Know your Equipment
Centrifugal pumps

Presented by

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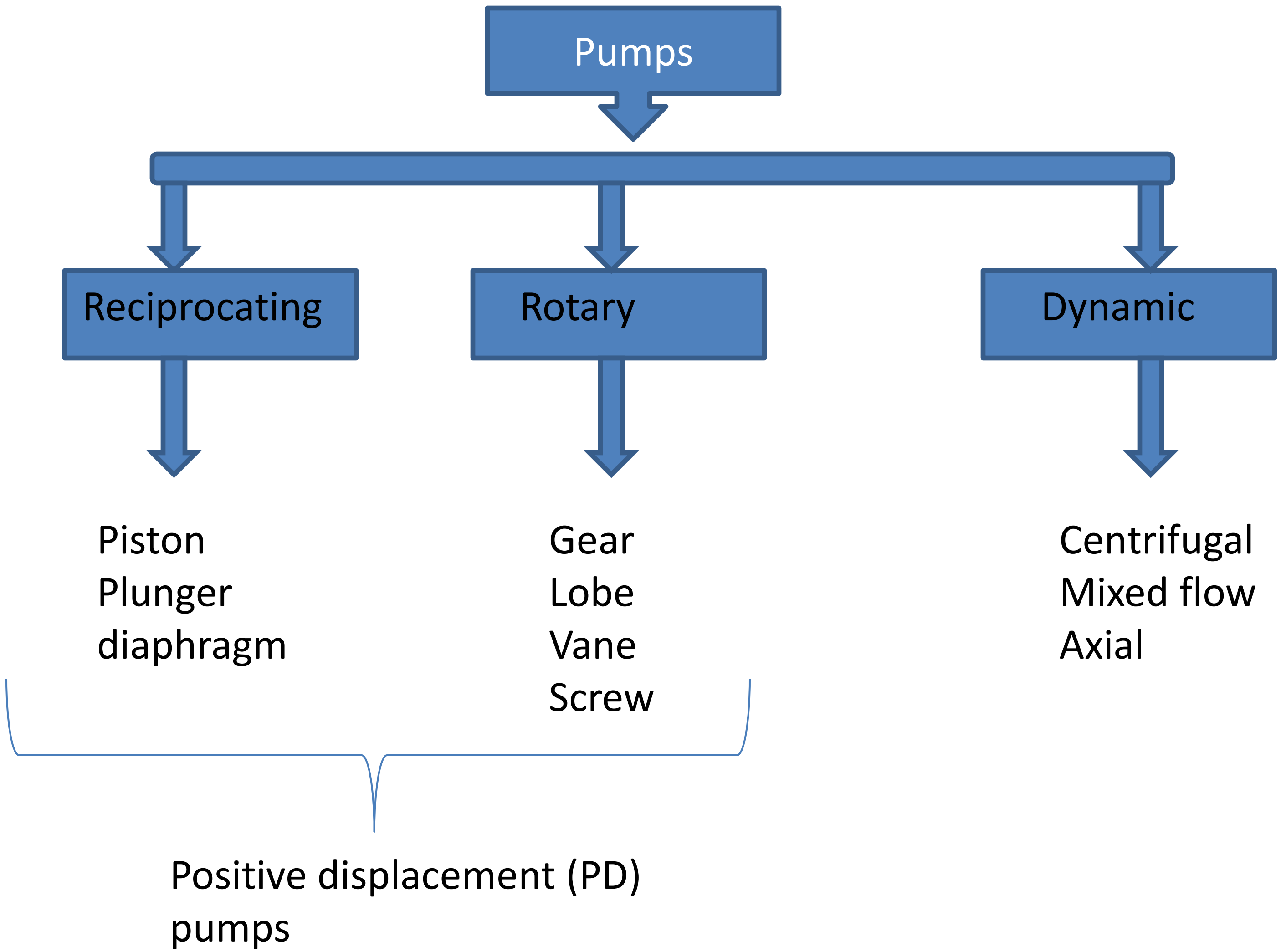
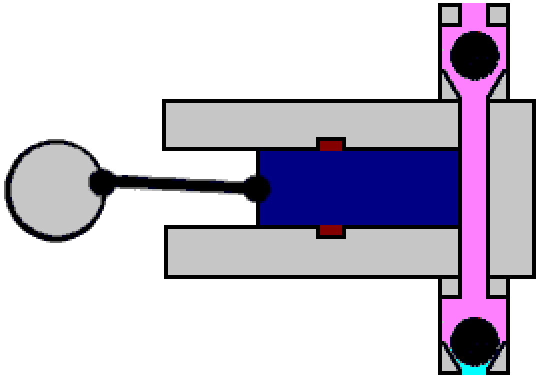
Types of pumps

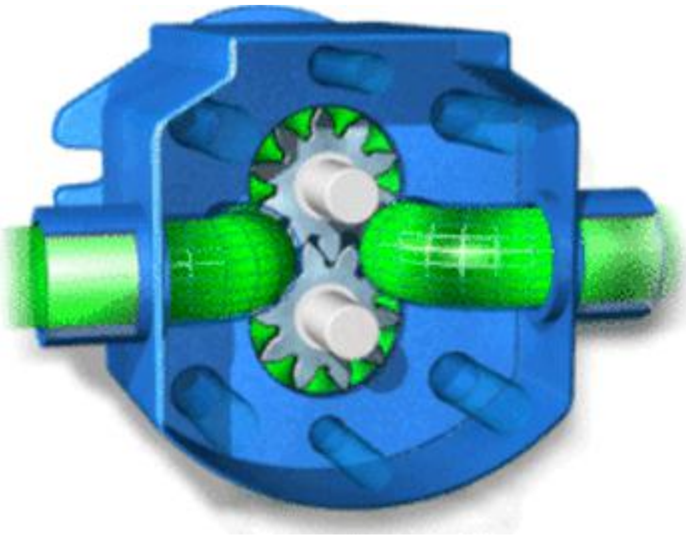


PD pumps

- PD pumps have positive boundary between suction and discharge and these pumps simply transfers the liquid from suction port to discharge port . Flow reversal is not possible in case of PD pumps .



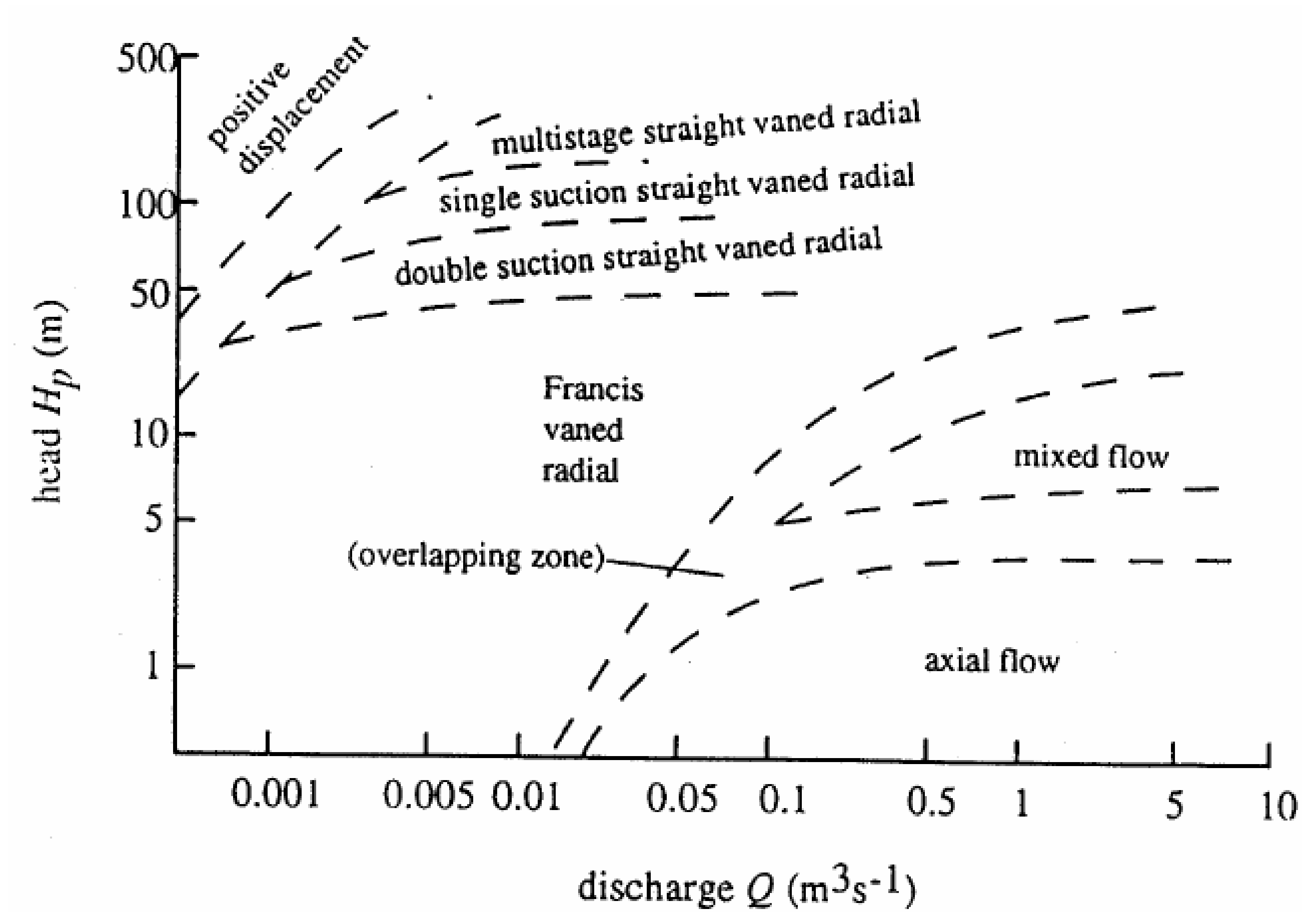
Gear Pump



Comparison of diff. types of pumps

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

Centrifugal vs Other pumps

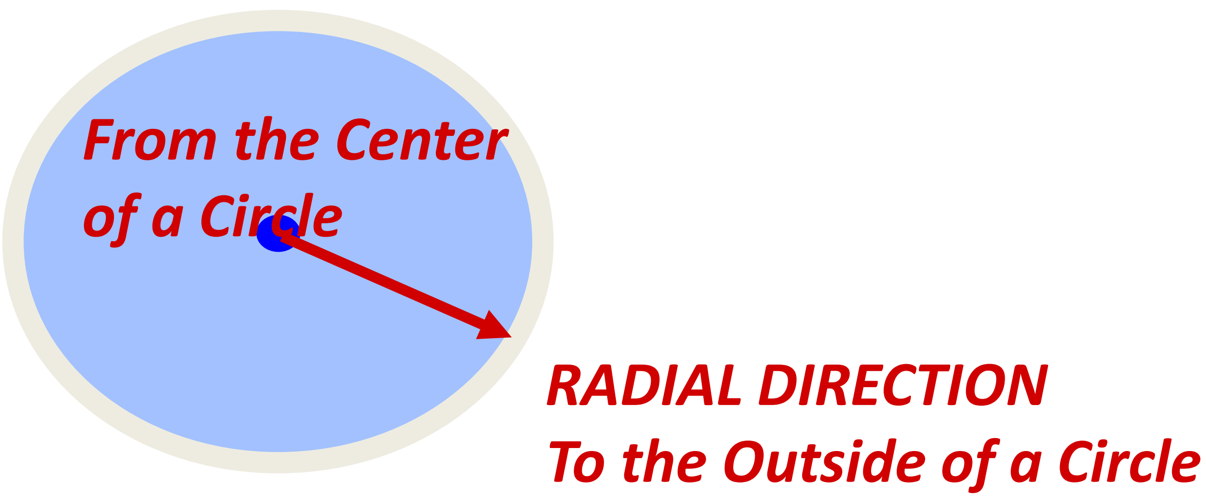


Centrifugal pump

A Centrifugal pump is a mechanical device used for

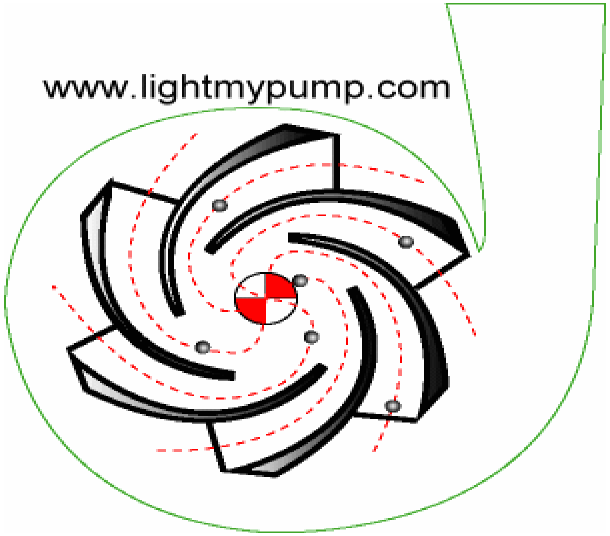
- ❑ Transportation of liquids
- ❑ Raising height of liquids
- ❑ Pressurization of liquids

By using centrifugal action



Centrifugal pump

- Transfers mechanical energy to liquids using centrifugal action.
- Uses impeller to transfer kinetic energy to liquids.
- Volute casing is used to convert part of this kinetic energy into pressure energy.



Centrifugal pump - main components

- Impeller
- Casing
- Bearing housing
- Shaft
- Shaft seal (mechanical seal / stuffing box)

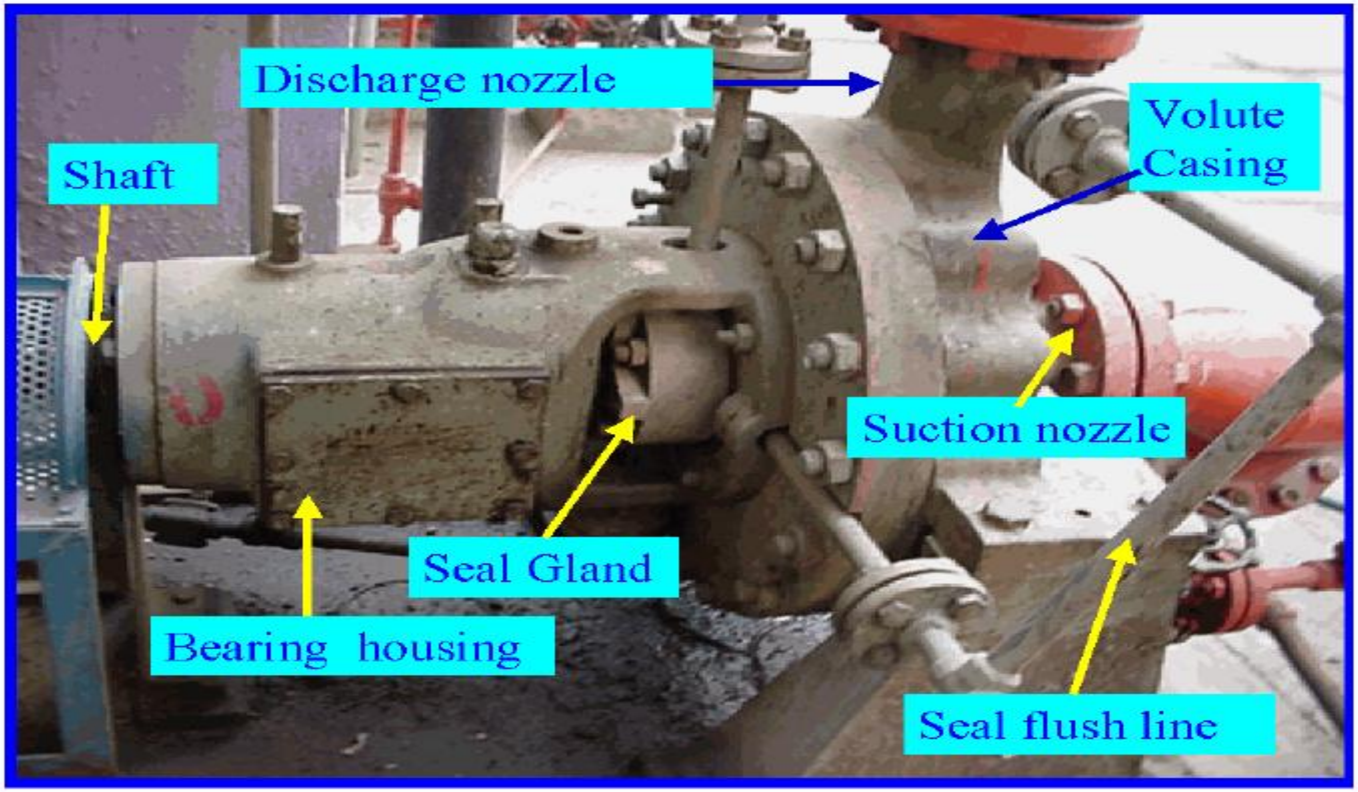
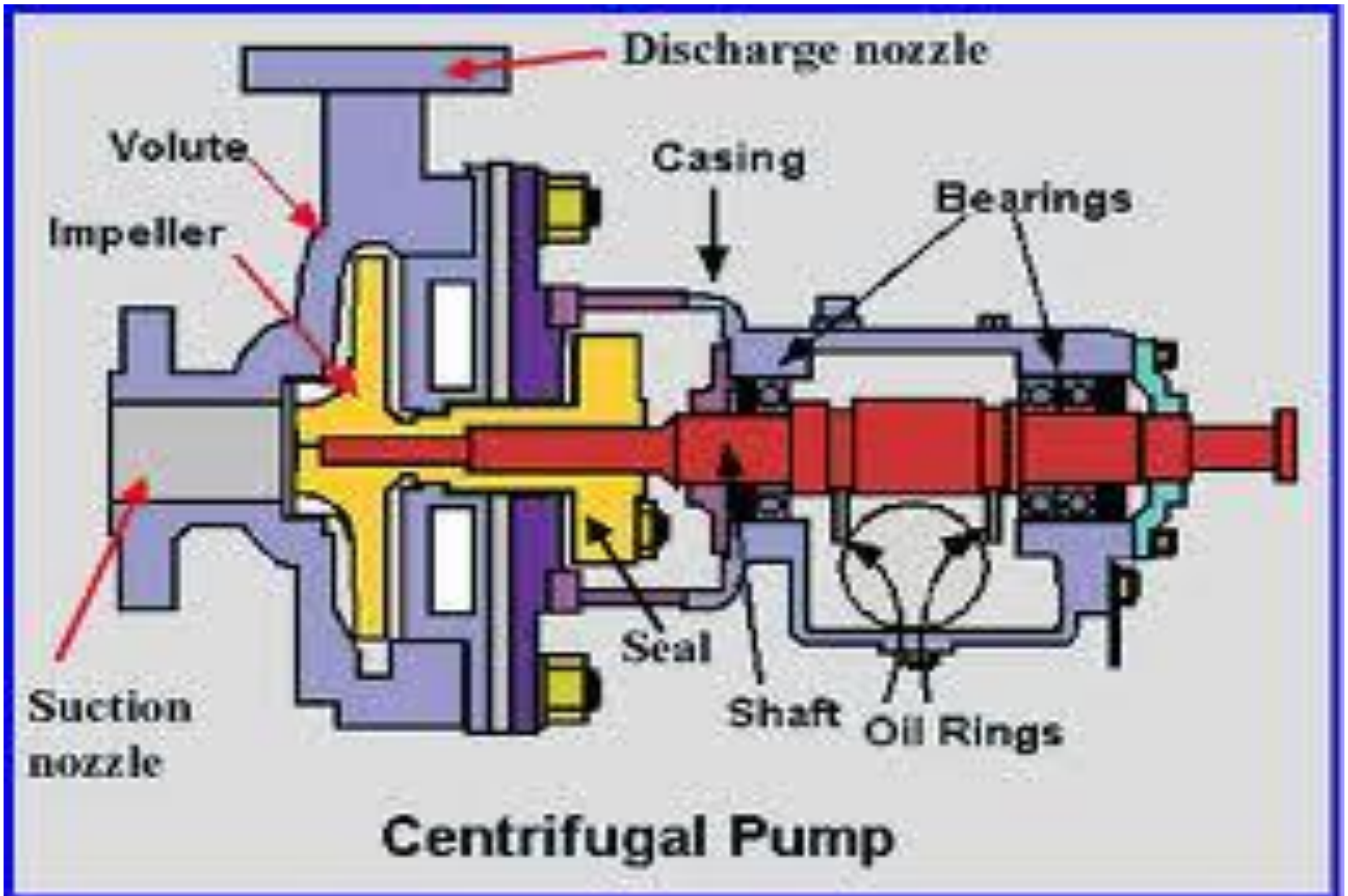


Figure B.02: General components of a Centrifugal Pump

Centrifugal pump - main components cont.



Vertical Inline centrifugal Pump

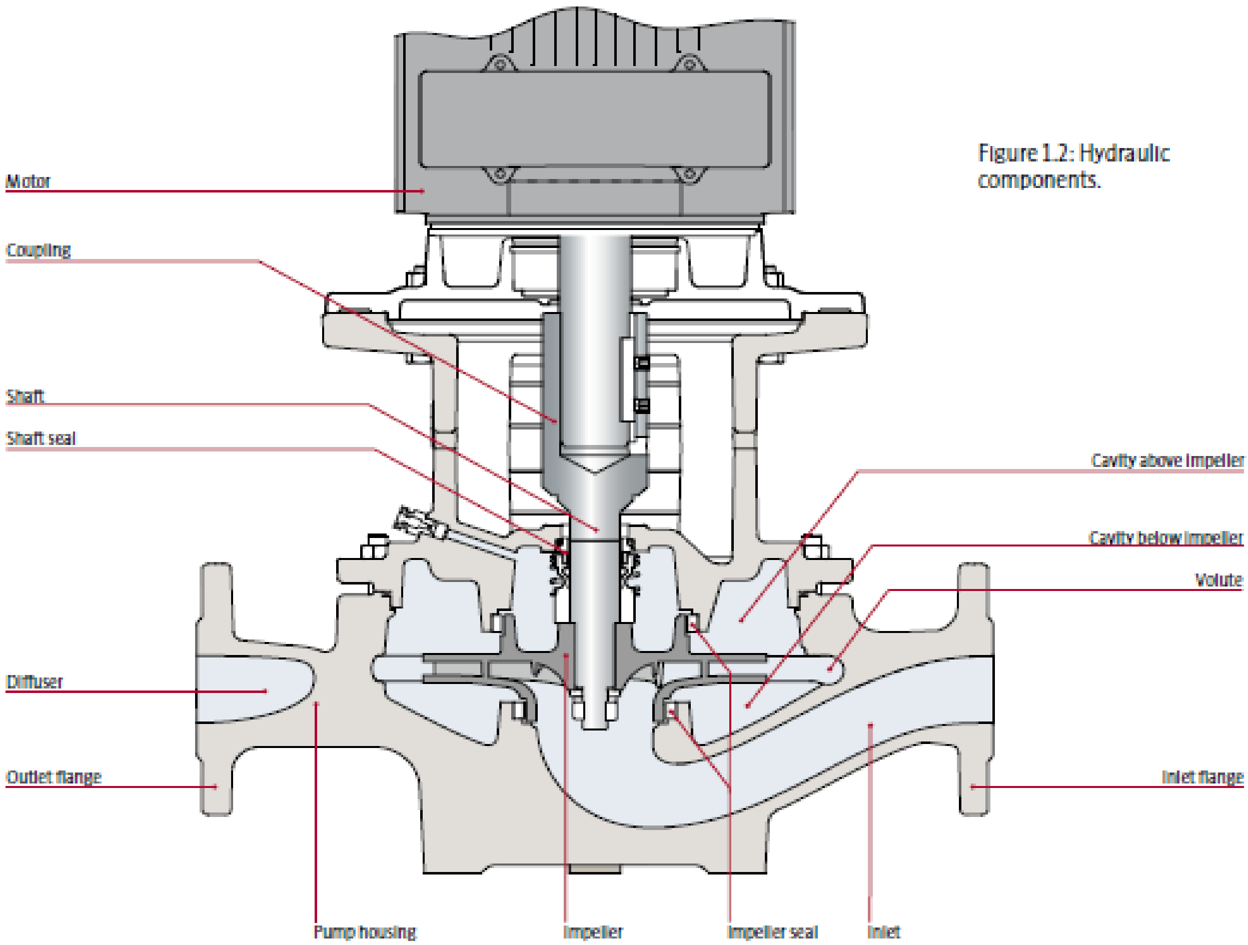
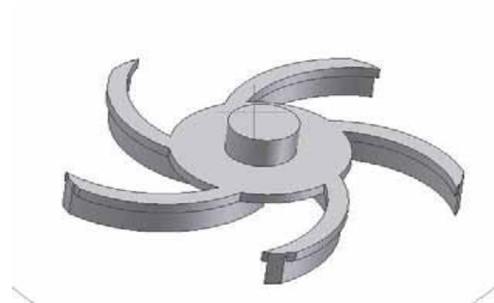


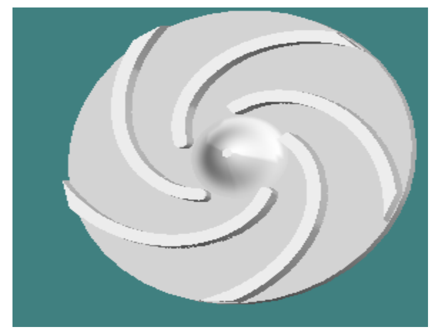
Figure 1.2: Hydraulic components.

Impeller -types

- Open impeller



- Semi open impeller



- Enclosed impeller

Open Impeller

- Used for clean, non abrasive & low power applications

- No disc friction loss due to shrouds → higher efficiency than semi open and closed impellers at same sp. speed

- Tight clearance between the impeller and the front and back casing walls is necessary to maximize efficiency.

- Difficult adjustment of the impeller axial position to compensate for wear.

Semi Open Impeller

- Have back shroud only

- Good for moderately abrasive slurries

- Can be adjusted axially to compensate for casing wear.

- More efficient than an enclosed impeller because of lower disc friction.

- High axial thrust due to difference in pressure profiles along the two sides of the shroud

- Pump-out vanes on the back side of the shroud are used for reducing high axial thrust

Enclosed impellers

- Have front and back shroud.

- Does not require tight axial clearances to prevent leakage.

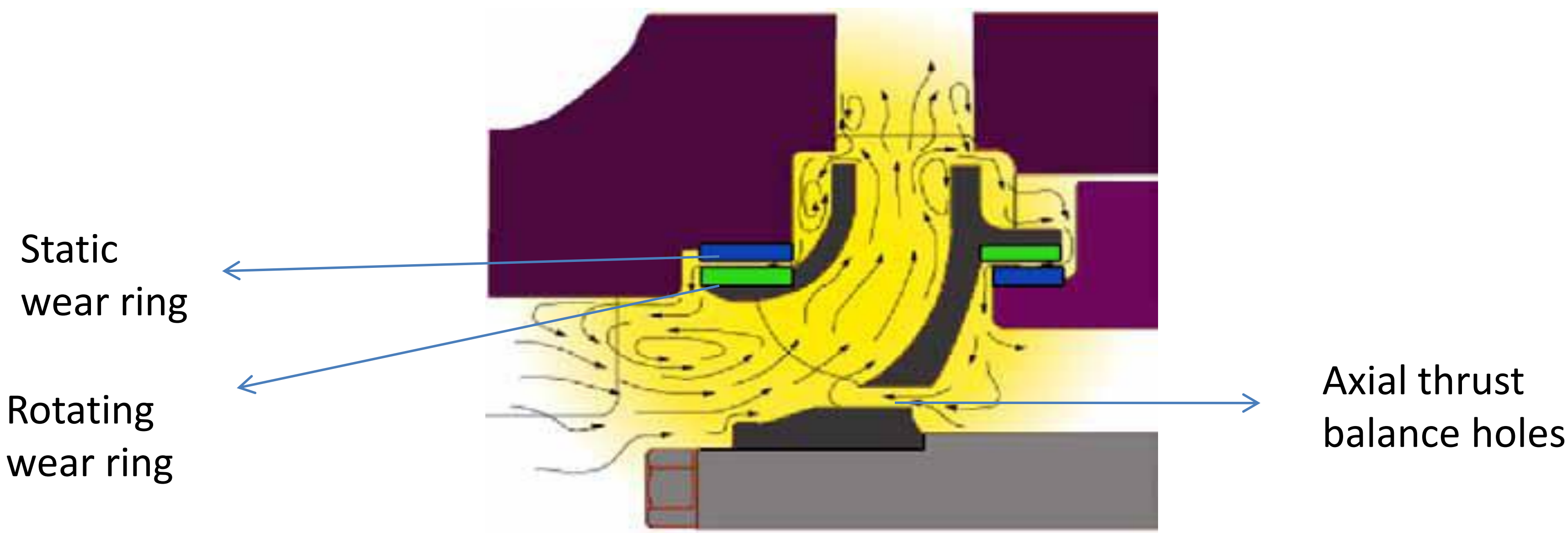
- Can tolerate moderate wear with little adverse effect on overall performance and efficiency.

- Disc friction lowers the efficiency of the pump relative to that of open impeller designs.

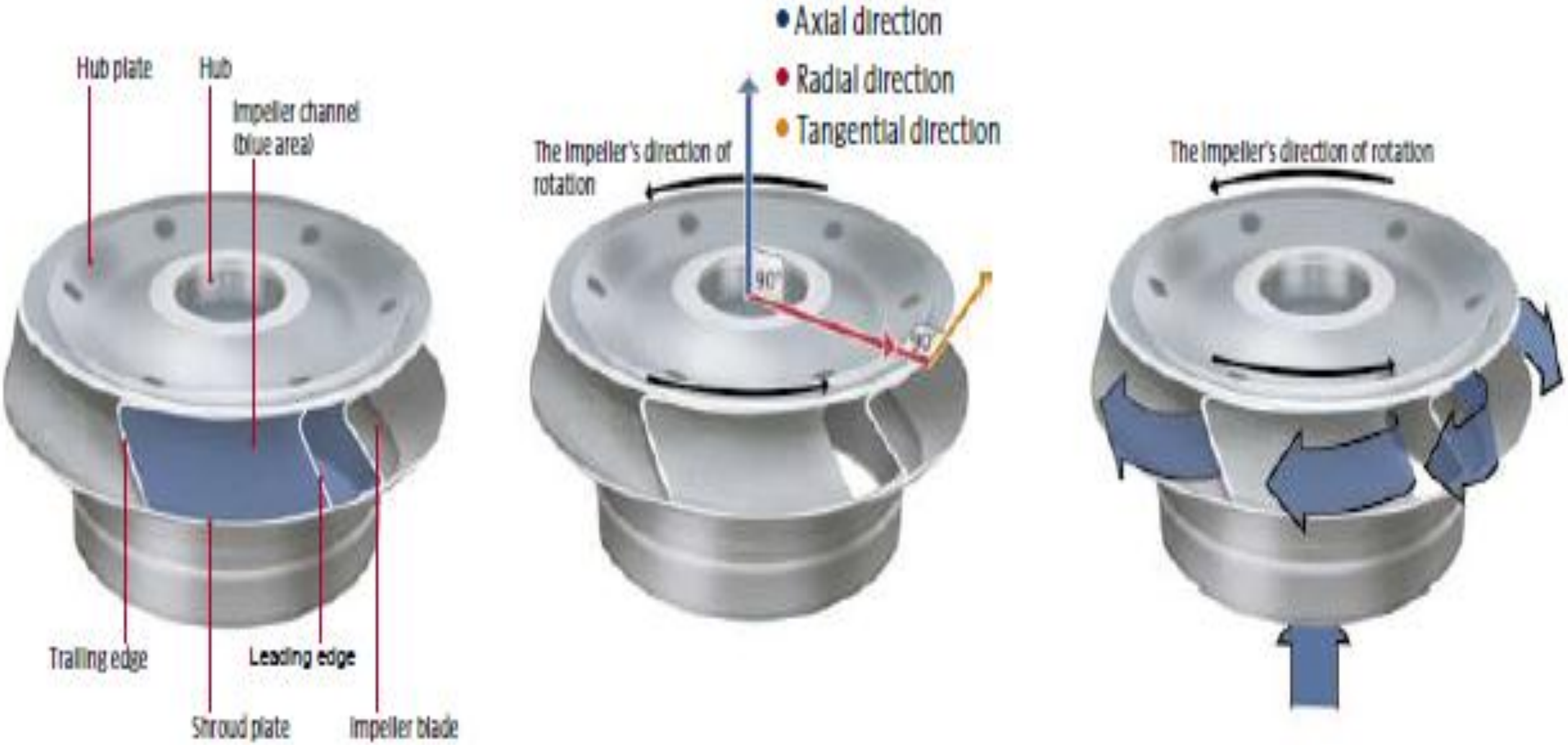
Enclosed impellers cont.

- Uses wear rings to prevent liquid leaking back to the pump suction by traveling through the gap between the front impeller shroud and the casing.

- Normally impeller balance holes are used to control axial thrust



Enclosed Impeller Components



Enclosed Impeller – leak flow and wear rings

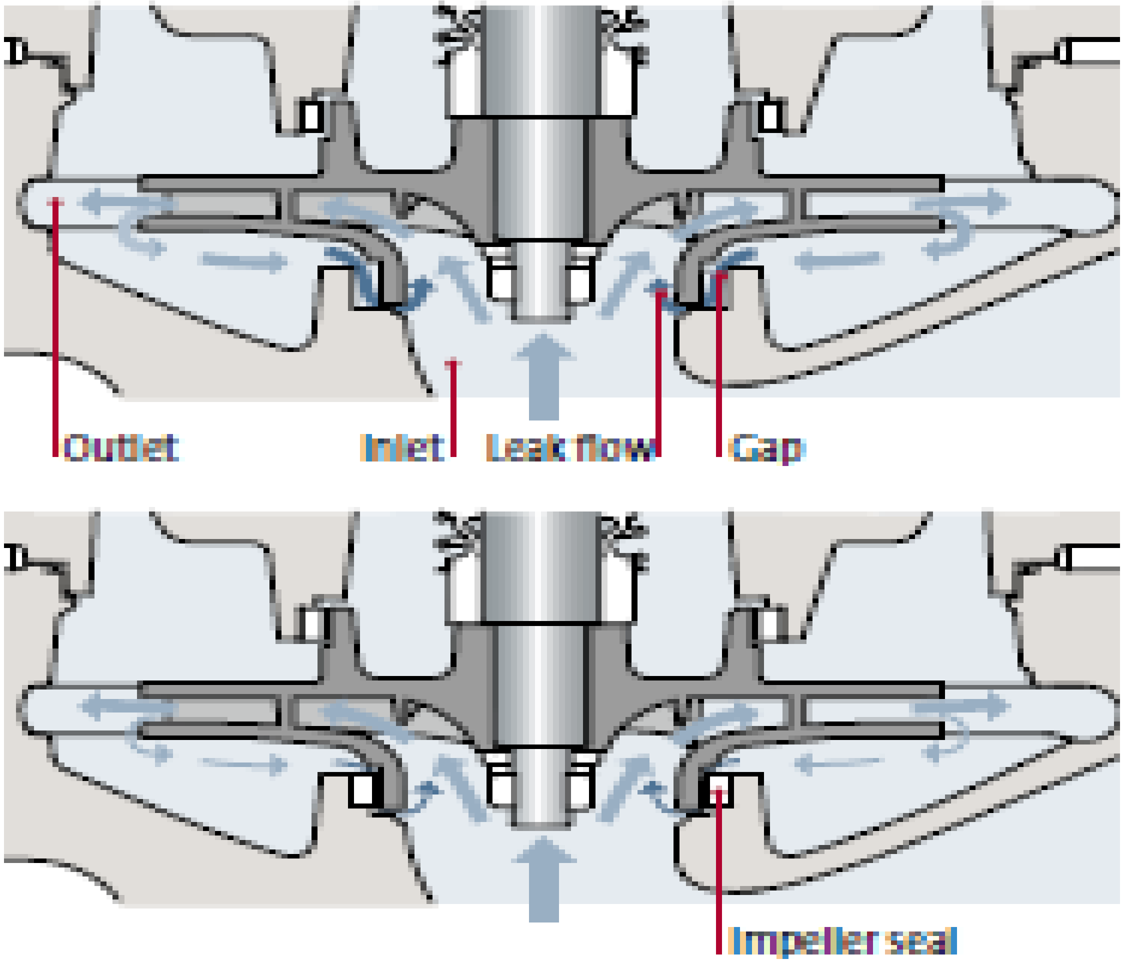


Figure 1.13: Leak flow through the gap.

Impeller – Axial thrust balancing

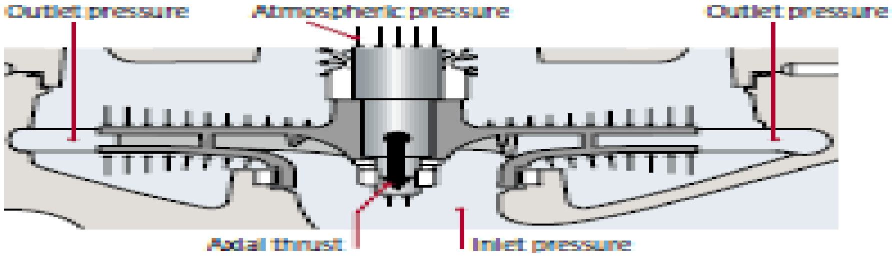


Figure 1.15: Pressure forces which cause axial thrust.

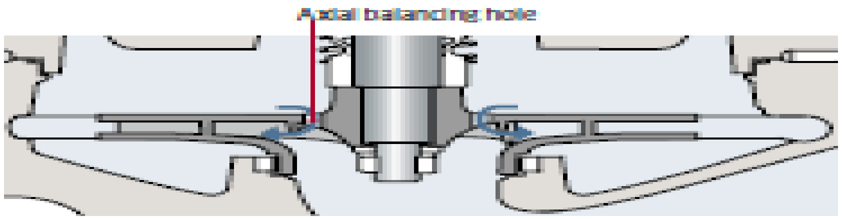


Figure 1.16: Axial thrust reduction using balancing holes.

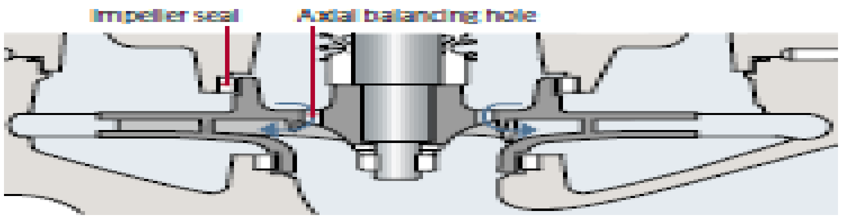


Figure 1.17: Axial thrust reduction using impeller seal and balancing holes.

Impeller – Axial thrust balancing

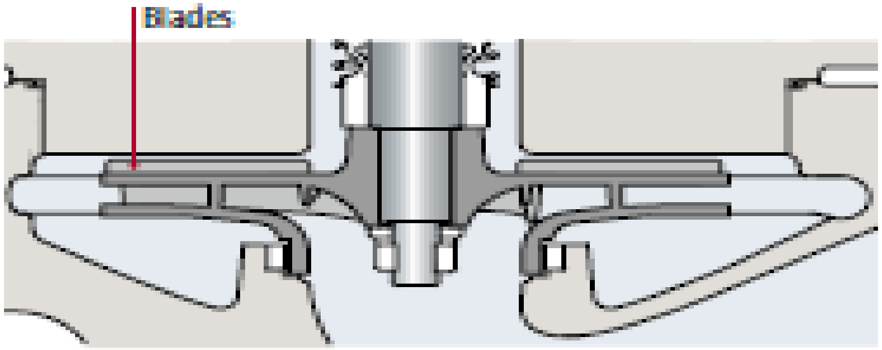


Figure 1.18: Axial thrust reduction through blades on the back of the hub plate.

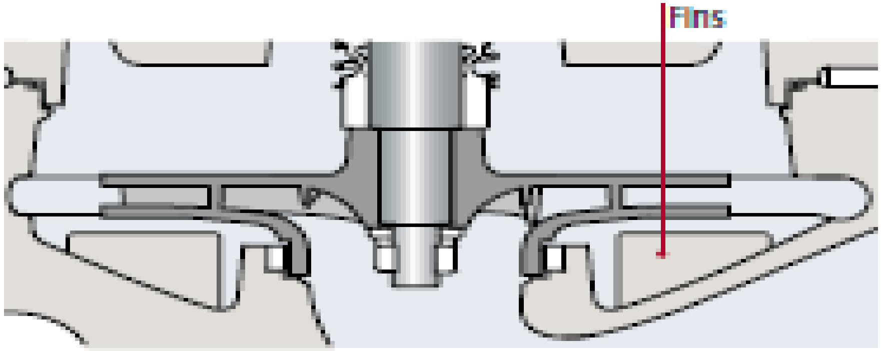
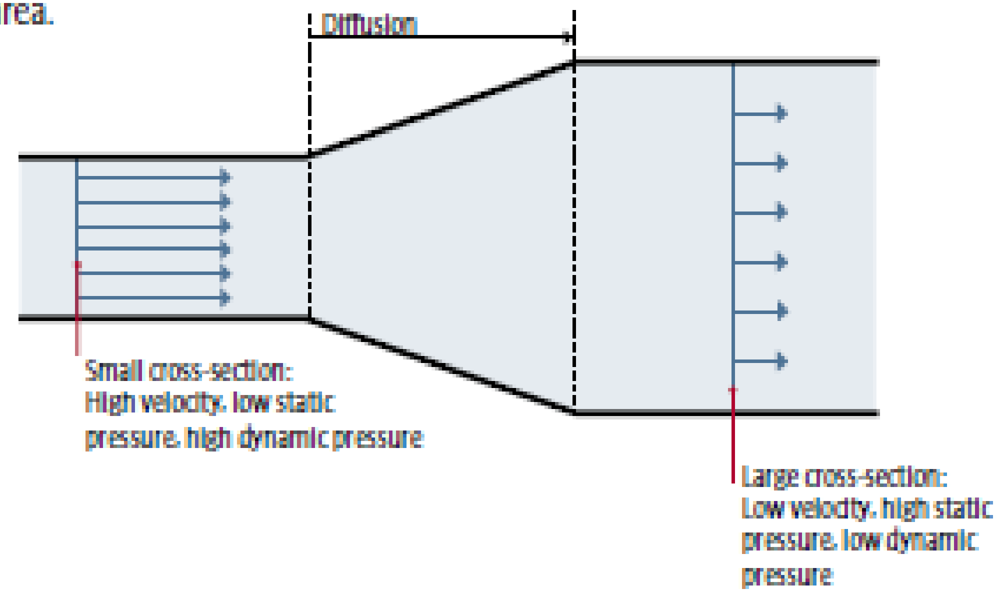


Figure 1.19: Axial thrust reduction using fins in the pump housing.

Diffuser and Volute casing

The volute casing collects the fluid from the impeller and leads into the outlet flange. The volute casing converts the dynamic pressure rise in the impeller to static pressure.

Figure 1.20: Change of fluid velocity in a pipe caused by change in the cross-section area.



Diffuser & volute casing

To have the same pressure along the volute, the cross-section area in the volute must be increased along the periphery from the tongue towards the throat. The throat is the place on the outside of the tongue where the smallest cross section area in the outlet diffuser is found.

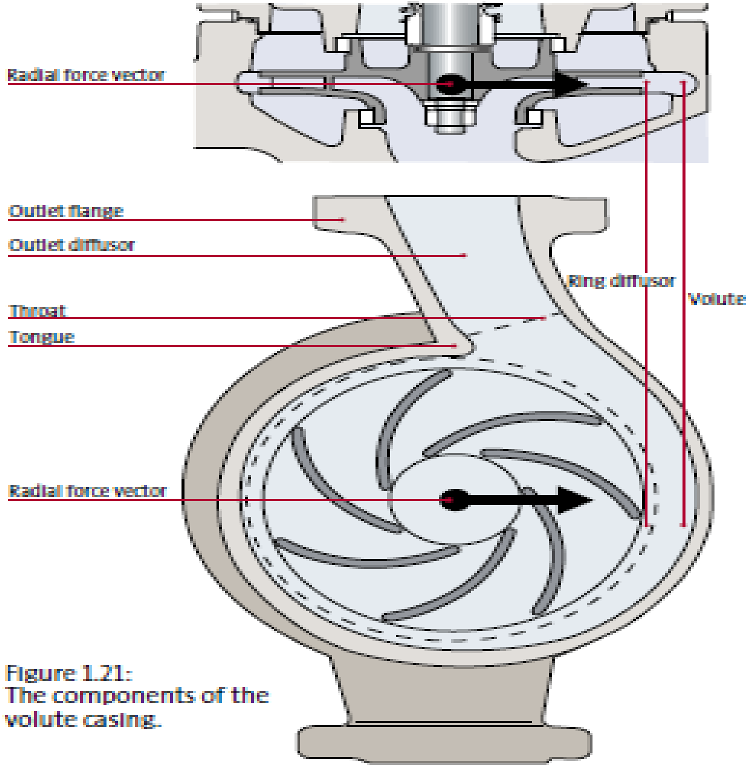


Figure 1.21:
The components of the volute casing.

Centrifugal Pumps - Classification

- Shaft Orientations (horizontal or vertical)
- Stage Numbers (single- or multi-stage)
- Specific Speeds (radial, mixed, or axial)
- Rotor Types (overhung or between-bearings)
- Impeller Types (enclosed, semi-open or open)
- Casing Types (radial-or axial-split, double wall)
- Many Other Variations

Suction and discharge flanges

- European Standard
  - » Cast iron - PN2.5 to PN 40 EN 1092-2
  - » Ductile iron - PN 10 to PN 63 EN 1092-2
  - » Cast Steel –- PN6 to PN100 EN 1092-2
- ANSI standard
  - » Cast iron - Class 25 to class 800 ANSI B 16.1
  - » Cast steel - Class 150 to class 2500 ANSI B16.5
- ISO Standard
  - » Cast iron – preferred series (PN10 to PN50) optional series (PN2.5 to PN40) — ISO 7005-2
  - » Ductile iron - preferred series (PN10 to PN420) optional series (PN2.5 to PN40) — ISO 7005-2
  - » Cast Steel - preferred series (PN10 to PN420) optional series (PN2.5 to PN40) — ISO 7005-1

Impeller design vs specific speed

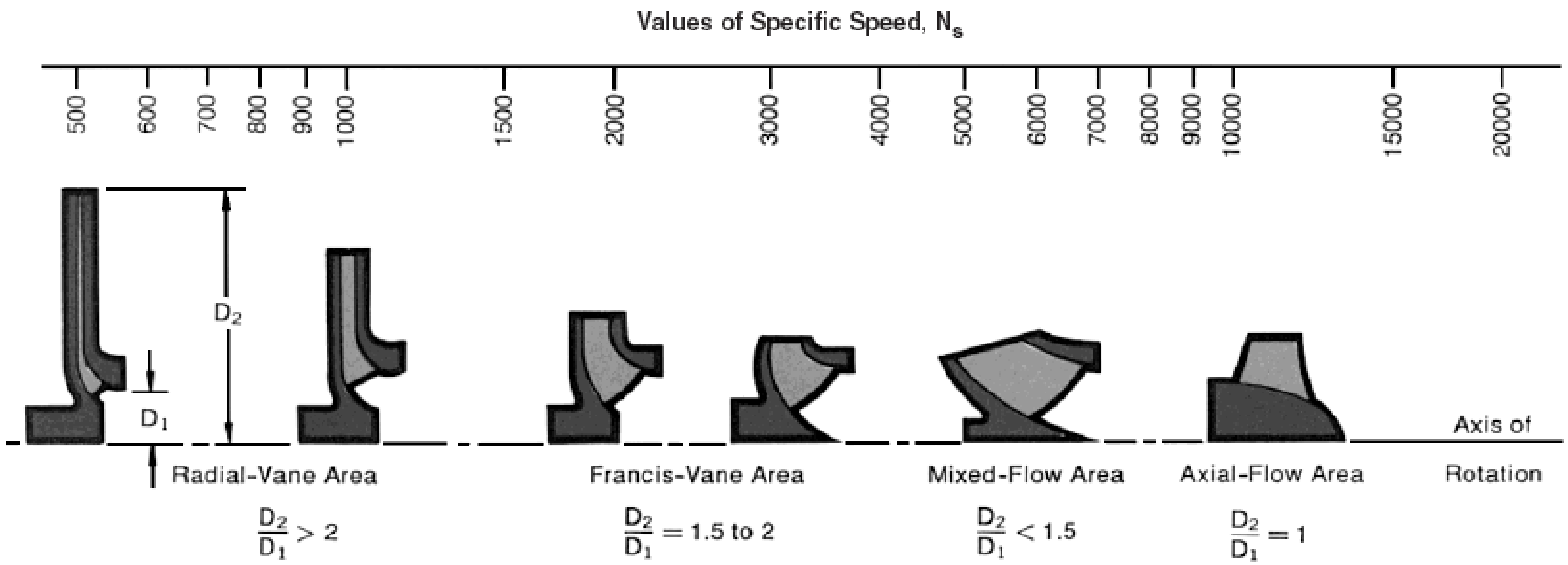
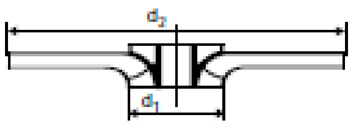
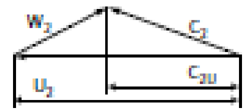
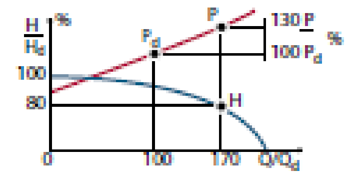
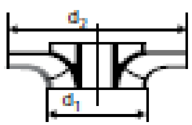
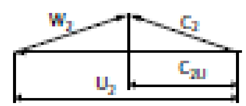
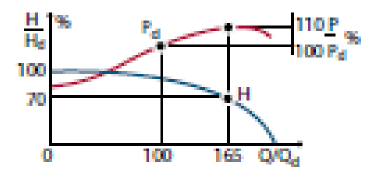
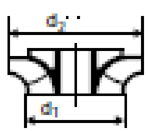
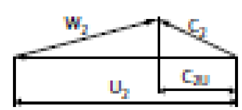
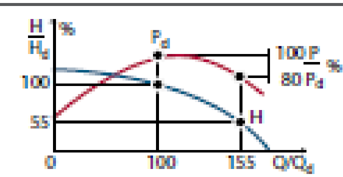
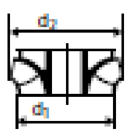
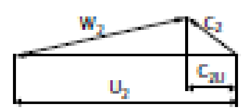
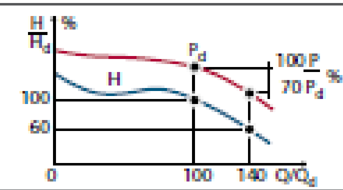
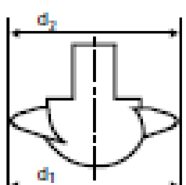
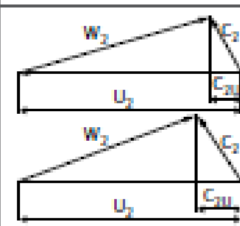
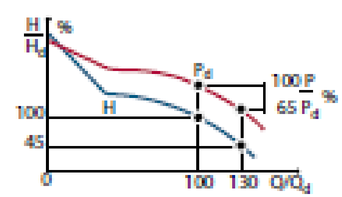


Fig. 3 Impeller Design vs Specific Speed

Impeller design – velocity diagram and performance curve

Impeller shape	n_q	Outlet velocity triangle	Performance curves
 $d_2/d_1 = 3.5 - 2.0$	15		
 $d_2/d_1 = 2.0 - 1.5$	30		
 $d_2/d_1 = 1.5 - 1.3$	50		
 $d_2/d_1 = 1.2 - 1.1$	90		
 $d_1 = d_2$	110		

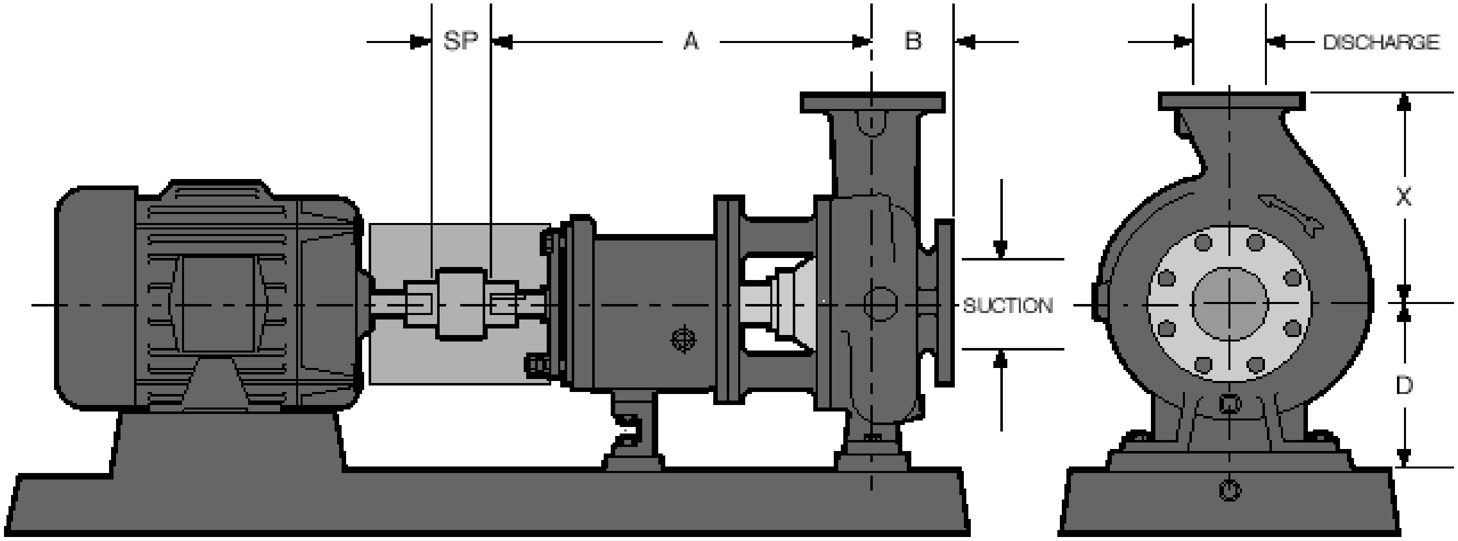
Centrifugal pumps- API 610 classification

Table 1 — Pump classification type identification

Pump type			Orientation		Type code
Centrifugal pumps	Overhung	Flexibly coupled	Horizontal	Foot-mounted	OH1
				Centreline-supported	OH2
			Vertical in-line with bearing bracket		OH3
		Rigidly coupled	Vertical in-line		OH4
		Close-coupled	Vertical in-line		OH5
			High-speed integrally geared		OH6
	Between-bearings	1- and 2-stage	Axially split		BB1
			Radially split		BB2
		Multistage	Axially split		BB3
			Radially split	Single casing	BB4
				Double casing	BB5
	Vertically suspended	Single casing	Discharge through column	Diffuser	VS1
				Volute	VS2
				Axial flow	VS3
			Separate discharge	Line shaft	VS4
				Cantilever	VS5
		Double casing	Diffuser		VS6
			Volute		VS7

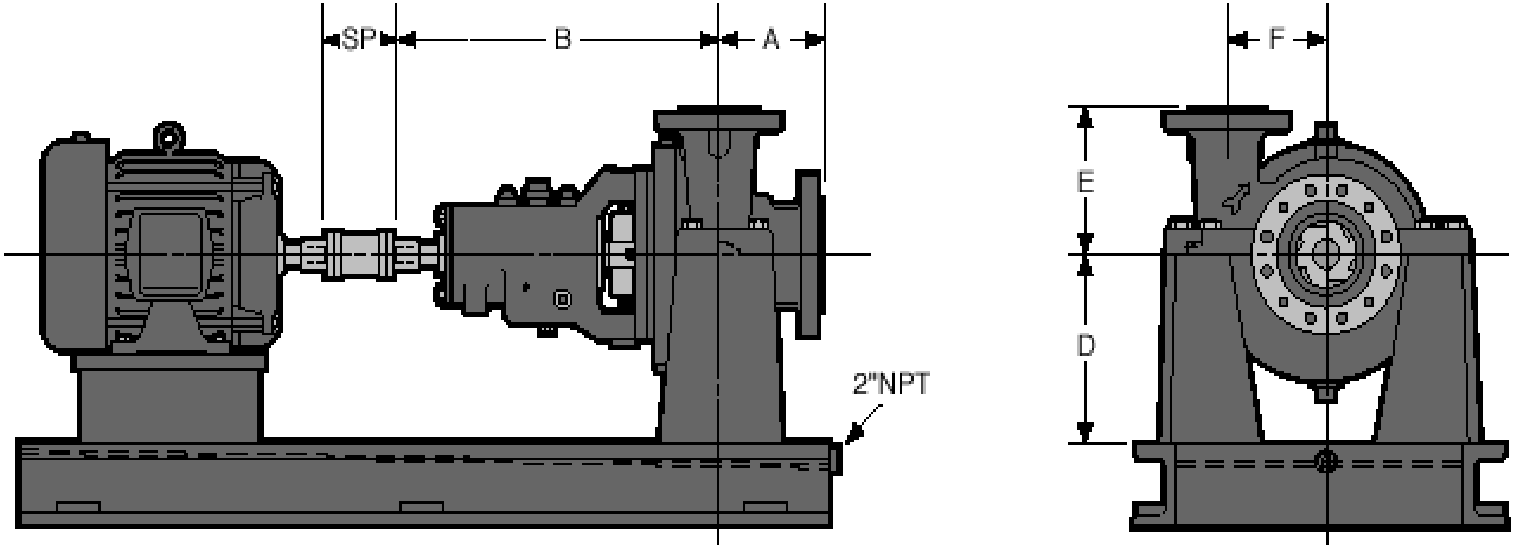
OH1 Foot mounted

- *Horizontal, End suction, overhung impeller, foot mounted casing*



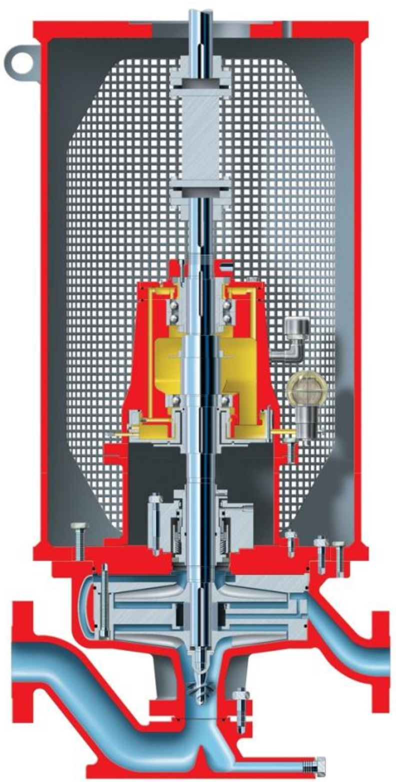
OH2 Centre line mounted

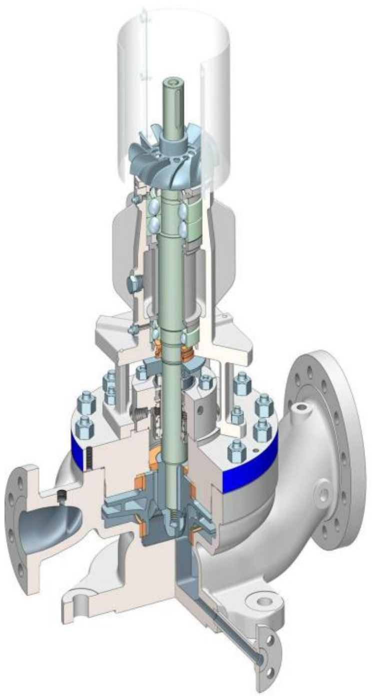
- ***Horizontal, End suction, overhung impeller, centre line mounted casing***



OH3 (Vertical Inline flexibly coupled)

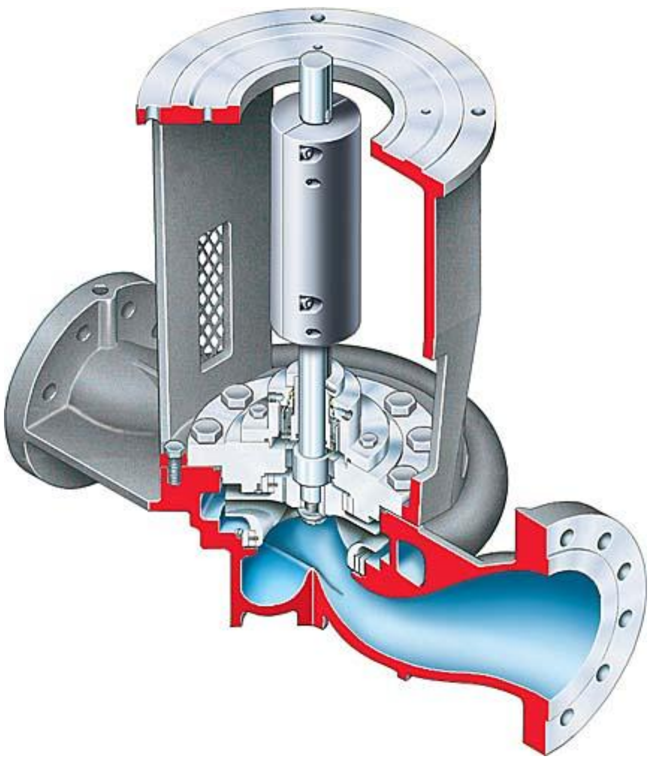
Vertical, In line, overhung impeller, flexibly coupled with pump bearing housing

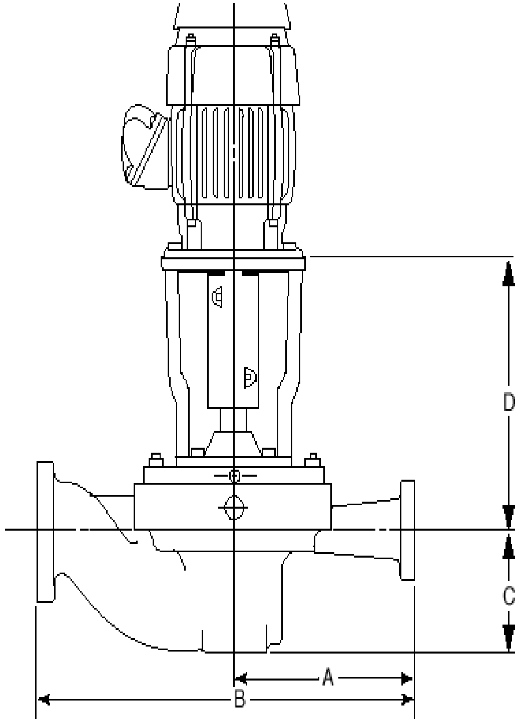




OH4 (vertical inline, rigidly coupled pump)

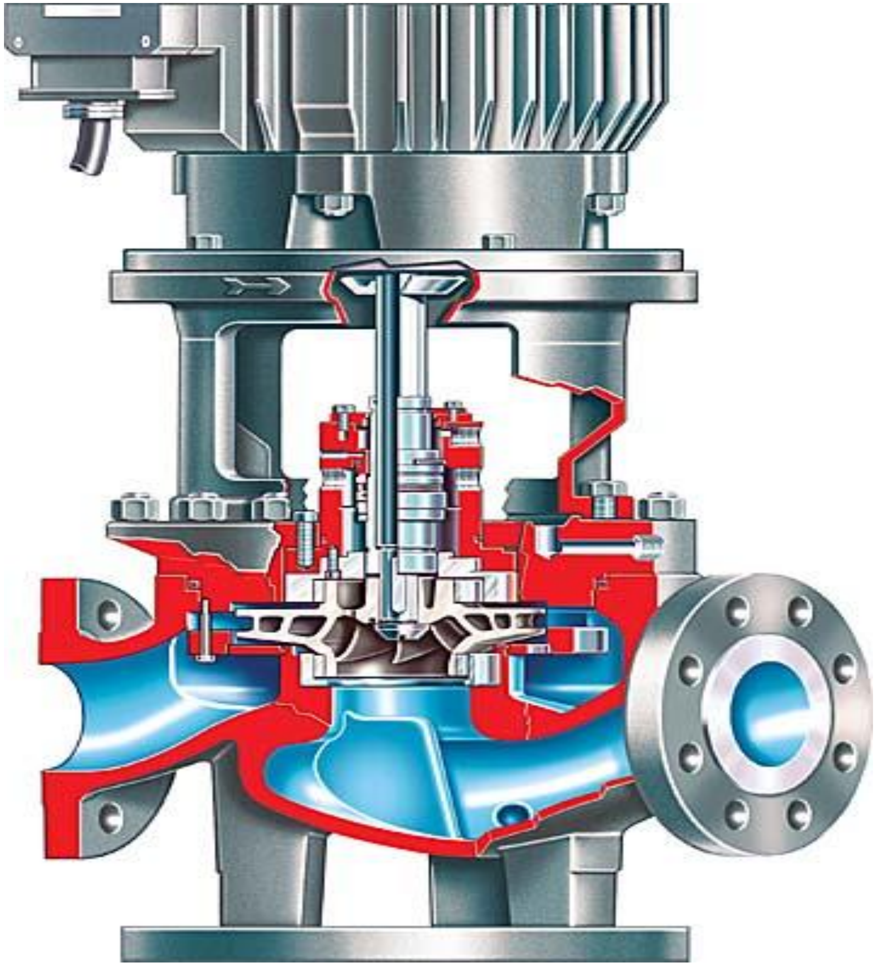
Vertical, In line, overhung impeller, rigidly coupled without pump bearing housing





OH5 (vertical Inline close coupled)

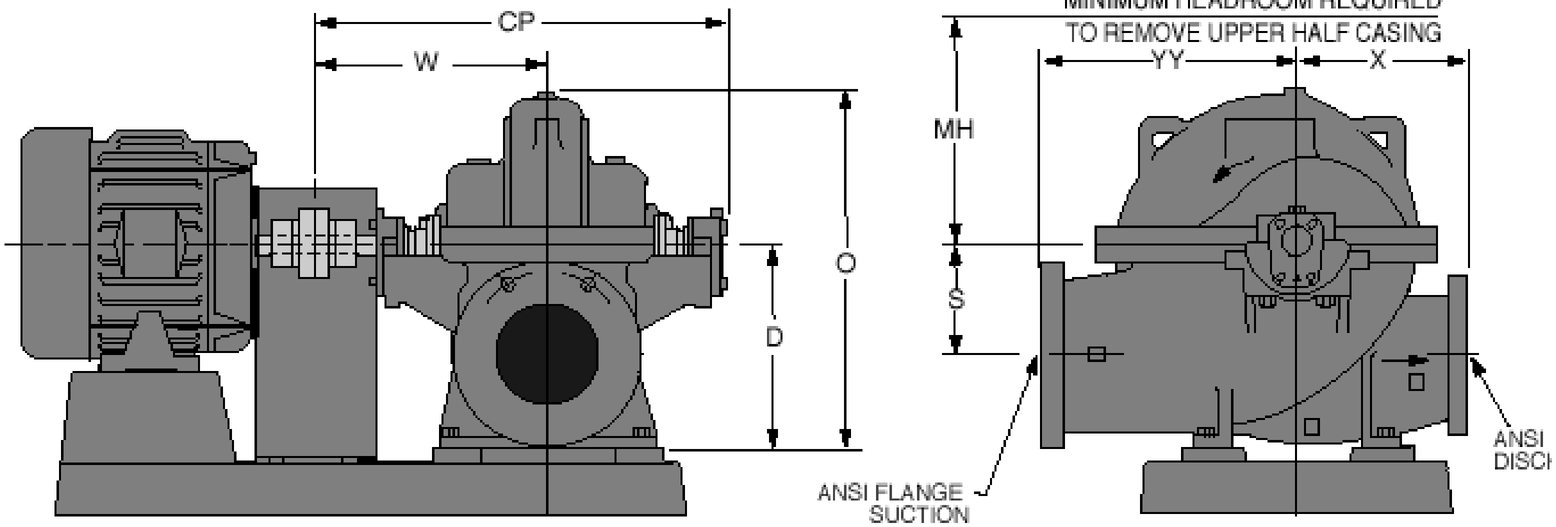
- *Vertical, In line, overhung impeller, close coupled without pump bearing housing*



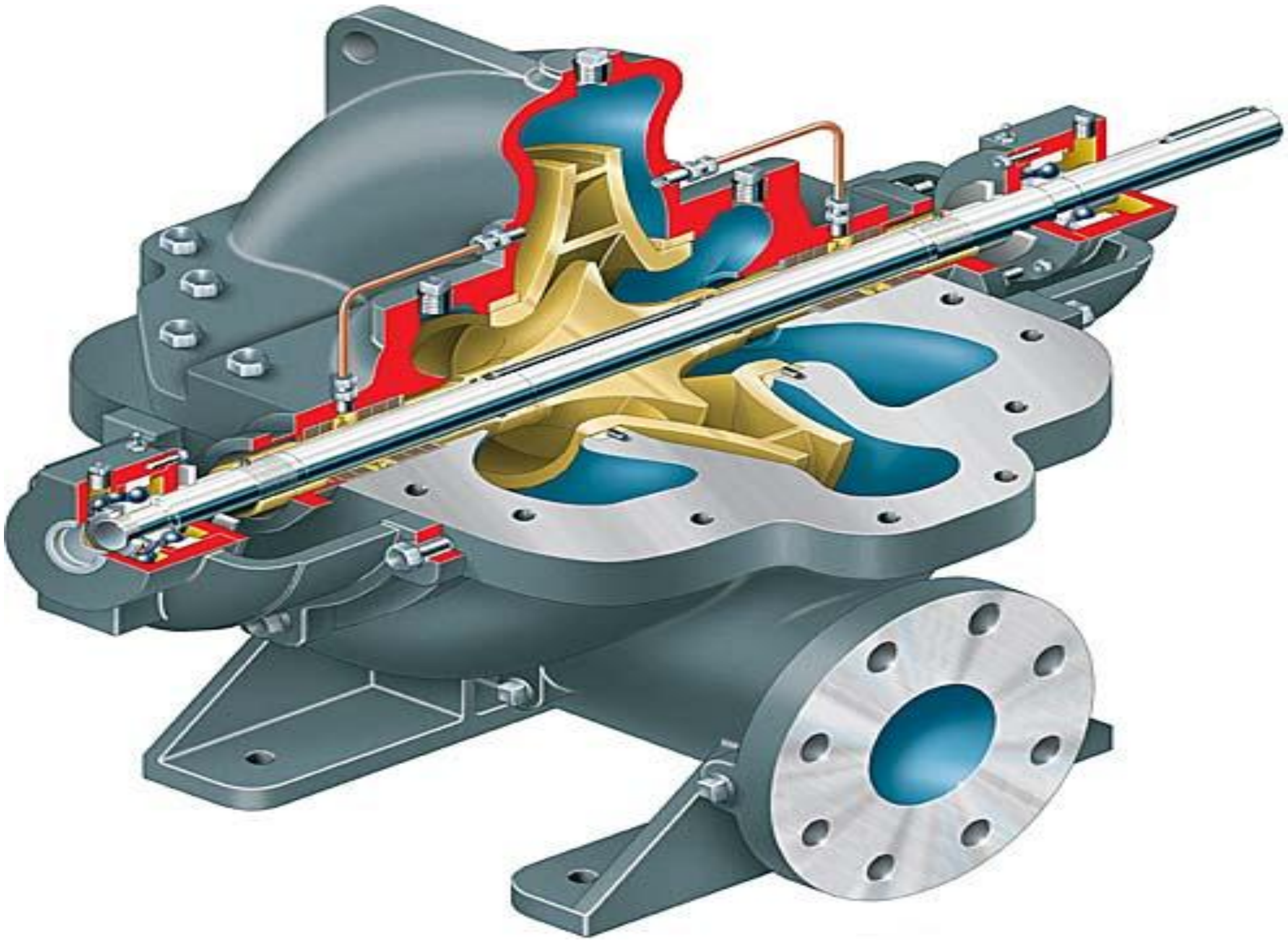
OH6 (Vertical inline integral geared)

- ***Vertical, In line, overhung impeller, integrally geared pump***

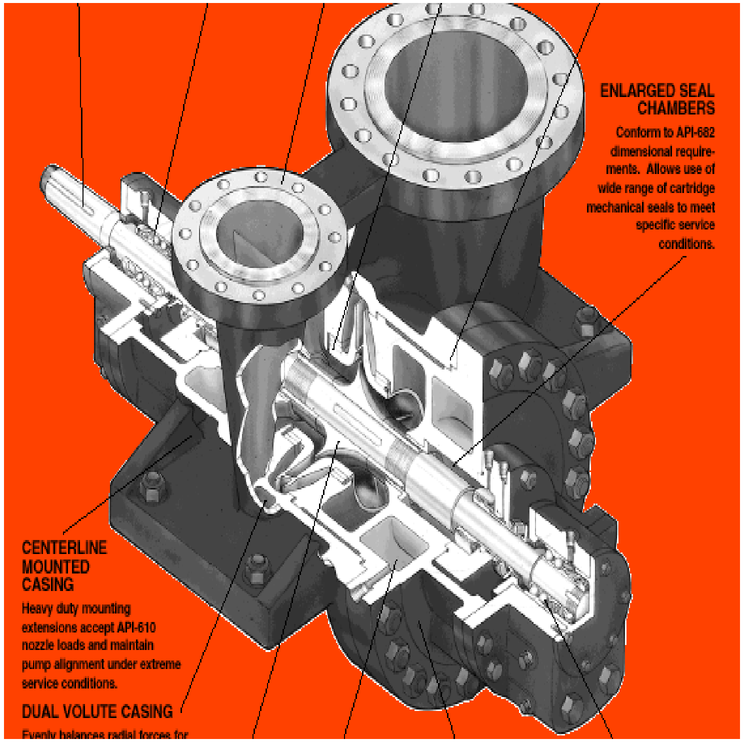
BB1 (Axial split 1 & 2 stage)

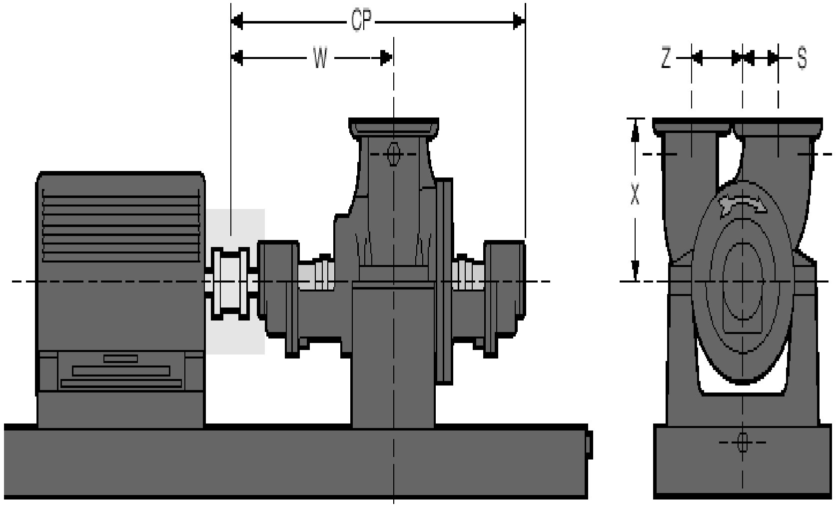


BB1 (Axial split 1 & 2 stage)



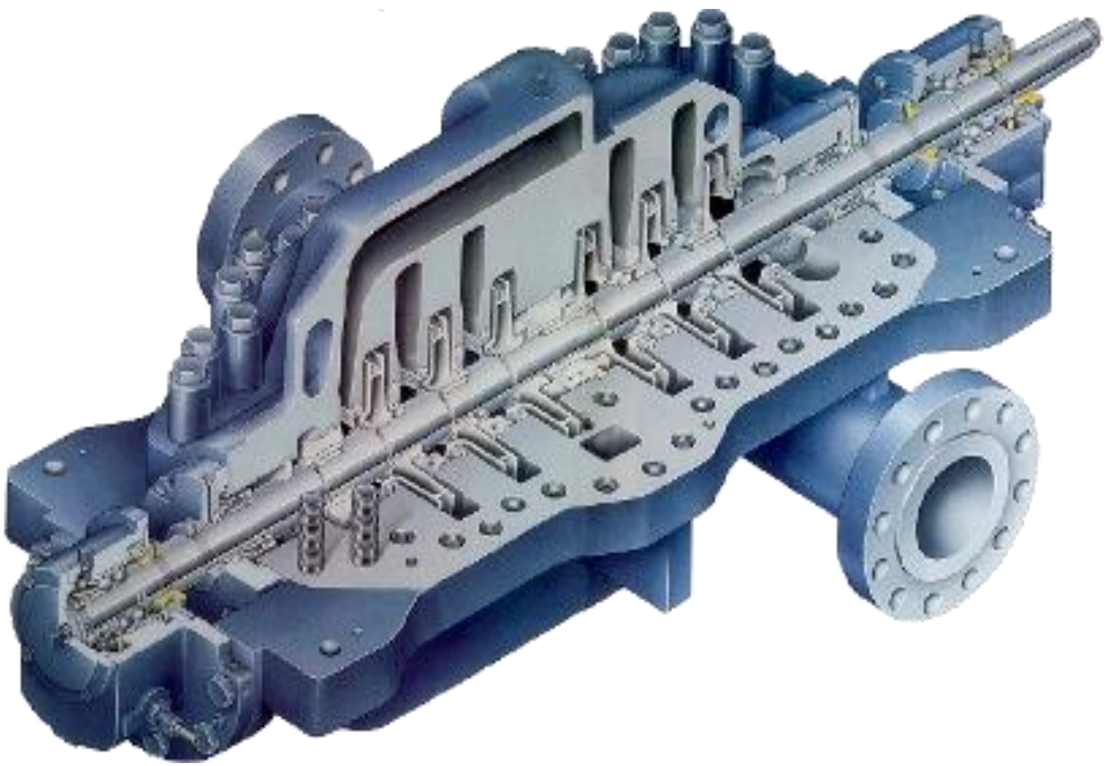
BB2 (Radial split 1 & 2 stage)



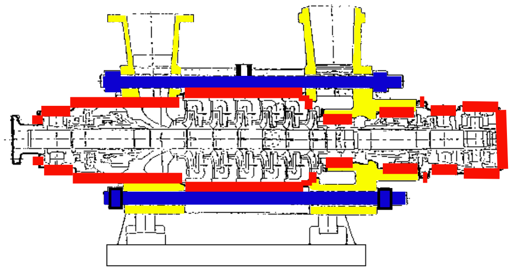


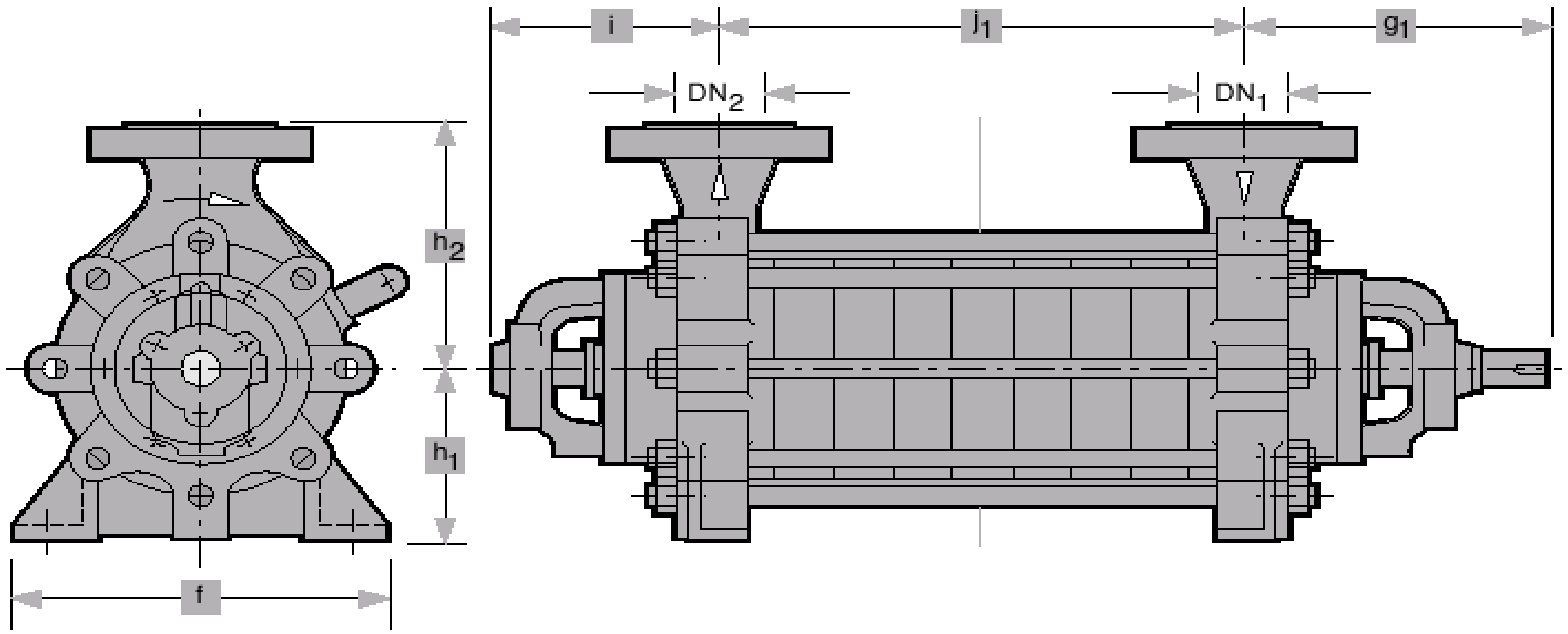
BB3 Multistage axial split pumps

BB3 Multistage axial split pumps

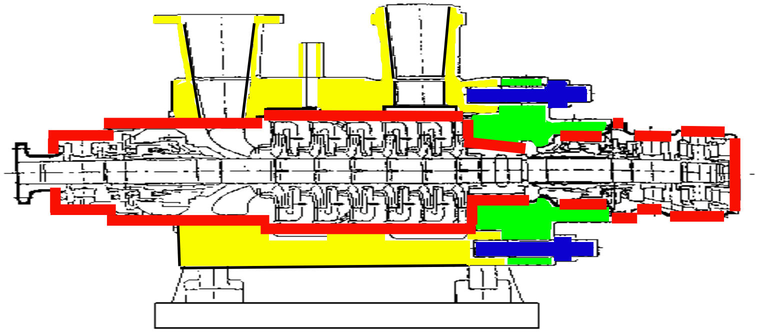


BB4 (Multistage radial split – Single casing) – segmental ring





BB 5 (Multistage radial split –Double casing) – Barrel pump



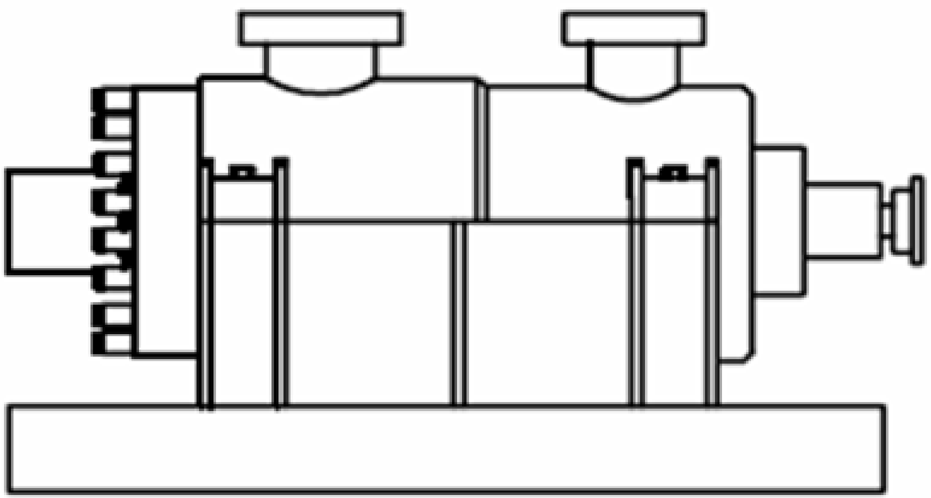
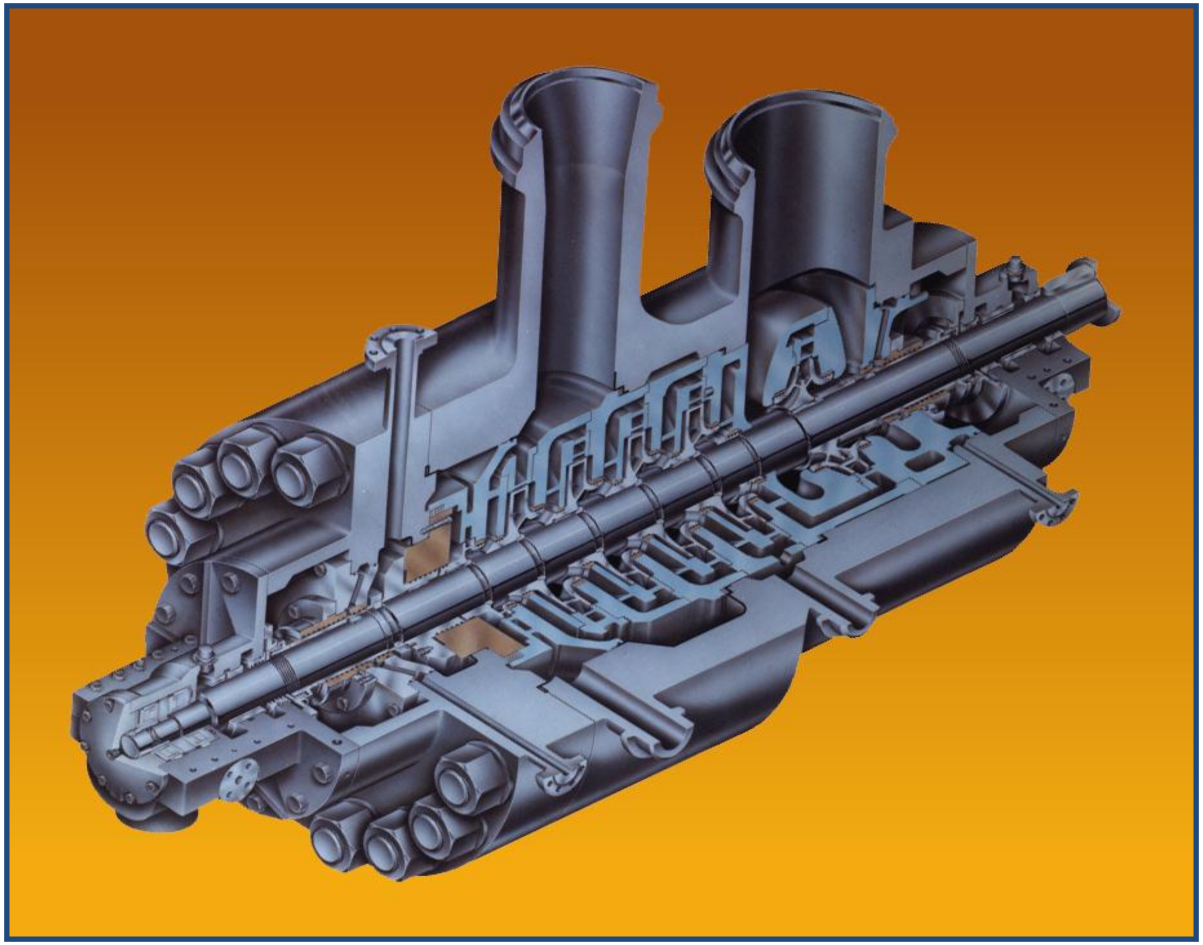
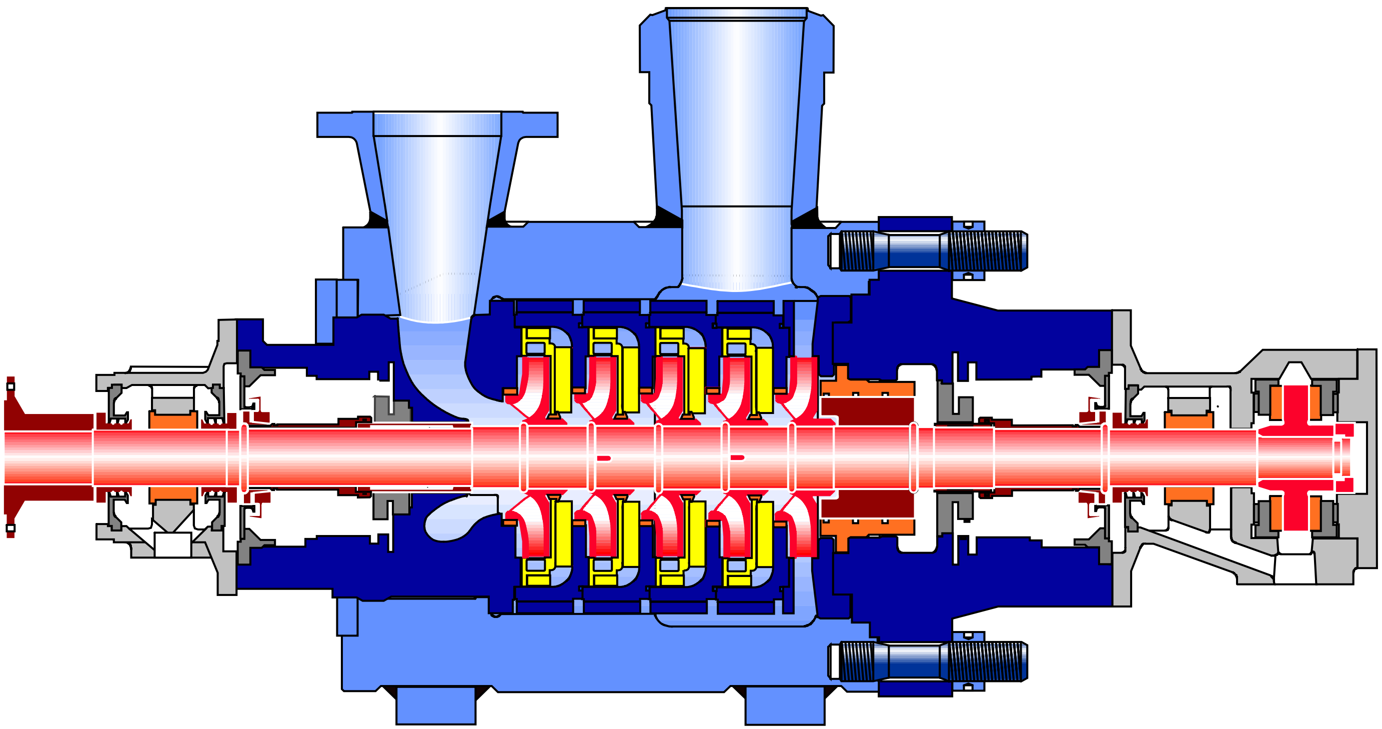


Figure 11 — Pump type BB5

BB 5 (Multistage radial split –Double casing) – Barrel pump



BB 5 (Multistage radial split –Double casing) – Barrel pump



BB 5 (Multistage radial split –Double casing) – Barrel pump

Vertically suspended VS1 – Turbine pump

4.2.12 Pump type VS1

Wet pit, vertically suspended, single-casing diffuser pumps with discharge through the column shall be designated pump type VS1.

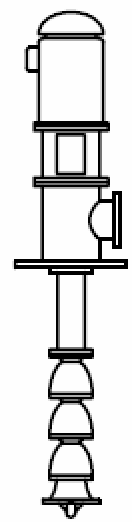


Figure 12 — Pump type VS1

Vertically suspended VS2 pump

4.2.13 Pump type VS2

Wet pit, vertically suspended single-casing volute pumps with discharge through the column shall be designated pump type VS2.

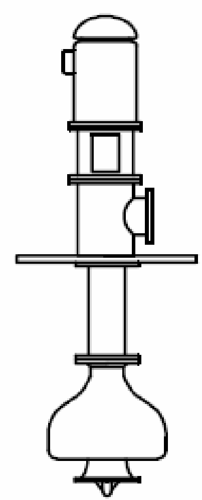


Figure 13 — Pump type VS2

Vertically suspended VS3

4.2.14 Pump type VS3

Wet pit, vertically suspended, single-casing axial-flow pumps with discharge through the column shall be designated pump type VS3.

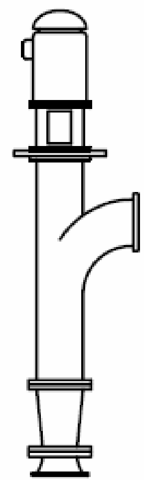
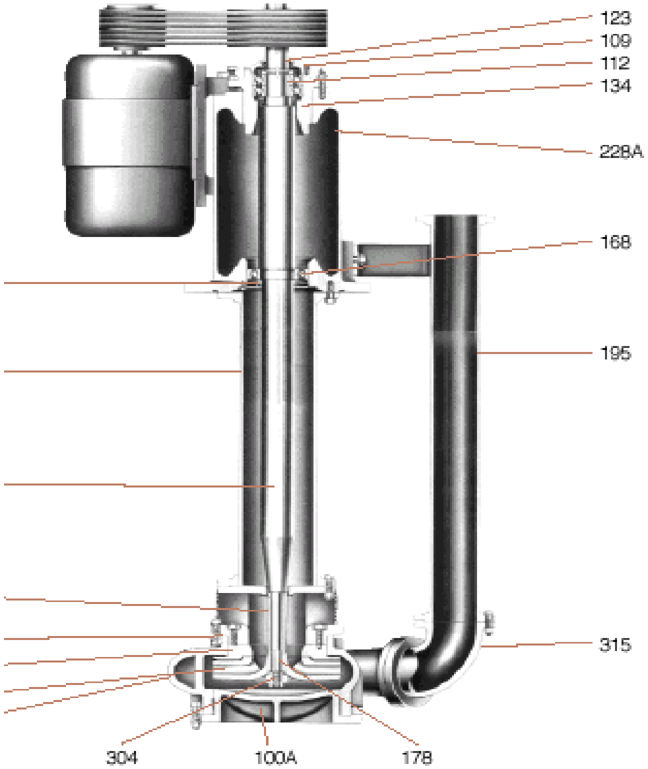


Figure 14 — Pump type VS3

VS 4 & 5 (Sump Pump)



Vertically suspended VS6 – double casing

4.2.17 Pump type VS6

Double-casing diffuser vertically suspended pumps shall be designated pump type VS6.

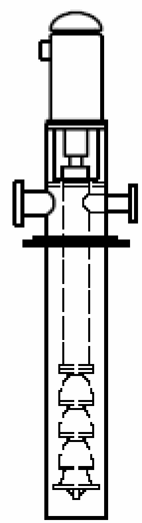
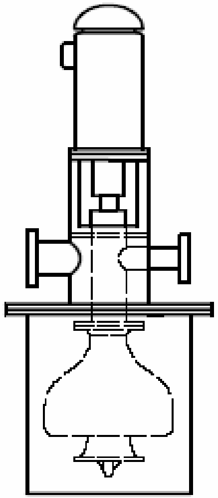


Figure 17 — Pump type VS6

Vertically suspended VS7

4.2.18 Pump type VS7

Double-casing volute vertically suspended pumps shall be designated pump type VS7.



Velocity Triangle

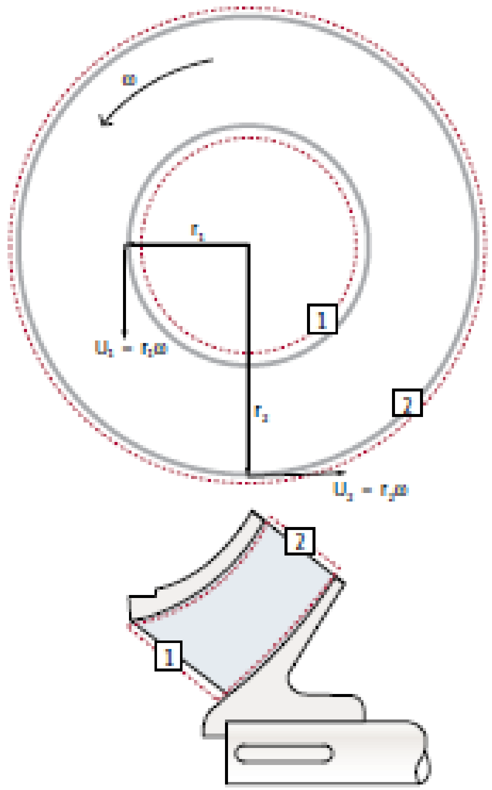
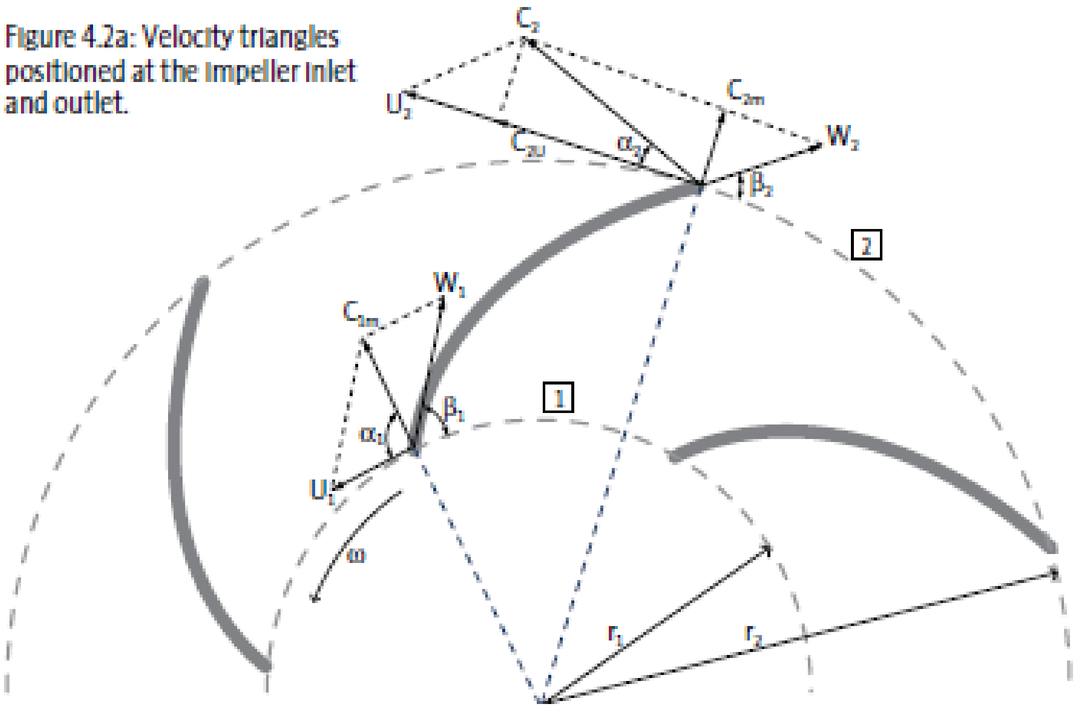


Figure 4.6: Control volume for an impeller.

Velocity triangle

Figure 4.2a: Velocity triangles positioned at the impeller inlet and outlet.



The second plane is defined by the meridional velocity and the tangential velocity.

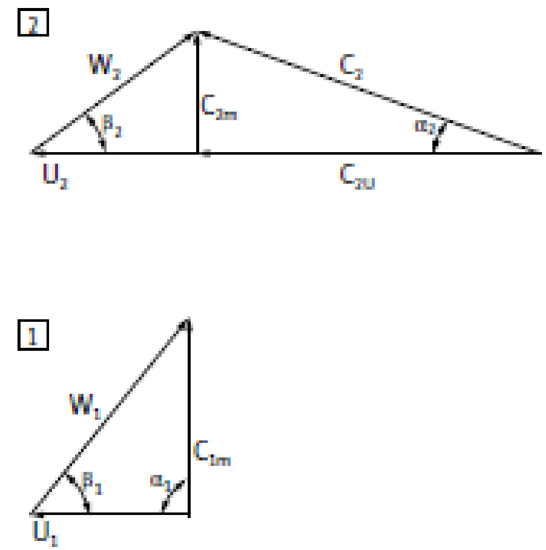


Figure 4.2b: Velocity triangles

Blade shape and theoretical pump curve

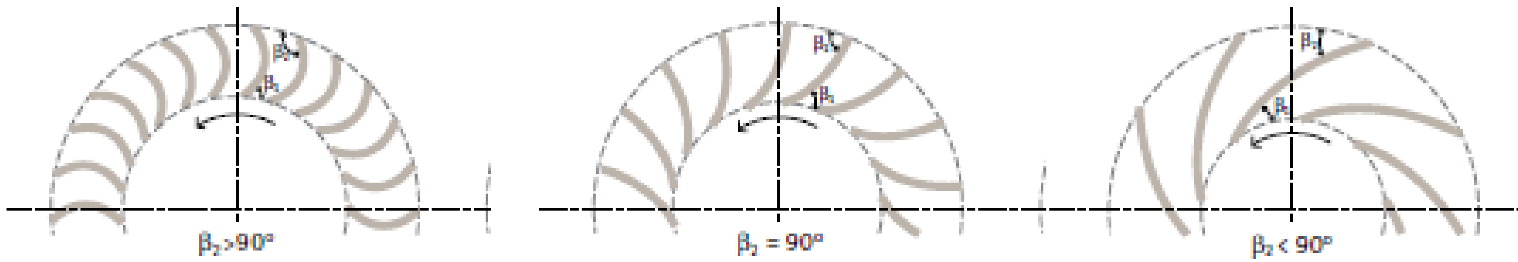


Figure 4.7: Blade shapes depending on outlet angle

$$H = \frac{U_2^2}{g} - \frac{U_2}{\pi \cdot D_2 \cdot b_2 \cdot g \cdot \tan(\beta_2)} \cdot Q \quad [m]$$

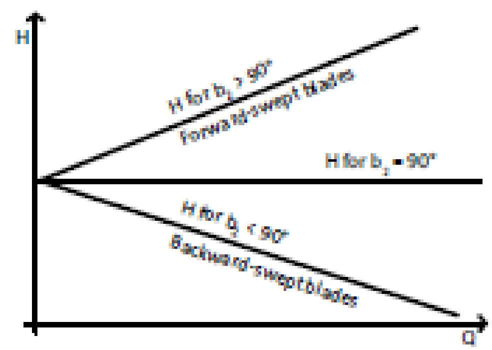


Figure 4.8: Theoretical pump curves calculated based on formula (4.21).

Real pump curves are, however, curved due to different losses, slip, inlet rotation, etc.

Pump losses

	Loss	Smaller flow (Q)	Lower head (H)	Higher power consumption (P_2)
Mechanical losses	Bearing			X
	Shaft seal			X
Hydraulic losses	Flow friction		X	
	Mixing		X	
	Recirculation		X	
	Incidence		X	
	Disk friction			X
	Leakage	X		

Chart 5.1: Losses in pumps and their influence on the pump curves.

Pump losses

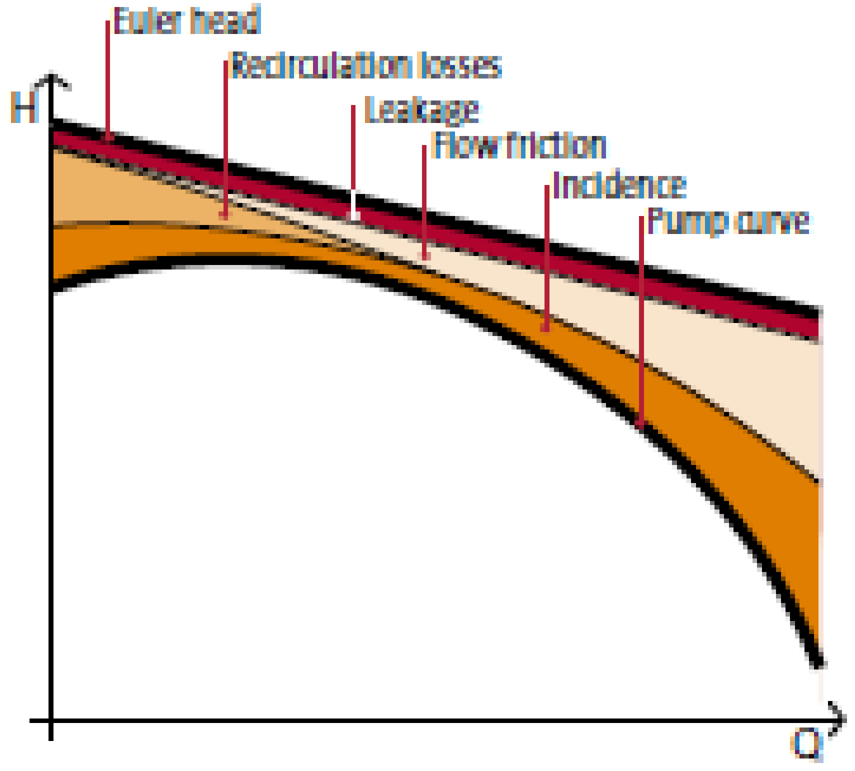


Figure 5.1: Reduction of theoretical Euler head due to losses.

Pump Losses

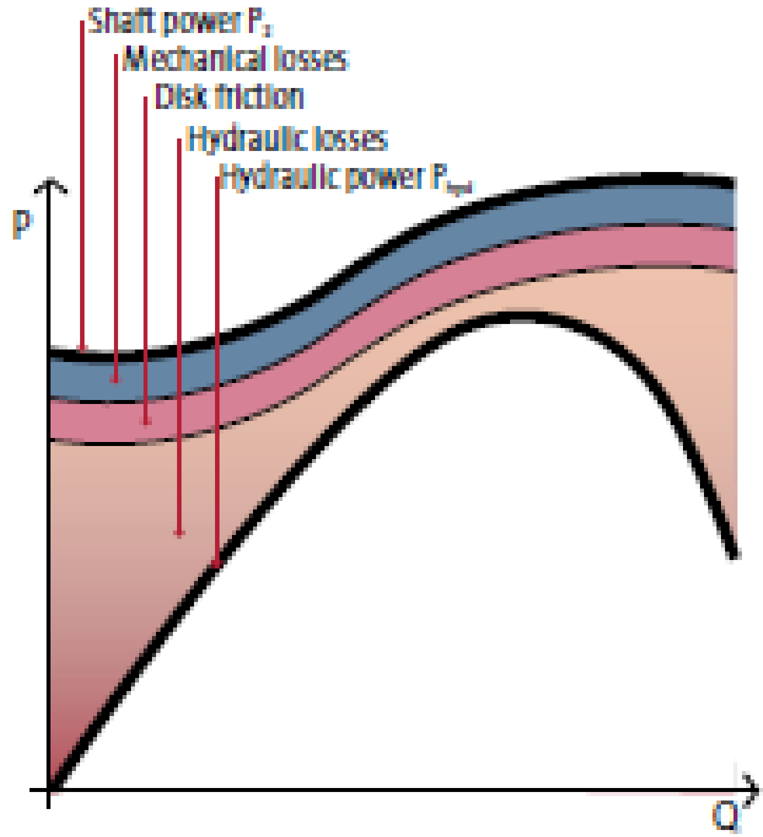
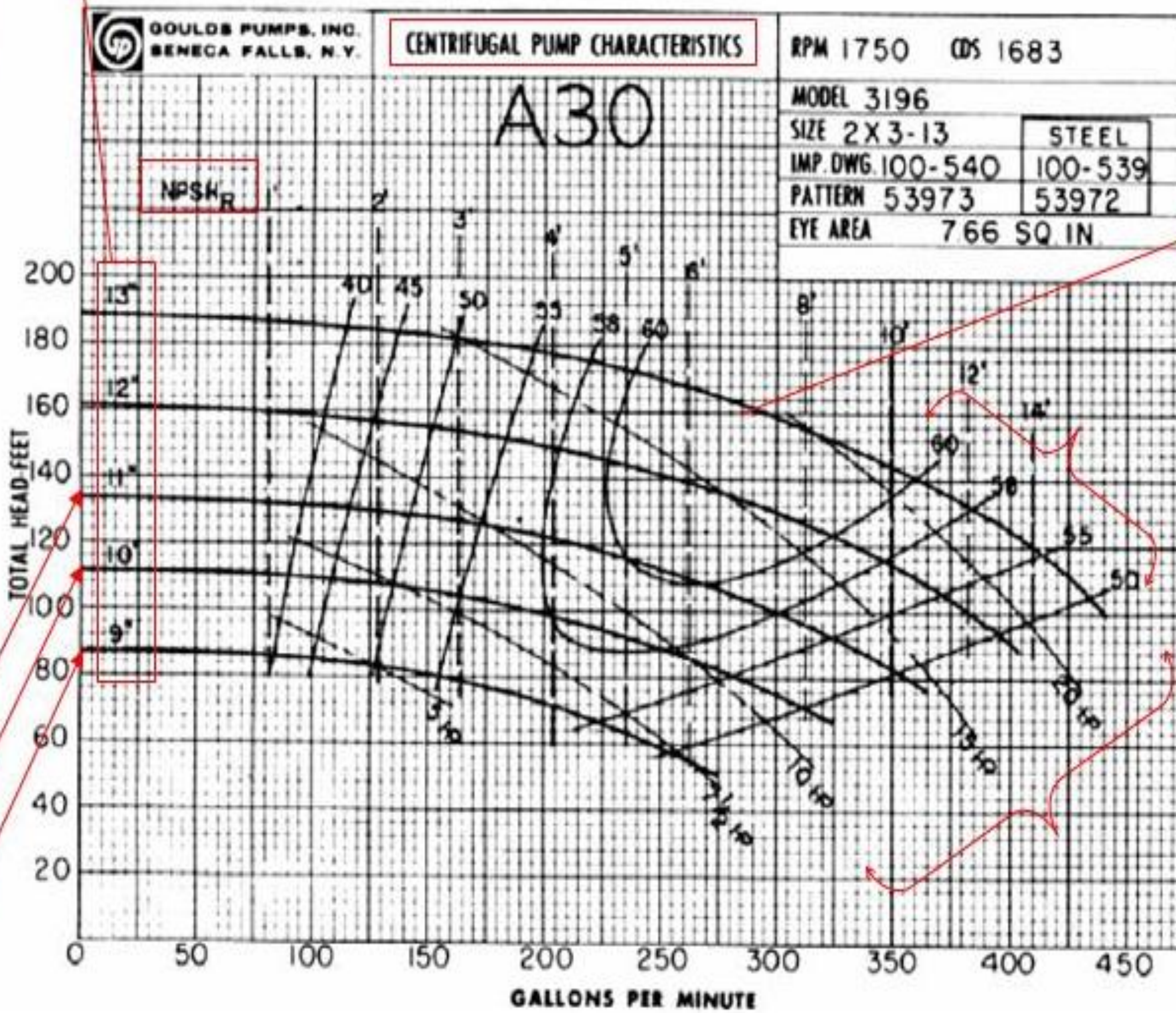


Figure 5.2: Increase in power consumption due to losses.

Impeller Diameters

Power (kW)= Q x H / (367 x Eff. Pump)



Best Efficiency Point

Efficiencies

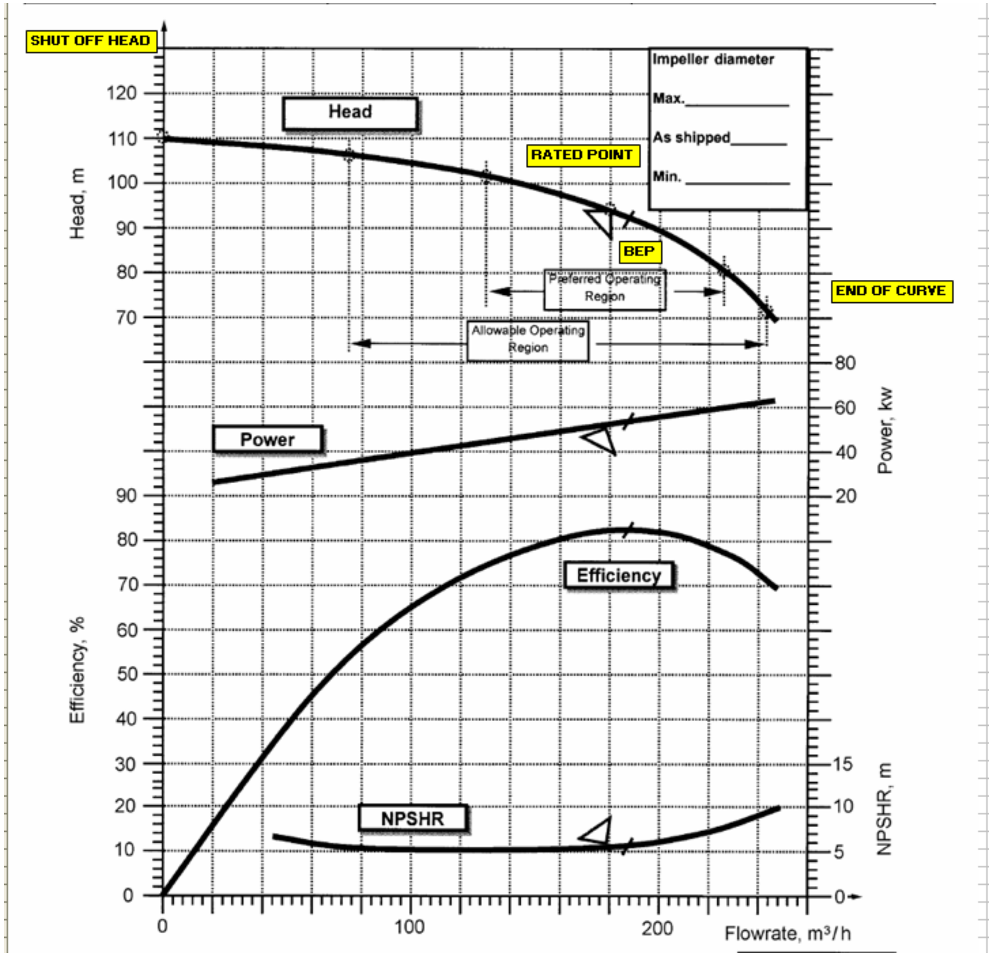
Family of curves

Head (m)

Shut off heads for impeller dia. 9", 10", 11" etc.

Capacity (m³/s)

Pump performance curve



Performance curve – different characteristics

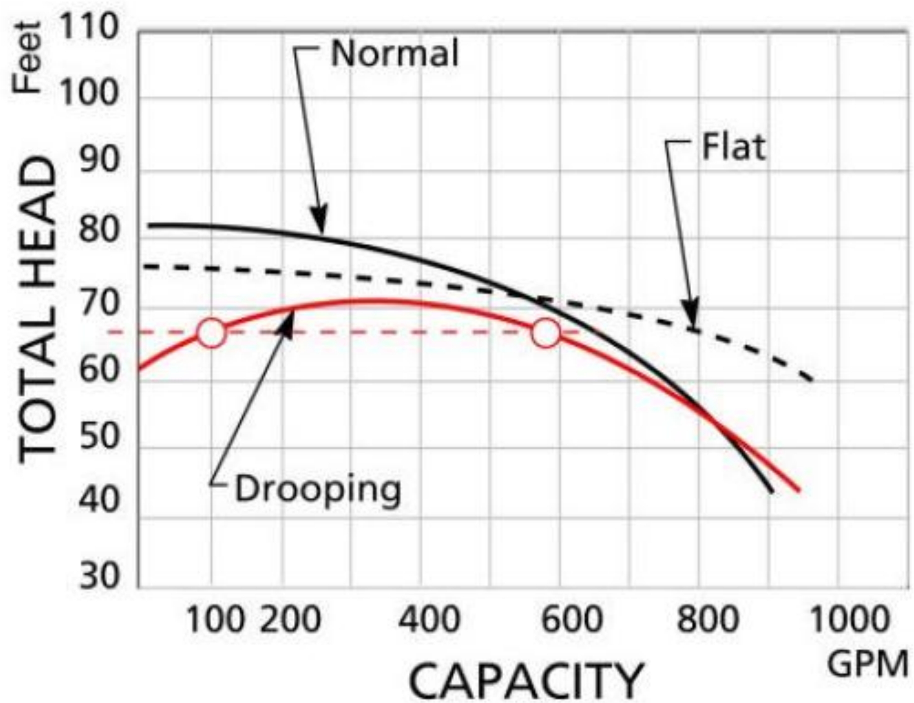


Figure 12 Different types of radial pump characteristic curve profiles.

Performance curves – different types

- *Pump curve with 150% head rise between capacities of peak efficiency and shut-off are STEEP RISING curves.*
- *Pump curve with 10-25% head rise between capacities of peak efficiency and shut-off are STEADY RISING curves.*
- *Pump curve with >10% head rise between capacities of peak efficiency and shut-off are FLAT curves.*
- *Hunting or Drooping curves*

System Resistance - Head

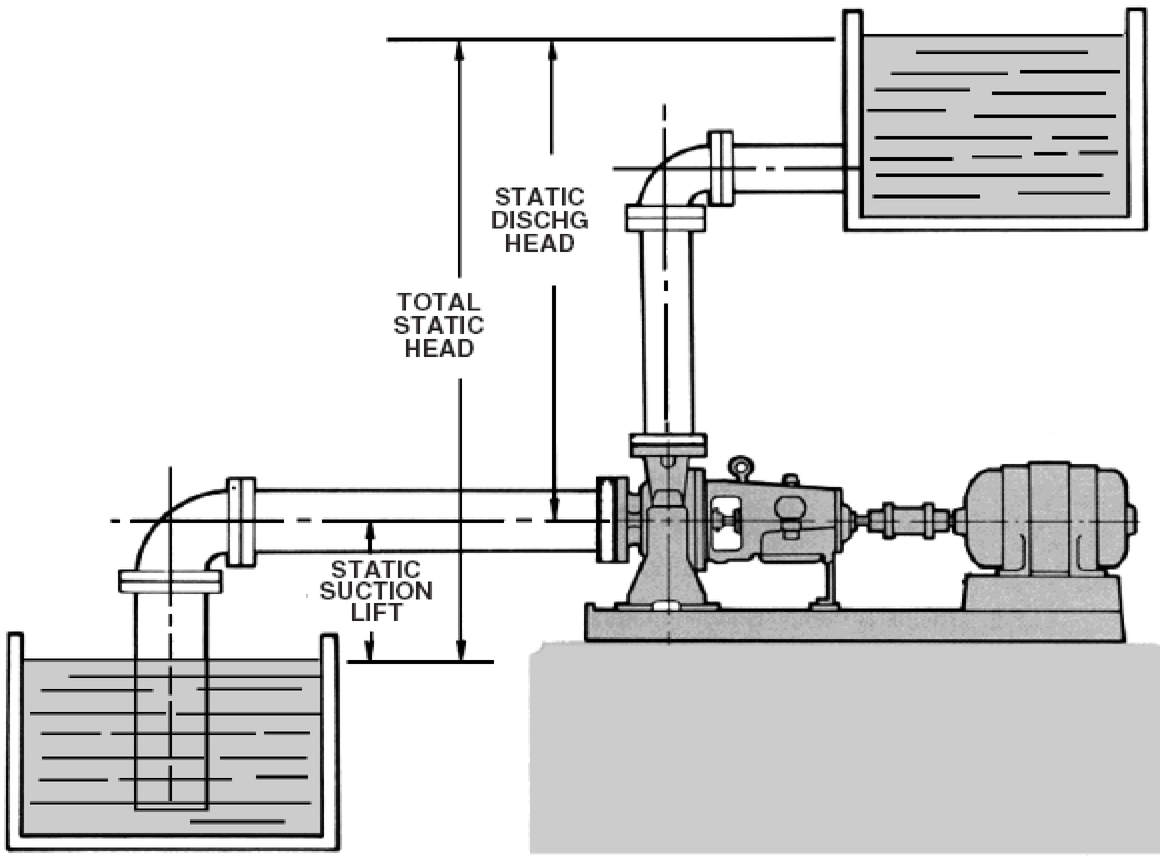


Fig. 2-a Suction Lift –
Showing Static Heads in a Pumping System Where the Pump is Located Above the Suction Tank. (Static Suction Head)

System resistance - Head

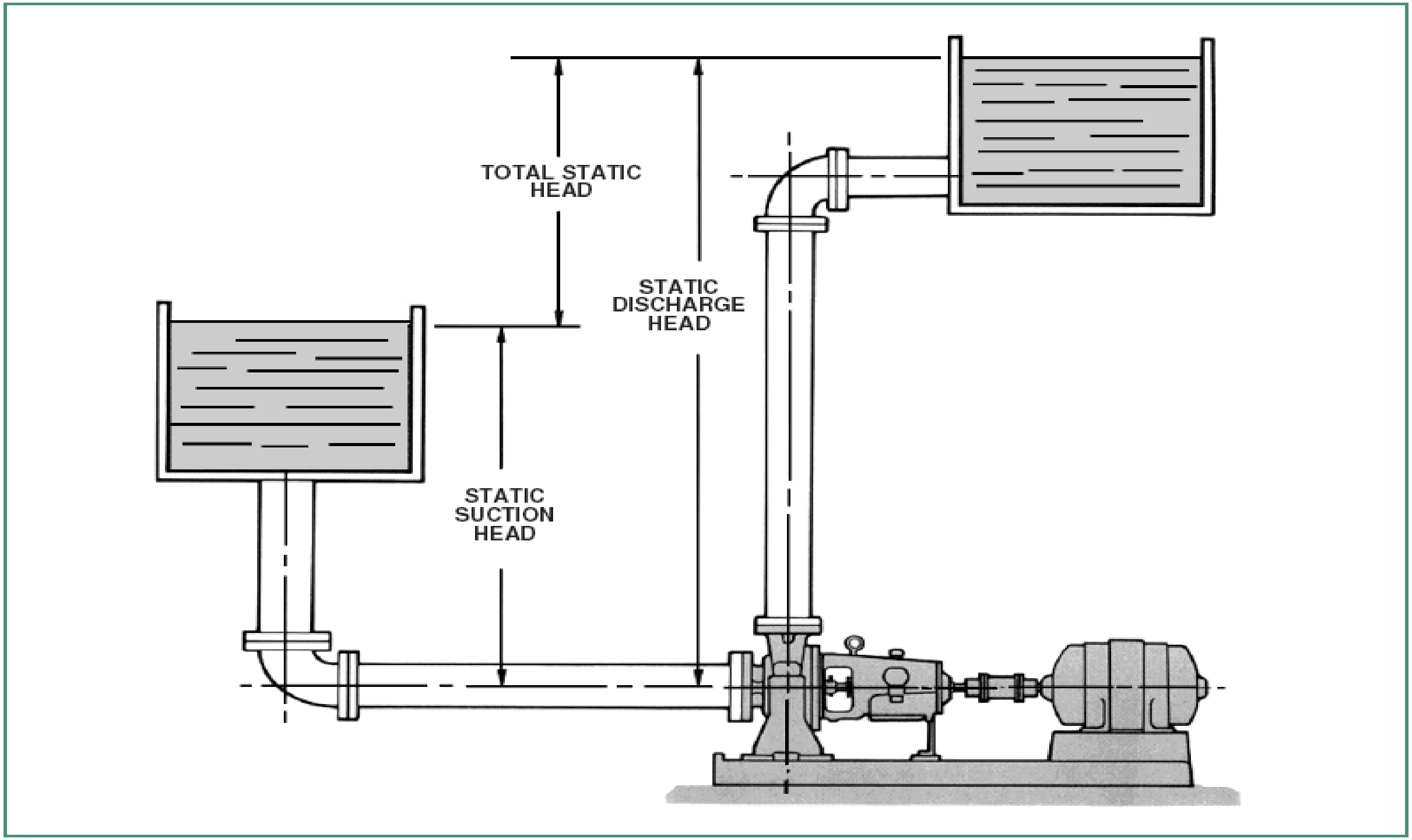


Fig. 2-b Suction Head –
Showing Static Heads in a Pumping System Where the Pump
is Located Below the Suction Tank. (Static Suction Head)

System resistance curve

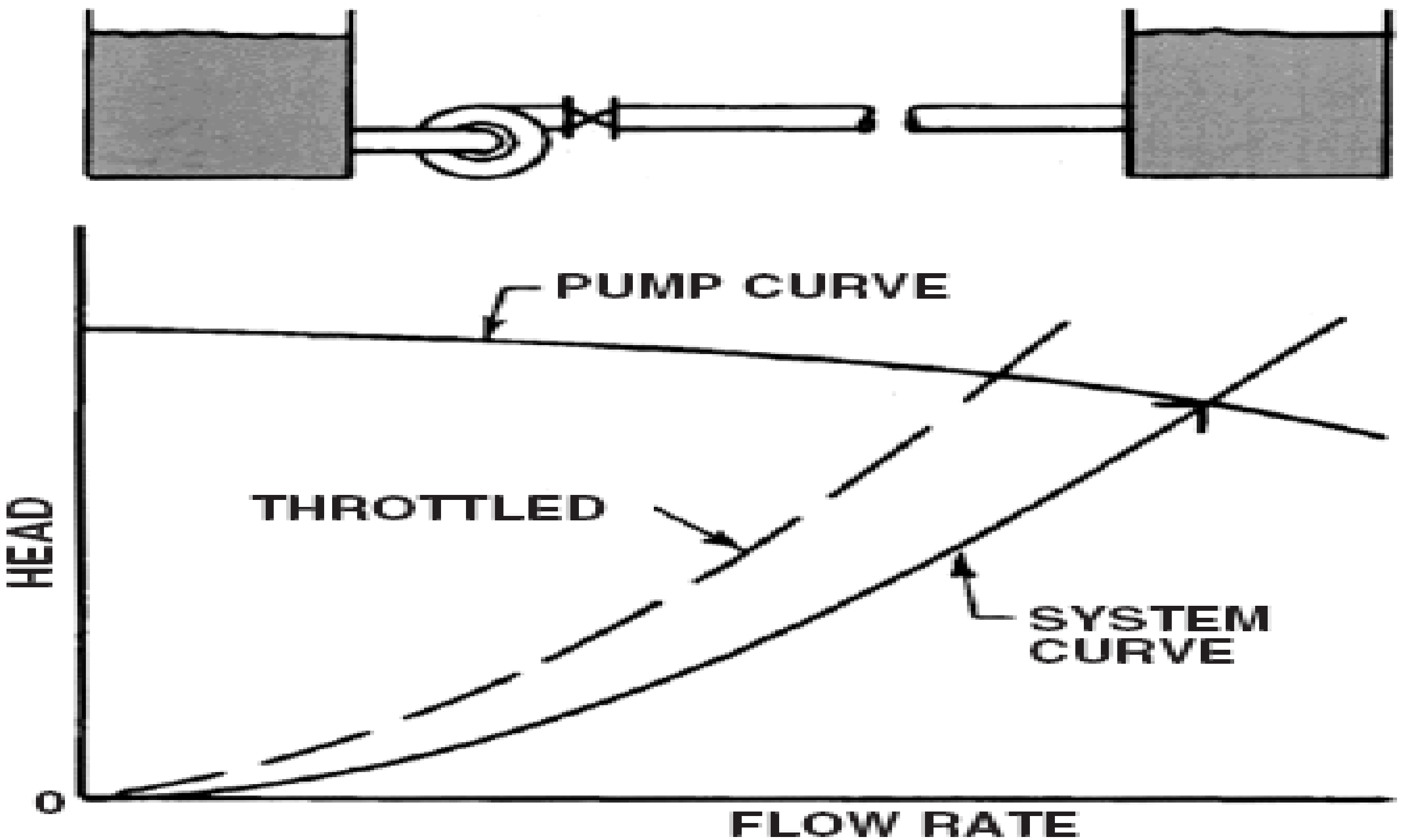


Fig. 1 No Static Head - All Friction

System resistance curve - cont.

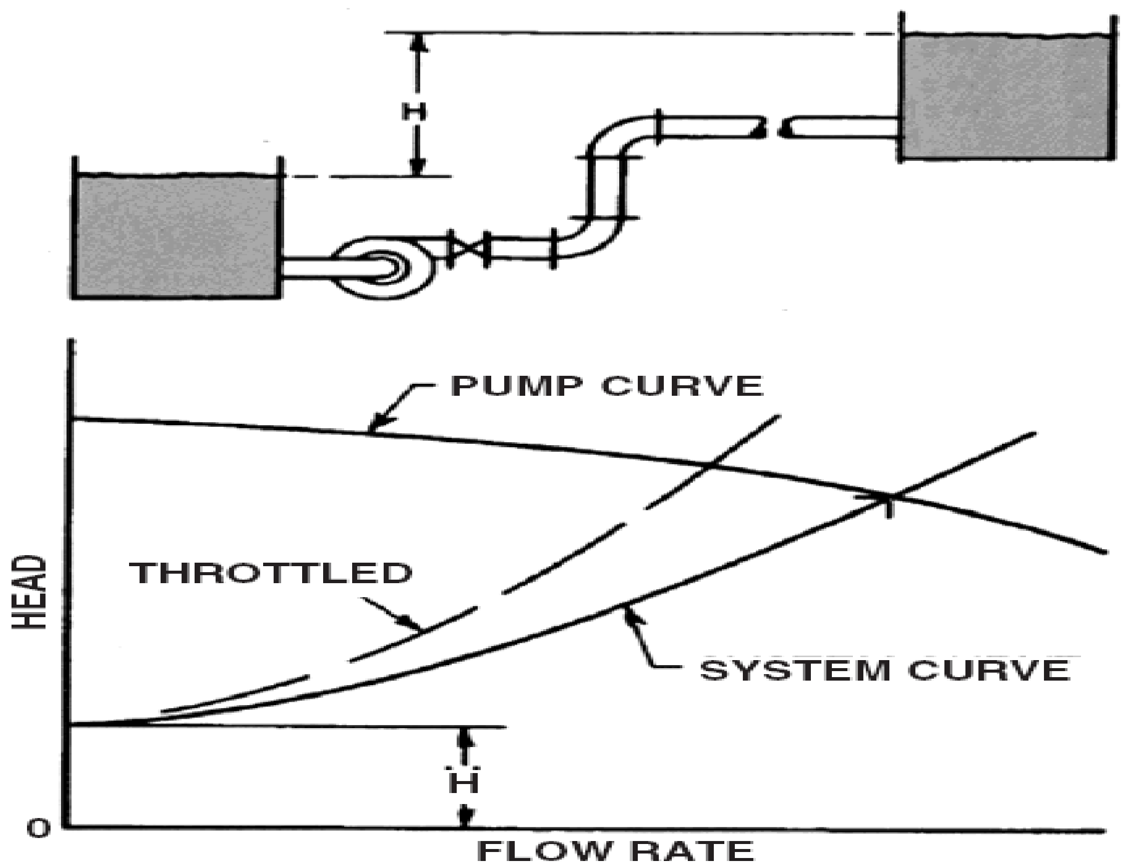


Fig. 2 Positive Suction Head

Open & closed circulation systems

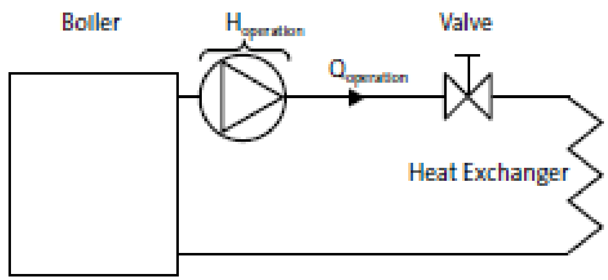


Figure 3.1: Example of a closed system.

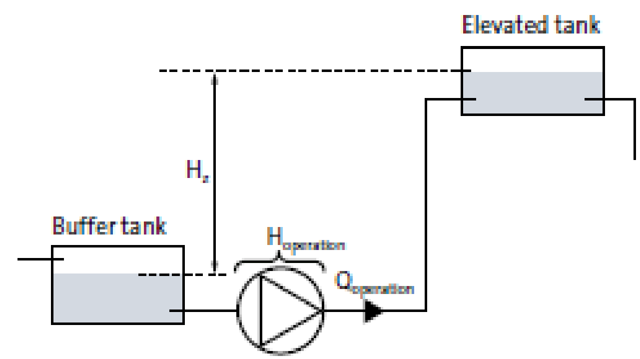


Figure 3.3: Example of an open system with positive geodetic lift.

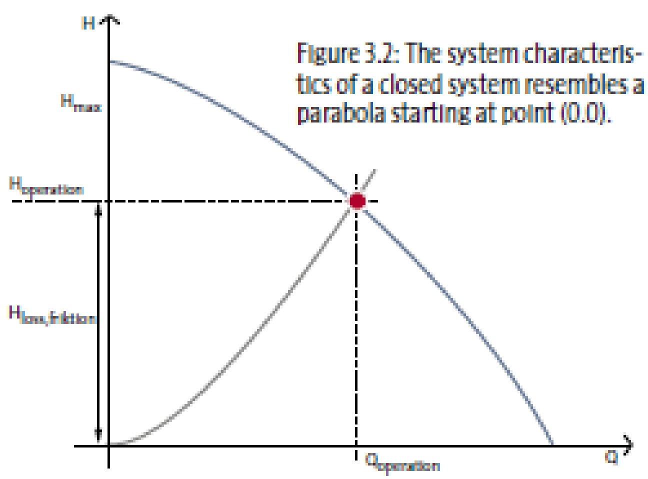


Figure 3.2: The system characteristics of a closed system resembles a parabola starting at point (0.0).

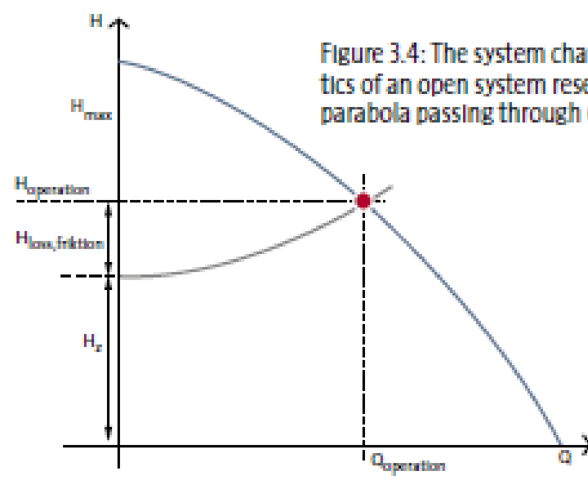


Figure 3.4: The system characteristics of an open system resembles a parabola passing through $(0,H_z)$.

System resistance curve cont.

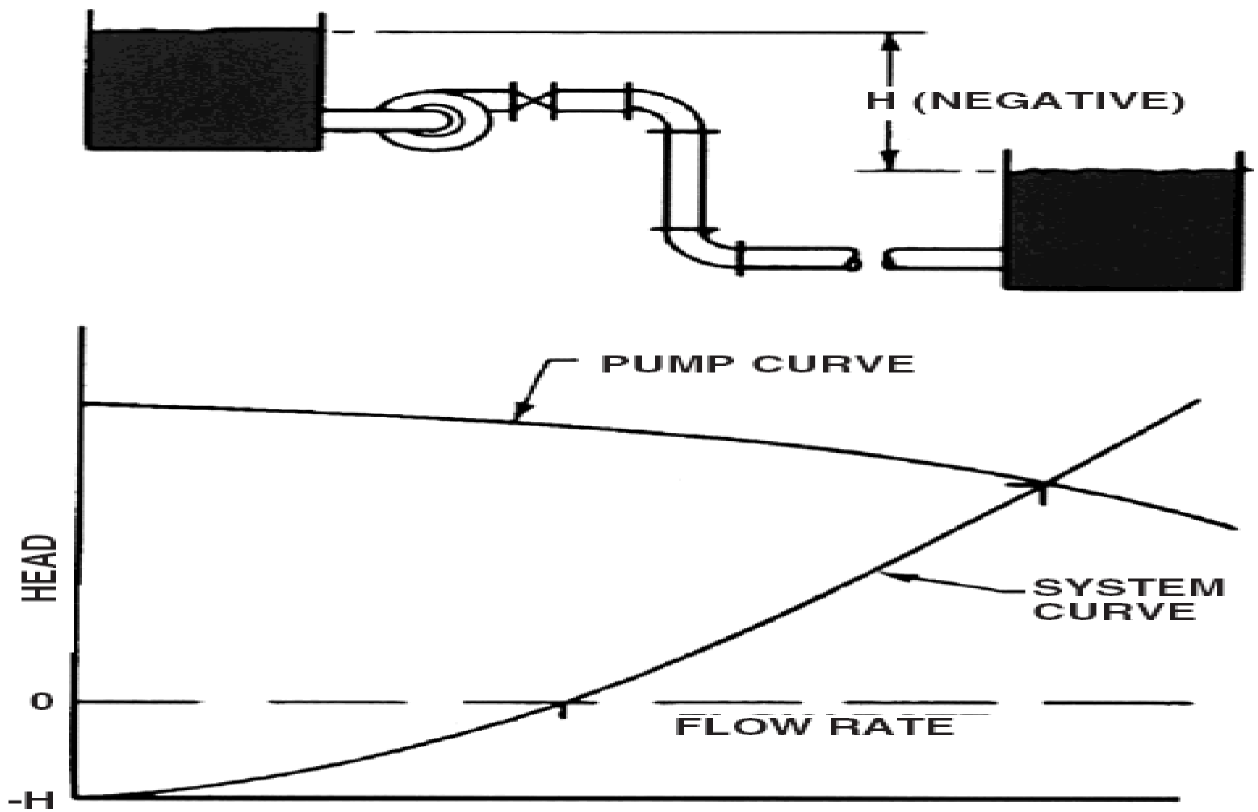


Fig. 3 Negative (Gravity) Head

System resistance curve – cont.

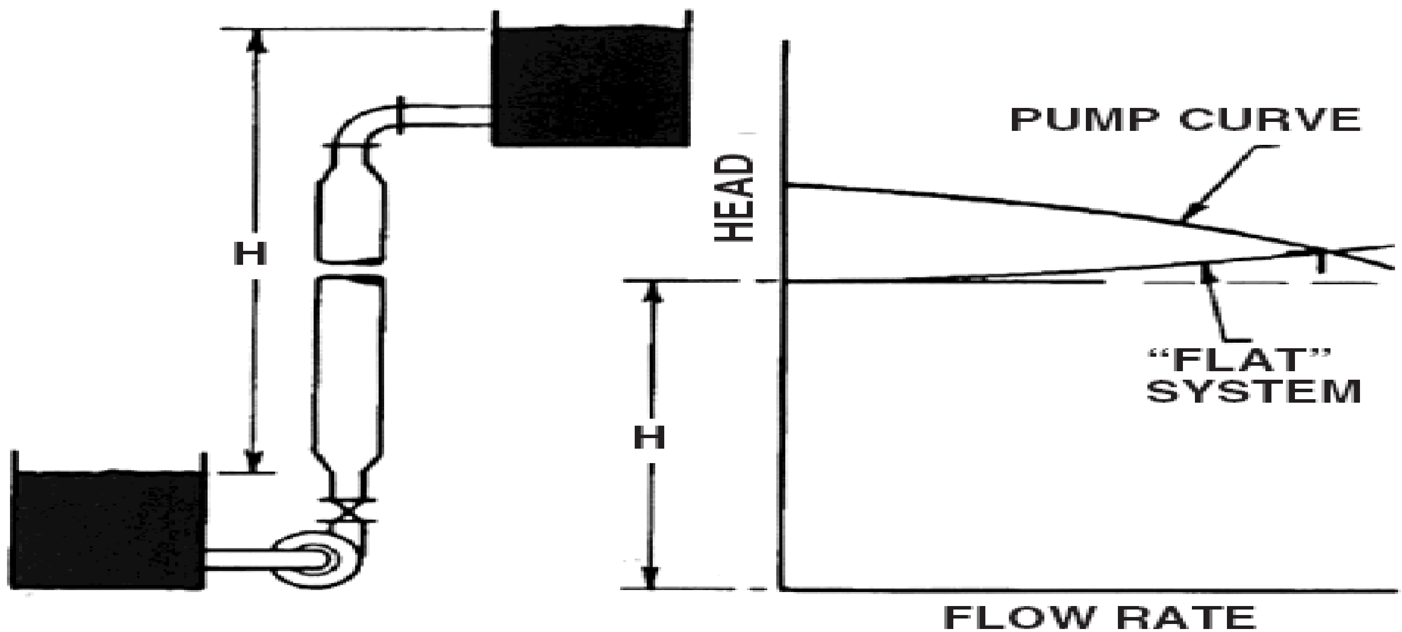


Fig. 4 Mostly Lift - Little Friction Head

Pumps - Parallel and series operation

- ***Parallel operation*** *pumps should have the same head. If static head is high, curve reversal or 'dip' should be avoided. If frictional resistance is high the curve should be steeply rising.*
- ***Series operation*** *pumps should have the same capacities. A possibility of "motor burnout" occurs if the pump operates too far right of the BEP*

Pumps – parallel and series operation

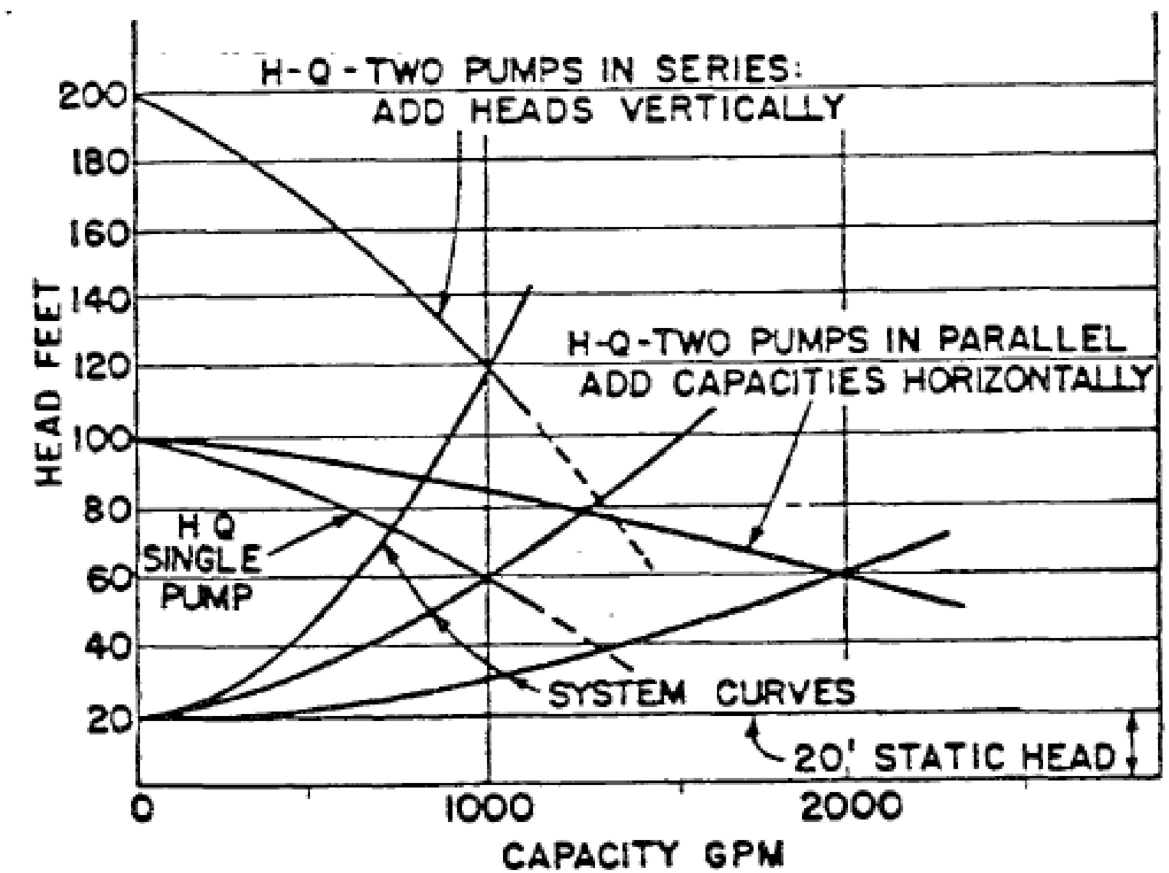


Fig. 17

Parallel pump operation

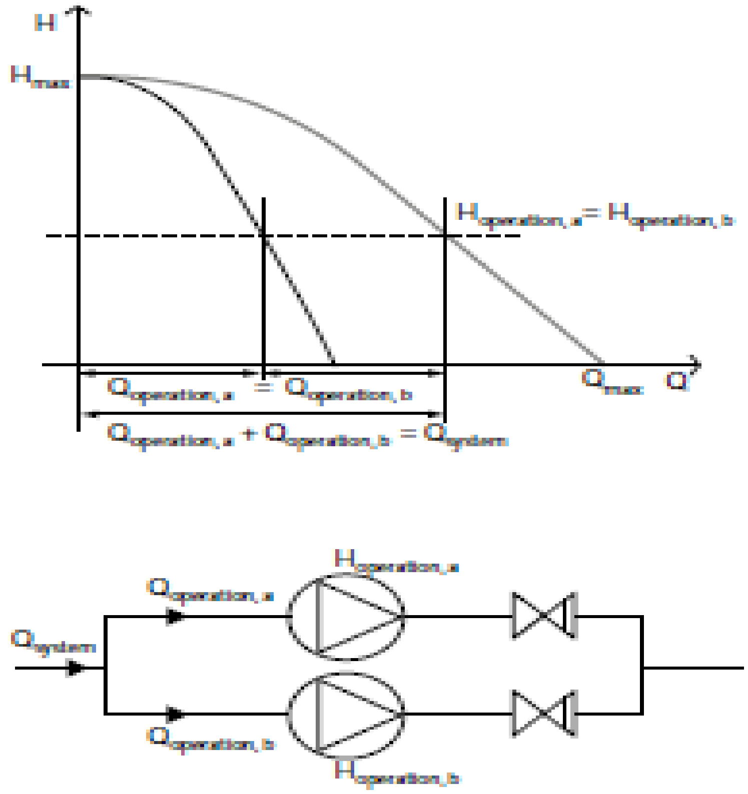


Figure 3.5: Parallel-connected pumps.

Series pump operation

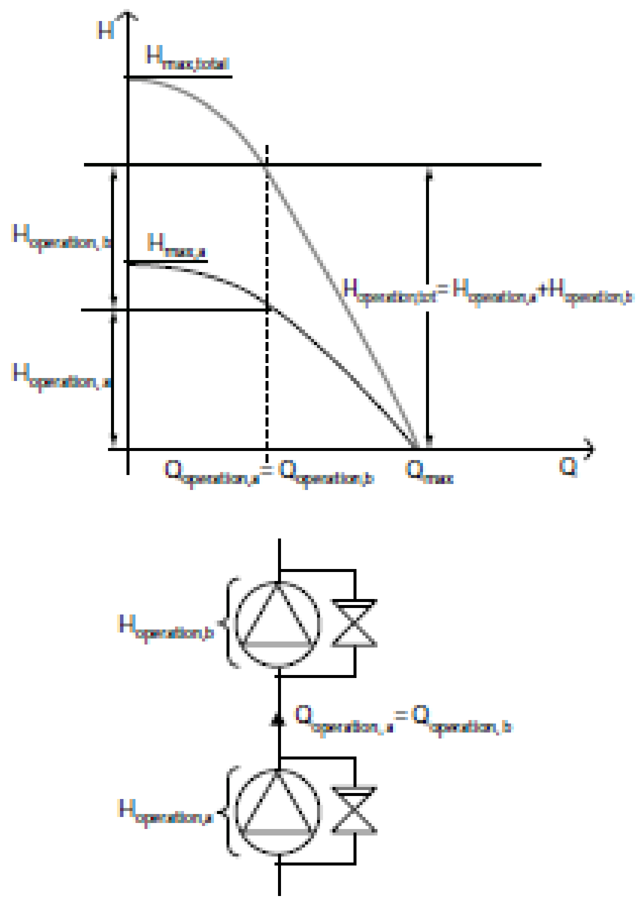
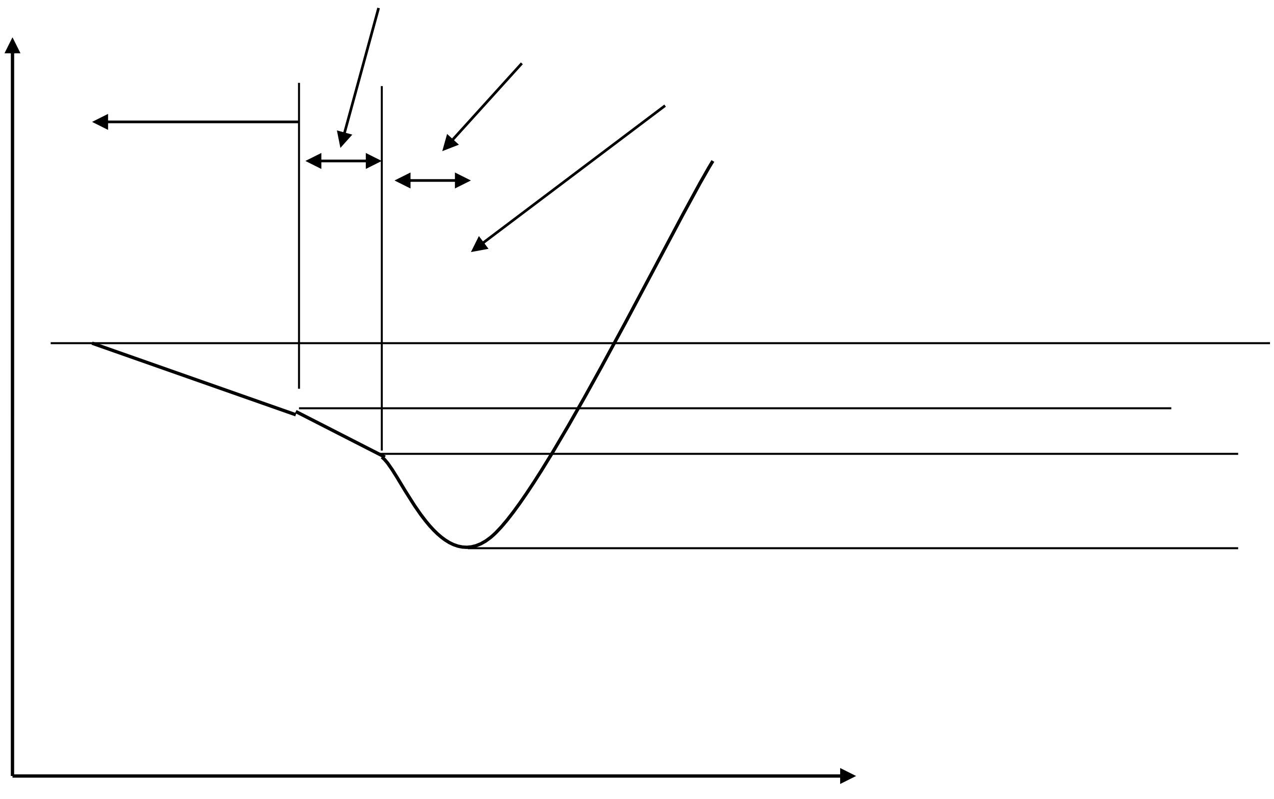


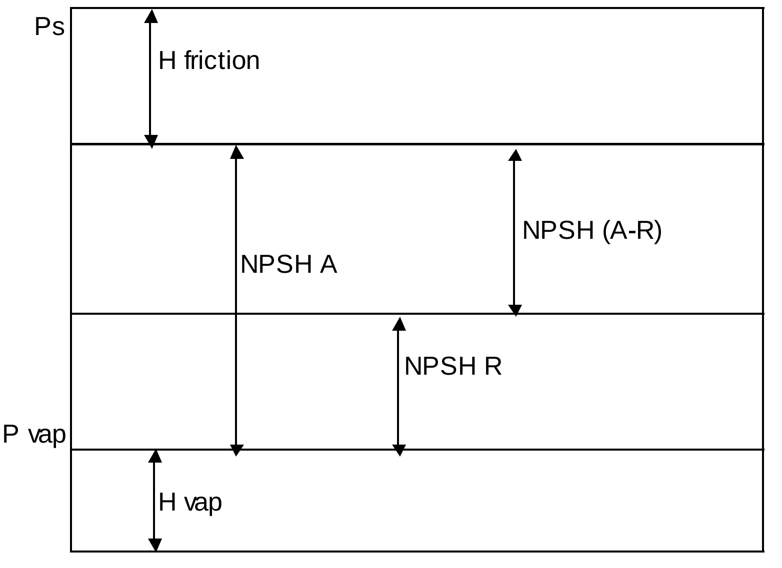
Figure 3.6: Pumps connected in series.

NPSH



NPSH

- ***Net Positive Suction Head (NPSH) is a statement of the minimum suction conditions required to prevent cavitations in a pump.***



NPSHA

- *Is the potential energy of the installation and is expressed in feet of liquid head.*

NPSHR

- *Is pressure above vapour pressure of liquid at pump centreline.*
- *Head necessary to overcome frictional and turbulence losses between pump suction nozzle and entrance to impeller.*
- *NPSHR increases with capacity and speed (sq. of speed)*
- *Pumps with higher NPSHR are cheaper.*

- *Review if suction vessel can be lifted.*
- *Review suction line size.*
- *Review if suction vessel operating pressure can be increased.*
- *Review if fluid can be pumped as sub-cooled.*
- *Split the capacity of the pump.*
- *Specify the pump with suction inducer.*
- *Review piping layout and option of relocating suction side equipment to discharge side.*

- *Review the other alternate type of pump like submersible type etc.*
- *Review NPSHA w.r.t. to all conditions (start-up, pumpout etc).*
- *Use booster pumps.*

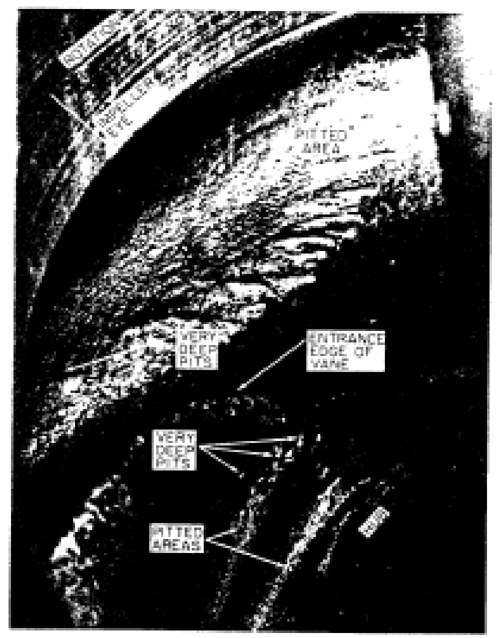
- *Occurs when pressure falls below vp of liquid.*
- *Is caused when insufficient NPSH is available.*

Cavitation may result in the following :

- *Reduction in pump efficiency*
- *Reduced in pump capacity*
- *Head may be reduced*
- *Power consumption may be erratic*
- *Severe cavitation may cause damage to impeller*

Cavitation may result in the following (Cont'd) :

- *Causes noise and vibration*
- *Rise in thrust bearing temperature.*



Impeller damaged by cavitation [30]. (DeLaval Turbine, Inc.)

SPECIFIC SPEED

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$$

- *AN INDEX RELATING FLOW, TOTAL HEAD, AND ROTATING SPEED FOR PUMPS OF SIMILAR GEOMETRY. SPECIFIC SPEED IS CALCULATED FOR PUMP'S PERFORMANCE AT BEST EFFICIENCY POINT WITH THE MAXIMUM DIA. IMPELLER.*

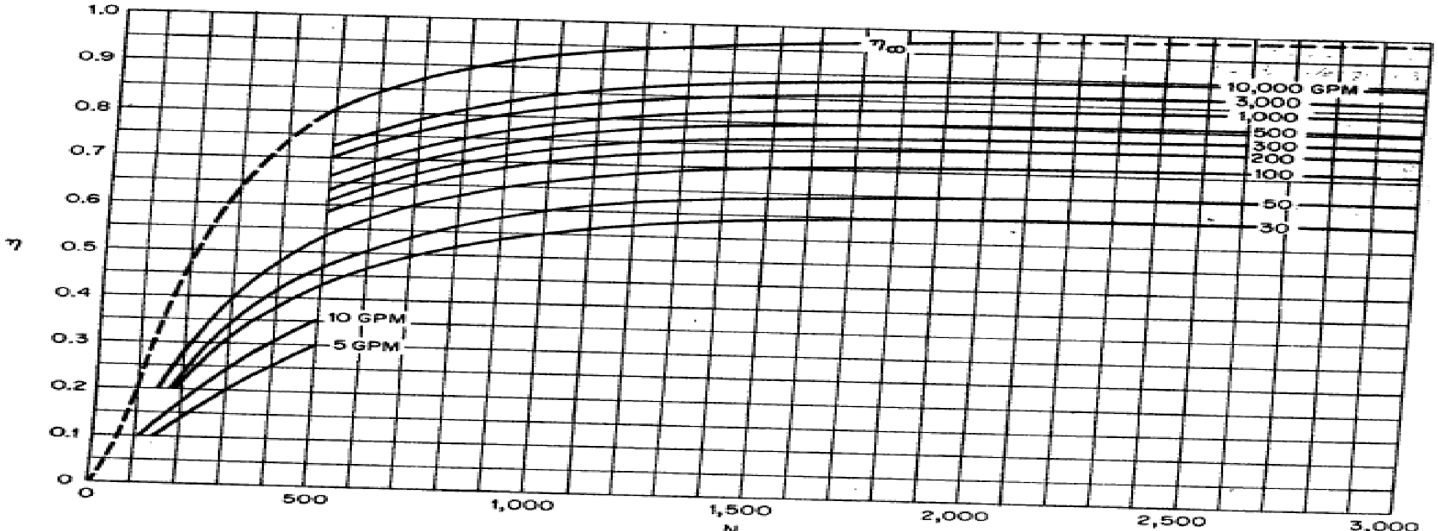


Fig. 5 Efficiency as a function of specific speed and capacity.

Suction specific Speed

- *An index relating flow, NPSHR, and rotating speed for pumps of similar geometry. Suction specific speed is calculated for pump's performance at best efficiency point with the maximum dia. Impeller and provides an assessment of a pump's susceptibility to internal recirculation.*

1. With impeller diameter, D, held constant:

A. $\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$

Where: Q = Capacity, GPM
H = Total Head, Feet
BHP = Brake Horsepower
N = Pump Speed, RPM

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

C. $\frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3$

2. With speed, N, held constant:

A. $\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$

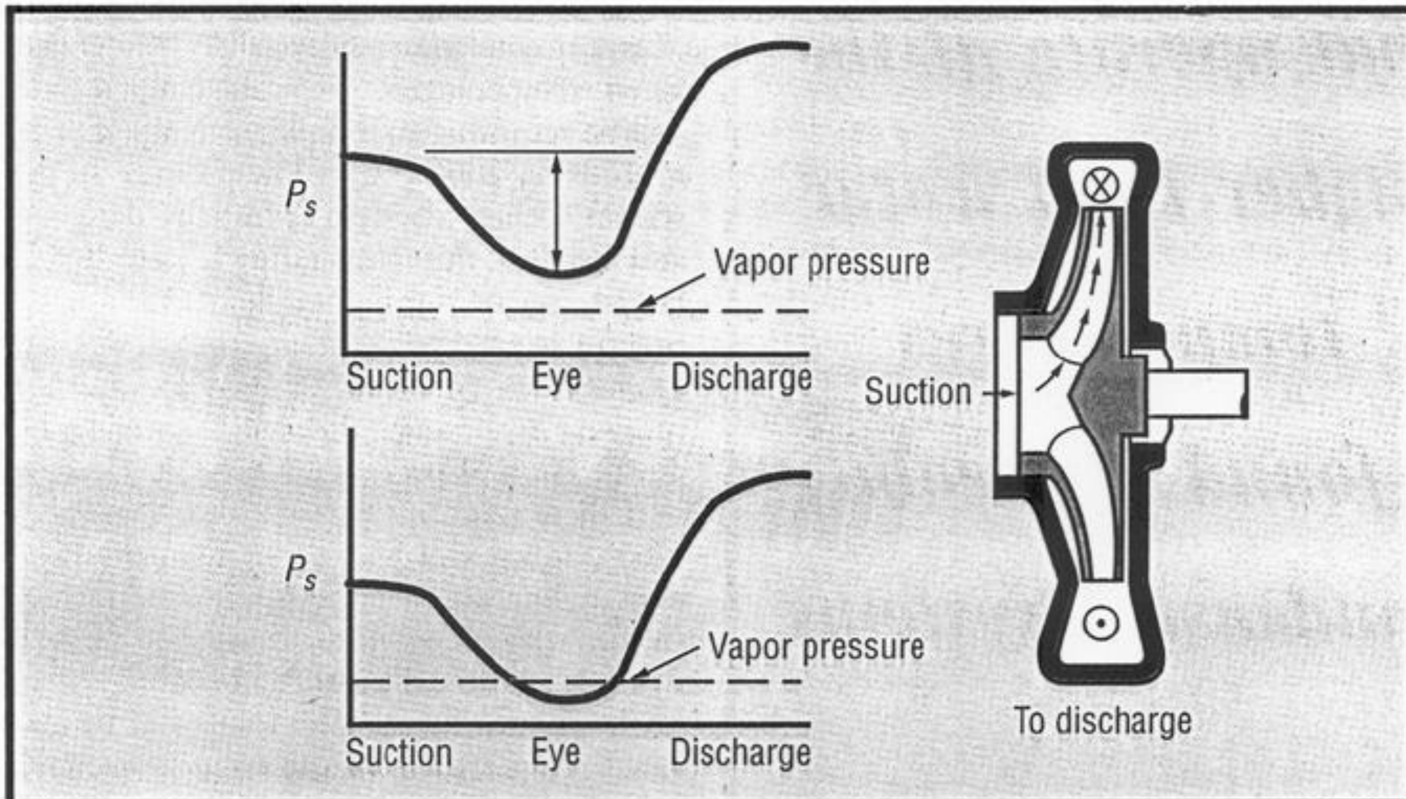
B. $\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2$

C. $\frac{BHP_1}{BHP_2} = \left(\frac{D_1}{D_2}\right)^3$

Pump Suction Limitations

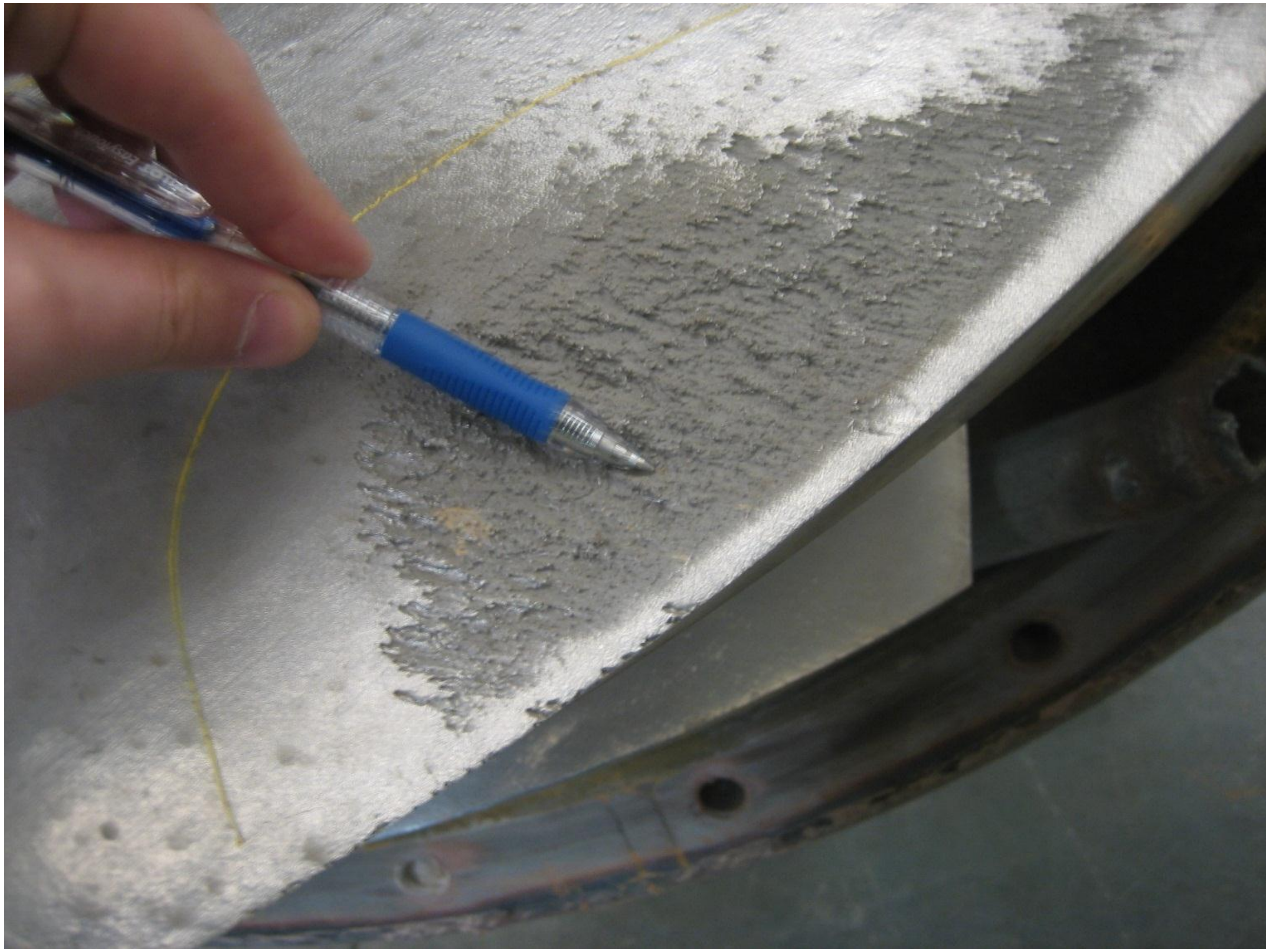
- Cavitation
  - Local vaporization and condensing of pumped fluid in flow stream.
  - Occurs when the absolute pressure falls to the vapor pressure of the liquid.
  - Why?
- Effects of cavitation in pumps
  - Reduction in pump head and efficiency.
  - Vibration, noise, and damage.

Pump Cavitation



Cavitation and Cavitation Erosion

Cavitation Erosion



Net Positive Suction Head

NPSHA (available) is a system design outcome.

$NPSHA = P + H_s – V_p - H_f$

where:

- P = pressure at liquid surface or point in suction line, feet
- H_s = static lift or head to eye of impeller, feet
- V_p = vapor pressure of fluid at max operating temperature, feet
- Hf = friction loss from pressure measurement to pump suction, feet

Net Positive Suction Head

NPSHR (required) is a pump performance characteristic determined by testing for deviations in head output and for cavitation inception.

Performance parameters:

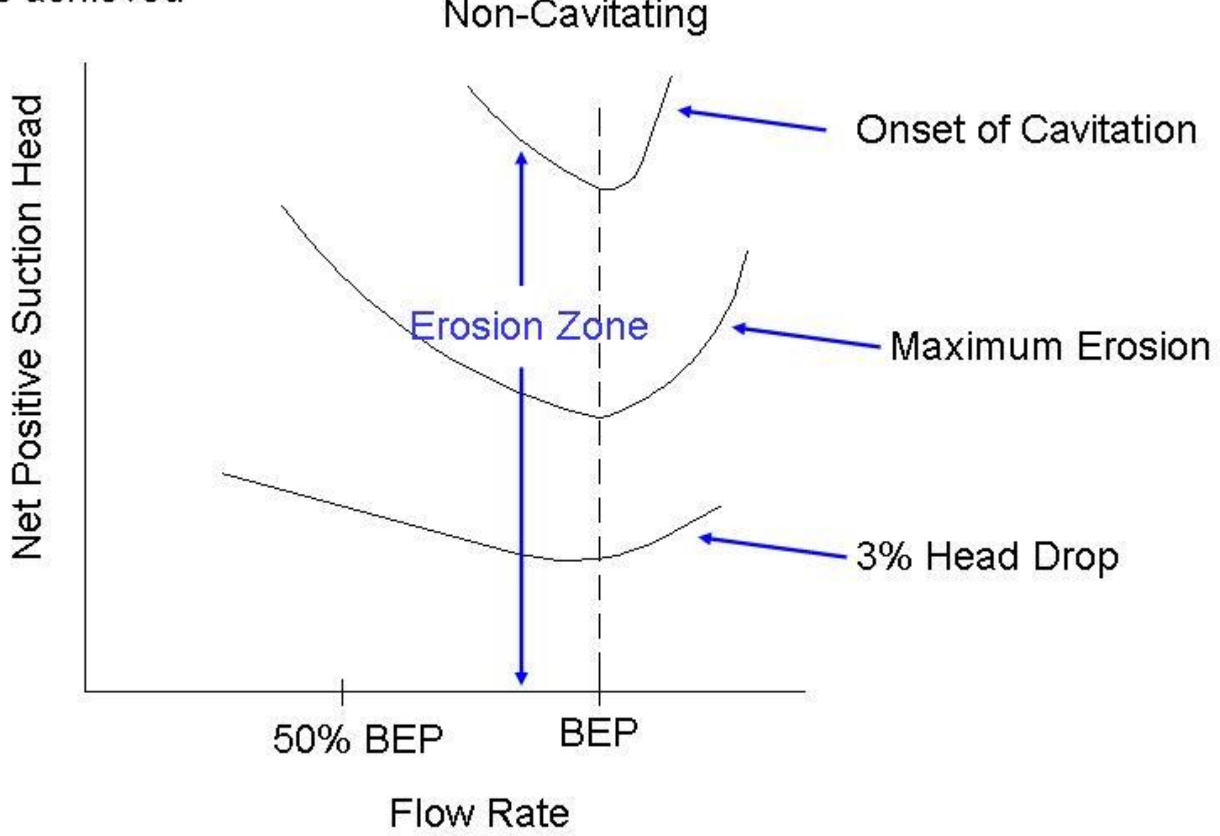
- NPSHR-3% head (Industry standard)
- NPSHR-incipient (Technical standard for high-energy).

All NPSHR parameters increases as:

- Pump speed increases
- Pump size increases
- Flow rate increases within a given pump.

Cavitation Zones

Note: 3% drop is used to define NPSHR, but effects are present before 3% is achieved



Boiler Feedwater Pump Calculations

- Pump Suction Performance
  - Suction Specific Speed (Nss) is a parameter which defines a pump's suction performance:
    - Based on suction flow per impeller inlet (eye)
    - Higher Nss
      - More "aggressive" designs
      - Lower relative NPSHR
      - Higher propensity for vibration cavitation damage.
  - Suction Specific Speed

$$Nss = \frac{rpm \times (\text{Flow Rate per eye, gpm})^{0.5}}{(\text{NPSHR-3\%head, ft})^{0.75}}$$

  - Suction Specific Speed Limits:

    Nss < 11,000 for medium-duty boiler feedwater pumps

    Nss < 10,000 for heavy-duty boiler feedwater pumps.

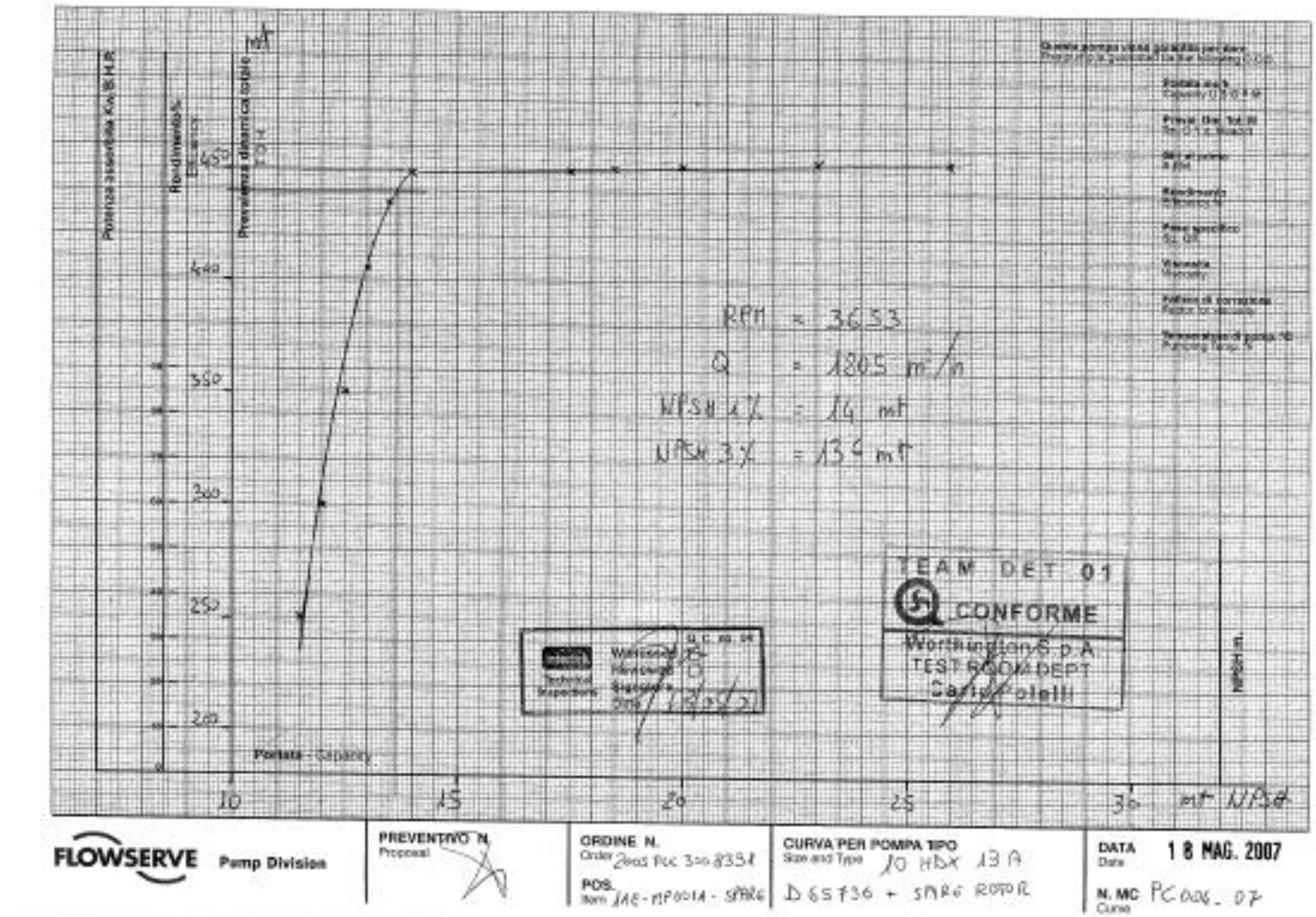
Boiler Feedwater Pump Calculations

$$Nss = \frac{RPM \times (\text{Flow Rate per eye, GPM})^{0.5}}{(\text{NPSHr-3\%head, ft})^{0.75}}$$

- Known
  - Maximum Nss (from specification)
  - Flow Rate (from process requirements)
  - NPSHa (from suction source)
- Solve For
  - Maximum allowable RPM (at least 2-pole motor speed for BFP's)

- For NPSH-challenged Applications:
  - Divide system flow using two 50% pumps
  - Adding a low-speed booster pump in series
  - Use double-suction first stage impeller.

NPSH$_R$ Test



RPM = 3653
Q = 1805 m³/h
NPSH 1% = 14 mt
NPSH 3% = 13.4 mt
TEAM DET 01
CONFORME
Worthington S.p.A.
TEST ROOM DEPT
10
15
20
25
30
mt NPSH
Portata - Capacity
FLOWSERVE Pump Division
PREVENTIVO N.
Proposal
ORDINE N.
Order
POS.
Item
CURVA PER POMPA TIPO
Size and Type
10 HDX 13 A
D65736 + SPARE ROTOR
DATA
Date
18 MAG. 2007
N. MC
Curve
PC006_07

Net Positive Suction Head

For a pump to perform,

NPSHA > NPSHR

For a pump to work well over time,

NPSHA >> NPSHR with margin

NPSH Margin Factor, R = NPSHA / NPSHR

- R = 1.1 to 3.5 depending on service

Cavitation Mitigation/Prevention

- Increase static head at suction – increases system NPSHA
- Increase suction line size to reduce friction losses – increases NPSHA
- Decrease vapor pressure by cooling of fluid – increases NPSHA
- Reduce flow rate per pump – reduces friction losses and pump NPSHR
- Select slower pump speed – decreases pump NPSHR
- Always provide the correct NPSH margin!