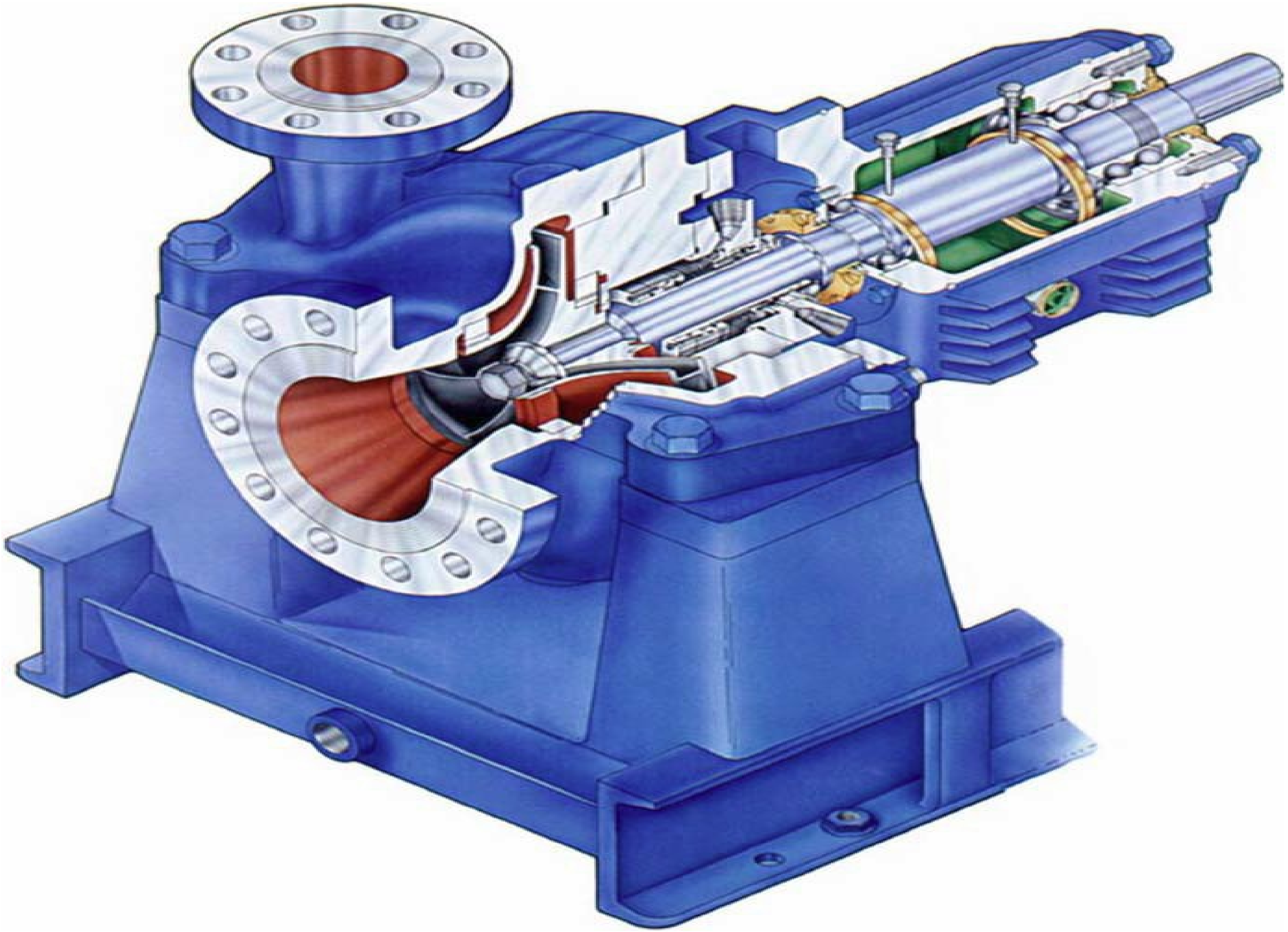
Centrifugal Pump Basics



What is Pump?

Pump is a machine to transport the liquid from one place to another place.

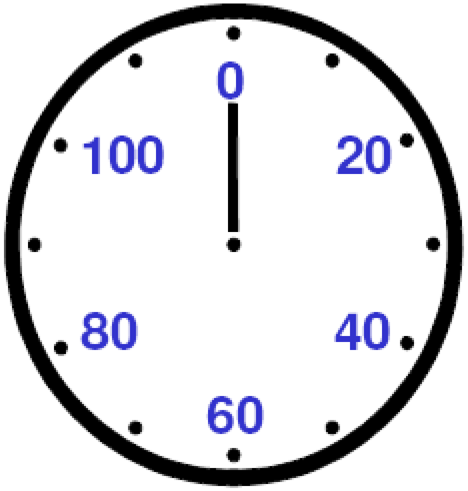
BASIC HYDRAULICS

ATMOSPHERIC PRESSURE

AT SEA LEVEL

1 Kg/cm^2 (bar)

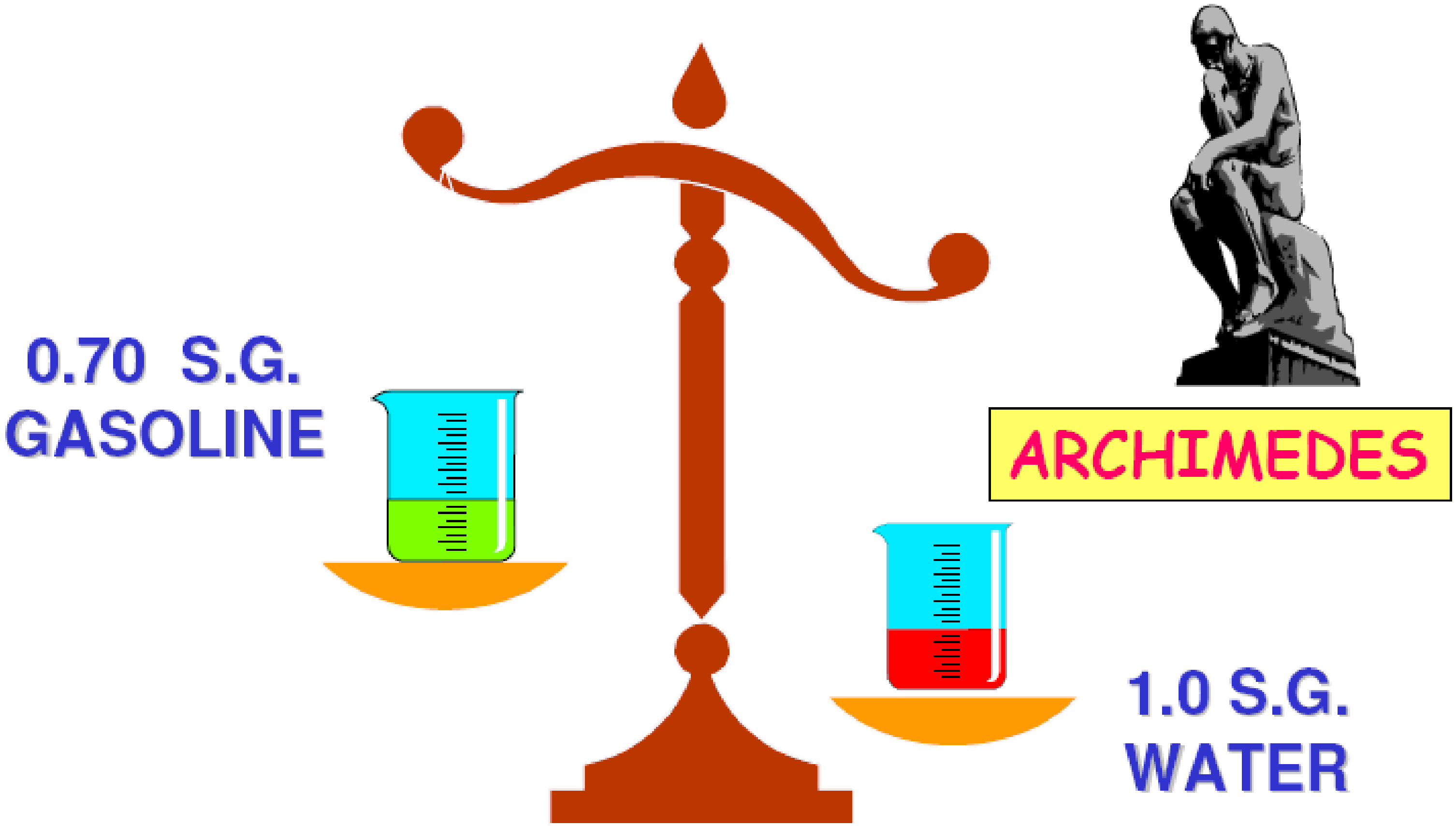
Gauge Pressure Vs Atmospheric Pressure



0 bar, gauge pressure

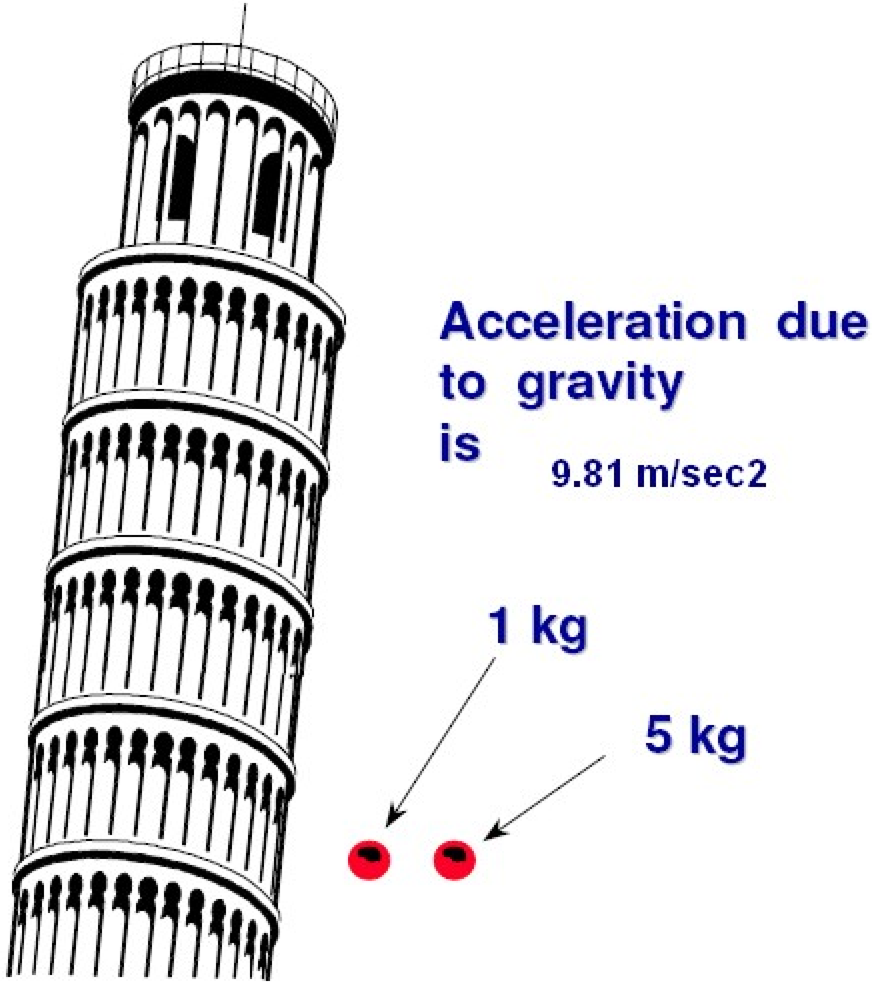
= 1 bar, atmospheric pressure

SPECIFIC GRAVITY



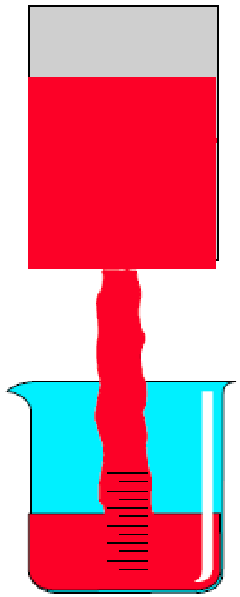
The mass difference between a liquid comparing with water is SG

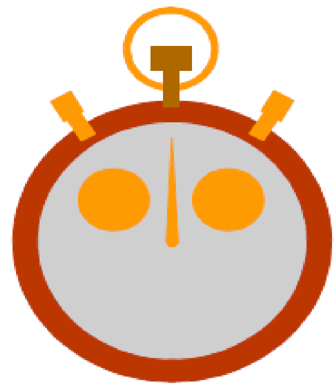
This was discovered by Archimedes (287 – 212 BC)



Gravity was discovered by Galileo Galilei – 1564-1642 AD

WHAT IS VISCOSITY?





SAYBOLT SECONDS UNIVERSAL
WATER AT 15^{0}C IS 31 SSU

Viscosity is a measure of thickness of a liquid.

The higher the viscosity the thicker the liquid. Propylene glycol & Motor oil are high viscous and Gasoline and Water are low viscous

Vapour Pressure

Defined as that absolute pressure at which the vapour contained in a substance is at equilibrium with its liquid or solid phase. Significant for centrifugal pump technology is only the actual transition between gaseous and liquid phases.

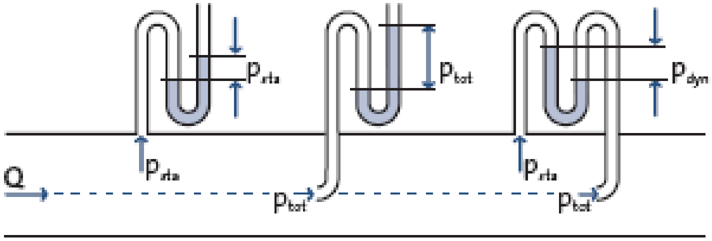
Pressure

Pressure is measure of force per unit area – Kgf/cm2, psi etc

Two types of Hydraulic pressure is

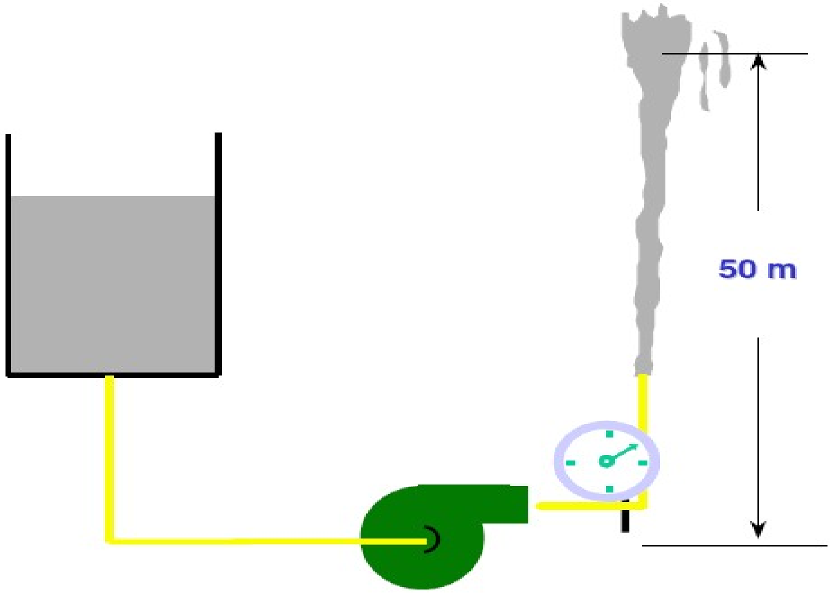
1. Static pressure : pressure of a non moving liquid.

2. Dynamic pressure: pressure caused by liquid velocity.

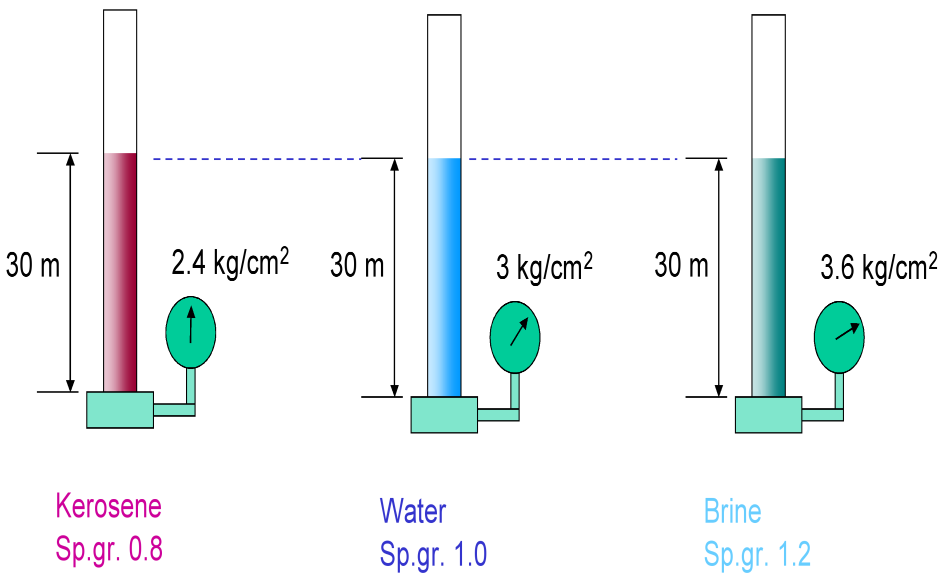


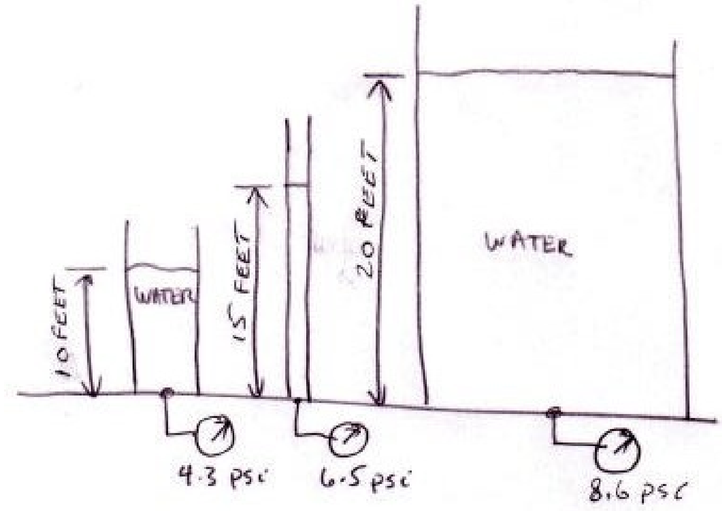
Head in m

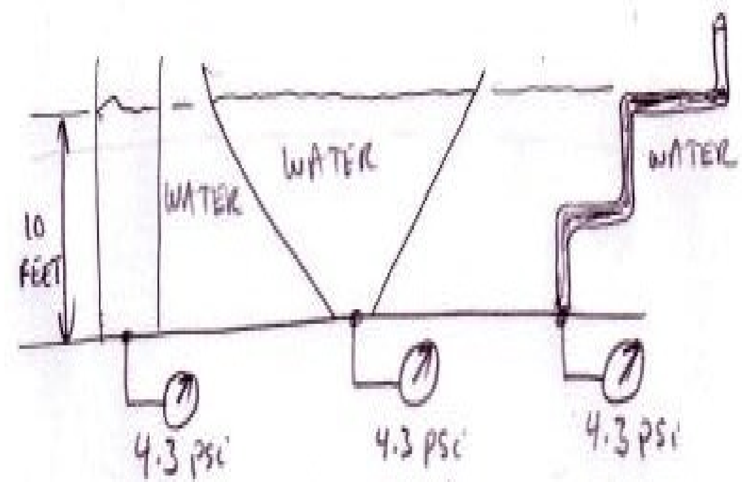
The head of the pump is an expression of
how much height the pump can lift the liquid.
This is measured in terms of meter of water column,
independent on the Liquid density.



The relationship of pressure and head

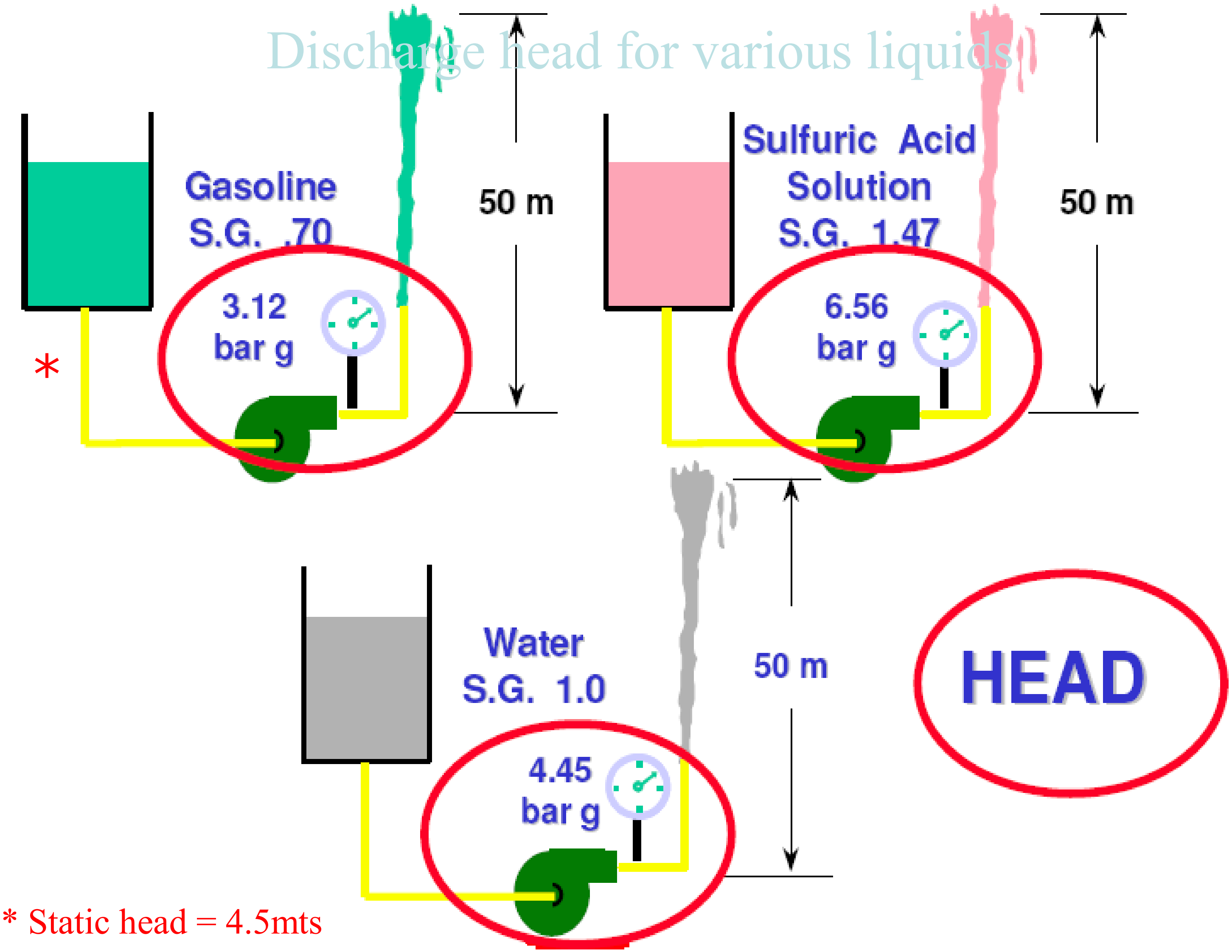




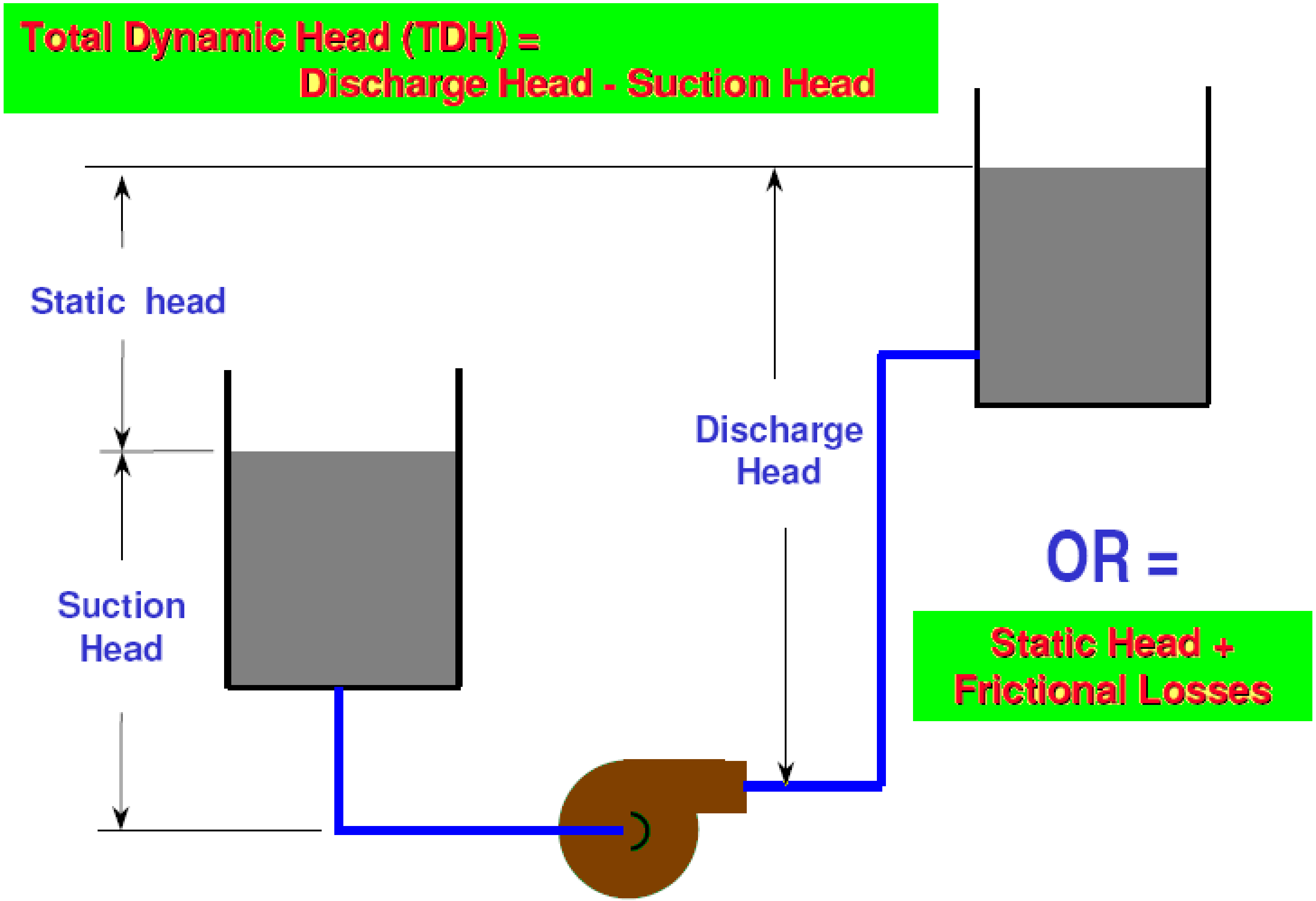


H (mts) = P (kgf/cm^2) * 10 / SG

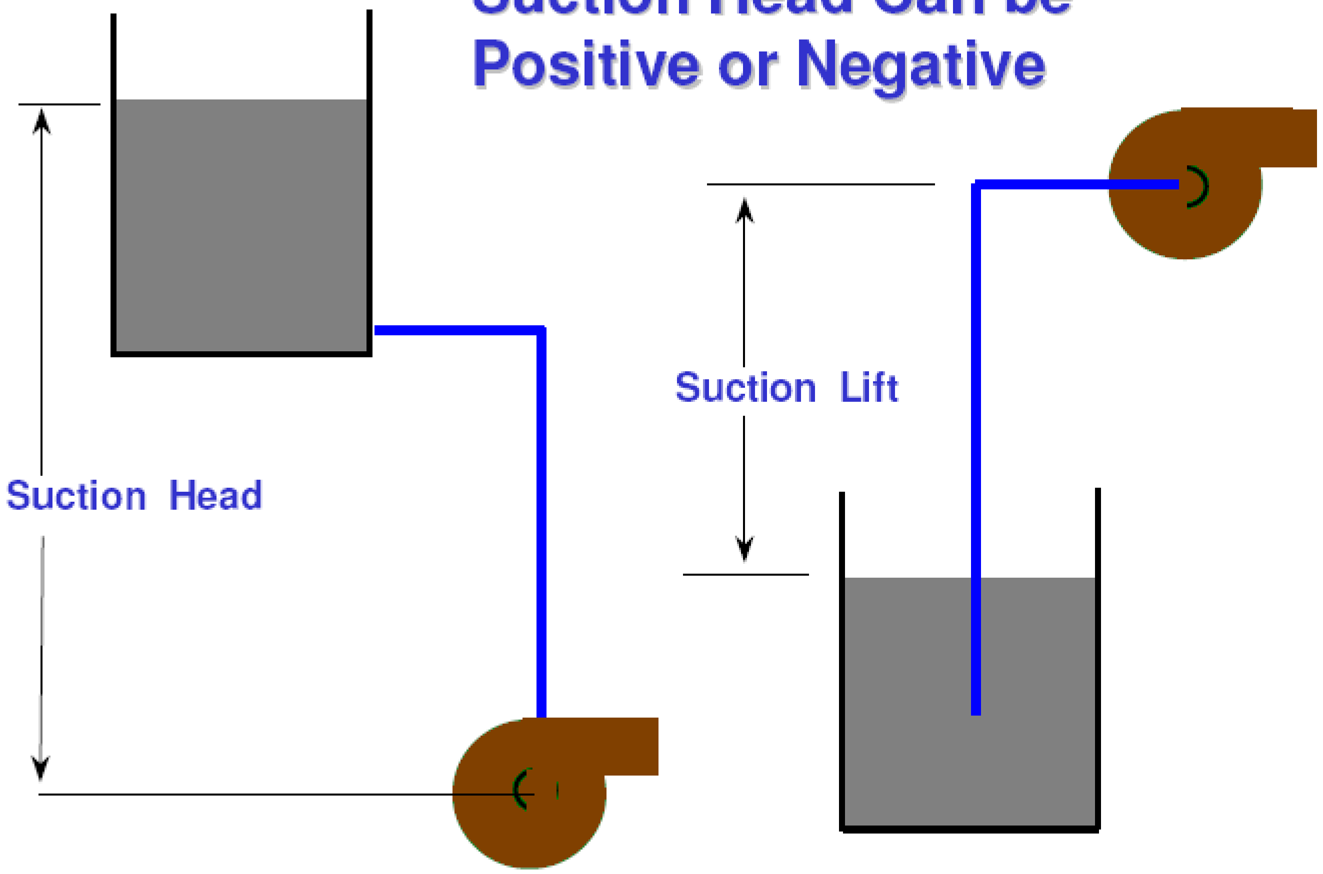
Discharge head for various liquids



* Static head = 4.5mts


Total Dynamic Head (TDH) =
Discharge Head - Suction Head
Static head
Discharge
Head
Suction
Head
OR =
Static Head +
Frictional Losses

Suction Head Can be Positive or Negative



Velocity

Distance traveled by liquid per unit time, meter/second

FLOW (Q)

Flow rate with which liquid is moved by the pump

Measured in m^3/hr or GPM or LPM

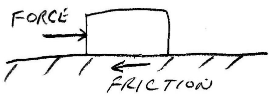
Capacity depends on

- Liquid characteristics – density, viscosity
- Pump size, inlet & outlet sections
- Impeller size
- Impeller rotational speed RPM
- Size & shape of cavities between vanes
- Pump suction & discharge temperature and pressure conditions

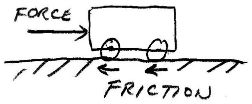
Flow(Q, m3/hr) = Area of pipeline (m2) X Velocity (m/sec)

Friction

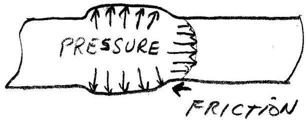
It is a form of resistance to the movement of flow.

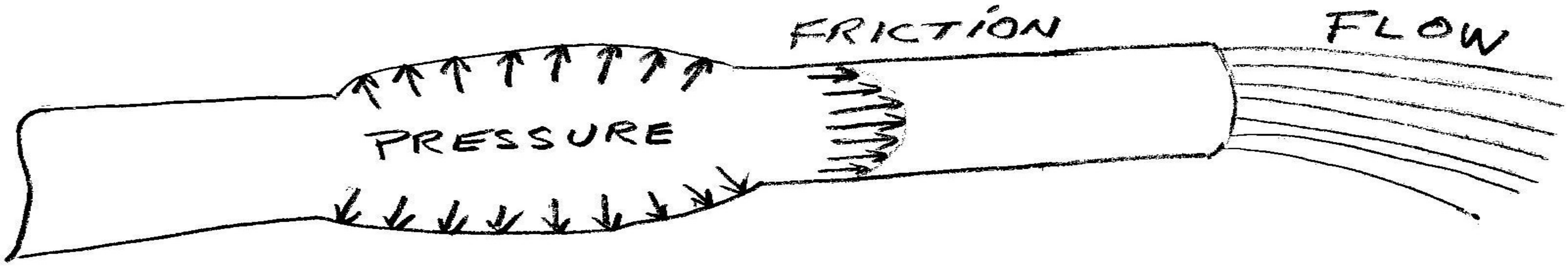


This is depending on velocity and the area.



This is measured in terms of head in meters , v^2/2g





Daniel Bernoulli

Bernoulli's Theorem

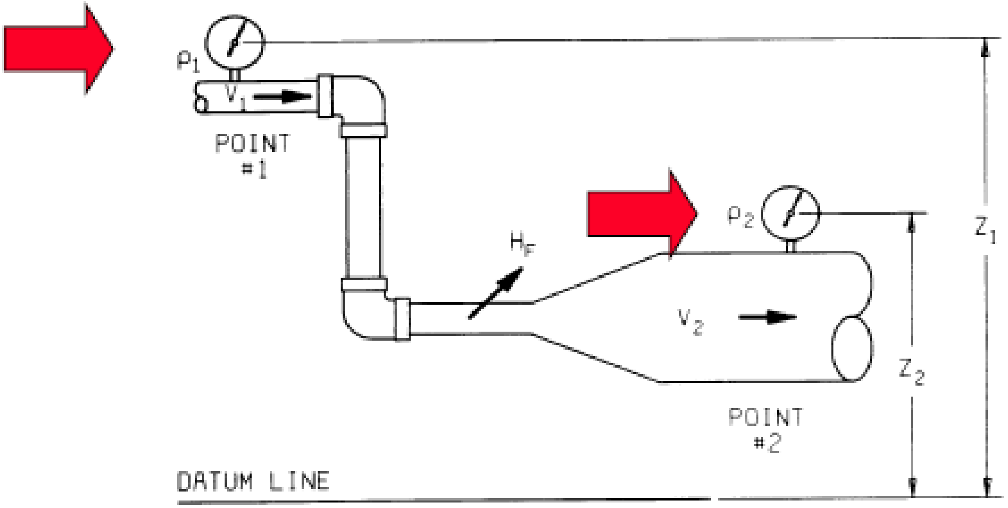
Bernoulli's Theorem states that;

Energy cannot be created or destroyed.

The sum of the three types of energy at any point in a system is the same at any other point in the system if there are no friction losses and no extra work is performed.

Bernoulli's Equation

For a system of flowing liquid with losses :



Energy in Point 1,
LESS Friction Losses,
equal Energy in Point 2

Bernoulli's Equation

Total head (H) :

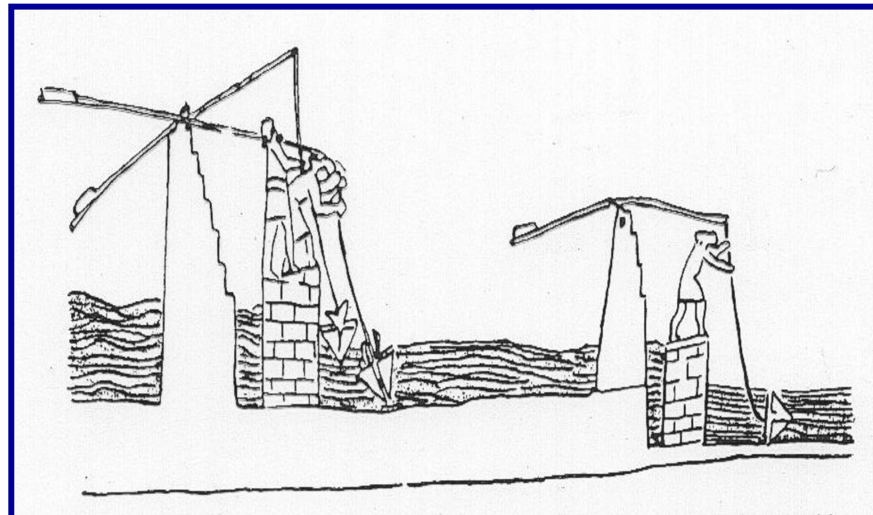
$$H = \frac{144\ p}{\gamma} + \frac{v^2}{2g} + Z = \text{Constant}$$

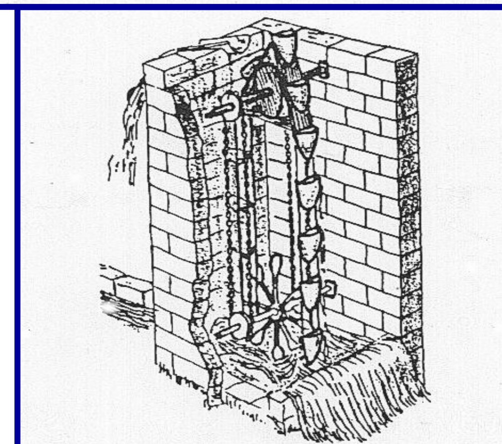
Pressure Energy $\frac{144p}{\gamma} = \text{Total Head}$

Velocity or Kinetic Energy $\frac{v^2}{2g} = \text{Dynamic Velocity Head}$

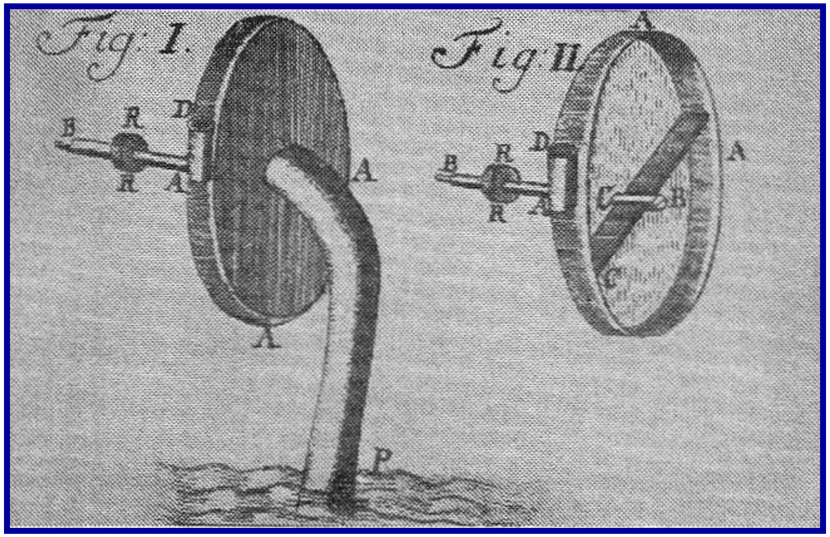
Potential or Elevation Energy $Z = \text{Static Elevation Head}$

Historical Development, Scooping Installations

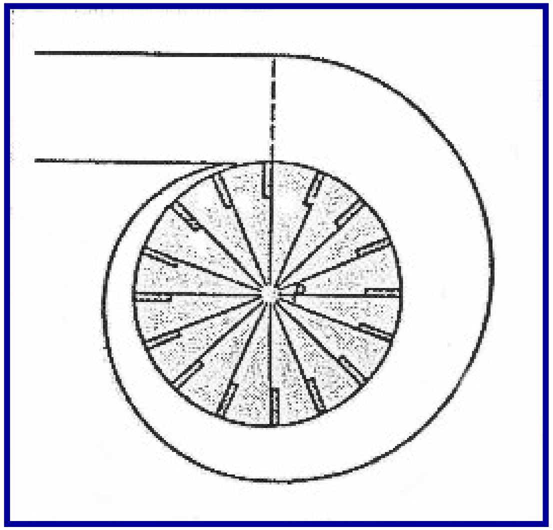




Historical Development, Centrifugal Pumps



1689
In the German scholarly journal “Acta Eruditorium“: Description of a centrifugal pump by Denis Papin



1705
Construction of a centrifugal pump with volute casing by Papin

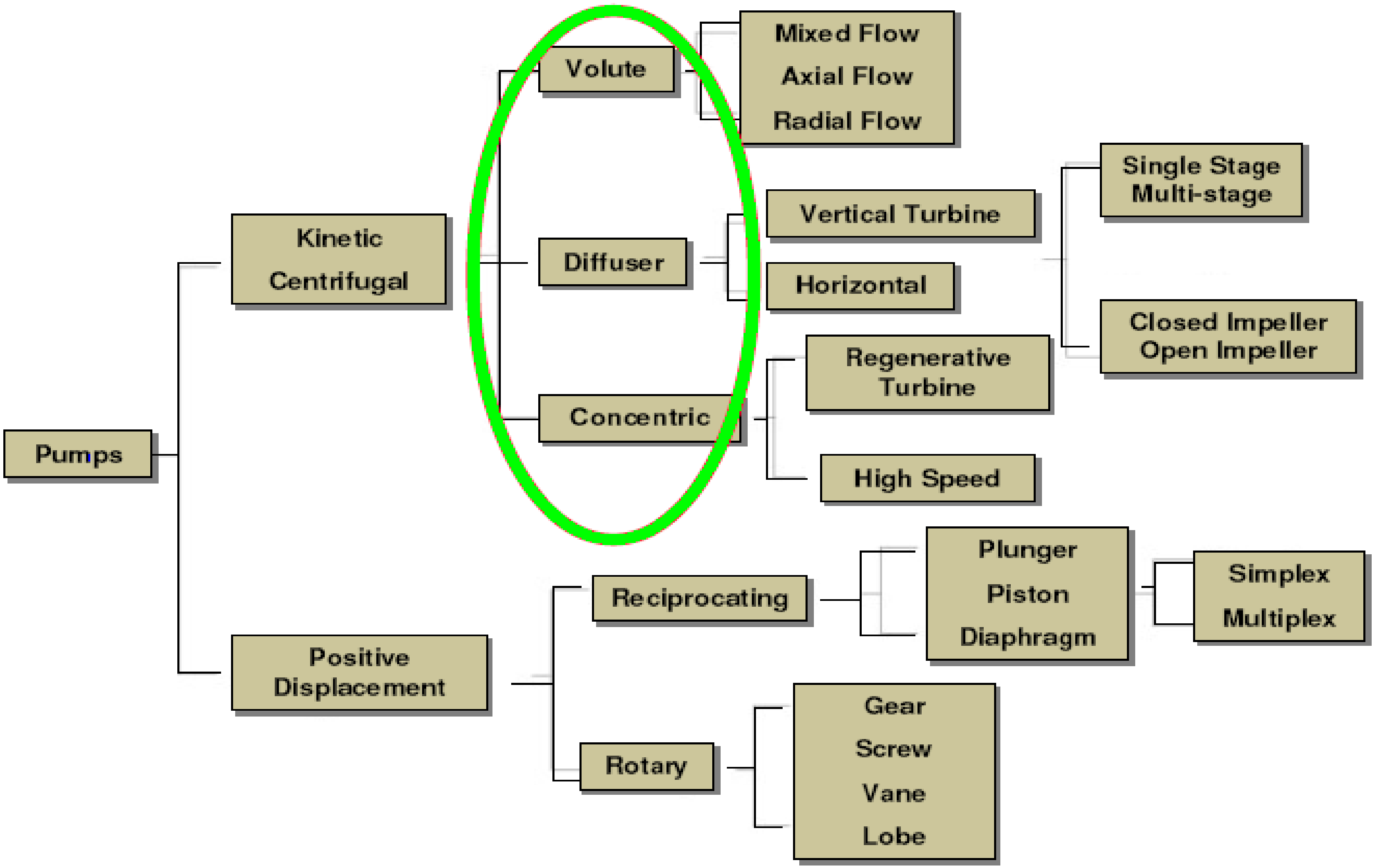
Definition

PUMP IS A MECHANICAL DEVICE

WHICH RAISES THE ENERGY LEVELS OF VARIOUS FLUIDS

BY CONVERTING

KINETIC ENERGY IMPARTED BY ITS PRIME MOVERS INTO HYDRAULIC ENERGY.


Pumps
Kinetic
Centrifugal
Volute
Diffuser
Concentric
Mixed Flow
Axial Flow
Radial Flow
Vertical Turbine
Horizontal
Single Stage
Multi-stage
Closed Impeller
Open Impeller
Regenerative
Turbine
High Speed
Positive
Displacement
Reciprocating
Rotary
Plunger
Piston
Diaphragm
Simplex
Multiplex
Gear
Screw
Vane
Lobe

Classification

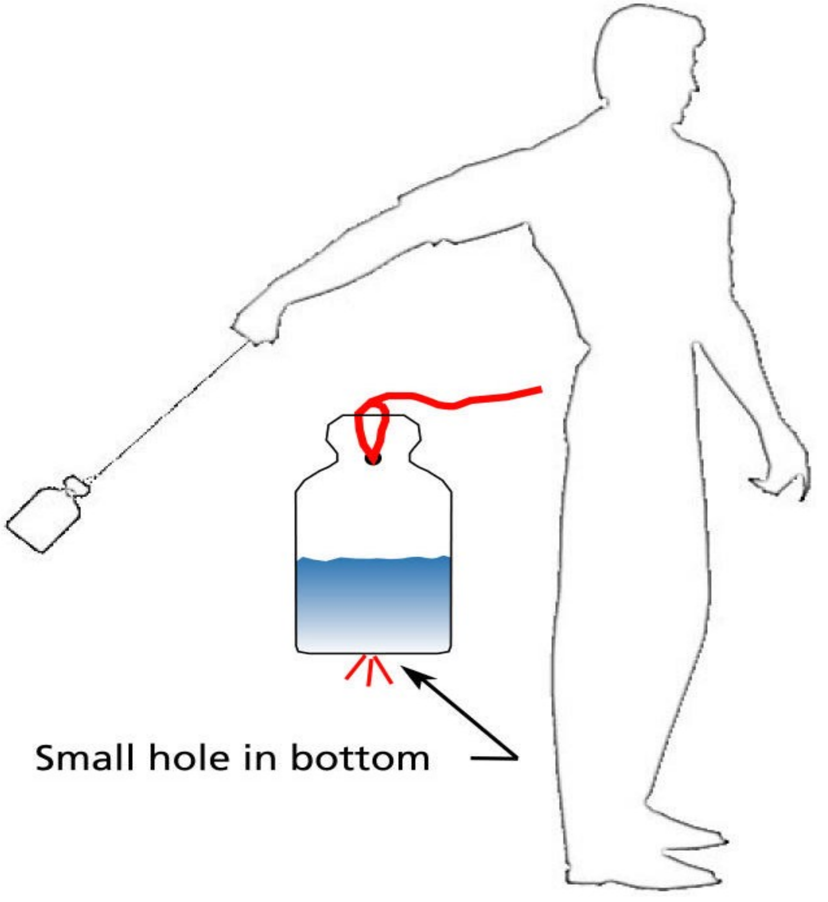
Pumps

- **Kinetic**
  - # Continuous energy addition
  - # Conversion of added energy to increase in kinetic energy (increase in velocity)
  - # Conversion increased velocity to increase in pressure
- **Positive Displacement**
  - # Periodic energy addition
  - # Added energy forces displacement of fluid in an enclosed volume
  - # Fluid displacement results in direct increase in pressure

CENTRIFUGAL Vs RECIPROCATING PUMPS

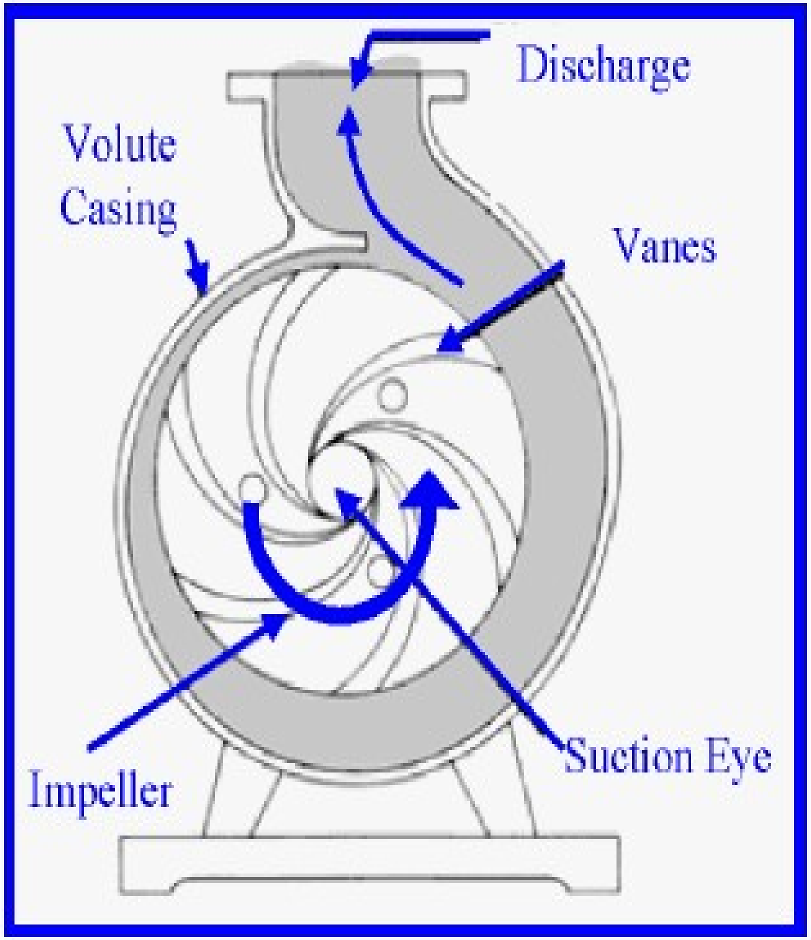
	CENTRIFUGAL	RECIPROCATING
1	RUN AT HIGH SPEEDS ie 3000rpm+	THEY RUN AT VERY LOW SPEEDS
		AND NEED SPEED REUDCING DEVICES
2	THE DISCHARGE DECREASES	THE DISCHARGE DOES NOT CHANGE
	WITH INCREASE IN DELIVERY HEAD	WITH THE VARIATION IN DELIVERY HEAD
3	EFFICIENT FOR HEADS UPTO 60M	BETTER SUITED FOR HIGH HEADS
	SINGLE STAGE , SUITABLE FOR	OVER 60M AND VISCOUS LIQUIDS
	COLD AND CLEAR WATER ,MOSTLY	

Centrifugal Force



A pail of water swinging in a circle → centrifugal force holds the water in the pale → a hole is bored at the bottom of the pale → water will be thrown out → the distance the water traverses and volume that flows out depends upon the velocity of the rotating pale

Working of a Centrifugal Pump



Impeller rotates exerting centrifugal force on the liquid

Kinetic energy is created

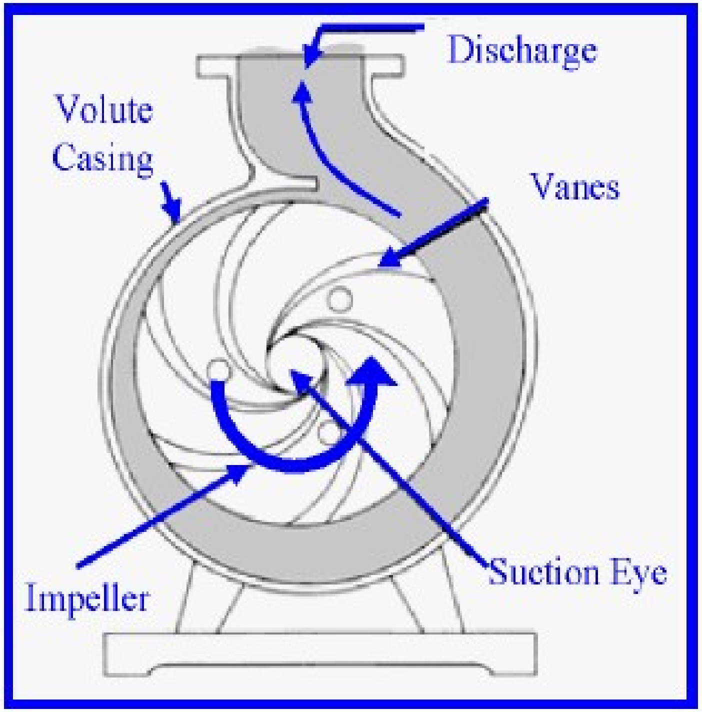
Centrifugal force throws the liquid out

Creating low pressure at the suction eye

This forces new liquid into the impeller inlet

Liquid thrown out of the impeller is met with resistance to flow

Working of a Centrifugal Pump



The impeller is offset in the volute to create a close clearance between the impeller and the volute at the cut water

The kinetic energy given to the liquid is proportional to the velocity at the edge of the impeller vane tip.

Faster the impeller rotates or bigger the impeller is, higher will be the liquid velocity at the vane tip.

Why Head is used to measure the energy of a centrifugal pump?

Pressure at any point in a liquid is caused by a vertical column of liquid due to its weight.

Height of this column is called Static head and is expressed in meters of liquid.

Head is a measurement of the height of a liquid column that the pump could create from the kinetic energy imparted to the liquid.

Pressure is dependent on the specific gravity of a liquid but head is not.

A given pump with a given impeller diameter and speed will raise a liquid to a certain height regardless of the weight of the liquid!

Various Heads

Static Suction Head (hs)

Static Discharge Head (hd)

Friction Head (hf)

Vapour Pressure Head (hvp)

Velocity Head (hv)

Total Suction Head (Hs)

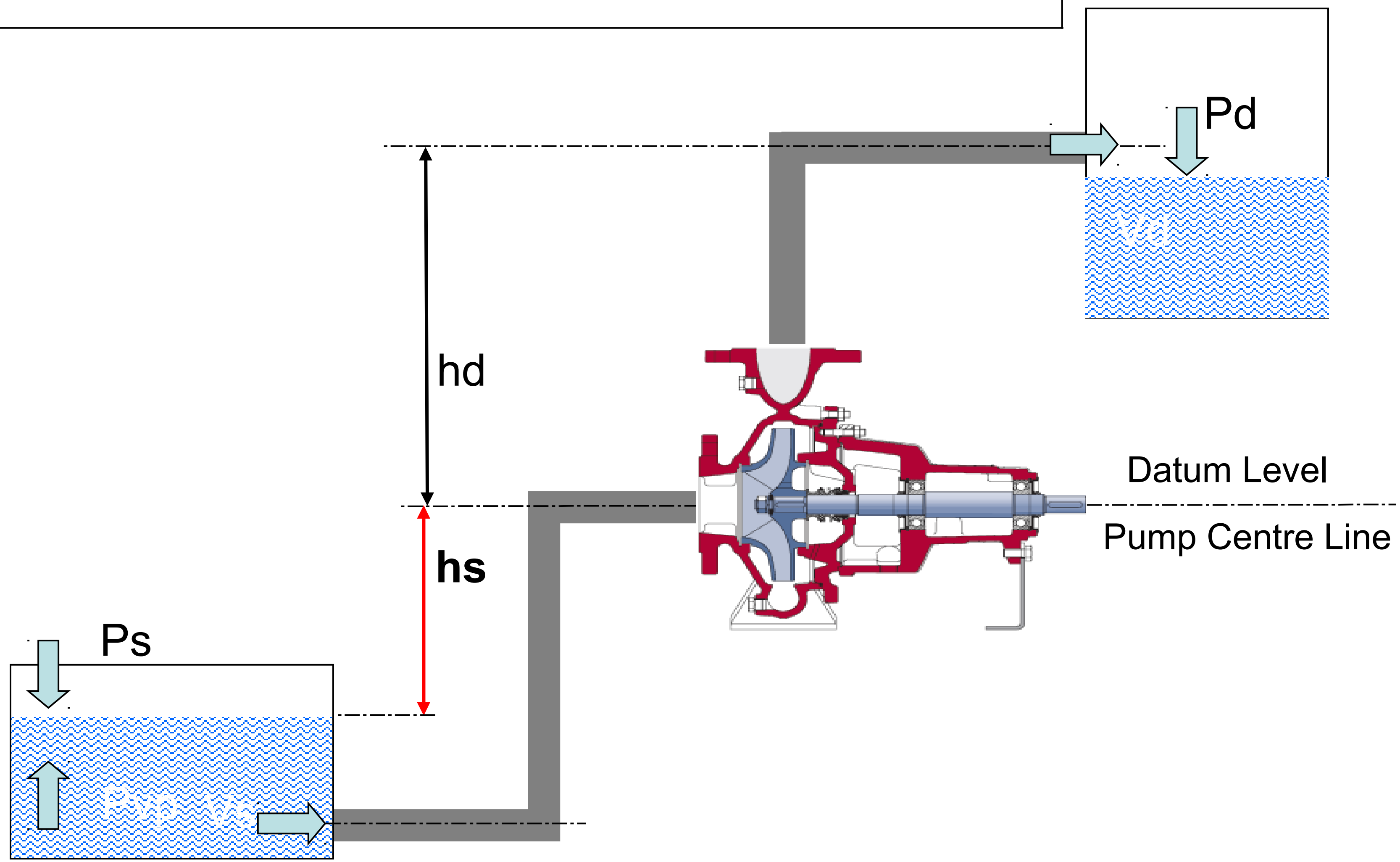
Total Discharge Head (Hd)

Total Differential Head (H_T)

Net Positive Suction Head Required (NPSHr)
Net Positive Suction Head Available (NPSHa)

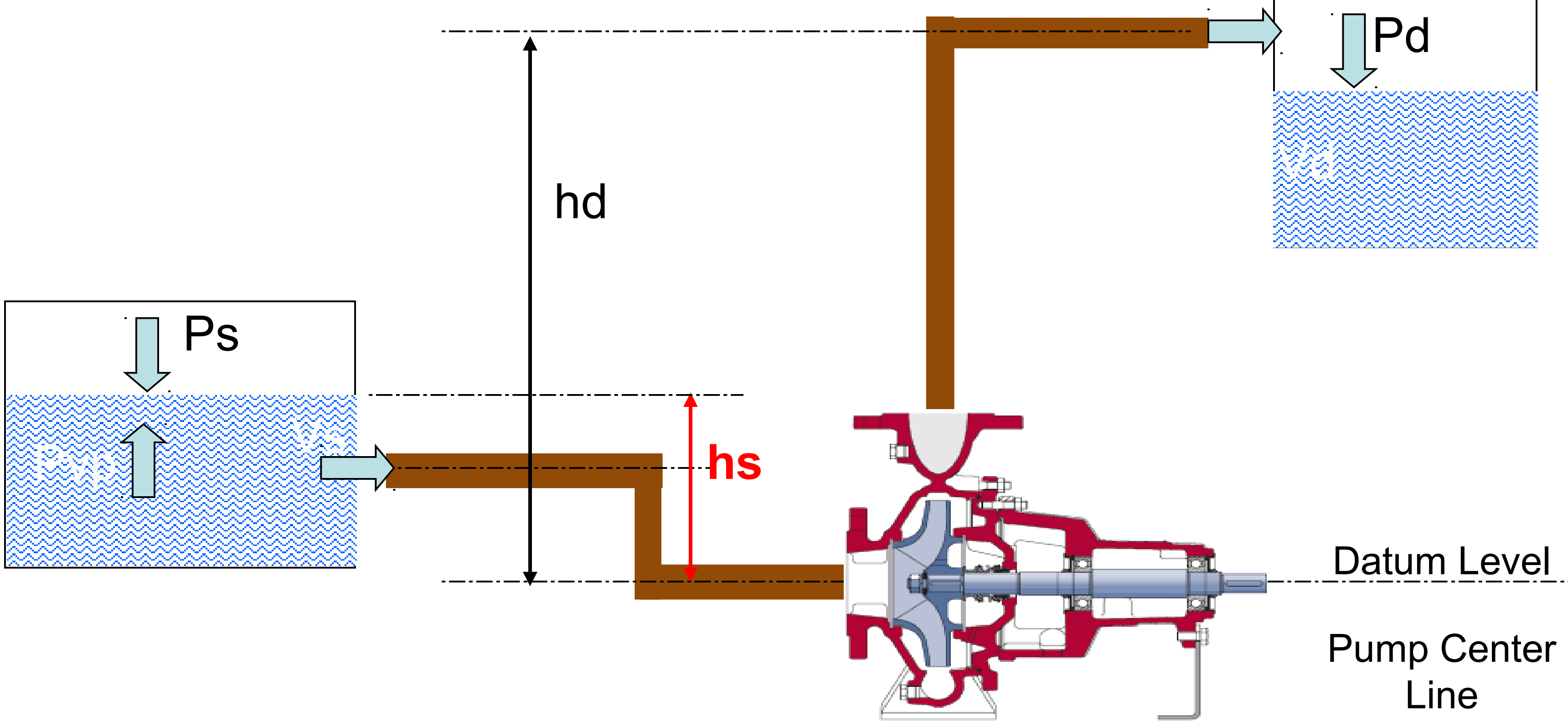
Static Suction Head (hs): Vertical distance between the pump centreline and the liquid surface in the suction tank.

Suction Lift (-hs): Liquid level is below pump center line.

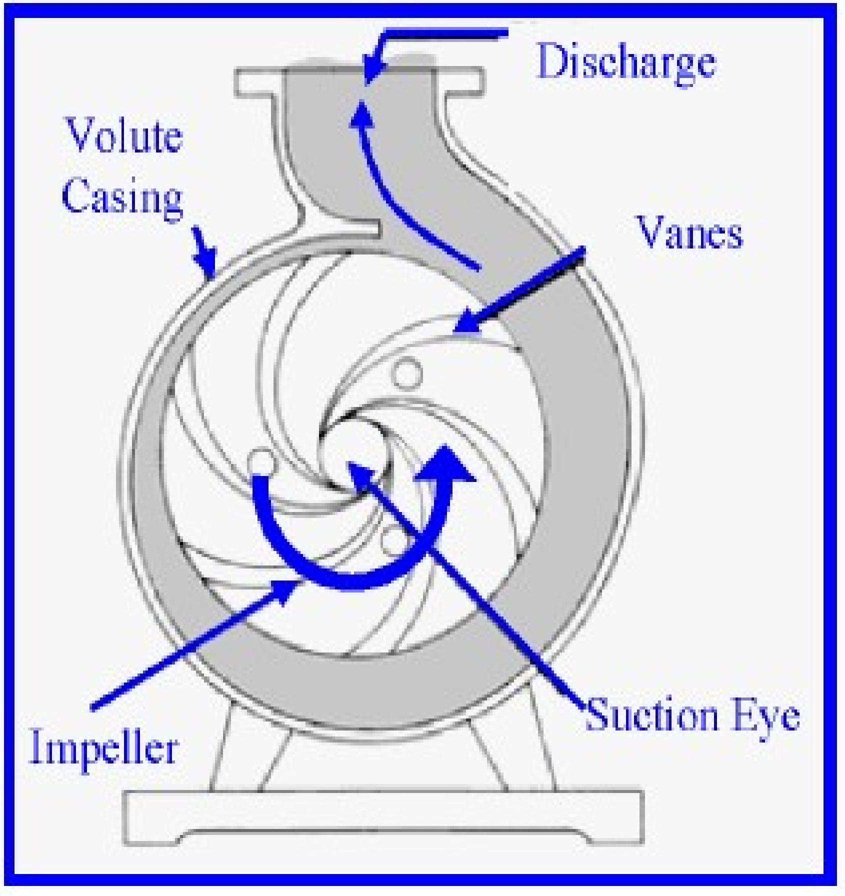


Static Suction Head (hs): Vertical distance between the pump centreline and the liquid surface in the suction tank.

Suction Head (+hs): Liquid level is above pump centre line.



Construction of Centrifugal Pumps



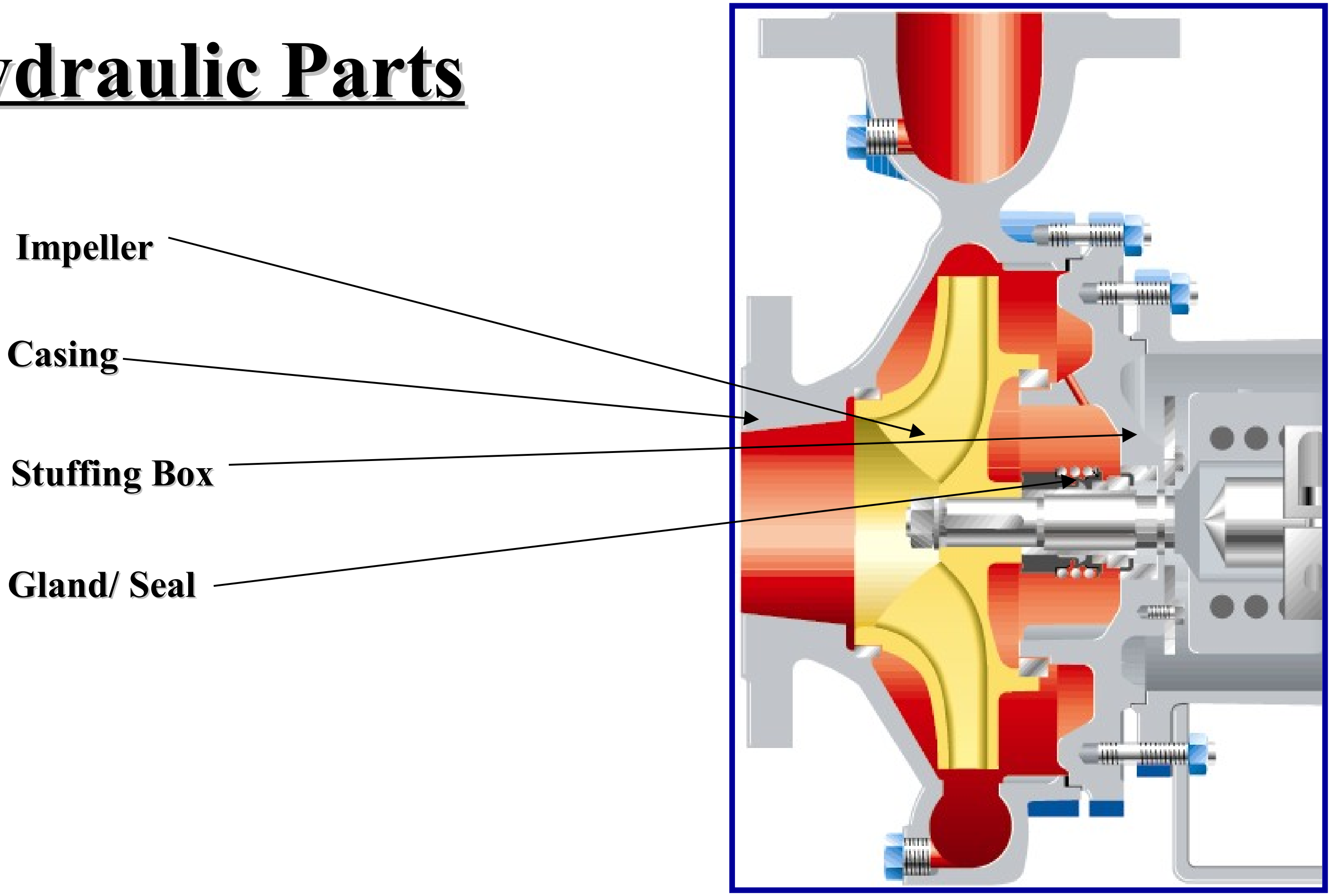
<u>Main Parts are –</u>

Hydraulic Parts
" Casing, Impeller …

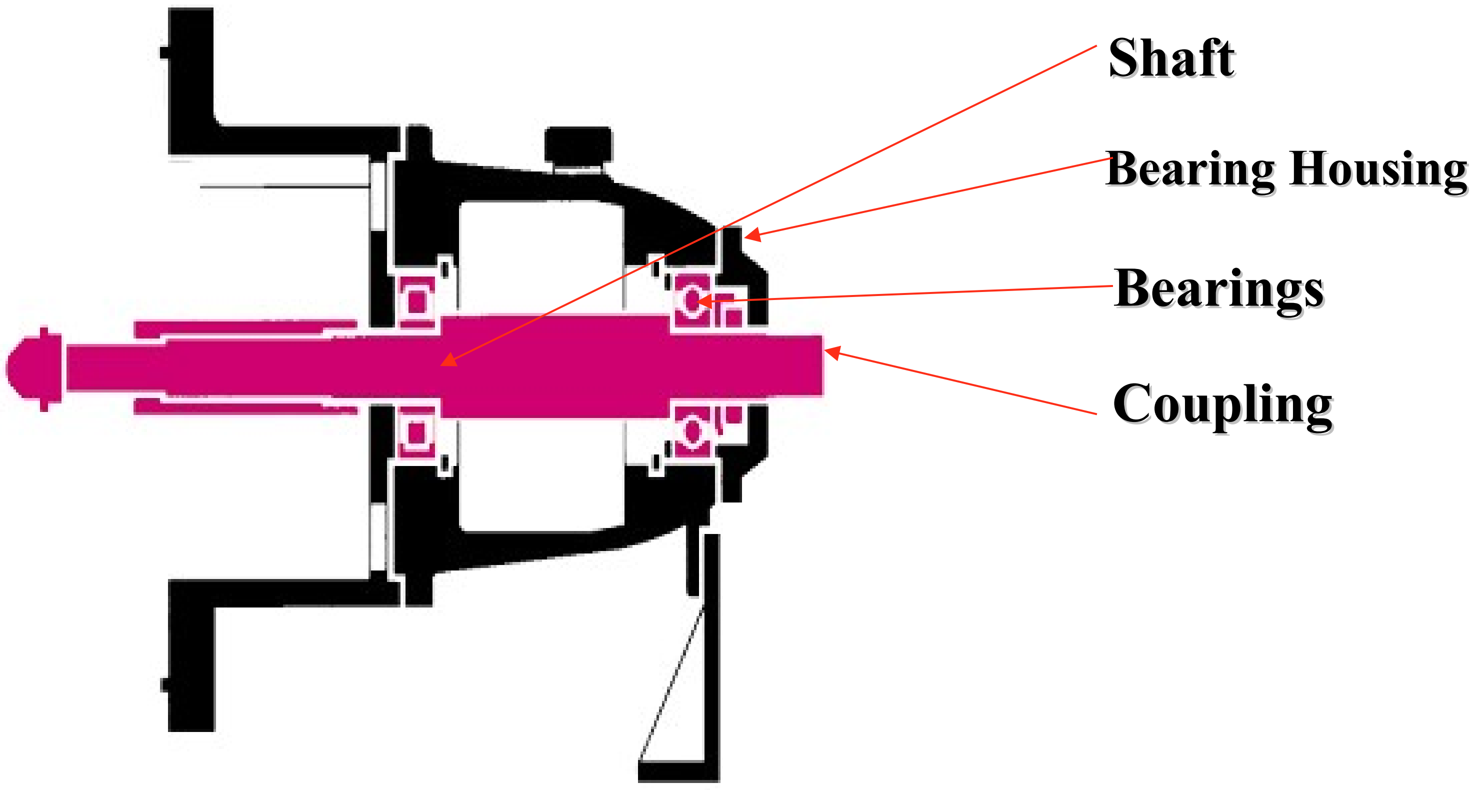
Mechanical parts
" Brg Housing, Shaft…

Parts of Pump

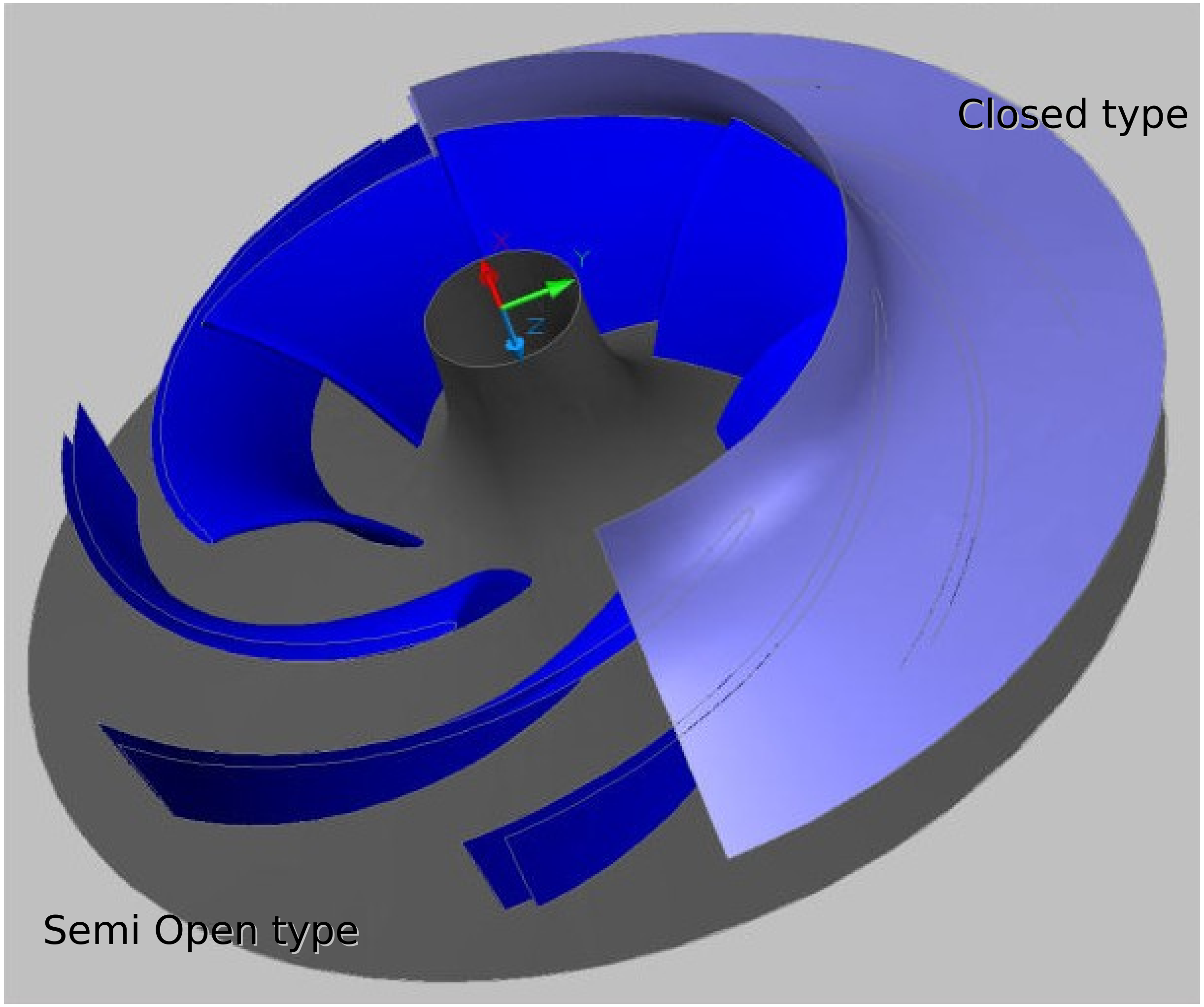
Hydraulic Parts



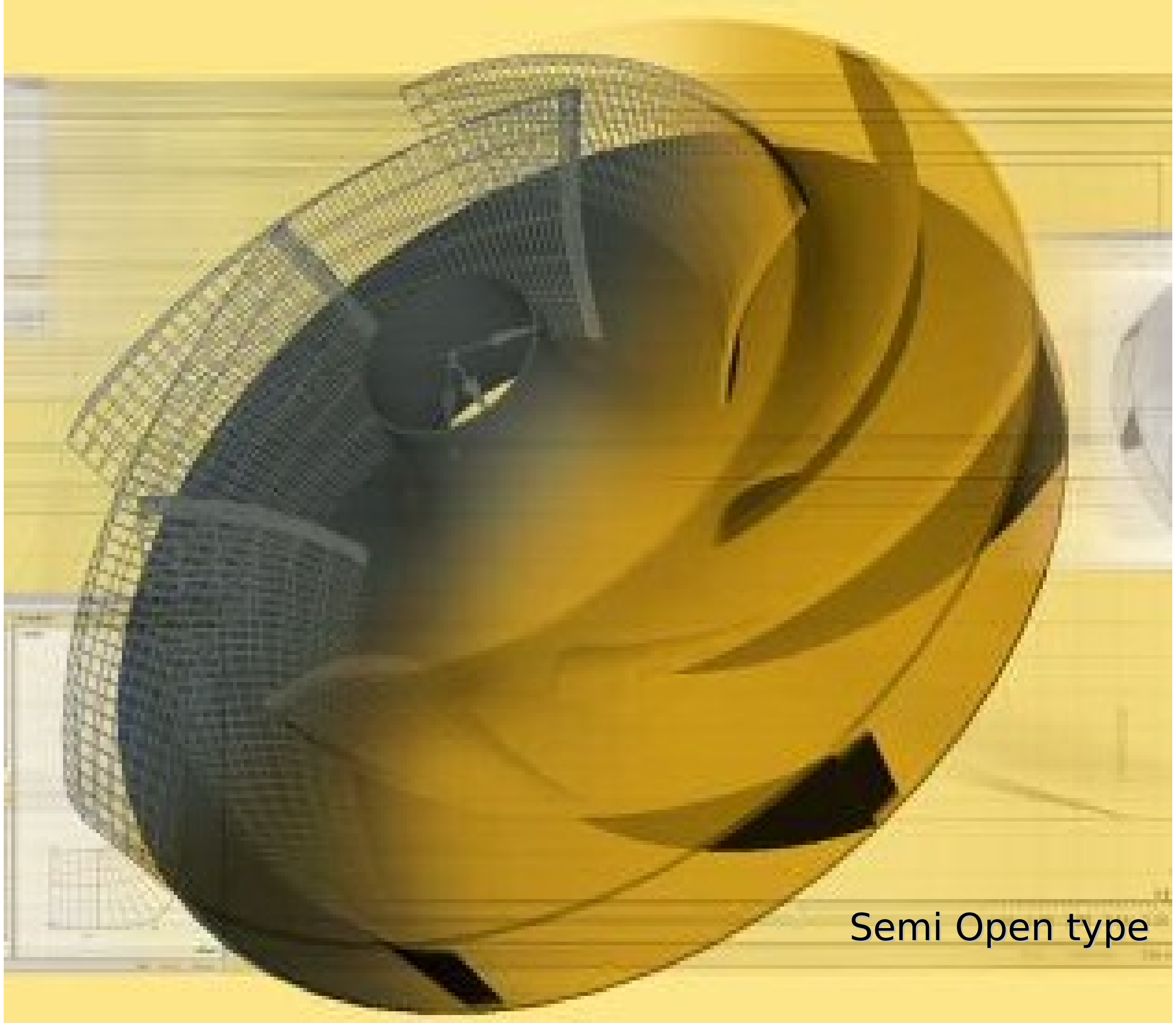
Mechanical Parts



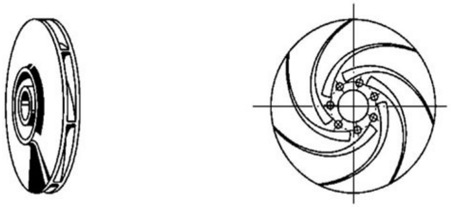
IMPELLER



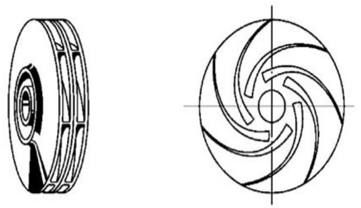
IMPELLER



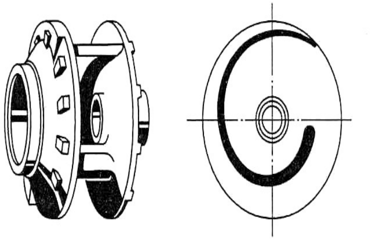
Impeller types (selection)



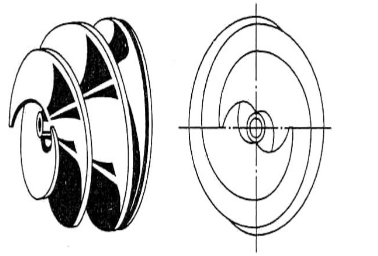
Radial impeller *)



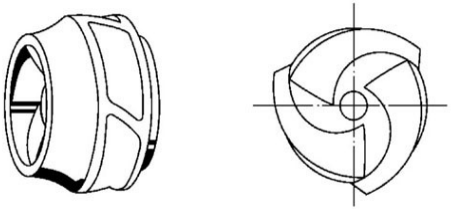
Double-flow radial impeller *)



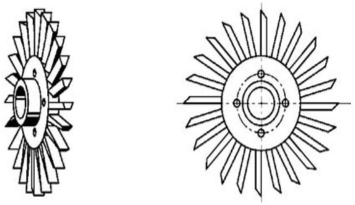
Closed single-vane impeller *) for waste water containing solid or long, stringy substances



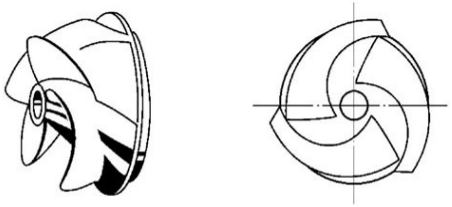
Worm type impeller for waste water with coarse, solid or long stringy substance- or for sludges with a dry solids content of 5 to 8%



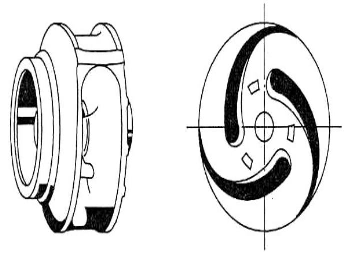
Closed mixed flow impeller *)



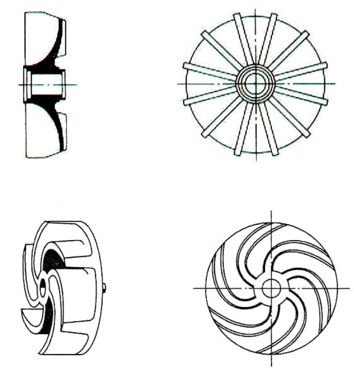
Star impeller for side channel pump (self-priming)



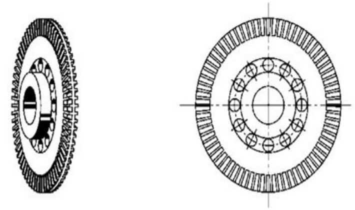
Open mixed flow impeller



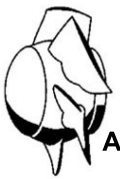
Closed channel impeller *) for sludge or liquids containing solids, neither of which liberate gases, without long fibrous matter



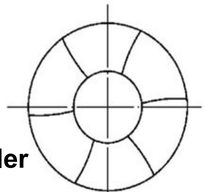
Free flow impeller for liquids with coarse or long, stringy substances containing gas bubbles



Peripheral impeller for very small specific speeds (n_q = 5 to 10)

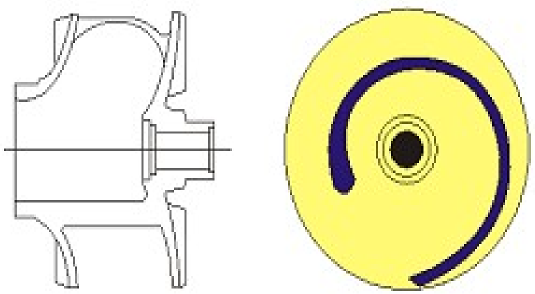


Axial impeller

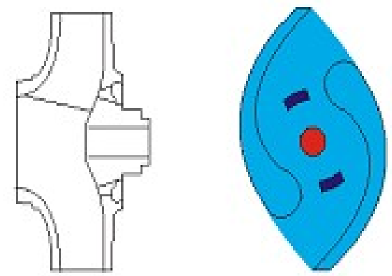


*) Plan view, with shroud removed

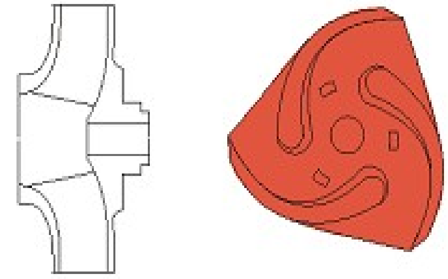
Non-clogg impellers



a. Single vane impeller, closed

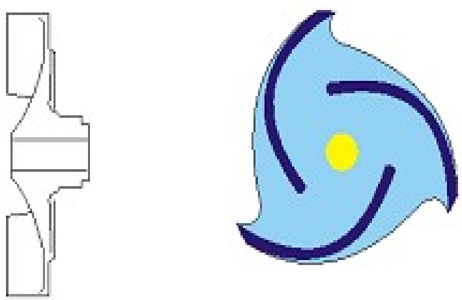


b. Two passage impeller, closed

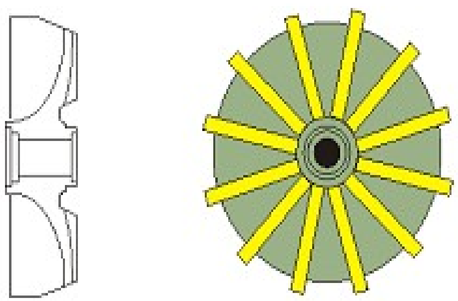


c. Three passage impeller, closed

Special Impellers



a. Three vane open impeller



b. Free flow impeller

SPECIFIC SPEED OF IMPELLER

SPECIFIC SPEED IS THE TERM USED TO CLASSIFY PUMPS ON THE BASIS OF THEIR PERFORMANCE AND DIMENSIONAL PROPERTIES .

IT IS THE SPEED IN RPM OF AN IMAGINARY PUMP GEOMETRICALLY SIMILAR IN EVERY RESPECT TO THE ACTUAL PUMP AND CAPABLE OF DELIVERING 75KG OF WATER PER SECOND TO A HEAIGHT OF 1M. SPECIFIC SPEED IN METRIC UNIT IS GIVEN BY:

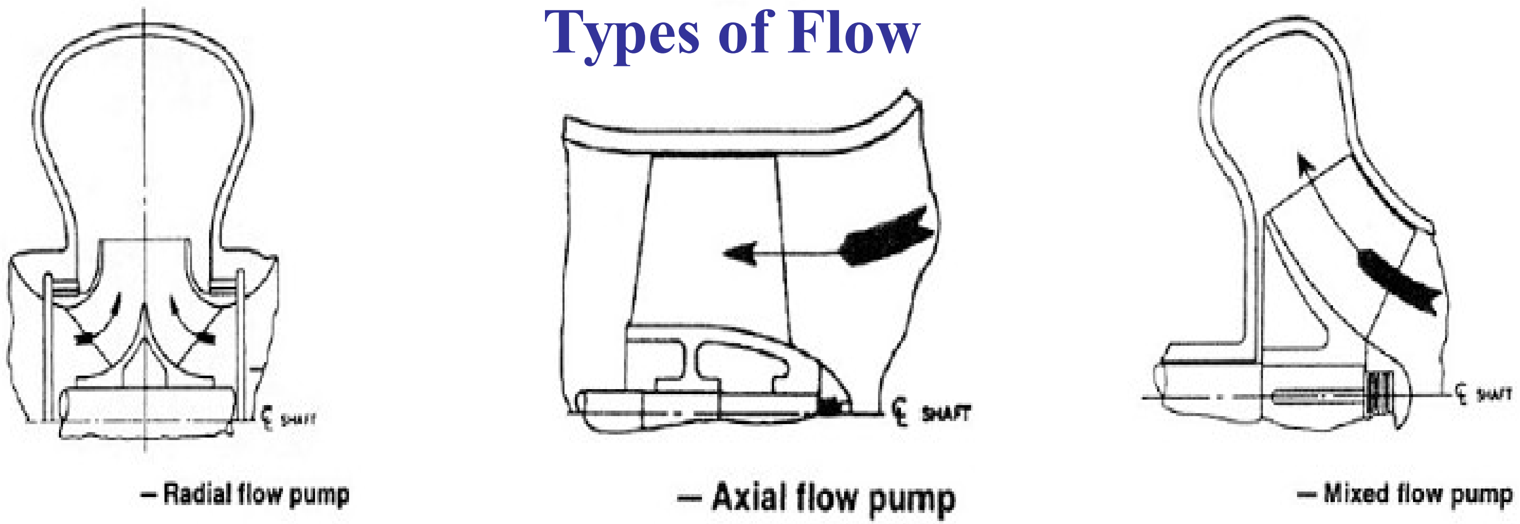
$$Ns = \frac{3.65 X N X Q^{1/2}}{H^{3/4}}$$

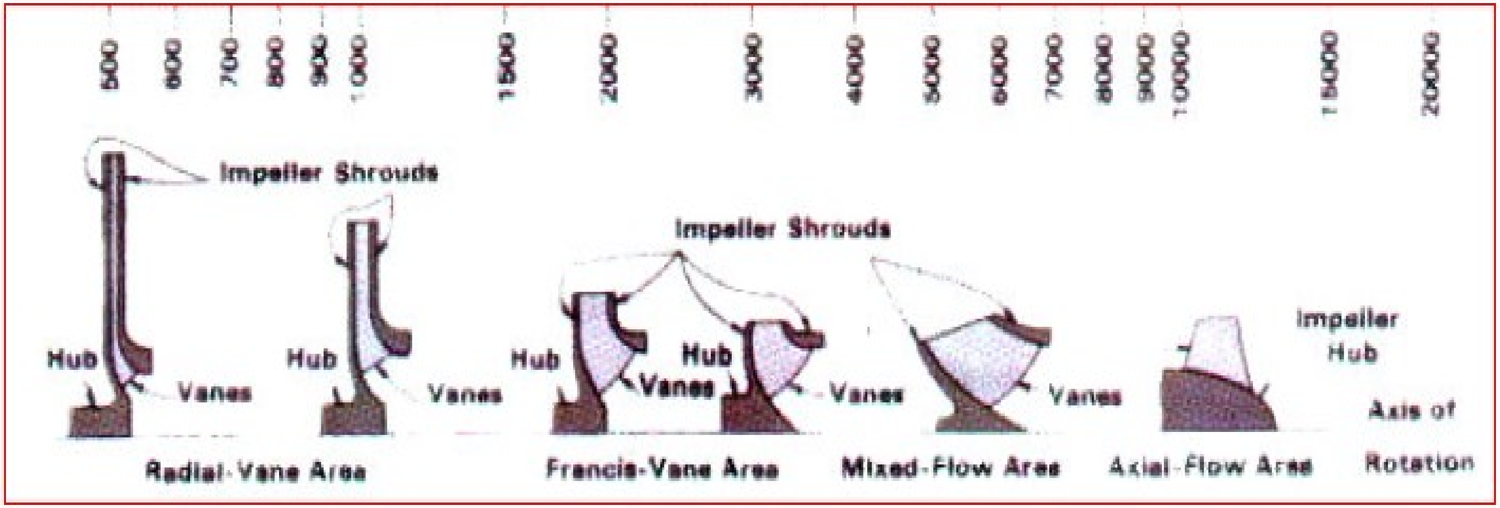
N – Speed in rpm

H – head in meters (per stage)

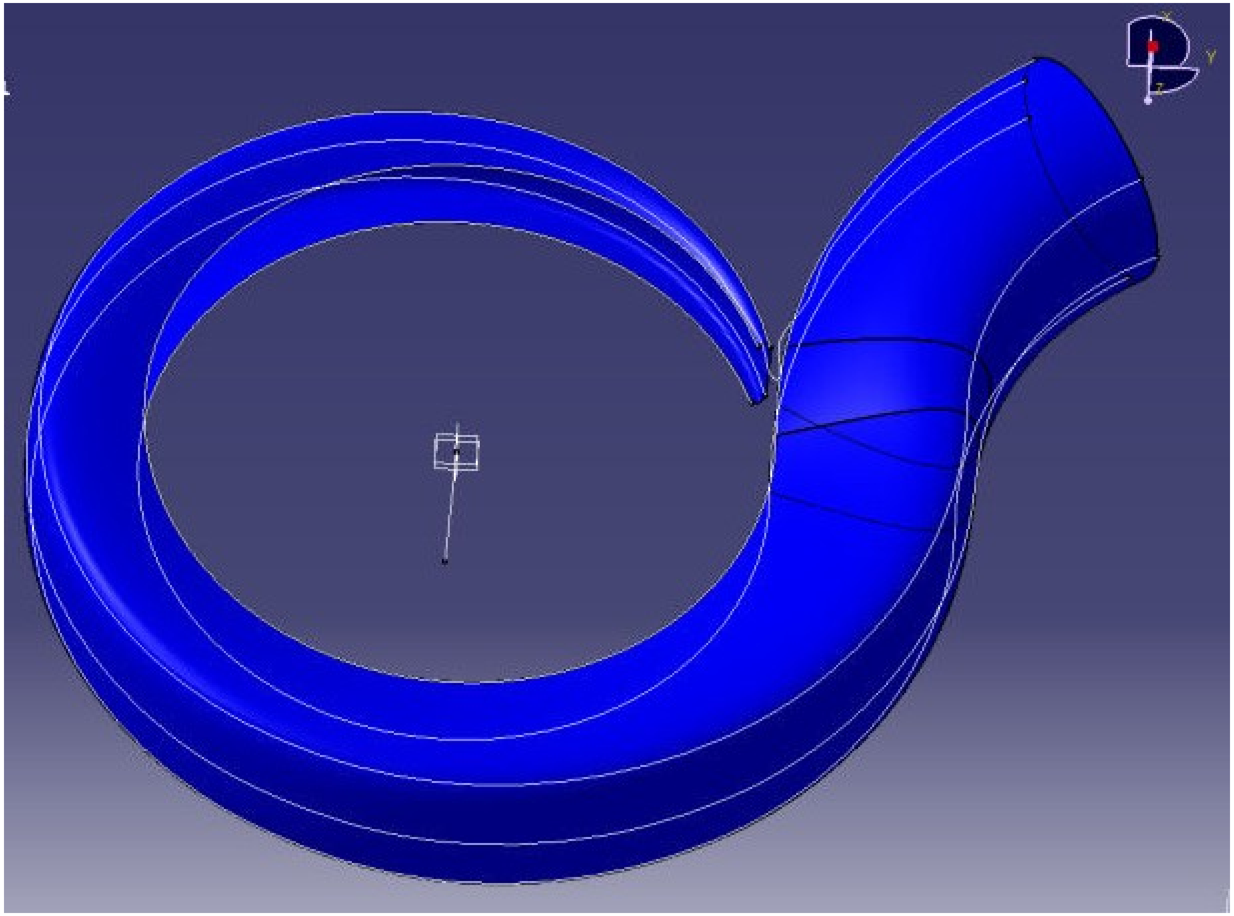
Q – Discharge in m^3/sec

Types of Flow

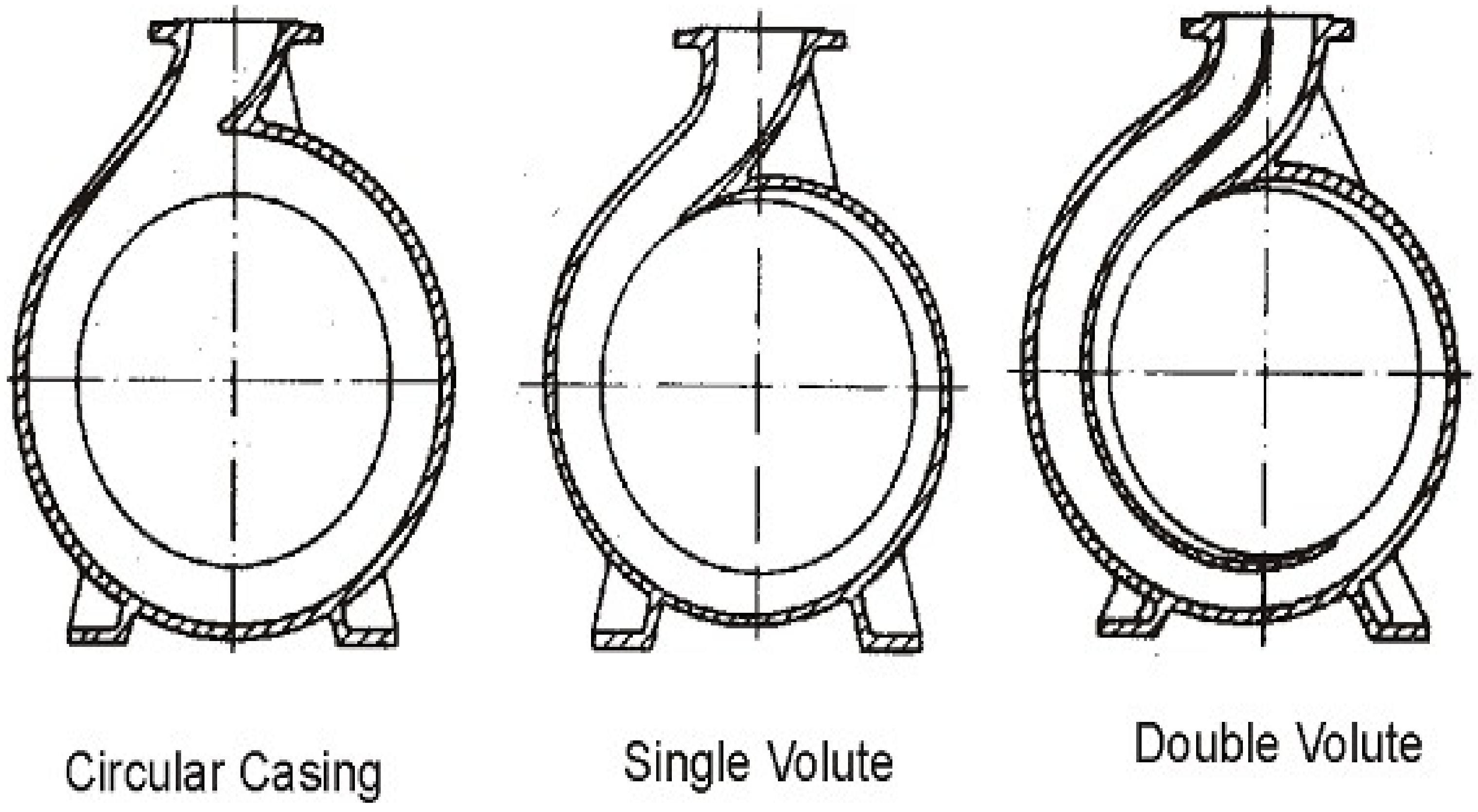




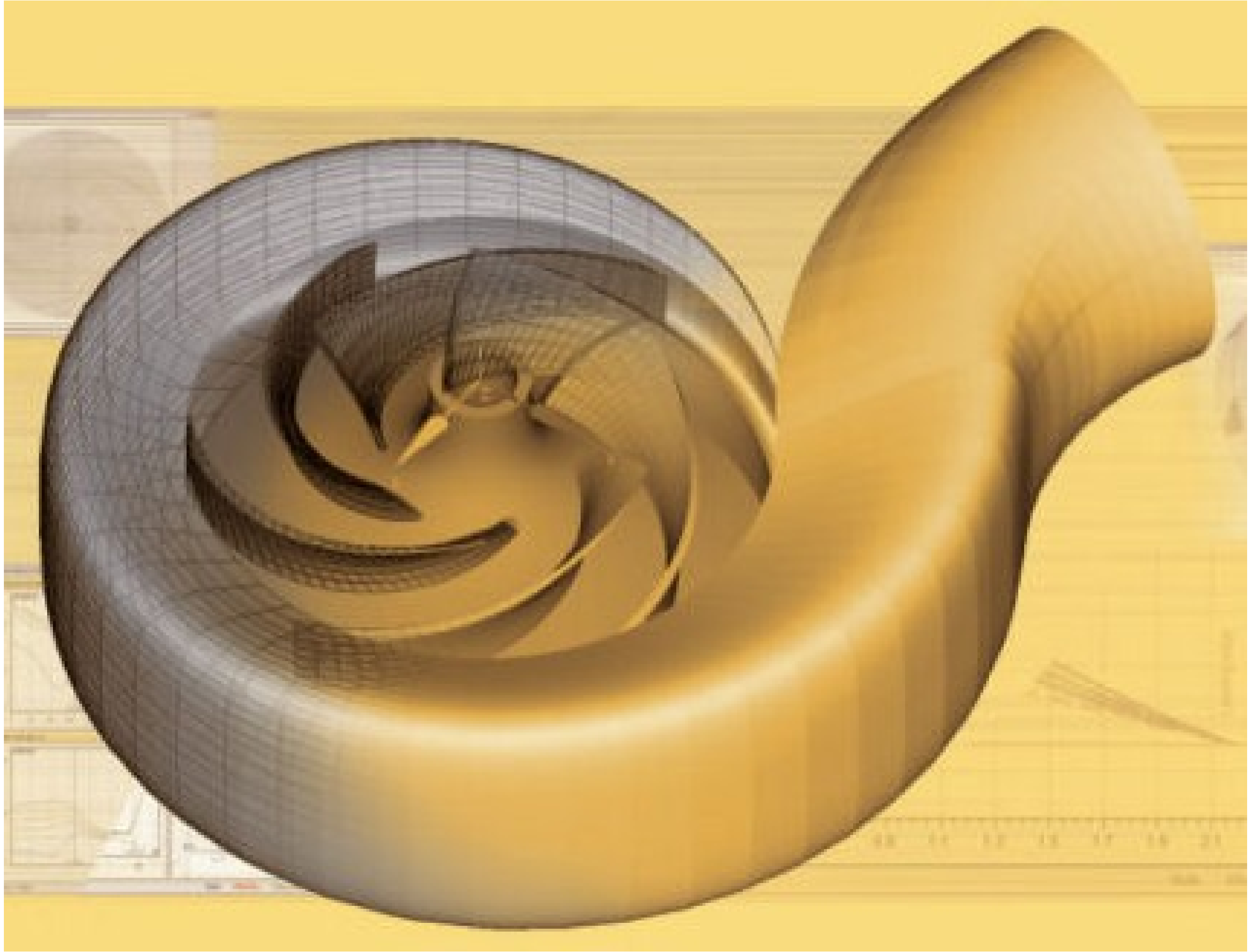
Volute Casing



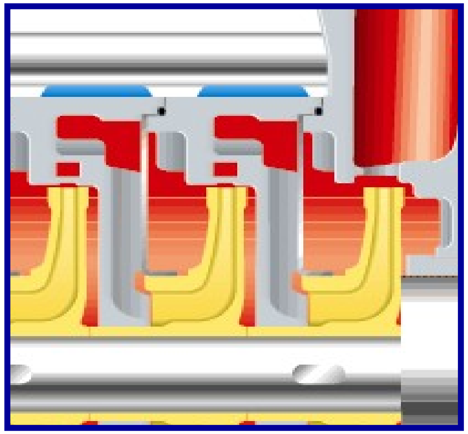
Types of Volute Casings



Typical Volute casing with Semi open Impelle

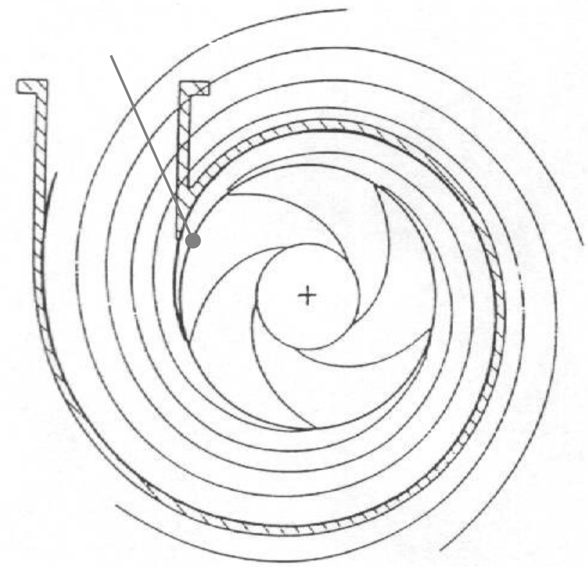


Diffuser / Return guide vanes

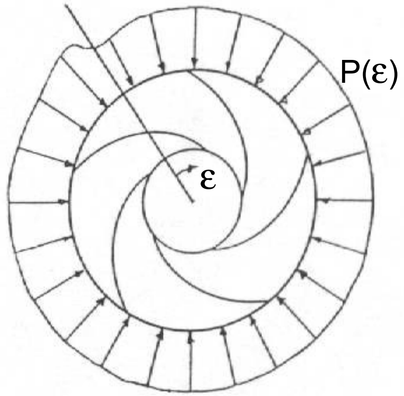


Diffuser devices

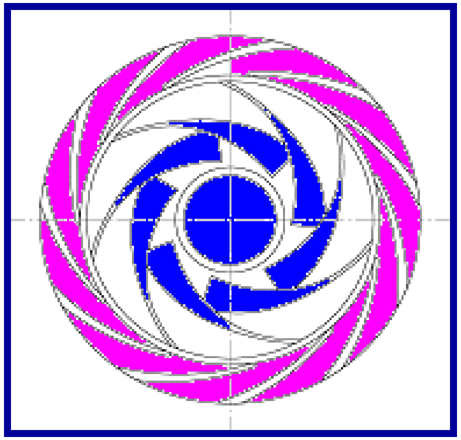
Volute



Form of volute casing based upon stream line at $Q = Q_{design}$



Pressure distribution on impeller circumference $Q = Q_{Design}$



"Diffusing" (diffuser effect), Conveyance to the next stage

SHAFT

SHAFT IS A COMPONENT THAT CARRIES ALL THE ROATATING PUMP PARTS AND ALSO PROVIDES POWER TO THE IMPELLER.

THE SHAFT HAS TO WITHSTAND THE ROTATING TORQUE ,AXIAL AND RADIAL THRUST.

SHAFT MATERIAL IS SELECTED CONSIDERING THE FOLLOWING:

1. **CRITICAL SPEED**
2. **ENDURANCE LIMIT**
3. **CORROSION RESISTANCE**
4. **NOTCH SENSITIVITY**

STUFFING BOX

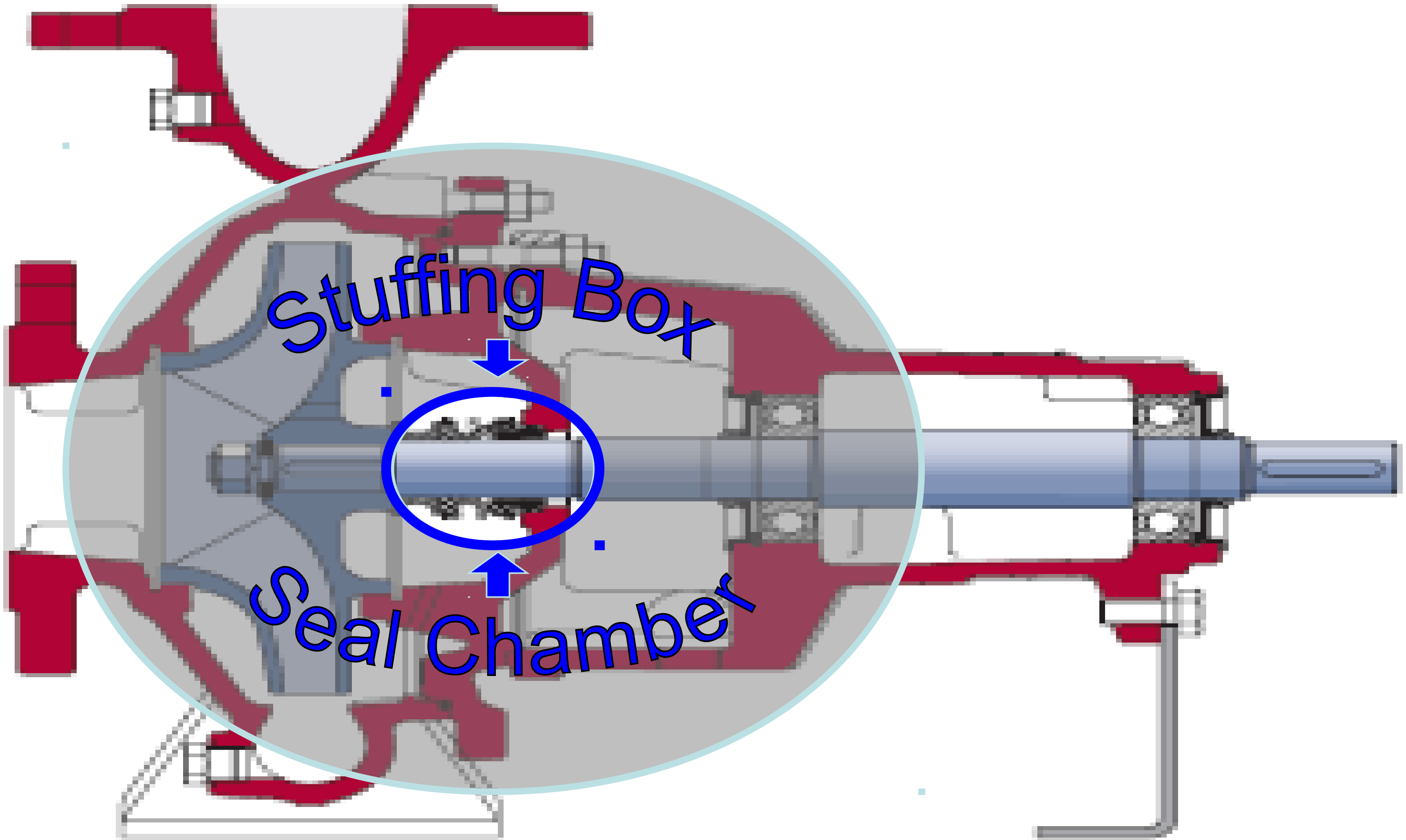
THE PURPOSE OF A STUFFING BOX IS TO SEAL OFF THE SPACE AROUND THE ROTATING SHAFT WHERE IT PASSES THROUGH THE DELIVERY CASING OF THE PUMP.

GLAND PACKING AND MECHANICAL SEAL_ARE COMMONLY USED IN PUM

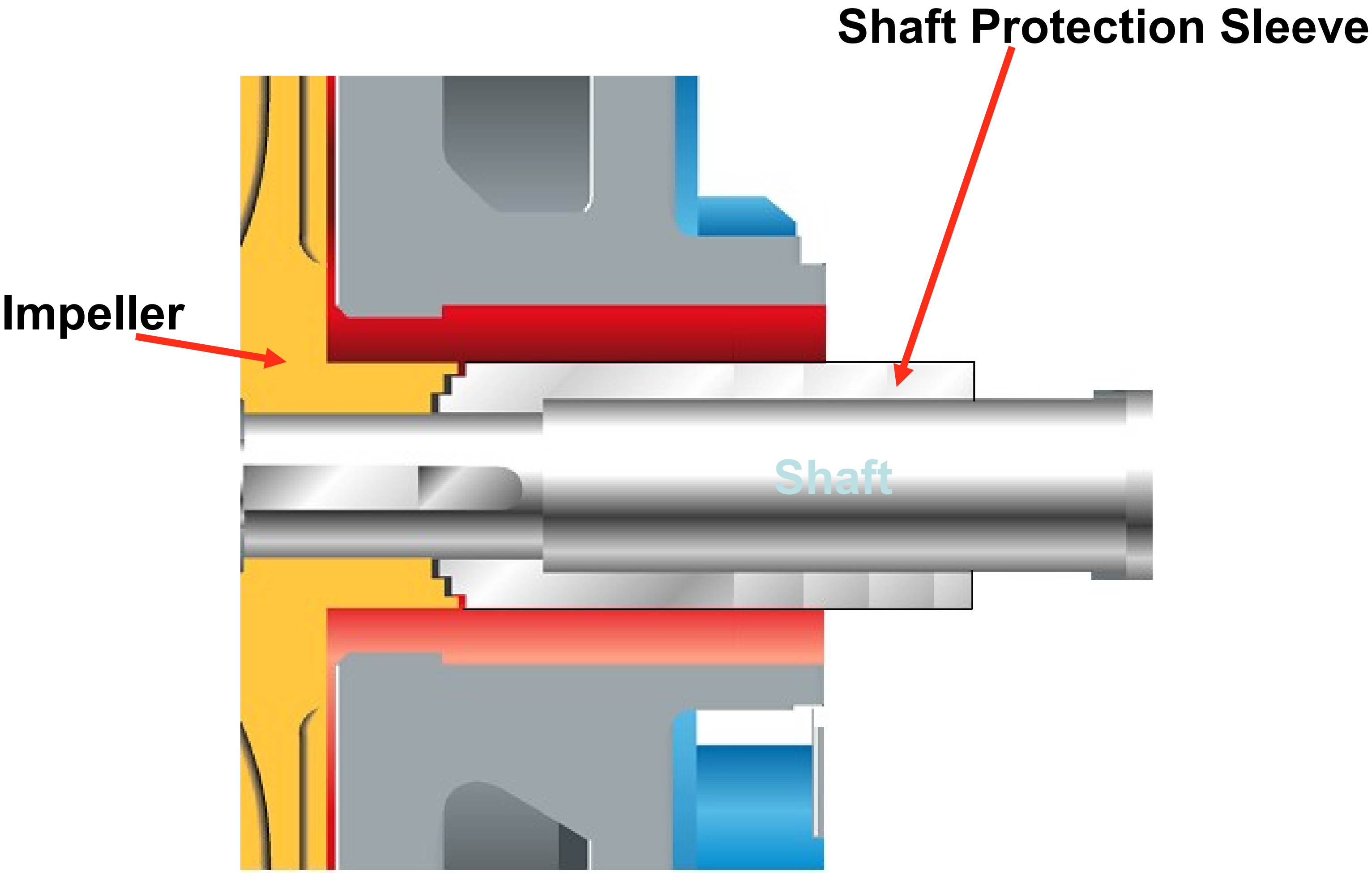
MECHANICAL SEAL OR SHAFT SEAL HAS A STATIONARY PART /FACE WHICH MATTS WITH THE ROTATING FACE VERY SMOOTHLY UNDER PRESSURE EXERTED BY A SPRING WHICH GETS ITS ENERGY PARTIALLY BY PRECOMPRESSION GIVEN MANUALLY AND FROM PRESSURE ENERGY OF THE LIQUID.

SEAL TYPES - O RING, BELLOW, CARTRIDGE

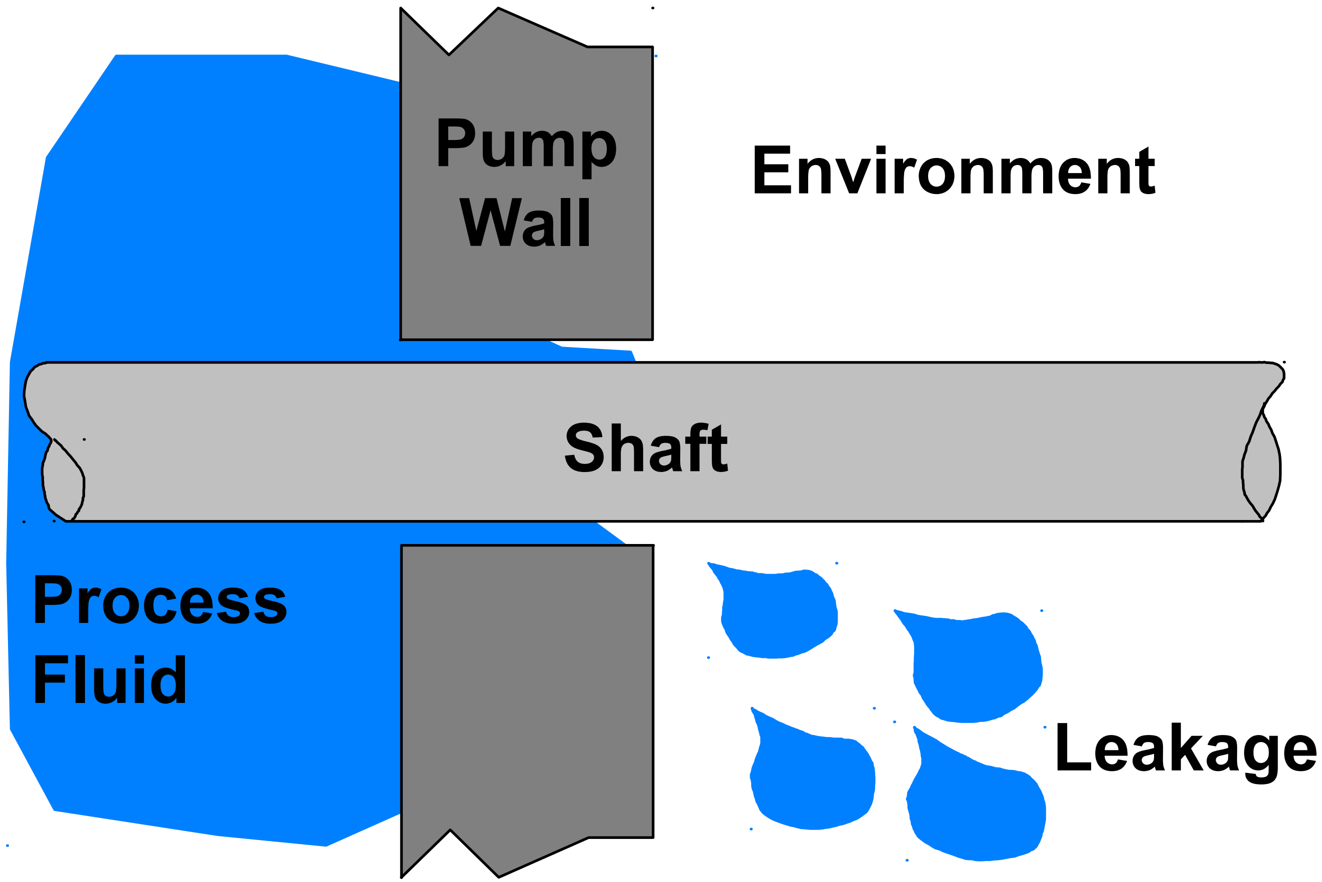
Need to Seal a Pump



Stuffing Box / Seal Chamber



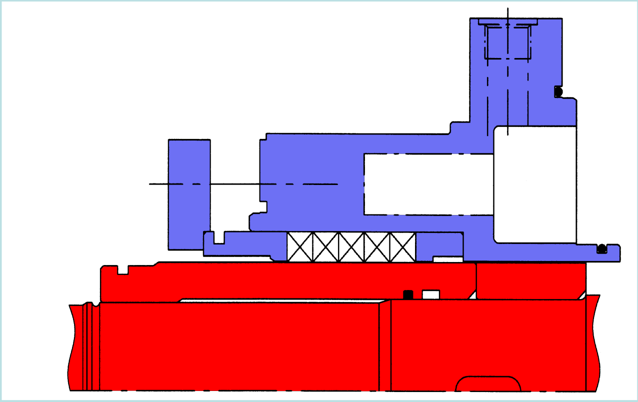
Need to Seal a Pump

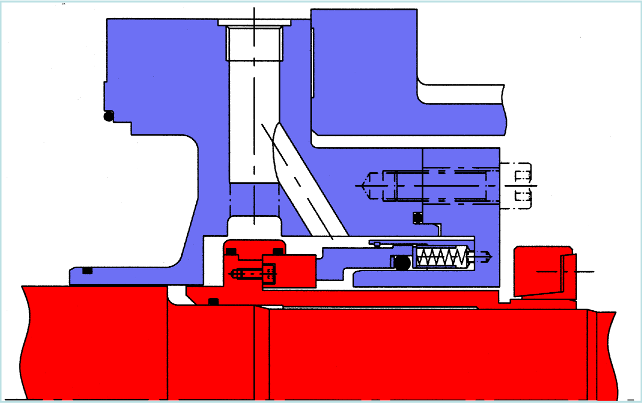


Seal Types

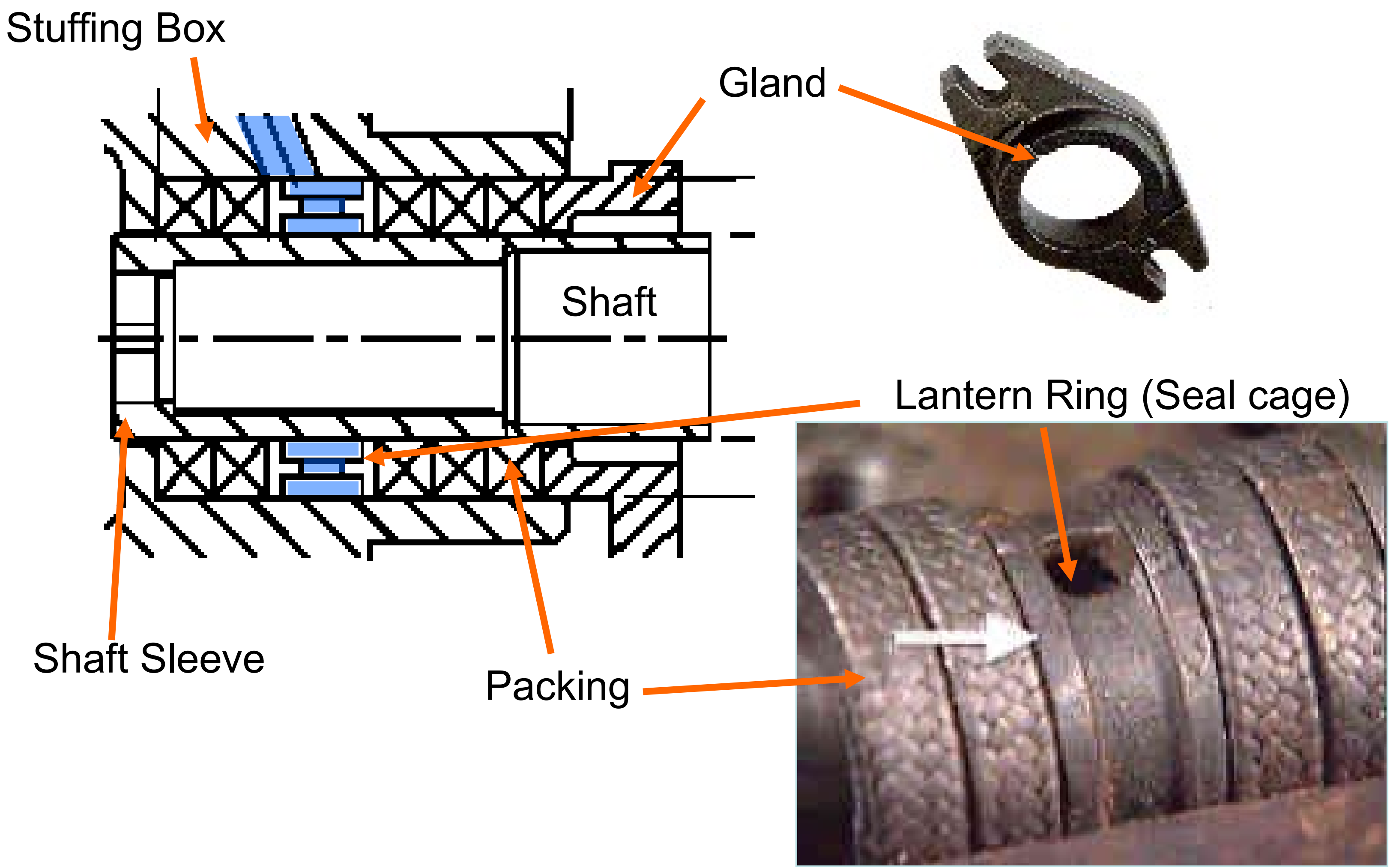
Gland Packing

Mechanical Seal

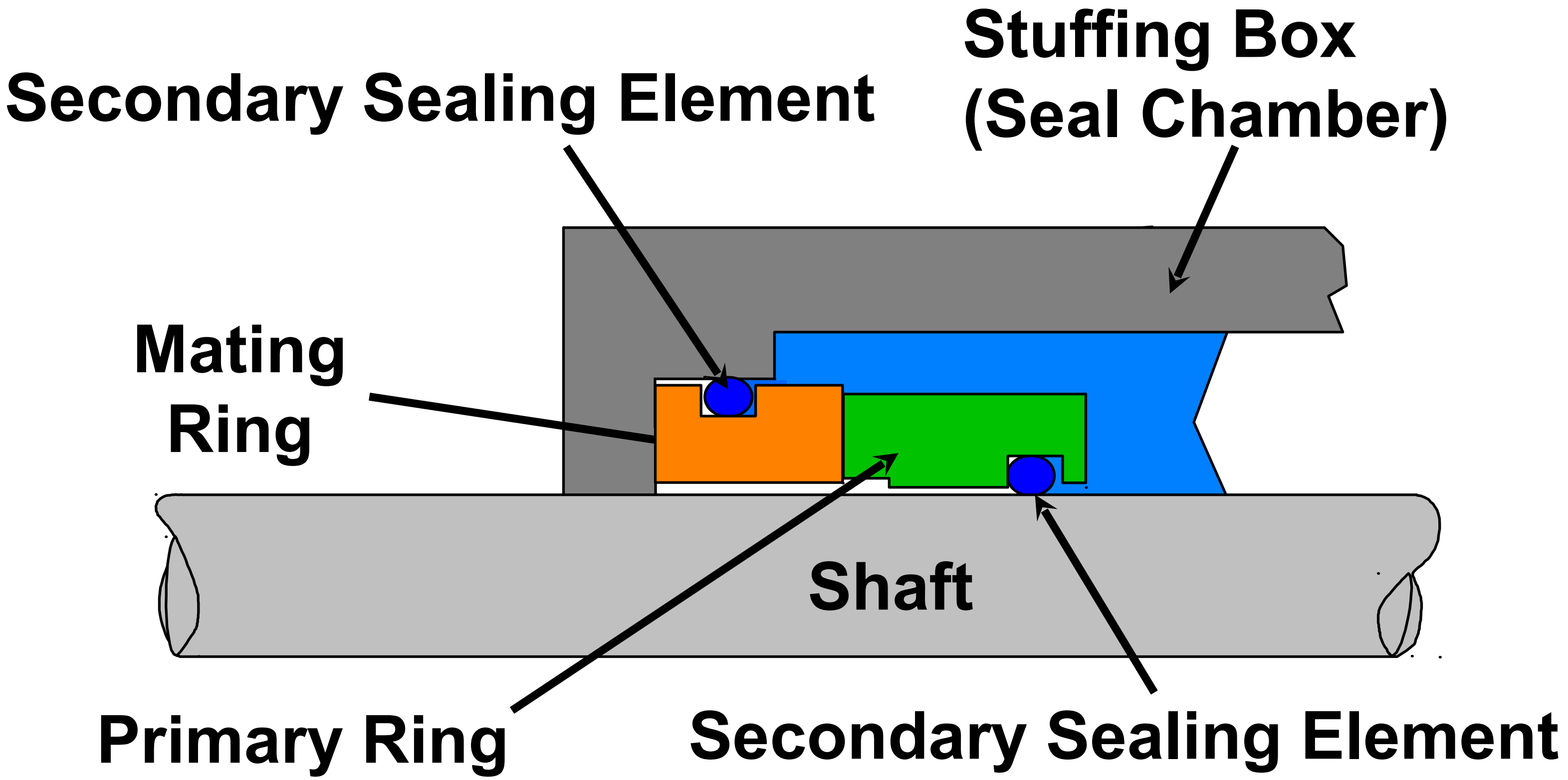




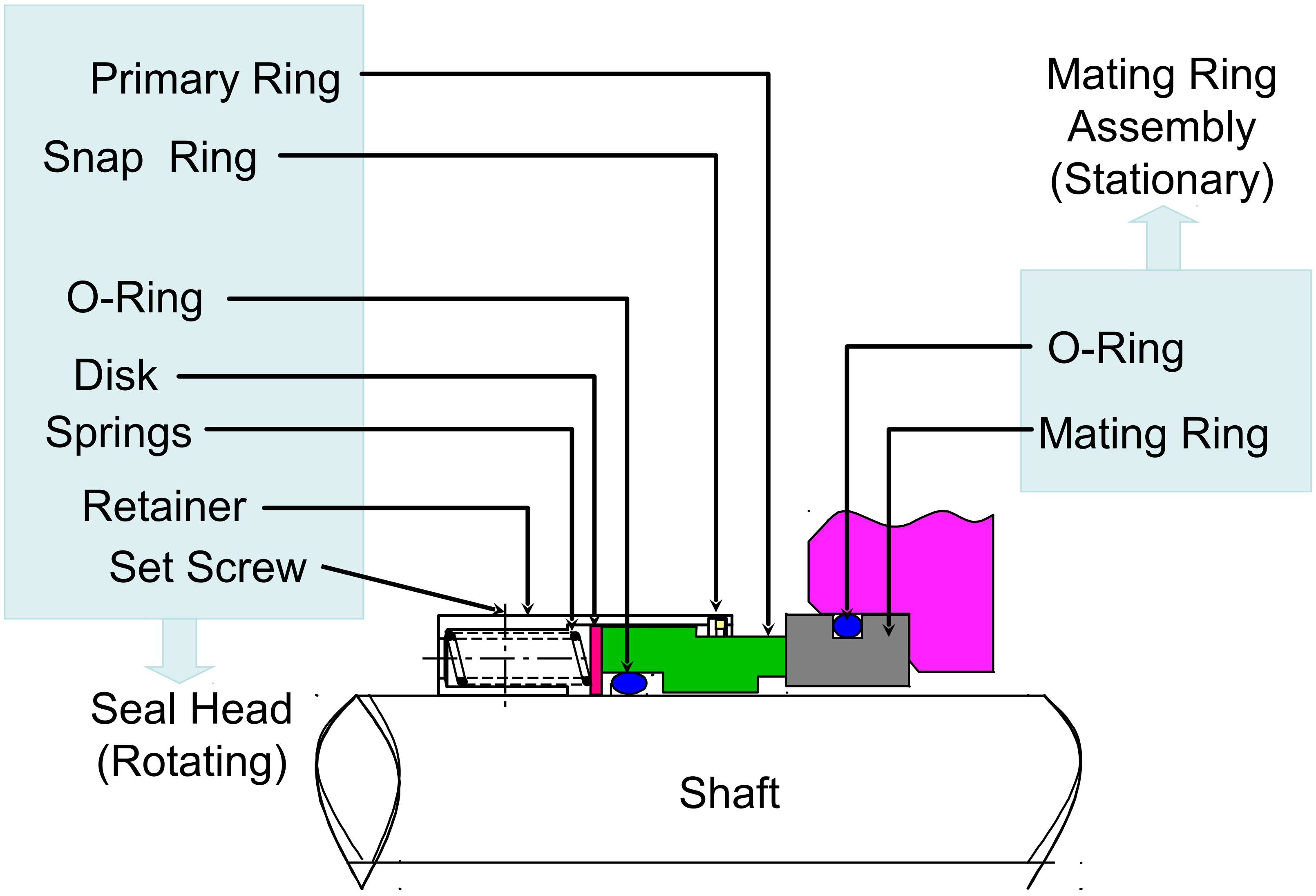
Gland Packing



Mechanical Seal

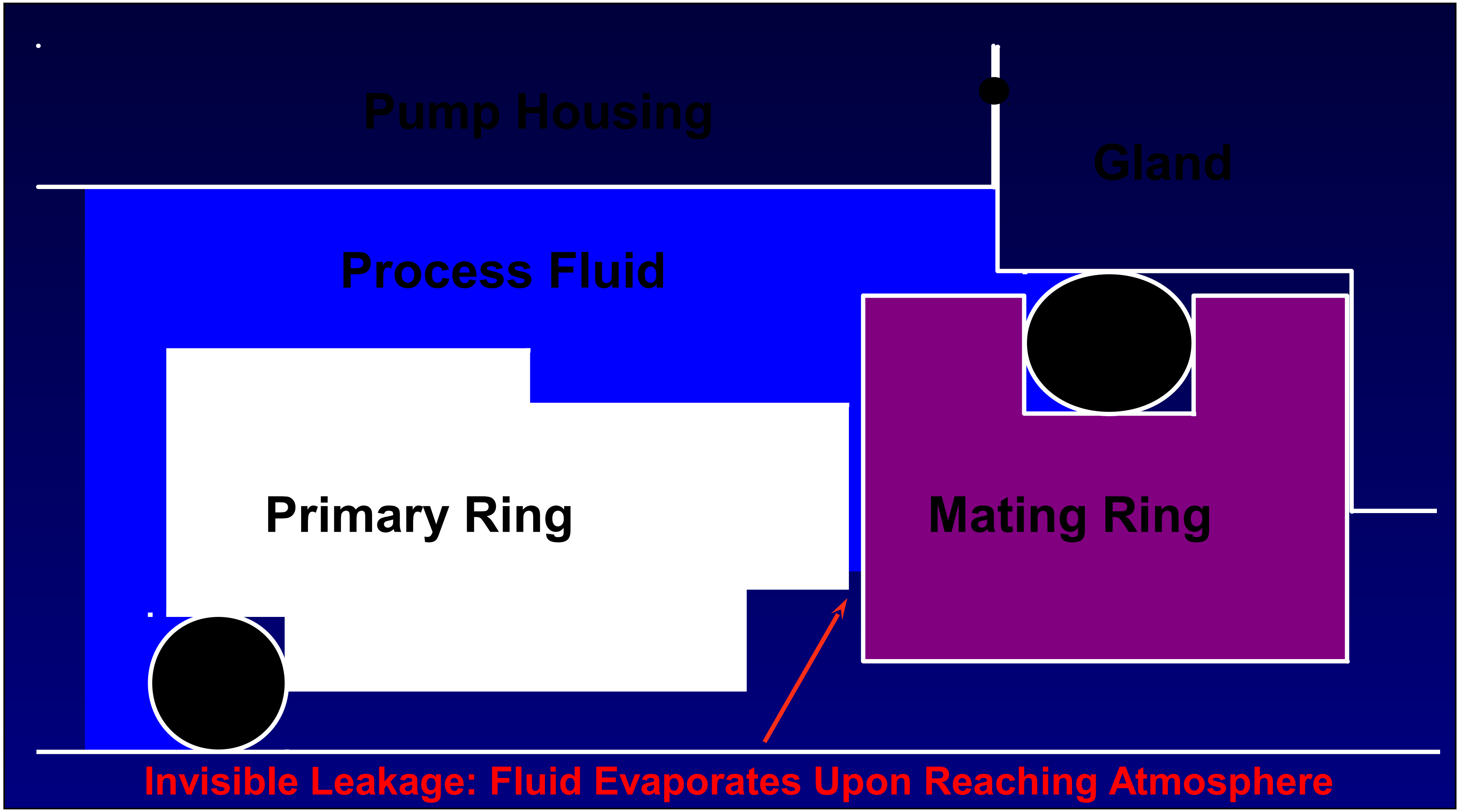


Mechanical Seal



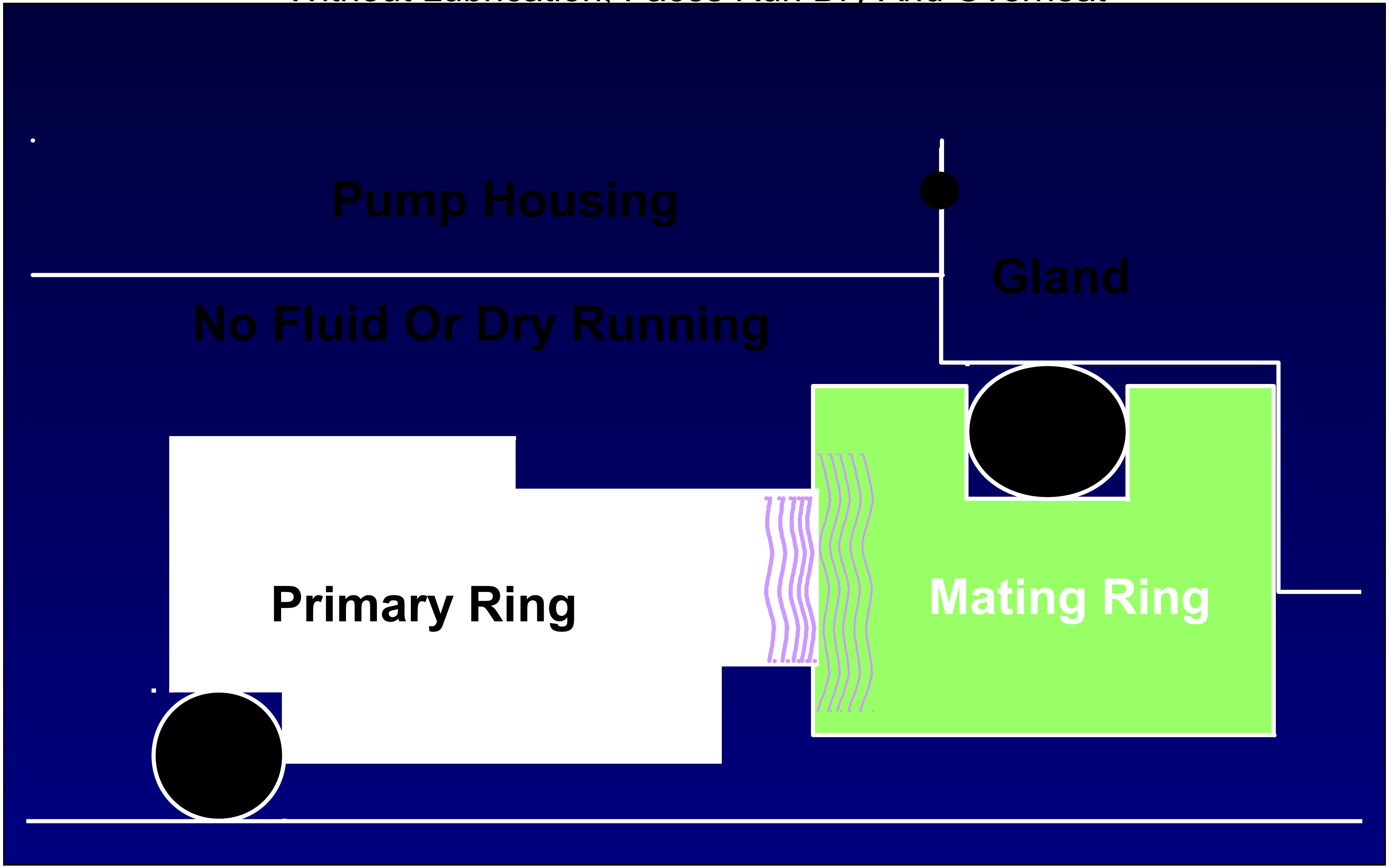
Mechanical Seal

Process Fluid Acts as Lubricant Between Faces



Mechanical Seal

Without Lubrication, Faces Run Dry And Overheat



BEARINGS

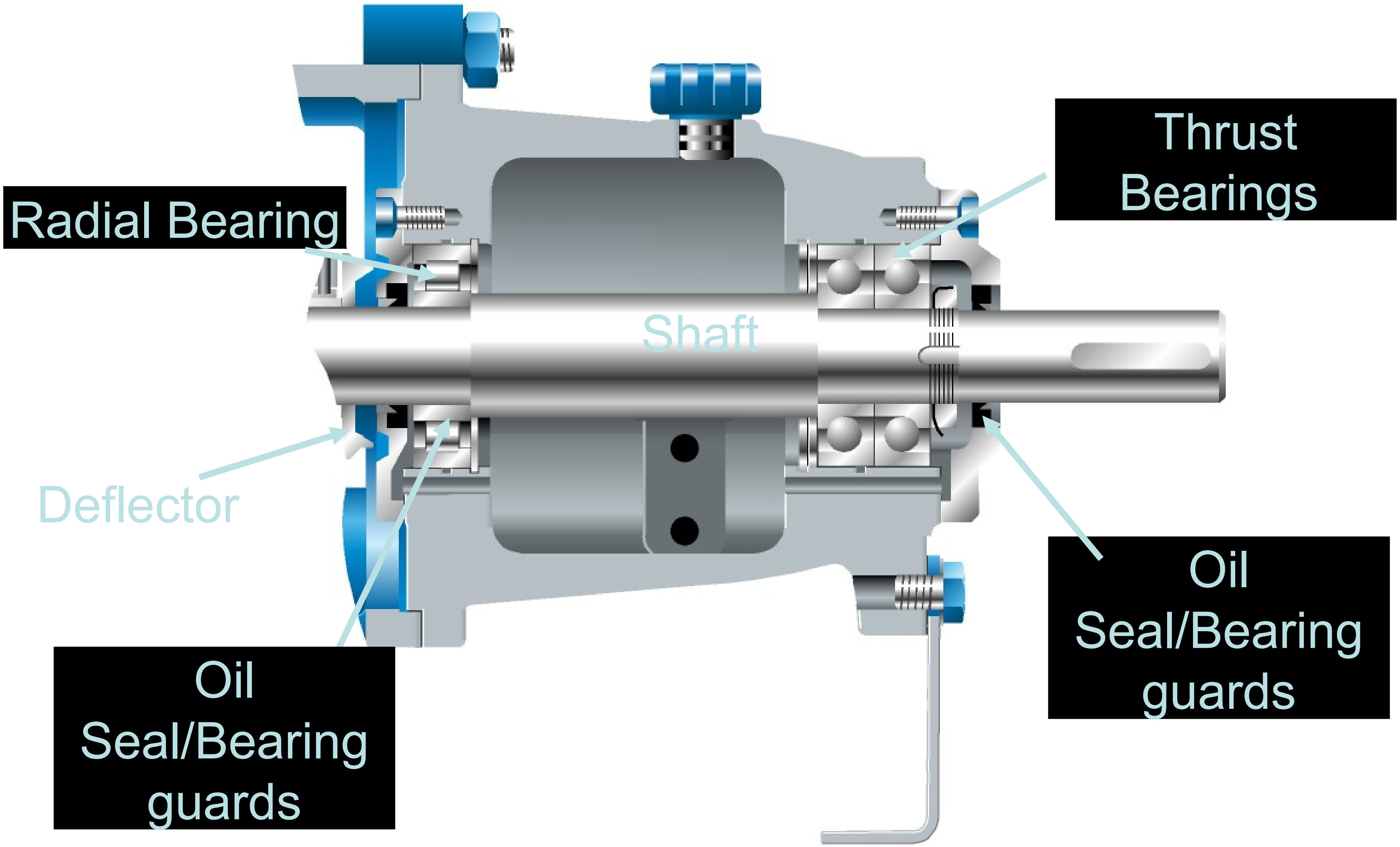
BEARINGS ARE THE MEDIUMS WHICH KEEP THE SHAFT OR ROTOR IN CORRECT ALIGNMENT WITH ITS STATIONARY PARTS UNDER THE ACTION OF AXIAL AND RADIAL THRUSTS.

BEARINGS WHICH ARE DESIGNED TO TAKE RADIAL THRUST ONLY ARE CALLED LINE BEARINGS AND THOSE DESIGNED FOR AXIAL THRUST ARE CALLED THRUST BEARINGS

TYPES

1. **BUSH BEARINGS**
2. **ANTIFRICTION BEARINGS**

Bearing Bracket



COUPLINGS

COUPLINGS ARE DEVICES USED FOR CONNECTING PUMP WITH THE PRIME MOVER. ITS MECHANICAL EQUIVALENT OF A FUSE

COUPLINGS ARE OF 2 TYPES

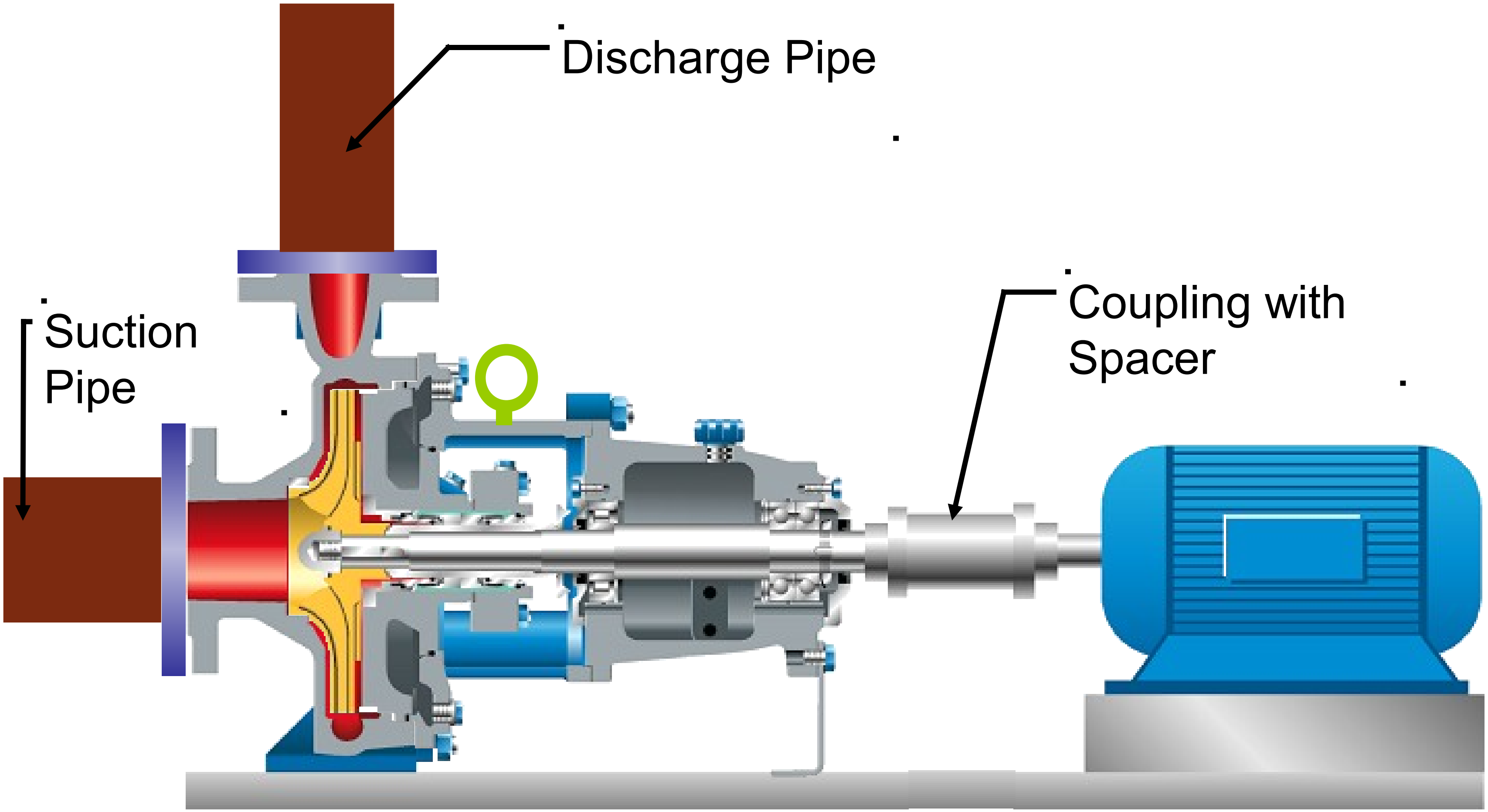
1. **RIGID**
2. **FLEXIBLE**

A COUPLING THAT CONNECTS TWO SHAFTS SOLIDLY FOR POWER TRANSMISSION IS A RIGID COUPLING. EX: SLEEVE AND CLAMP COUPLINGS

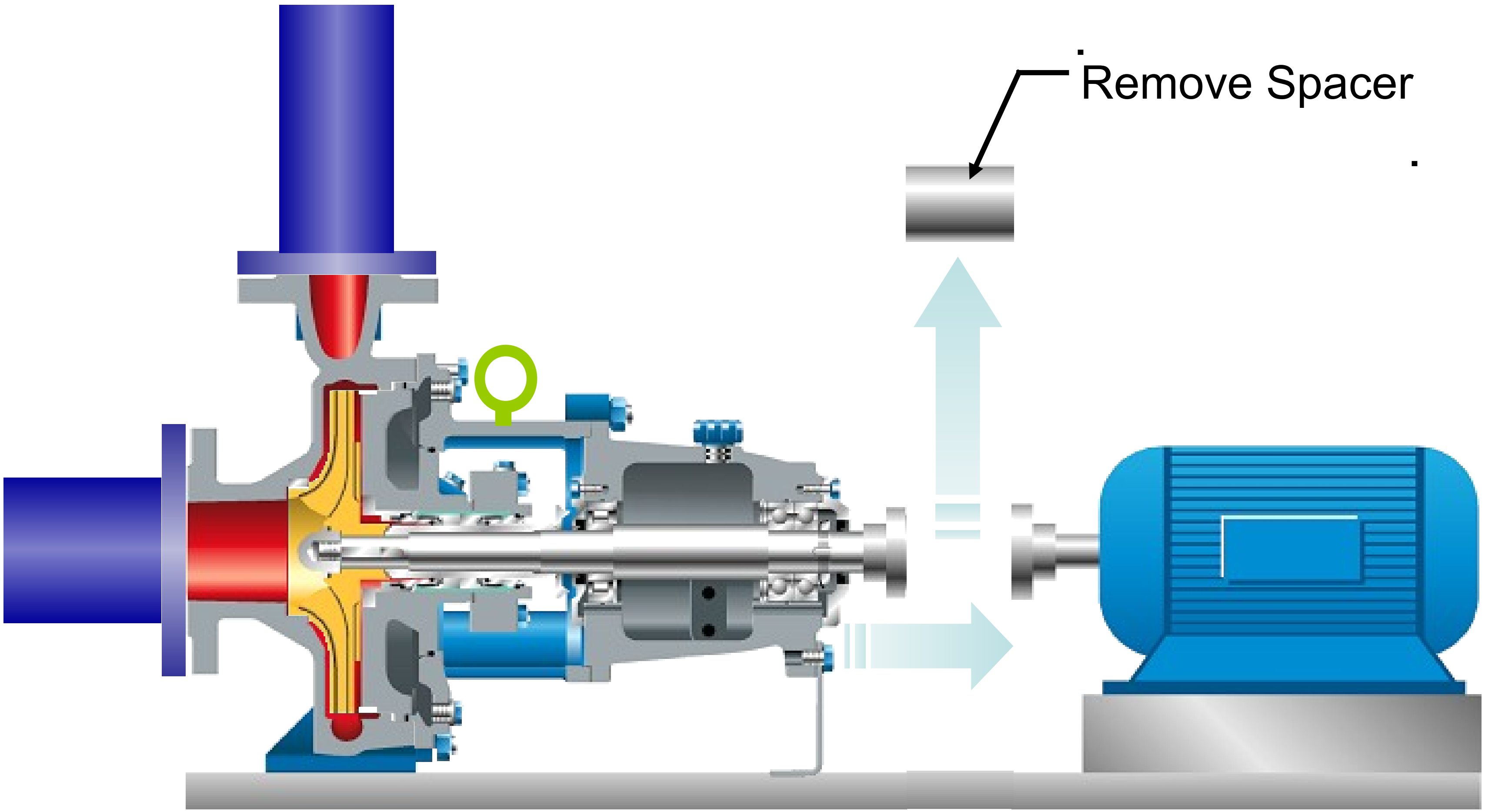
A FLEXIBLE COUPLING ALLOWS FOR EASY ASSEMBLY AND DISMANTLING , WITHOUT DISTURBING THE SHAFTS . THEY ARE USED FOR POWER TRANSMISSION BY MEANS OF MECHANICAL JOINT WITHOUT SLIP IN MOTION.

Ex: PIN AND BUSH TYPE, LOVEJOY , DISC TYPE COUPLINGS

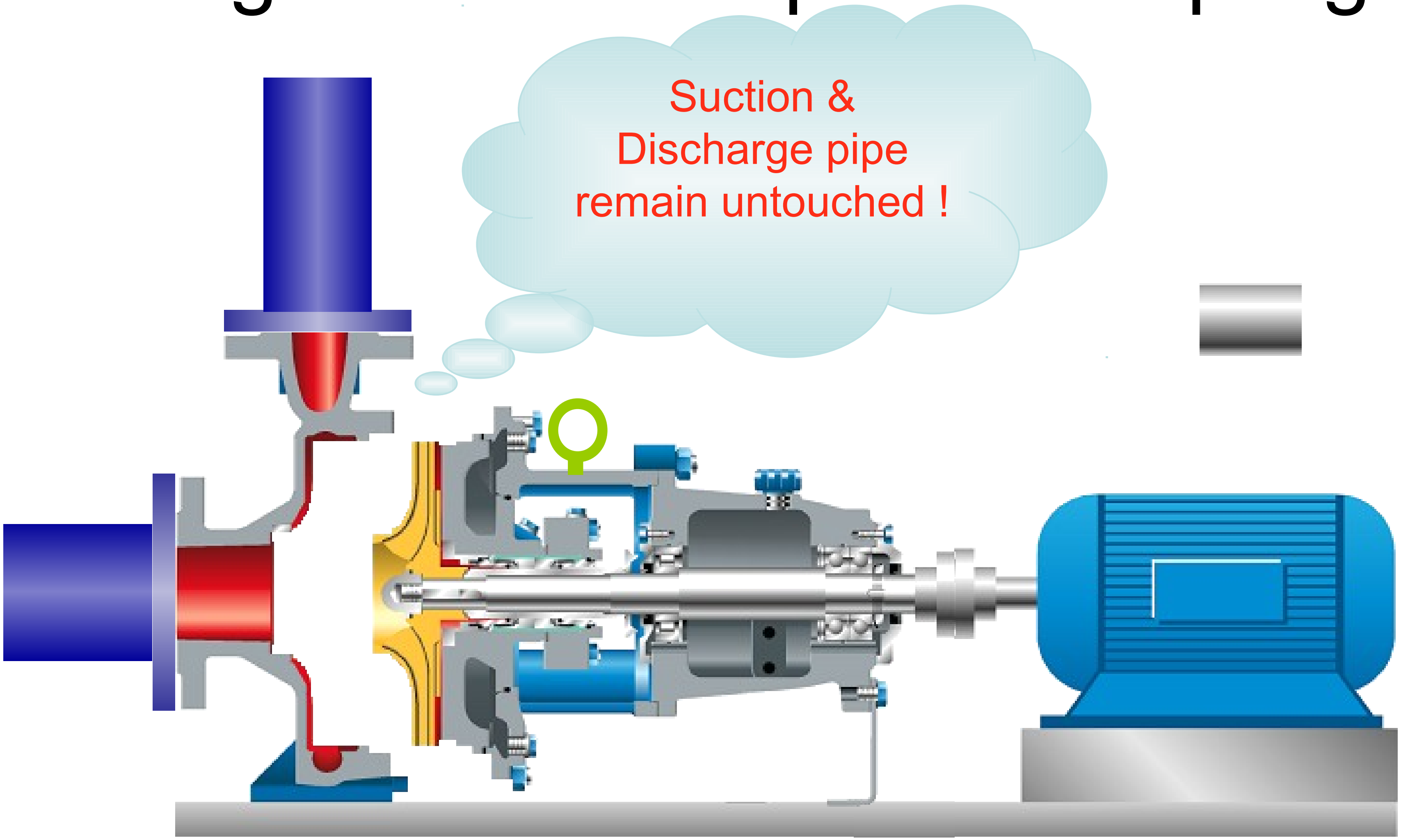
End-Suction, Back Pull-out Arrangement with Spacer Coupling



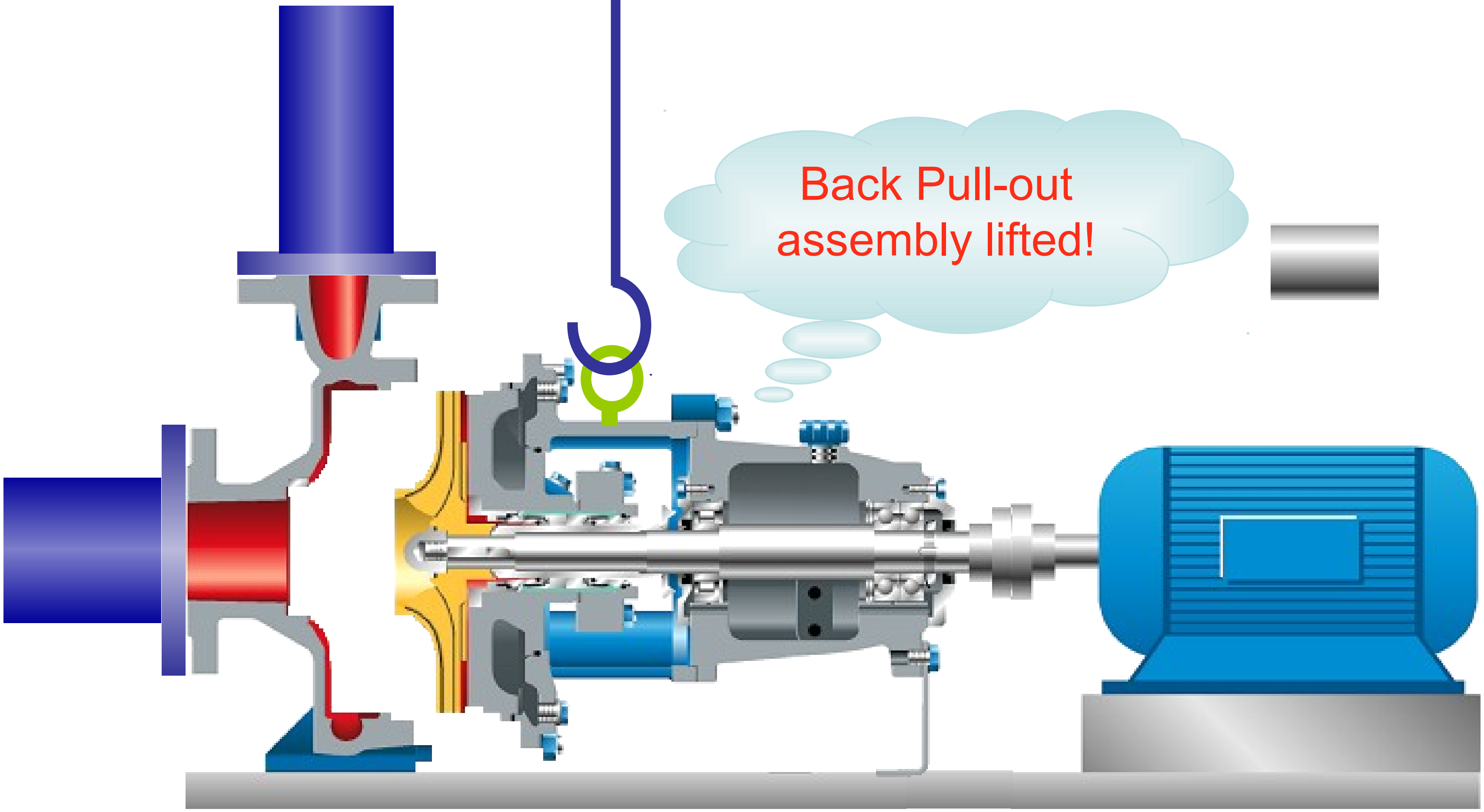
End-Suction, Back Pull-out Arrangement with Spacer Coupling



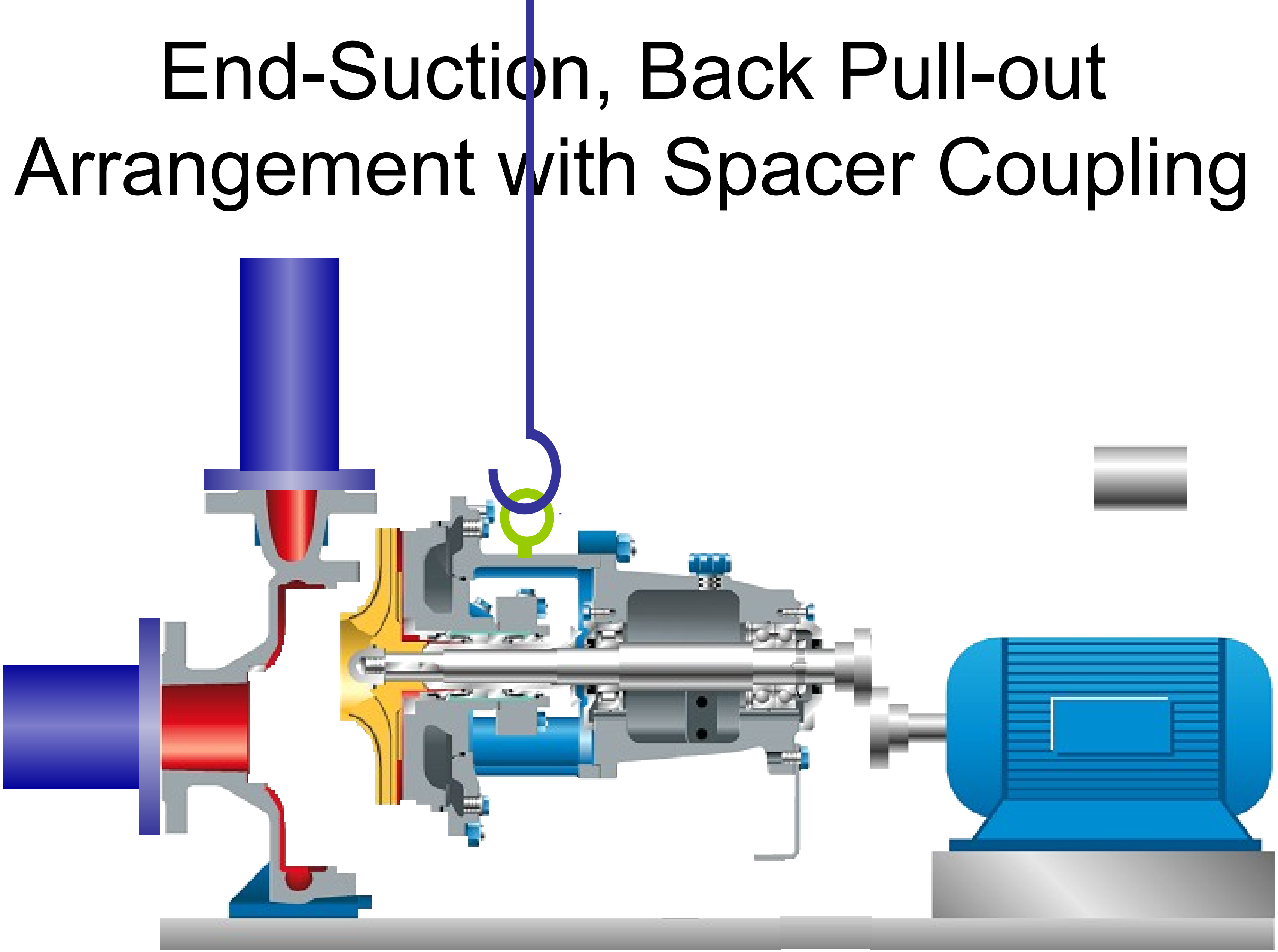
End-Suction, Back Pull-out Arrangement with Spacer Coupling



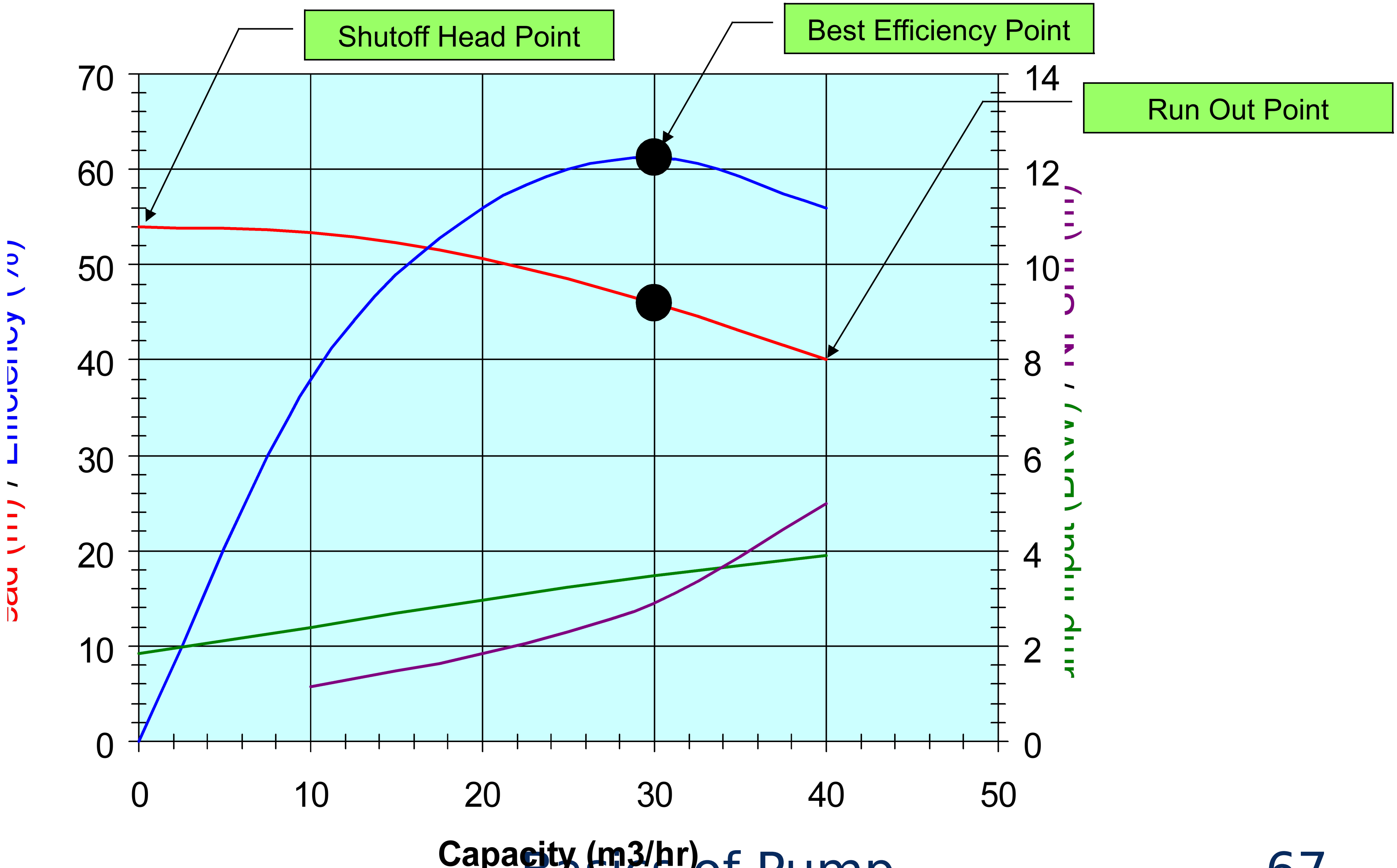
End-Suction, Back Pull-out Arrangement with Spacer Coupling



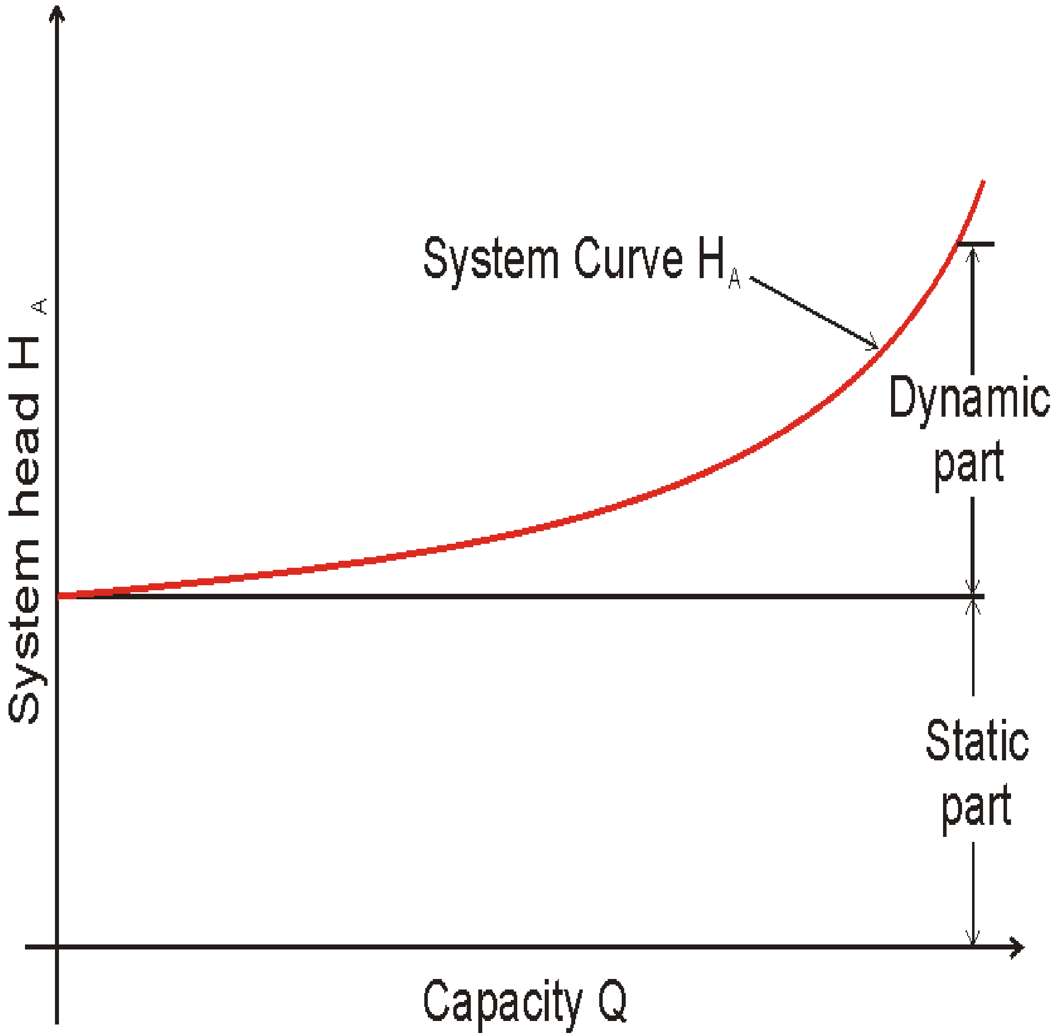
End-Suction, Back Pull-out Arrangement with Spacer Coupling



Pump Performance Curve



System characteristics curve



Static part =
Hgeo + (Pa-Pe) / (Density x Sp. gravity)

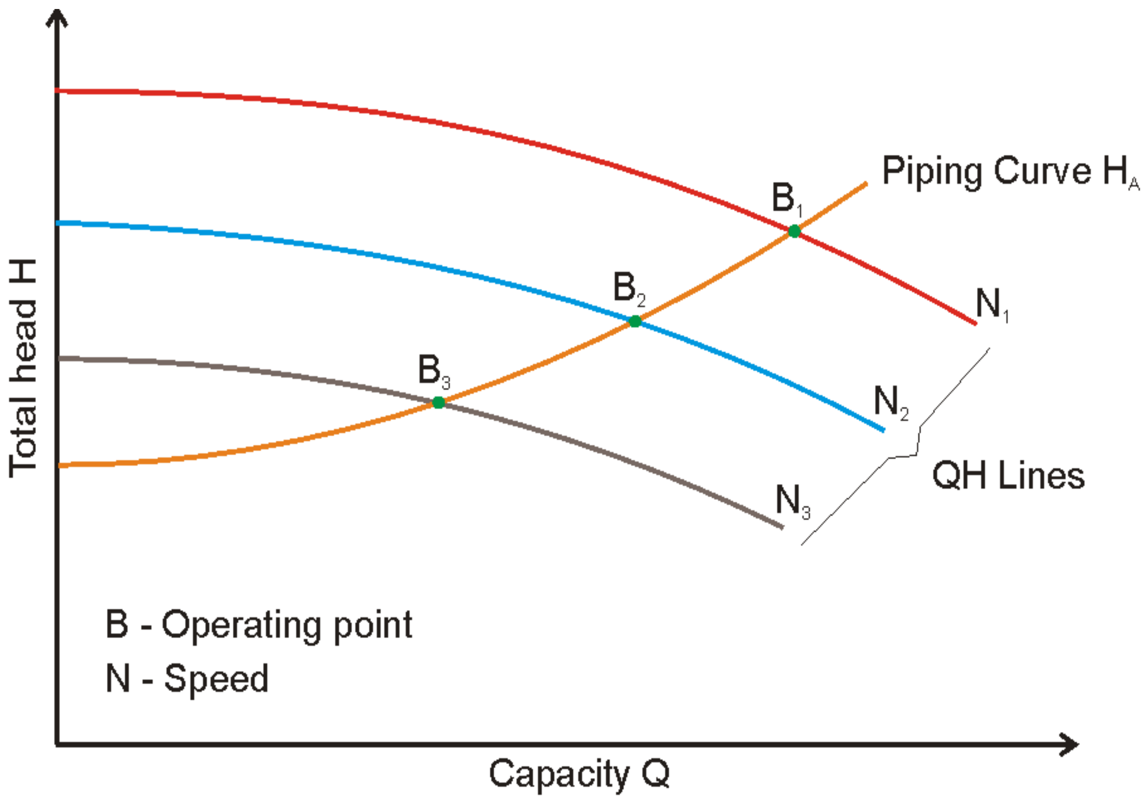
Dynamic part =
Hv + (Va^2 - Ve^2) / (2 x Density)

Where Hgeo = Static head in m
Hv = Head loss in m
Density in kg/m^3

(Pa - Pe) / (Density x Sp. gravity)
= The pressure head difference between the suction & discharge fluid levels in closed tanks

(Va^2 - Ve^2) / (2 x Density)
= The difference in velocity heads in the tank

Effect of speed on the pump performance



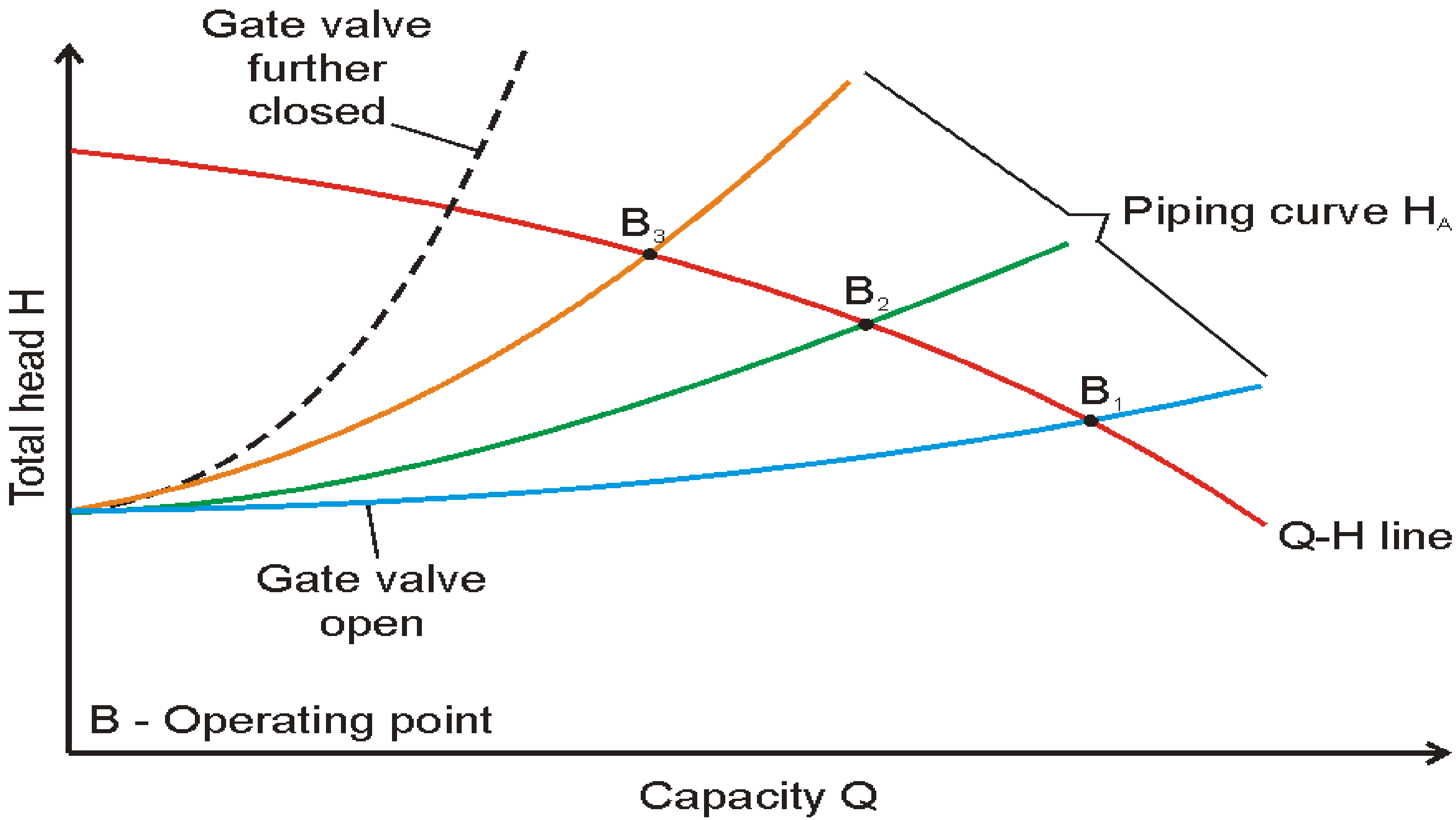
$$Q_2 = \frac{N_2}{N_1} \times Q_1$$

$$H_2 = \left(\frac{N_2}{N_1}\right)^2 \times H_1$$

$$P_2 = \left(\frac{N_2}{N_1}\right)^3 \times P_1$$

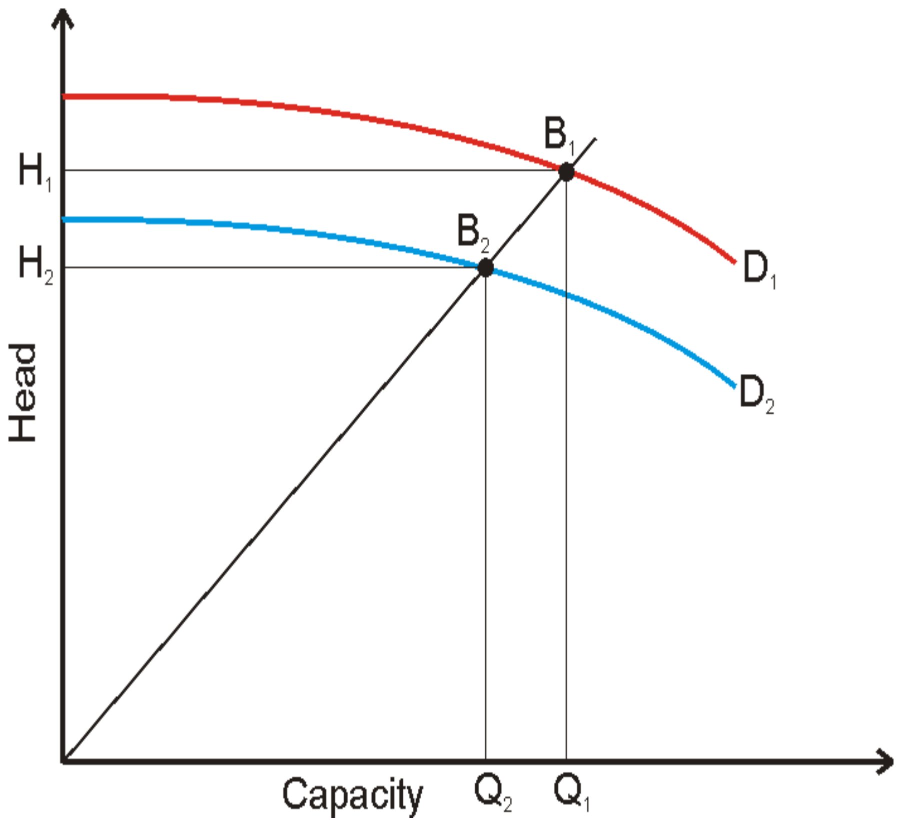
Position of the operating point changes from B1 to B3 on the piping curve H_A by raising the pump speed from B1 to B3

Effect of valve closing on the operating point



Position of the operating point changes from B1 to B3 on the QH line by progressively closing the valve

Effect of Impeller Trimming on pump performance



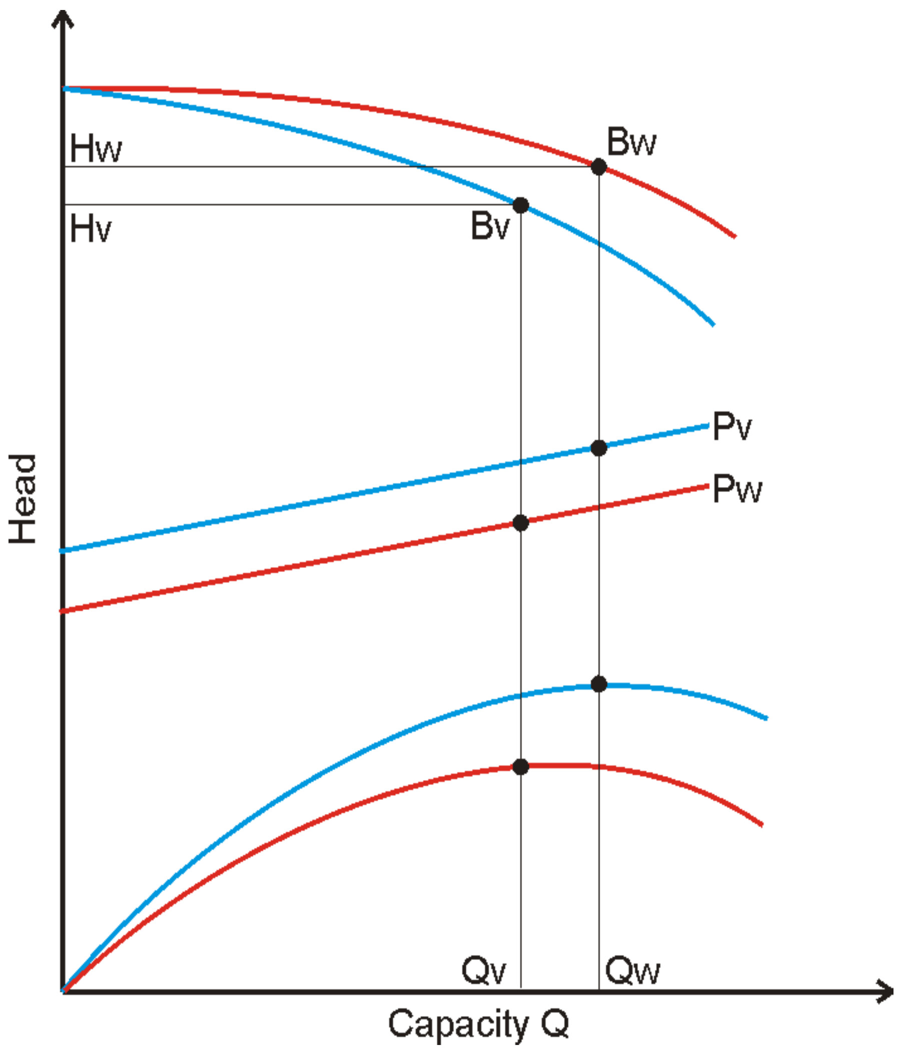
Trimming the impeller means reducing the diameter of the impeller thereby reducing output of the pump

While trimming the impeller; the relationship between
Capacity Q, Head H & impeller diameter D is :

$$\left(\frac{D_1}{D_2}\right)^2 \approx \frac{Q_1}{Q_2} \approx \frac{H_1}{H_2}$$

$$D_2 \approx D_1 X \sqrt{\frac{Q_2}{Q_1}} \approx D_1 X \sqrt{\frac{H_2}{H_1}}$$

Effect of viscous liquid



Increase in viscosity of the medium handled by the pump
Capacity Q - decreases
Head H - decreases
Efficiency - decreases

at the same time
Power input to pump - increases

The standard operating for water Bw with Qw, Hw, & w is converted to the viscous liquid operating point Bv with Qv, Hv & V

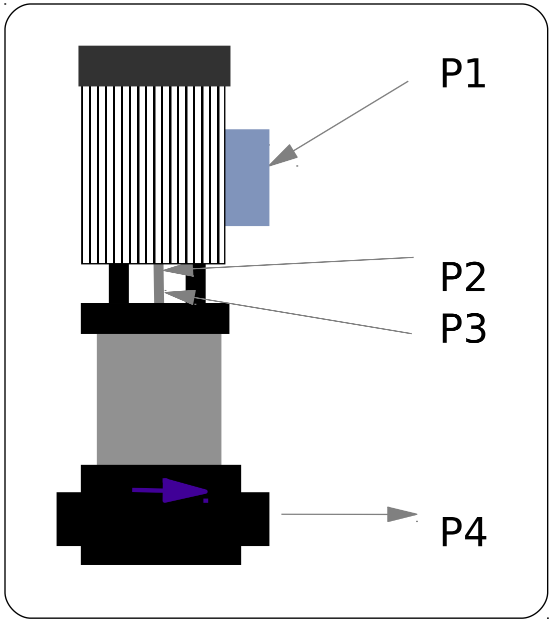
Power Curve

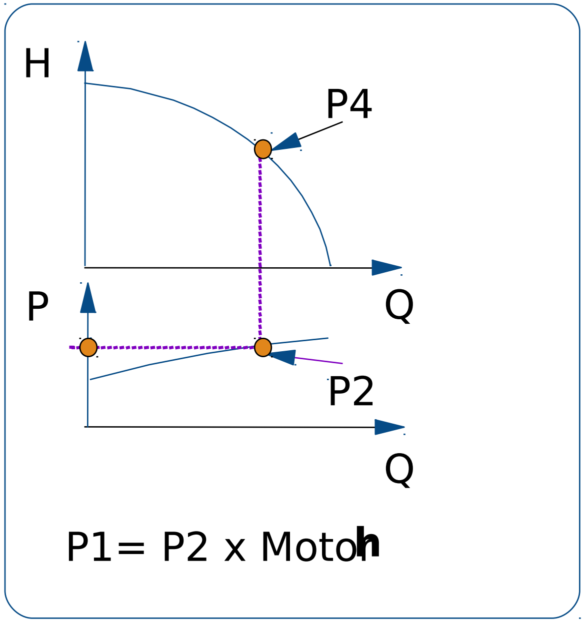
P1 – MOTOR INPUT FROM THE MAINS

P2 – MOTOR SHAFT OUTPUT

P3 – PUMP INPUT

P4 – PUMP OUTPUT





POWER CURVE - II

1 : Duty point with poor H

2 : Duty point with good H

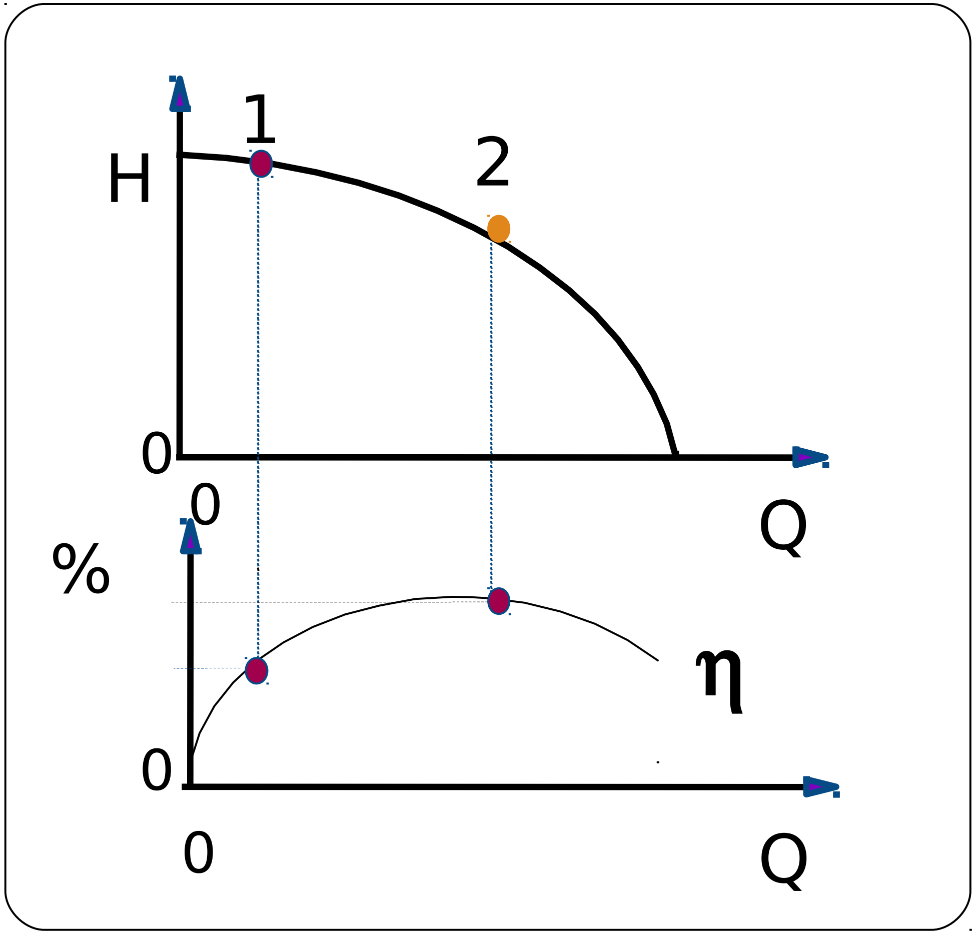
Pump Out put = Flow & head

Pump Input = Energy in kW

Efficiency = Output / Input

= Flow X Head / power

= (H X Q X Sg) / (367 X kW)



FACTORS AFFECTING PUMP PERFORMANCE

1. SPECIFIC GRAVITY

2. ALTITUDE

3. VISCOSITY

4. TEMPERATURE

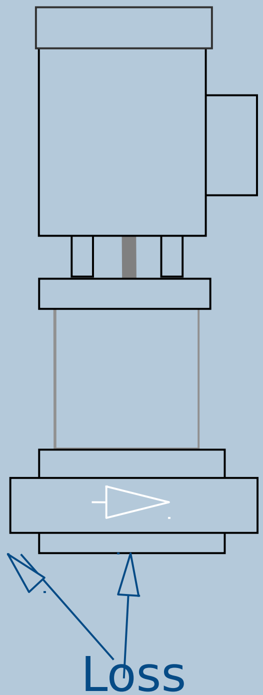
5. VAPOUR PRESSURE

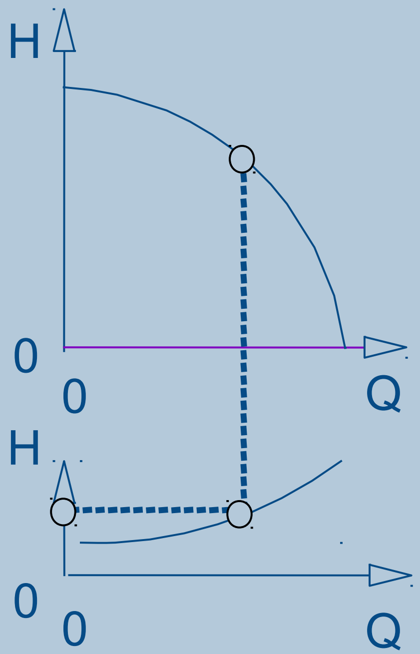
6. PERCENTAGE OF SOLIDS

NPSH

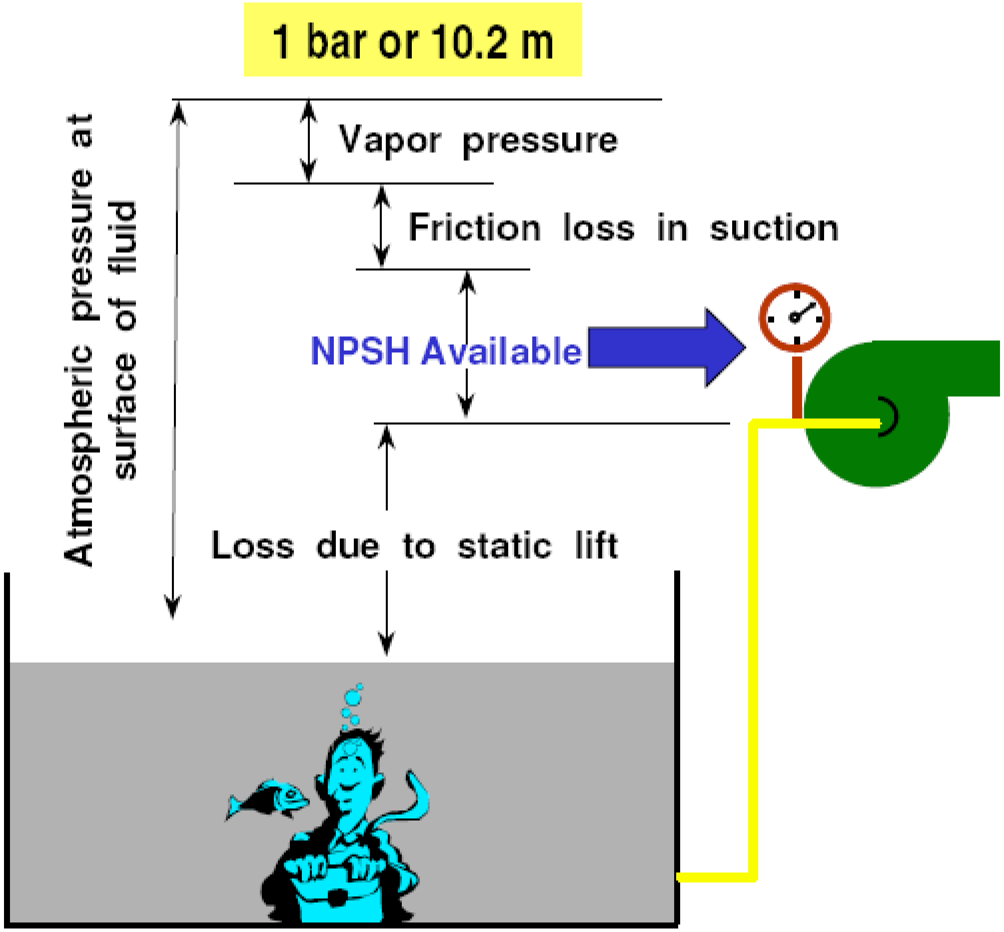
What is NPSH ?

Net **P**ositive
Suction **H**ead





NPSH is usually stated in meters


1 bar or 10.2 m
Atmospheric pressure at surface of fluid
Vapor pressure
Friction loss in suction
NPSH Available
Loss due to static lift

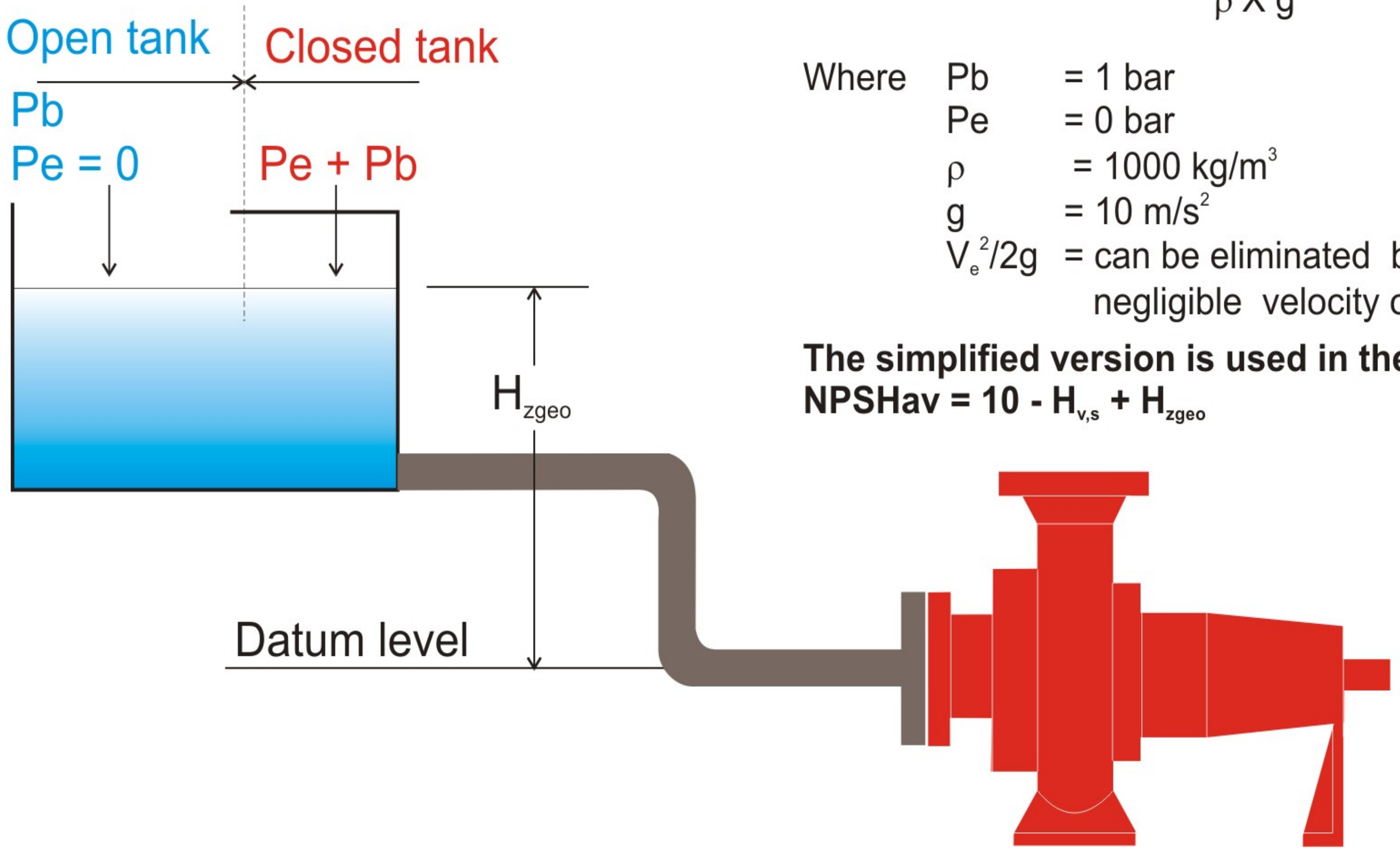
NPSHa - For suction head operation

NPSH available in m = Absolute pressure in m - Vapour pressure in m - Line losses in m + Difference in elevation in m

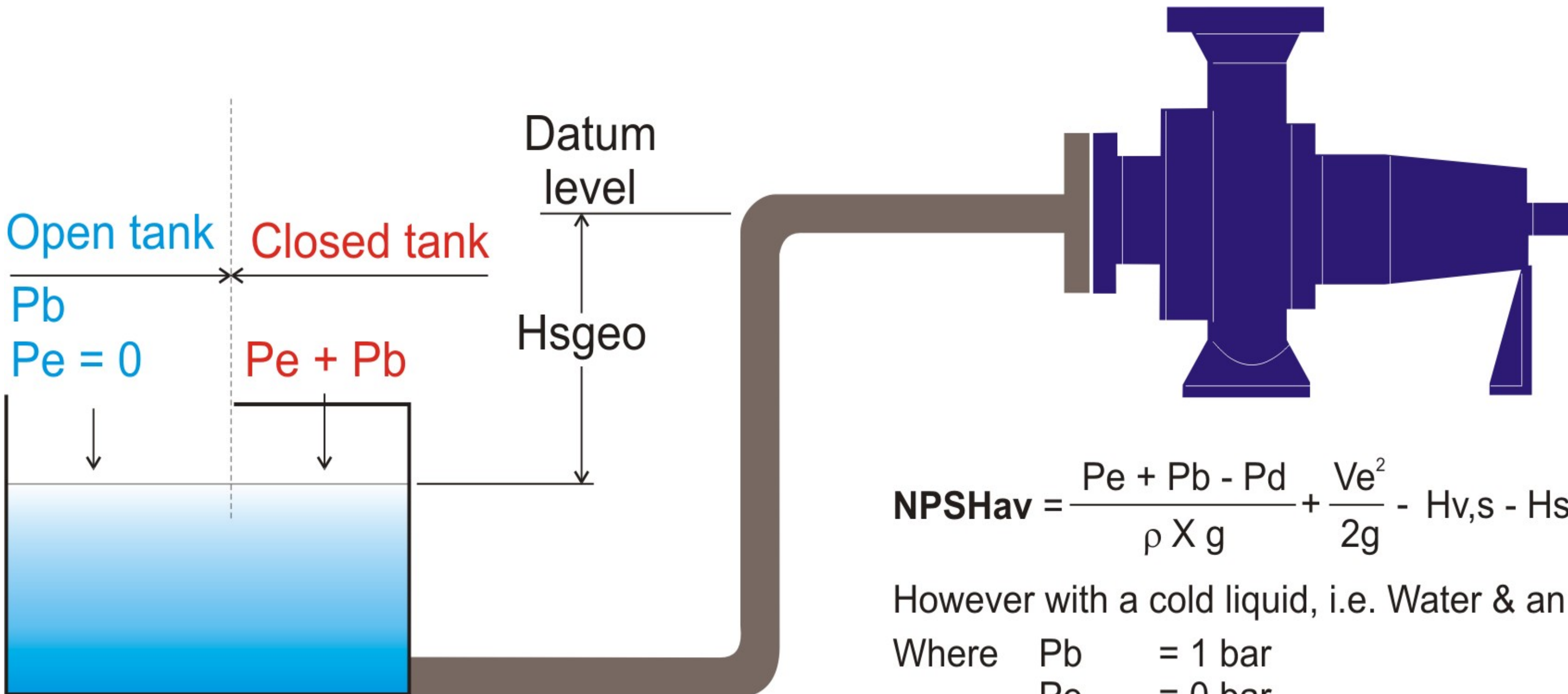
$$NPSHav = \frac{Pe + Pb - Pd}{\rho \times g} + \frac{Ve^2}{2g} - H_{v,s} + H_{zgeo}$$

Where
- Pb = 1 bar
- Pe = 0 bar
- ρ = 1000 kg/m^3
- g = 10 m/s^2
- $V_e^2/2g$ = can be eliminated because of the negligible velocity of liquid in the tank

The simplified version is used in the practice
$NPSHav = 10 - H_{v,s} + H_{zgeo}$



NPSHa - for Suction lift operation



$$\textbf{NPSHav} = \frac{Pe + Pb - Pd}{\rho \times g} + \frac{Ve^2}{2g} - Hv,s - Hsgeo$$

However with a cold liquid, i.e. Water & an open tank

Where Pb = 1 bar
Pe = 0 bar
ρ = 1000 kg/m^3
g = 10 m/s^2
$V_e^2/2g$ = can be eliminated because of the negligible velocity head of liquid in the tank

NPSH available in m = Absolute pressure in m - Vapour pressure in m - Line losses in m - Difference in elevation in m

The simplified version is used in the practice
NPSHav = 10-Hv,s - Hsgeo

NPSH Required (NPSHR)

Is the energy needed by the pump to operate satisfactorily.

NPSHR is the amount of energy (in meters of liquid) required to overcome friction losses from the suction opening to the impeller vanes.

NPSHR is a characteristic of the pump varying with pump design and operating conditions.

NPSHA > NPSHR

NPSHA must be greater than NPSHR to prevent the liquid from boiling at the point of lowest pressure in the pump

For maximum reliability an adequate margin between the available NPSH and the required NPSH must be provided

Margin – minimum 0.5mts

Why is a NPSH Margin Necessary?

The pump NPSHR is defined when a 3 % head drop occurs

NPSHR is measured on a test high with ideal suction piping

NPSHR is measured on deaerated, cold water.

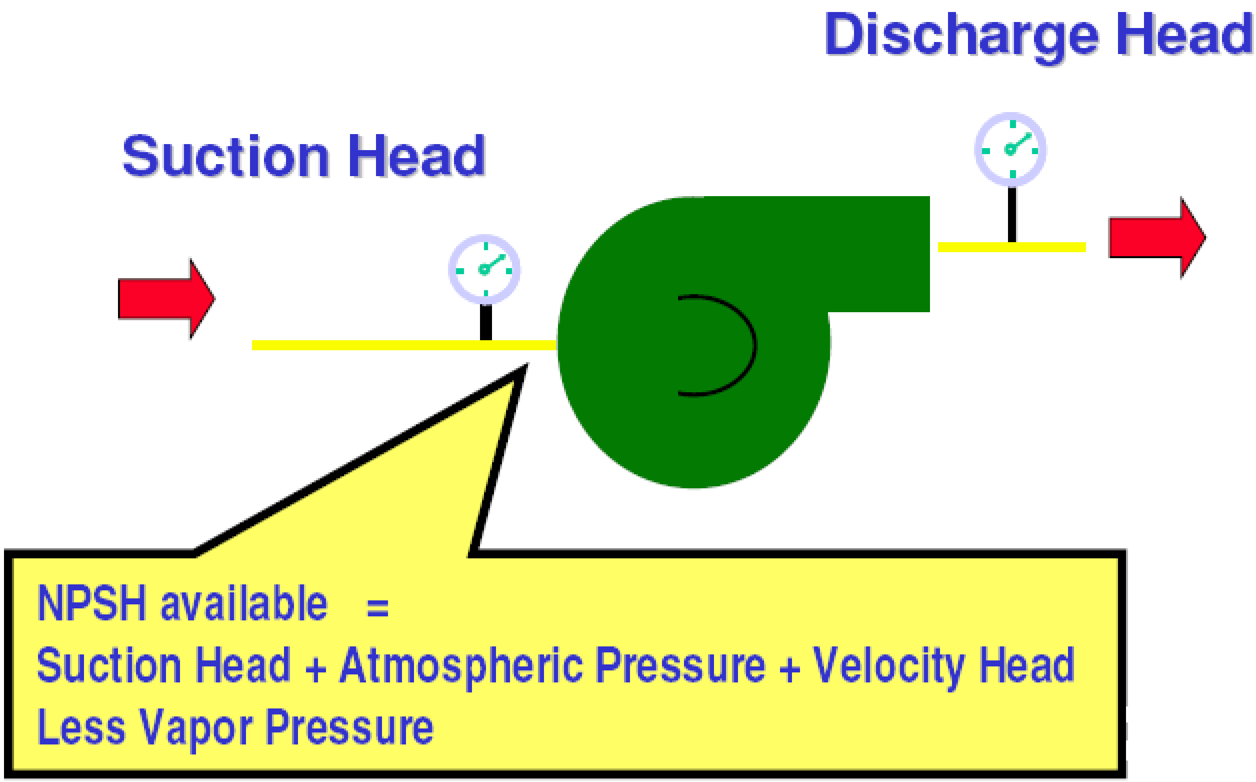
Process upsets can change flow rates.

Process improvements later may require higher flow rates.

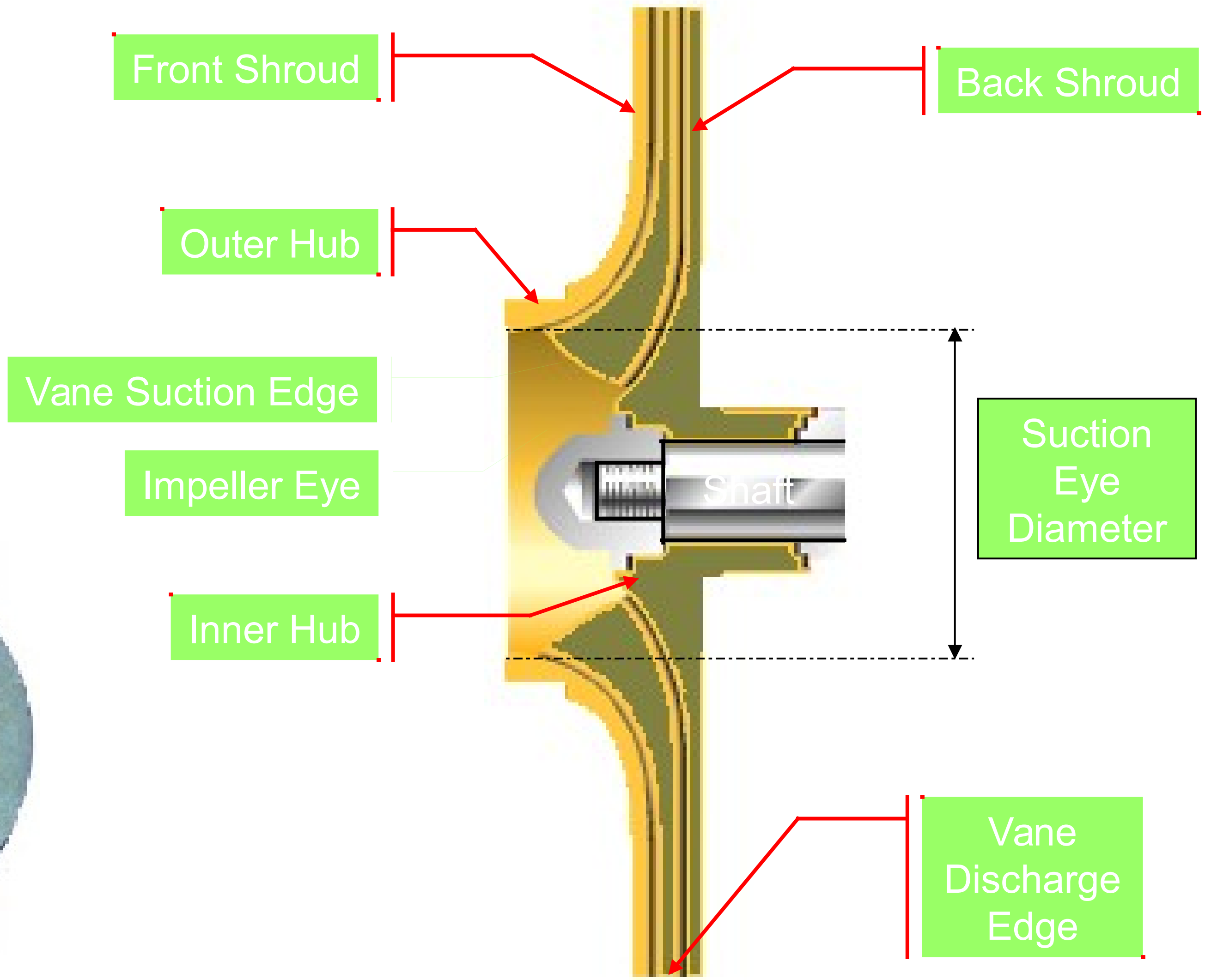
The process liquid vaporization characteristics may be significantly different than those of water

Solids accumulation in suction piping can reduce NPSHA.

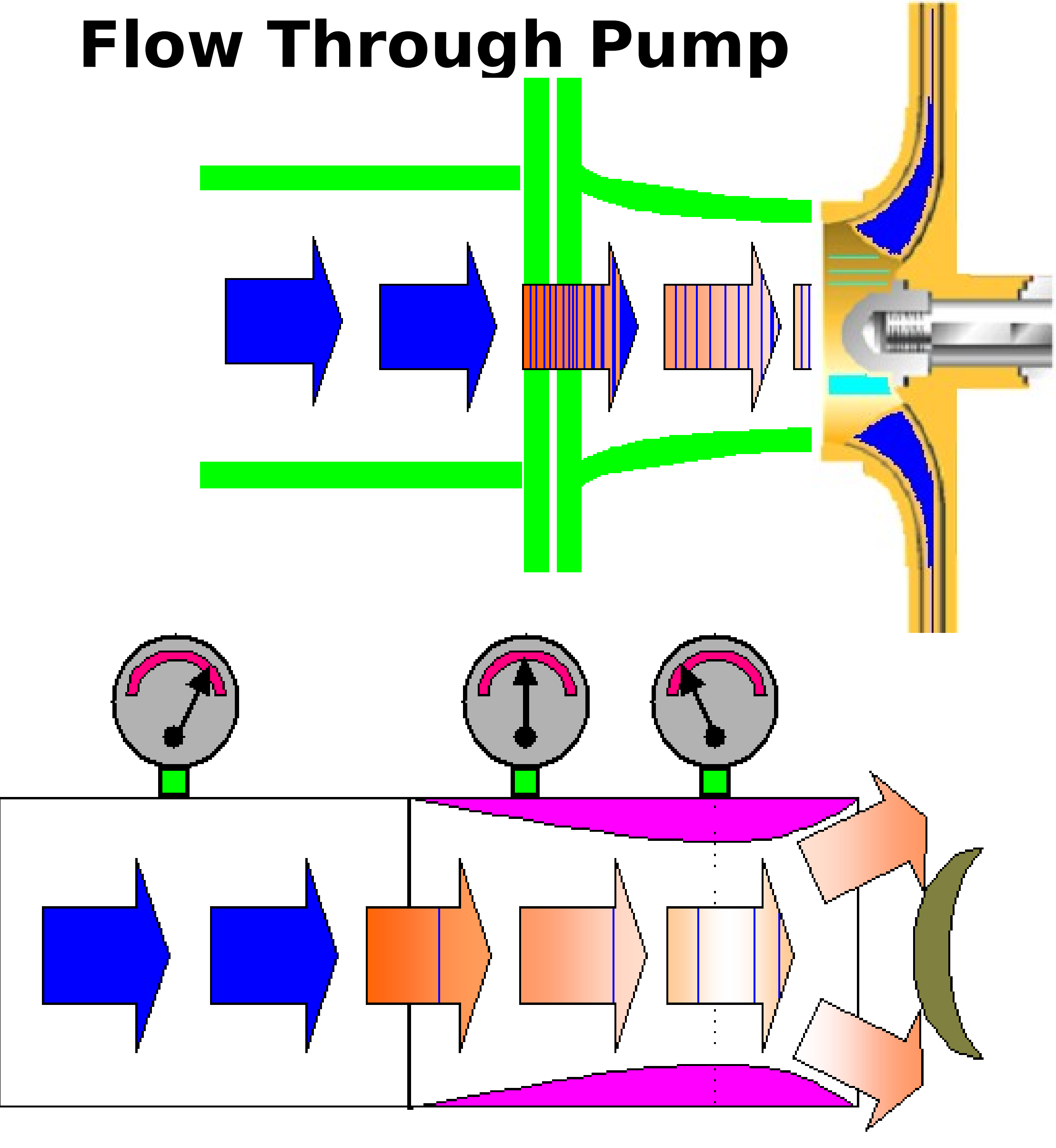
Total Dynamic Head (TDH) =
Discharge Head - Suction Head



Impeller Nomenclature



Flow Through Pump



The water flows through reduced cross-section area (like in a Venturi).

Water velocity goes up as its pressure goes down due to Venturi effect and frictional loss.

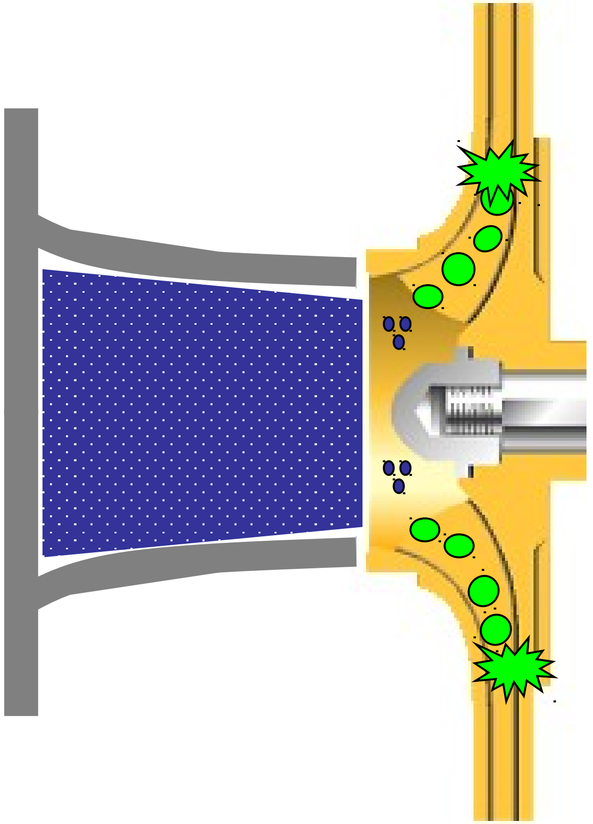
At the point of less cross-section (impeller eye) velocity is high and pressure is low.

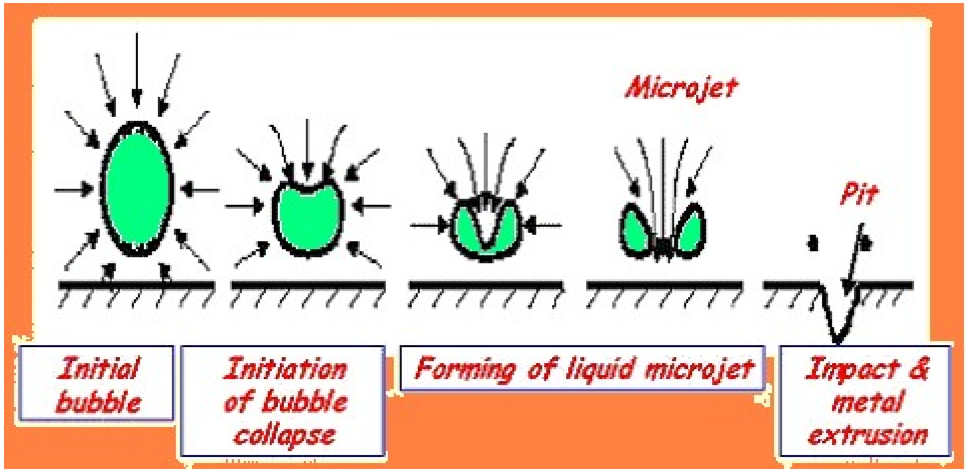
Pressure reduces further due to shock & turbulence as the liquid strikes the edges of impeller vanes.

Results in creation of low pressure around the impeller eye and beginning of impeller vanes.

CAVITATION

If the pressure drops below the vapour pressure of the liquid at the operating temperature, the liquid will vaporize.





Formation of Bubbles inside the liquid

New bubbles continue to form and older ones grow in size

Bubbles get carried by liquid at high velocity from impeller eye towards impeller exit

Bubbles eventually reach the regions of high pressure within the impeller

The pressure outside of the bubble exceeds that inside of the bubble

Hundreds of bubbles collapse by bursting inwards (implosion, not explosion!)

When bubbles collapse surrounding liquid rushes to fill the void forming a liquid micro jet

Creates highly localised hammering effect, pitting the impeller

An audible shock wave emanates outward from the point of collapse

Bubble Collapse pressures greater than 1GPa (10,000 bar) have been reported!

Life cycle of a bubble has been estimated to be in the order of 0.003 seconds!

This dynamic process of formation of bubbles inside the liquid, their growth and subsequent collapse is called CAVITATION.

Cavitation can be of two types

Vaporous: due to vaporisation of the liquid

Gaseous: due to formation of gas bubbles in a liquid containing dissolved gas

Cavitation - ***Heart Failure*** *of the Pump*

Obstruction to flow

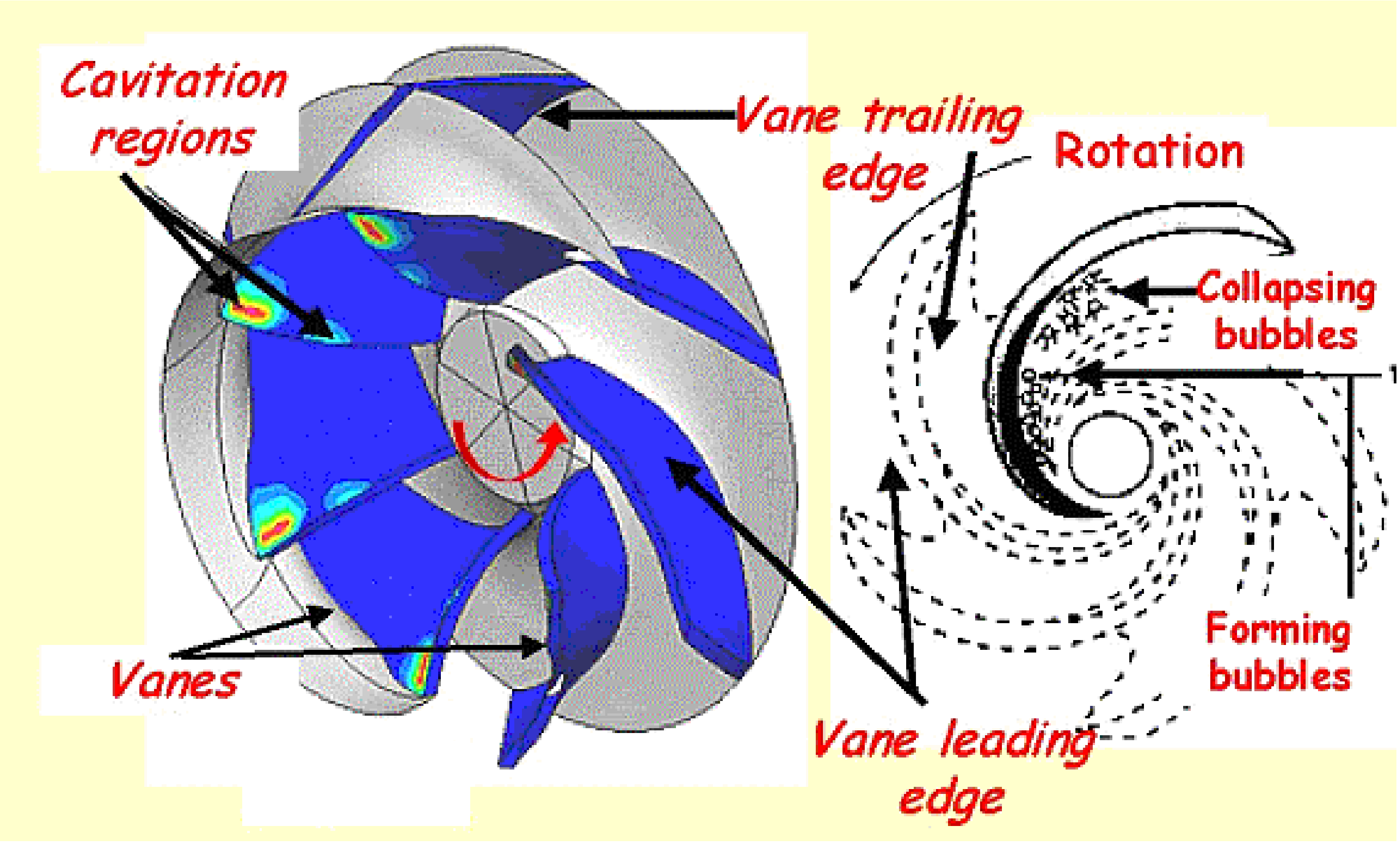
Impair performance – reduce capacity and head

Abnormal noise and vibrations

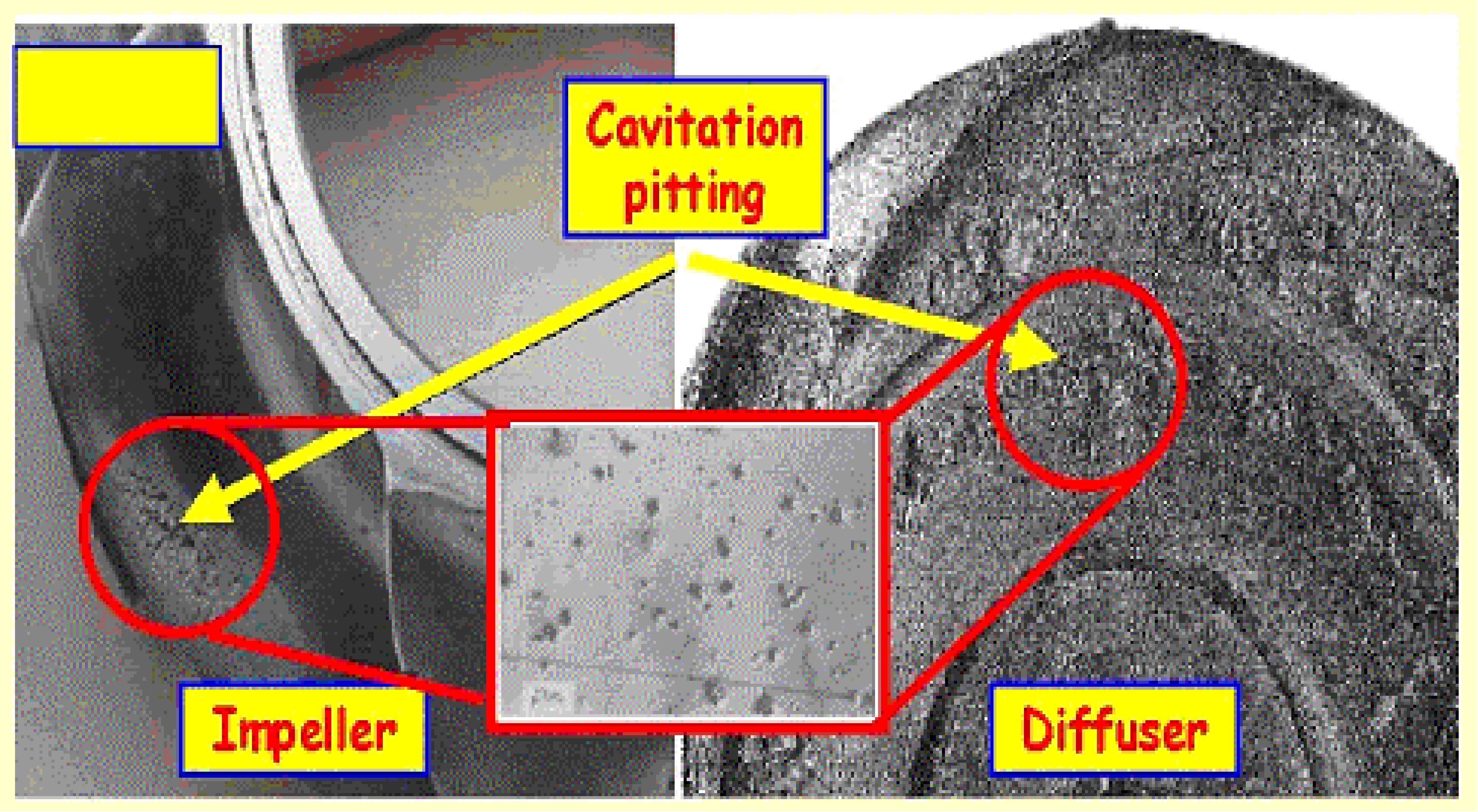
Damage impeller and other sensitive components

A Centrifugal pump can handle air in the range of 1/2 % by volume. Cavitation begins if this value is increased to 6%.

Impeller Cavitation Regions



Cavitation Pitting



NPSH

NPSHr - Net Positive Suction Head Required

- NPSHr is a function of the pump design
- NPSHr is determined based on actual pump test by pump manufacturer.
- NPSHr is the positive head in meters absolute required at the pump suction to overcome the pressure drop in the pump and maintain the majority of the liquid above its vapour pressure.
- “Net” refers to the actual pressure head at the pump suction flange and not the static suction head.
- NPSHr increases as capacity increases
- NPSHr is independent of liquid specific gravity

NPSH

NPSHa - Net Positive Suction Head Available

NPSHa is a function of the system design

NPSHa is calculated based on the system or process conditions

NPSHa is the total suction head corrected to the centerline of the first stage impeller less the vapour pressure head.

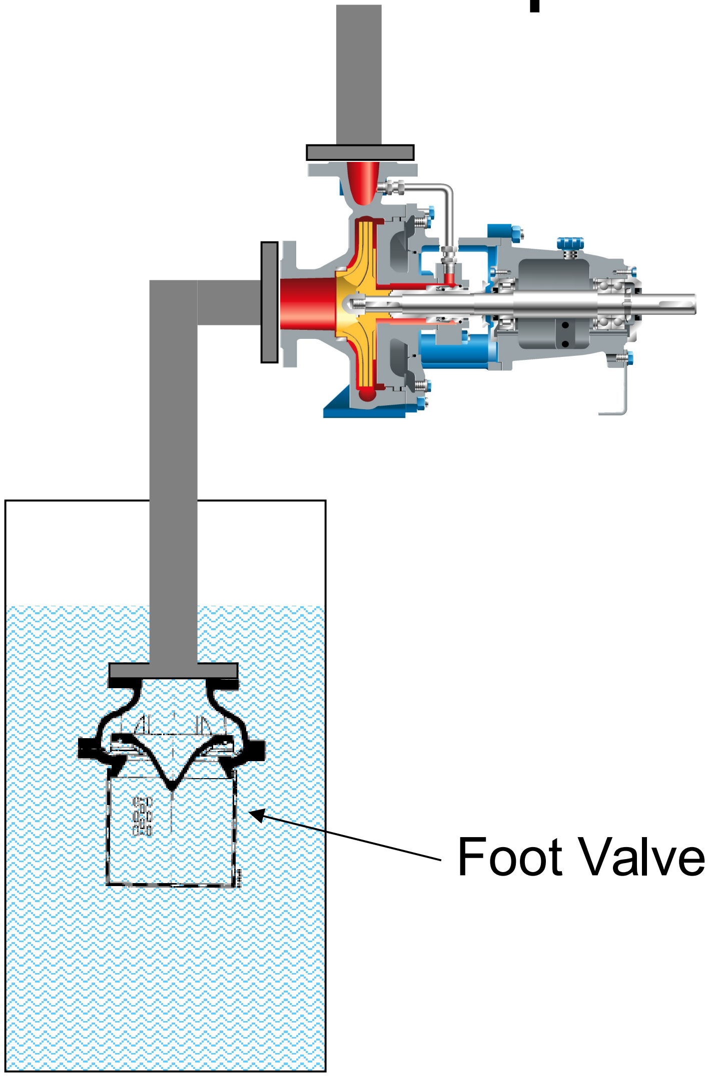
"Net" refers to the actual pressure head at the pump suction flange and not the static suction head.

NPSHa is independent of liquid specific gravity

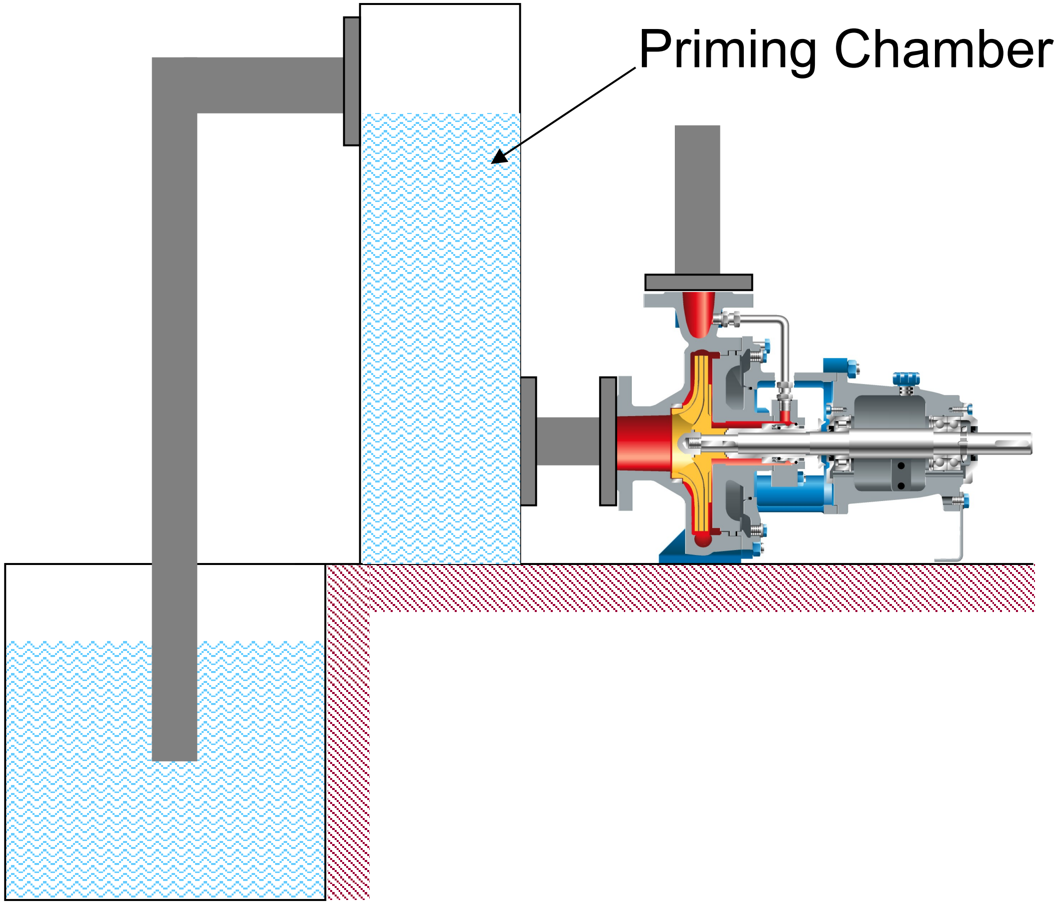
Pump Priming

- Centrifugal pumps can pump air at their rated capacity, but only at a pressure equivalent to the rated head of the pump.
- Centrifugal pump can produce only 1/8000 of its rated water pressure when handling air
- In other words, for every 1m water that has to be raised to fill the pump, the pump must produce a discharge head of approx. 8000 m, which is impossible!
- Hence, it is necessary to fill the waterways in a pump with liquid before starting it.
- A centrifugal pump is said to be PRIMED when the waterways of the pump is completely filled with liquid to be pumped.

Methods of Pump Priming



Methods of Pump Priming



Methods of Pump Priming