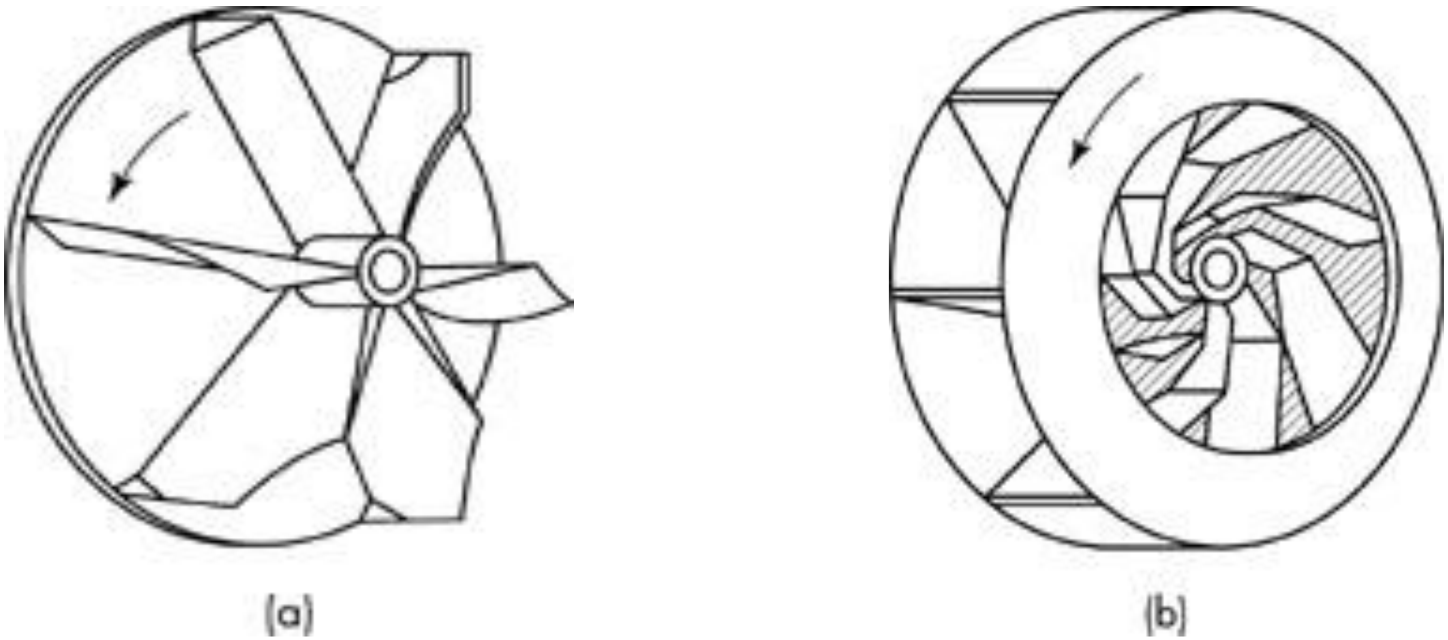


Single-suction centrifugal blower

Fans

- Large fans usually centrifugal, operating exactly the **same principle** as **the centrifugal pumps.**
- Their impeller blades may be curved forward, this would lead to instability in a pump, but not in a fan.
- The impellers are mounted inside light sheet-metal casings.
- Clearances are large & discharge heads low, from 5 to 60 in. (130 to 1500 mm) H_2O.
- Sometimes, as in ventilating fans, nearly all the added energy is converted to velocity energy and almost none to pressure head.

FANS



Impellers for centrifugal fans

CAVITATION

- https://youtu.be/2k1NRCRVZZM