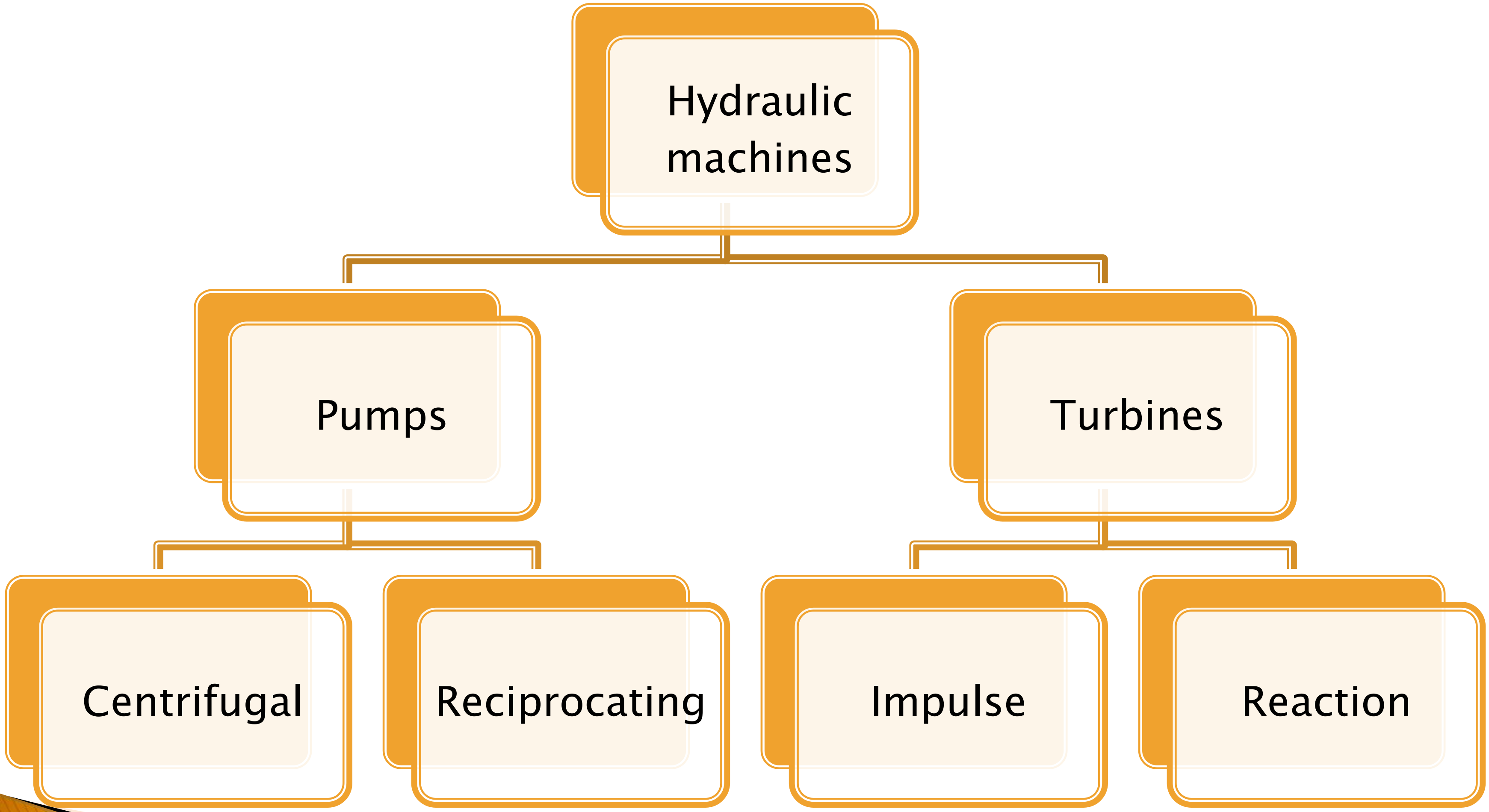
HYDRAULIC MACHINES

CLASSIFICATION

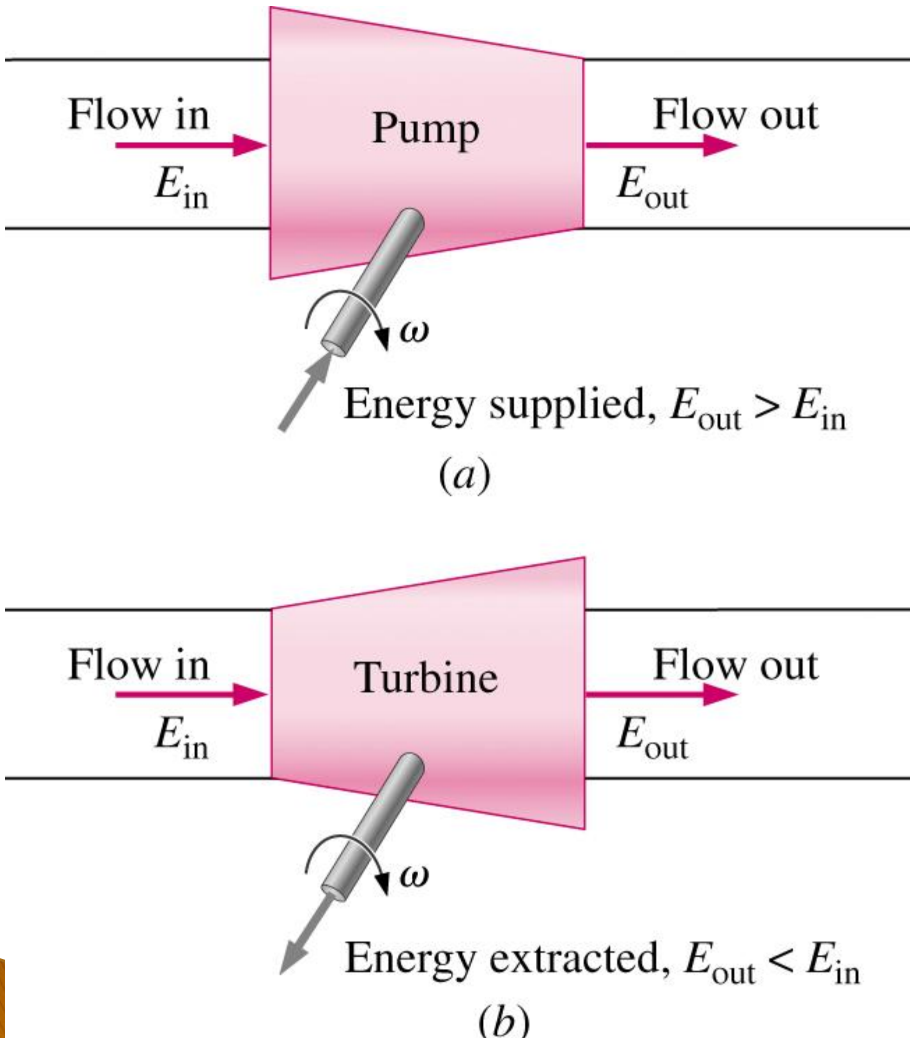


FLUID MACHINES

- Takes energy from the flow
  Turbine, Hydraulic motor

- Gives energy to the flow
  Pump, Compressor

Categories



- **Pump**: adds energy to a fluid, resulting in an increase in pressure across the pump.
- **Turbine**: extracts energy from the fluid, resulting in a decrease in pressure across the turbine.

PUMPS

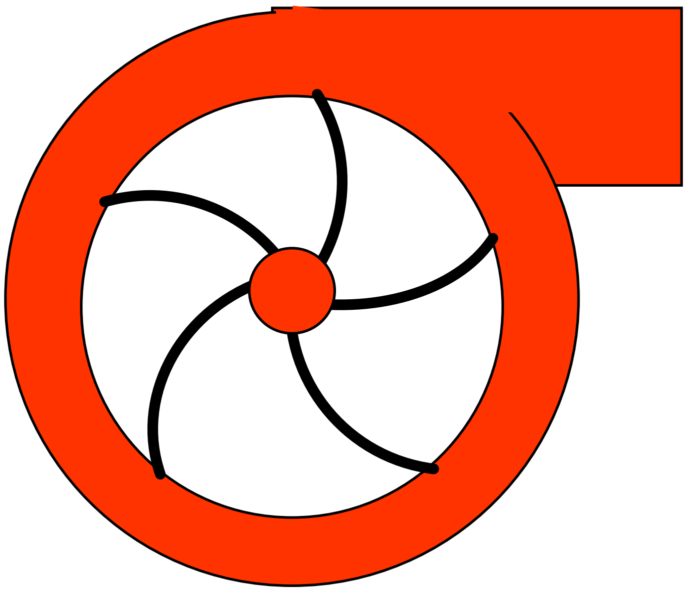
Pumps are divided into

- Roto-dynamic or centrifugal pumps
  - Move fluids with a rotating vane
- Positive displacement pumps
  - Move fluids strictly by precise machine displacements

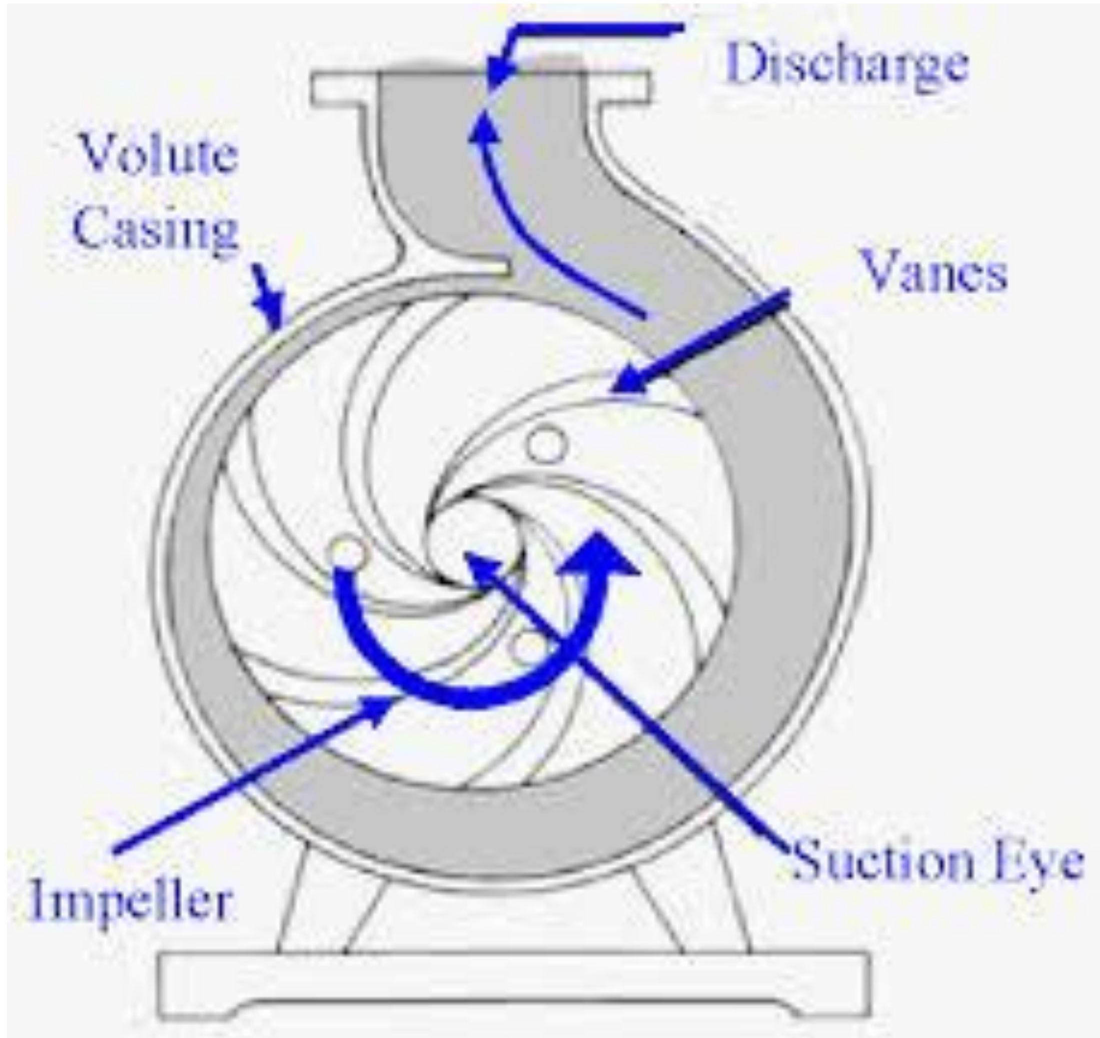
WHAT IS A CENTRIFUGAL PUMP?

Three basic components:

- Volute casing, body
  - or Diffuser
- Impeller
  - or impellers
- Driver (motor)



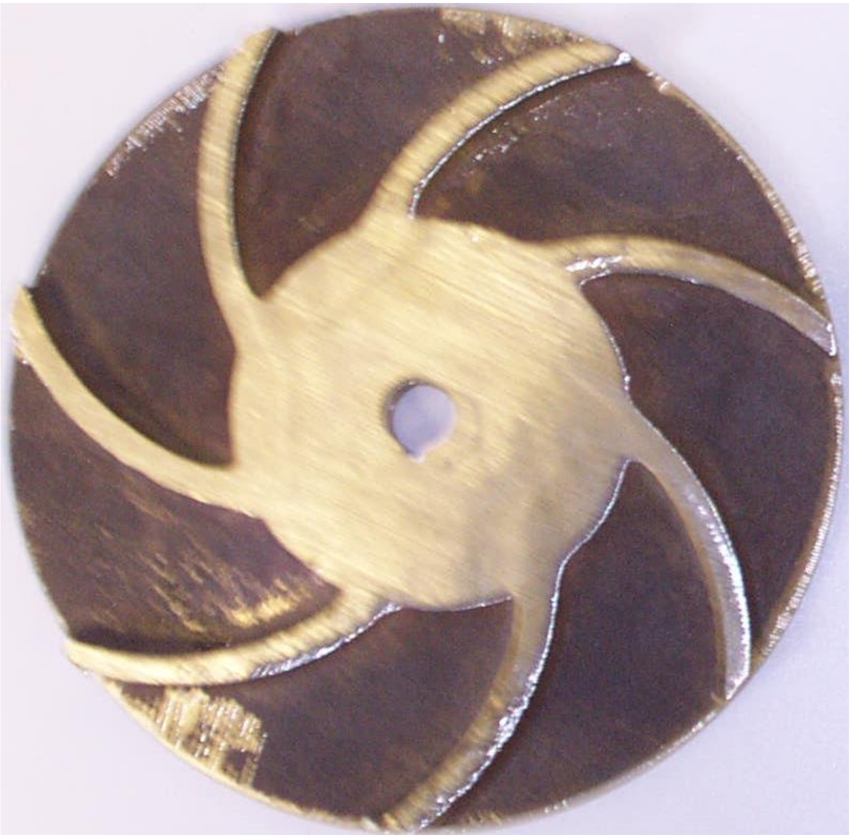
CENTRIFUGAL PUMPS



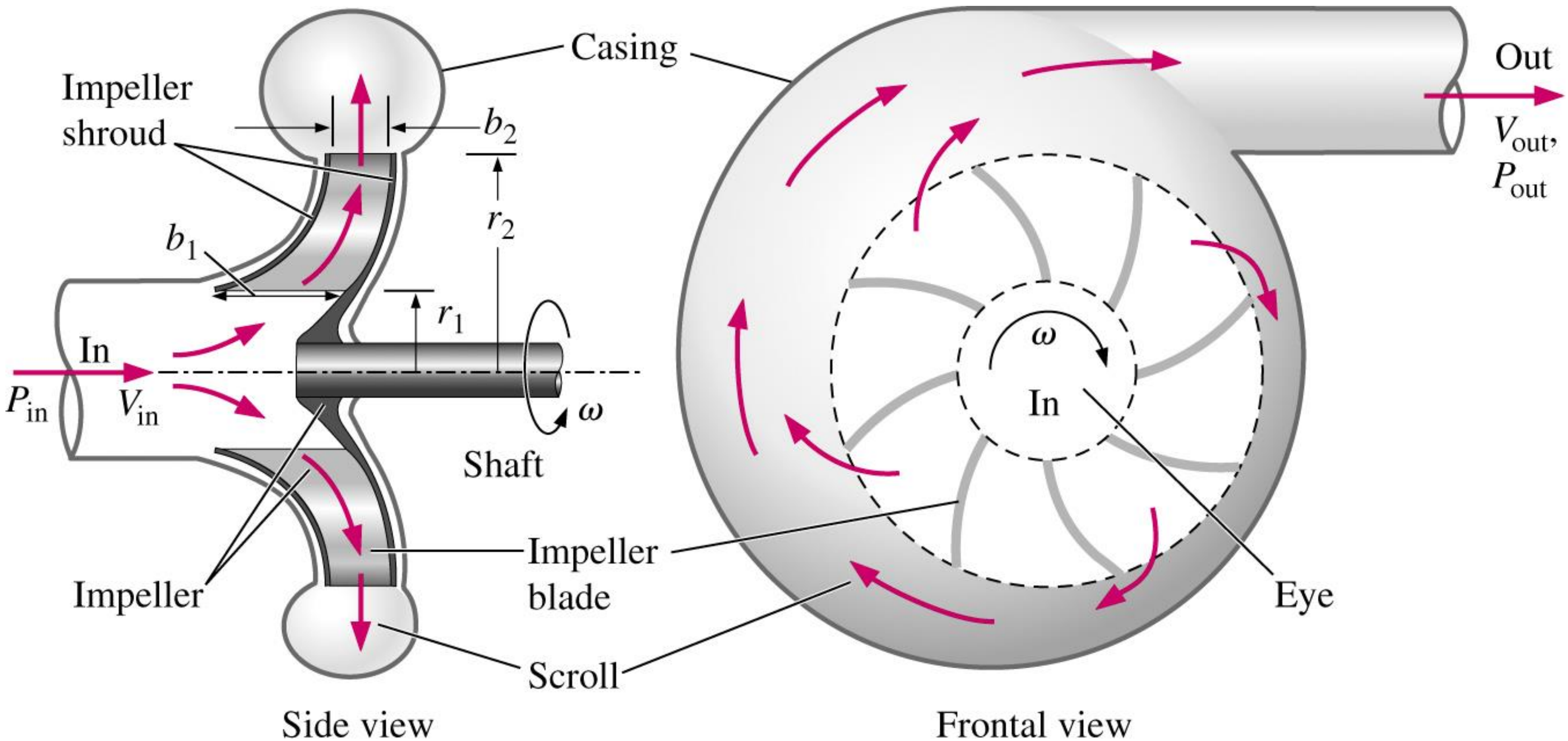
CENTRIFUGAL PUMP

- Consists of a series of blades attached at the centre of a shaft known as an **impeller** and rotated at high speed inside a casing.
- Fluid is fed in axially at the centre (eye) of the impeller & is thrown out in a roughly radial direction by the centrifugal action.
- As the impeller rotates, fluid is sucked in through the eye of the casing and flows radially outward.

Single suction impeller

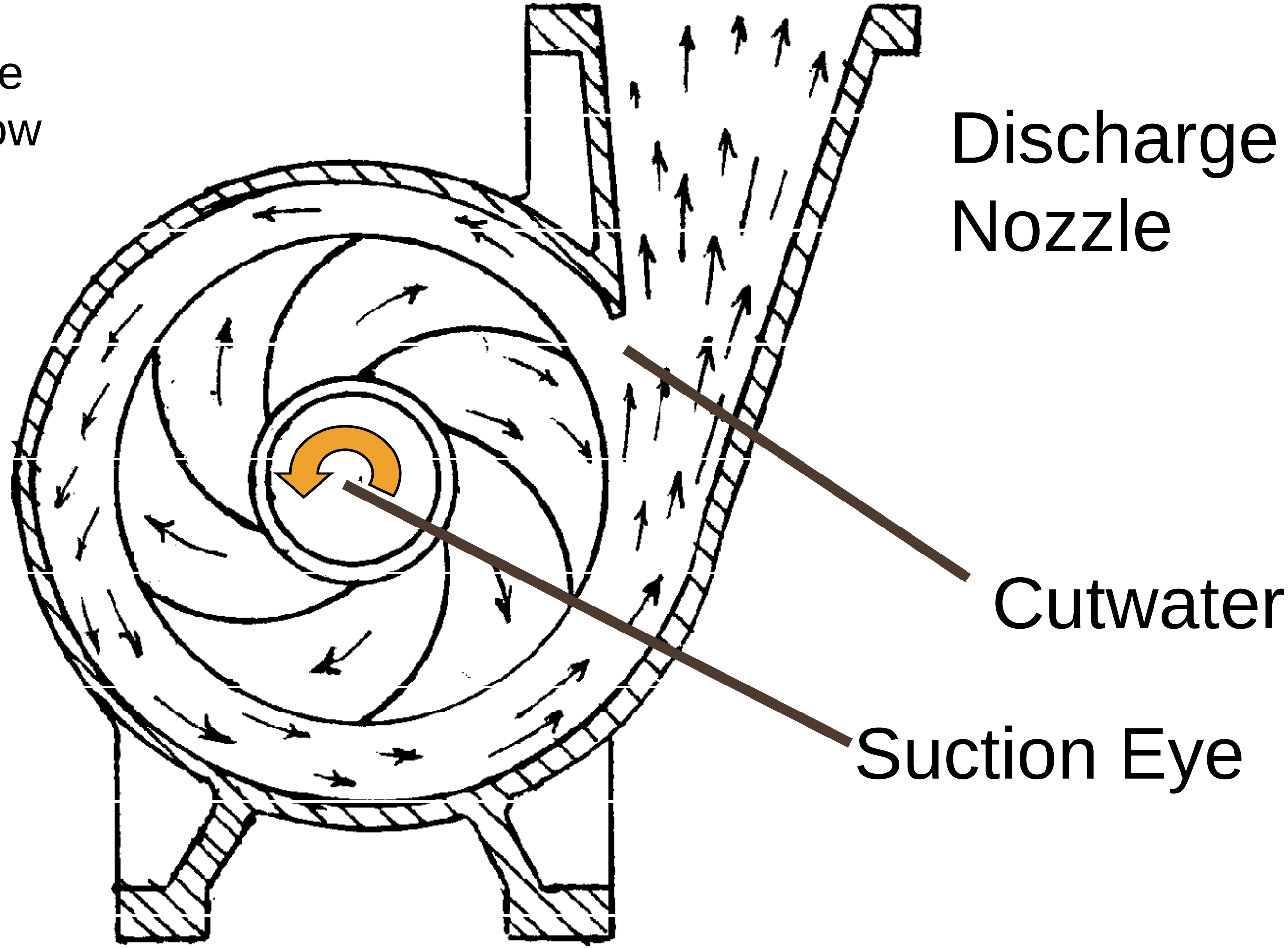


Centrifugal Pumps



IMPELLER AND VOLUTE

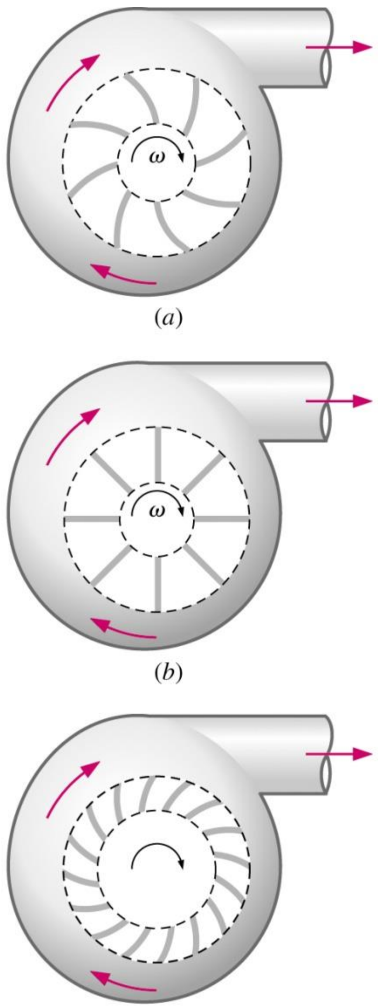
Arrows represent the direction of water flow



Operation of the Centrifugal Pump

- Energy is added to the fluid by the rotating blades, & both pressure and absolute velocity are increased as the fluid flows from the eye to the periphery of the blades.

CENTRIFUGAL PUMPS: BLADES

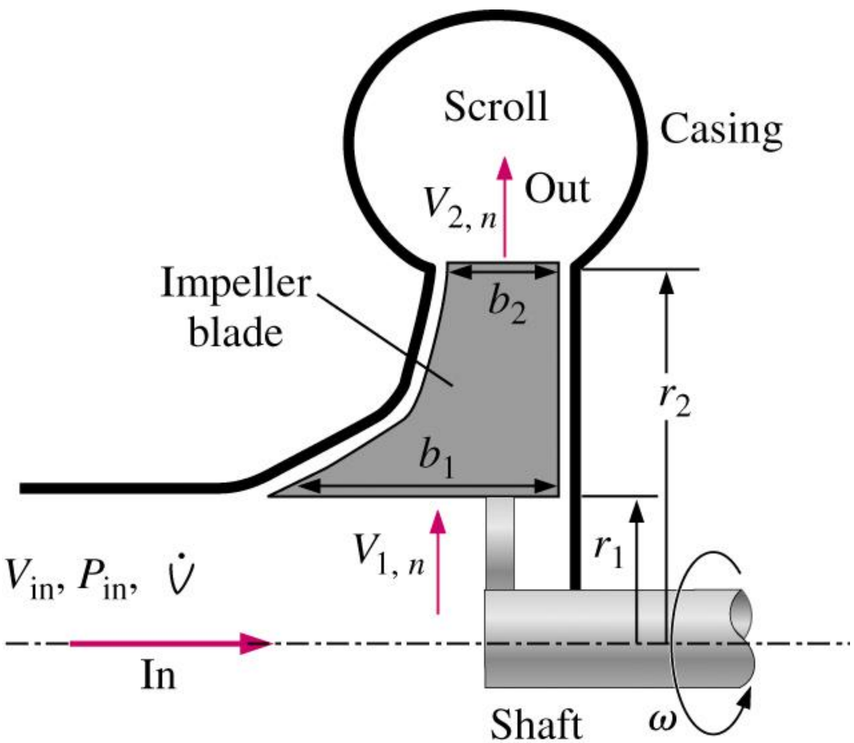


(a) Backward inclined

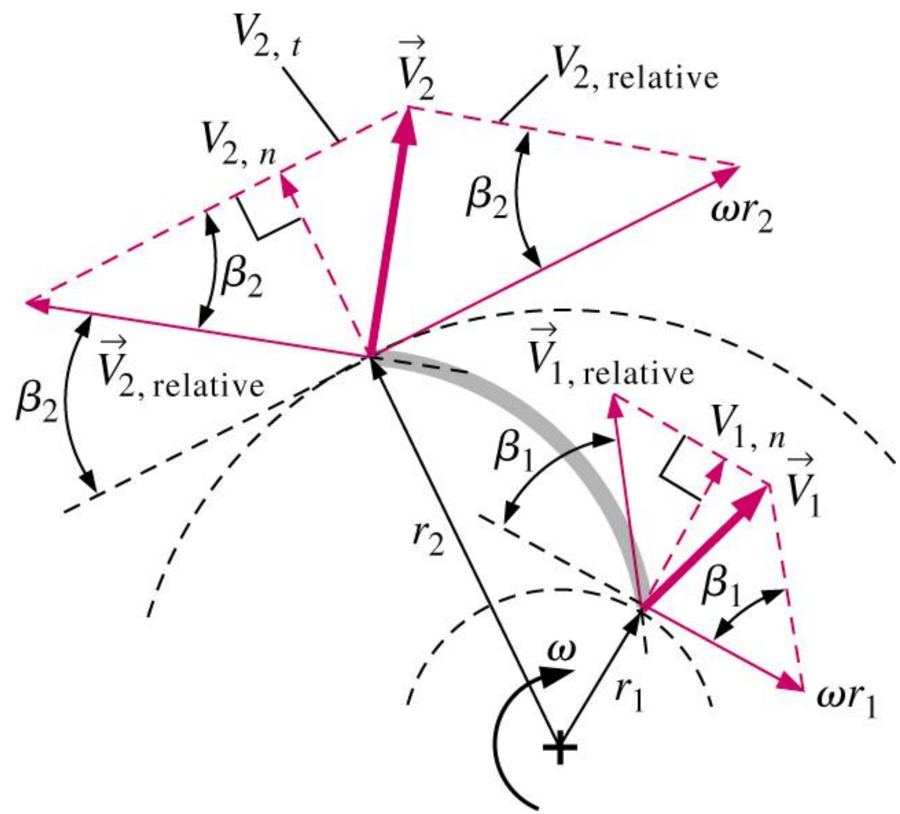
(b) Radial

(c) Forward inclined

Centrifugal Pumps: Blade Design



Side view of impeller blade.

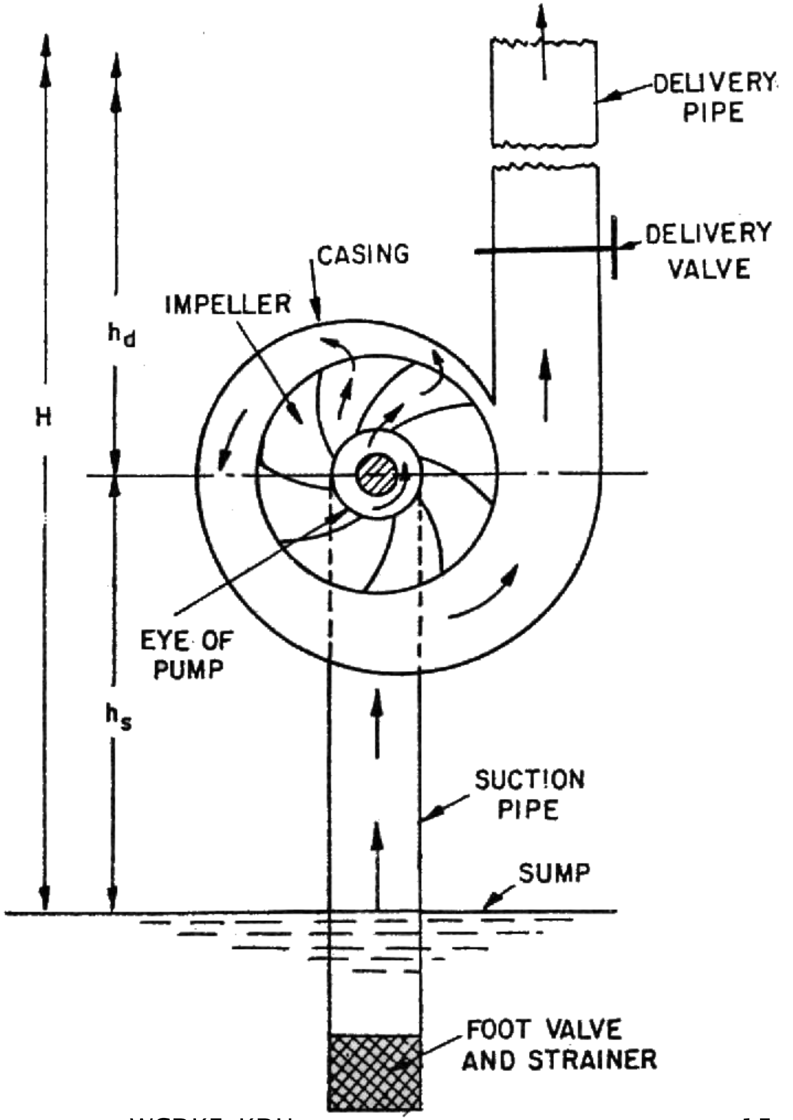


Vector analysis of leading and trailing edges.

MAIN PARTS OF CENTRIFUGAL PUMPS

1.Impeller:

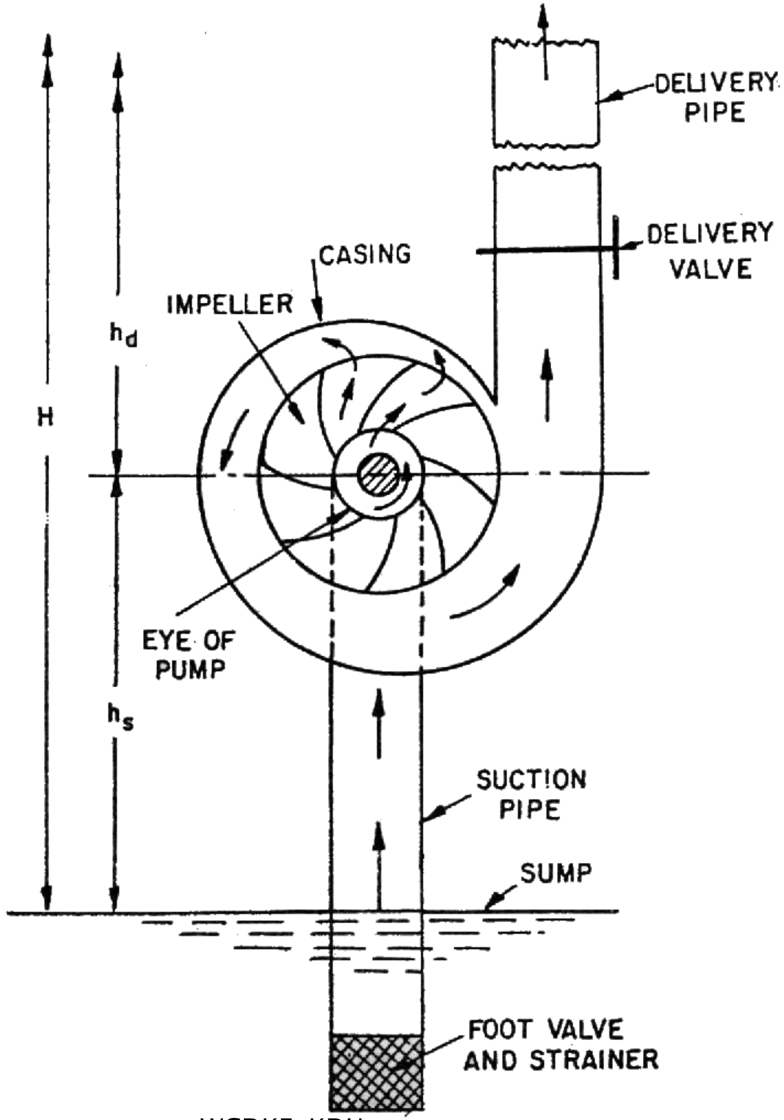
- which is the rotating part of the centrifugal pump.
- It consists of a series of backward curved vanes (blades).
- The impeller is driven by a shaft which is connected to the shaft of an electric motor.



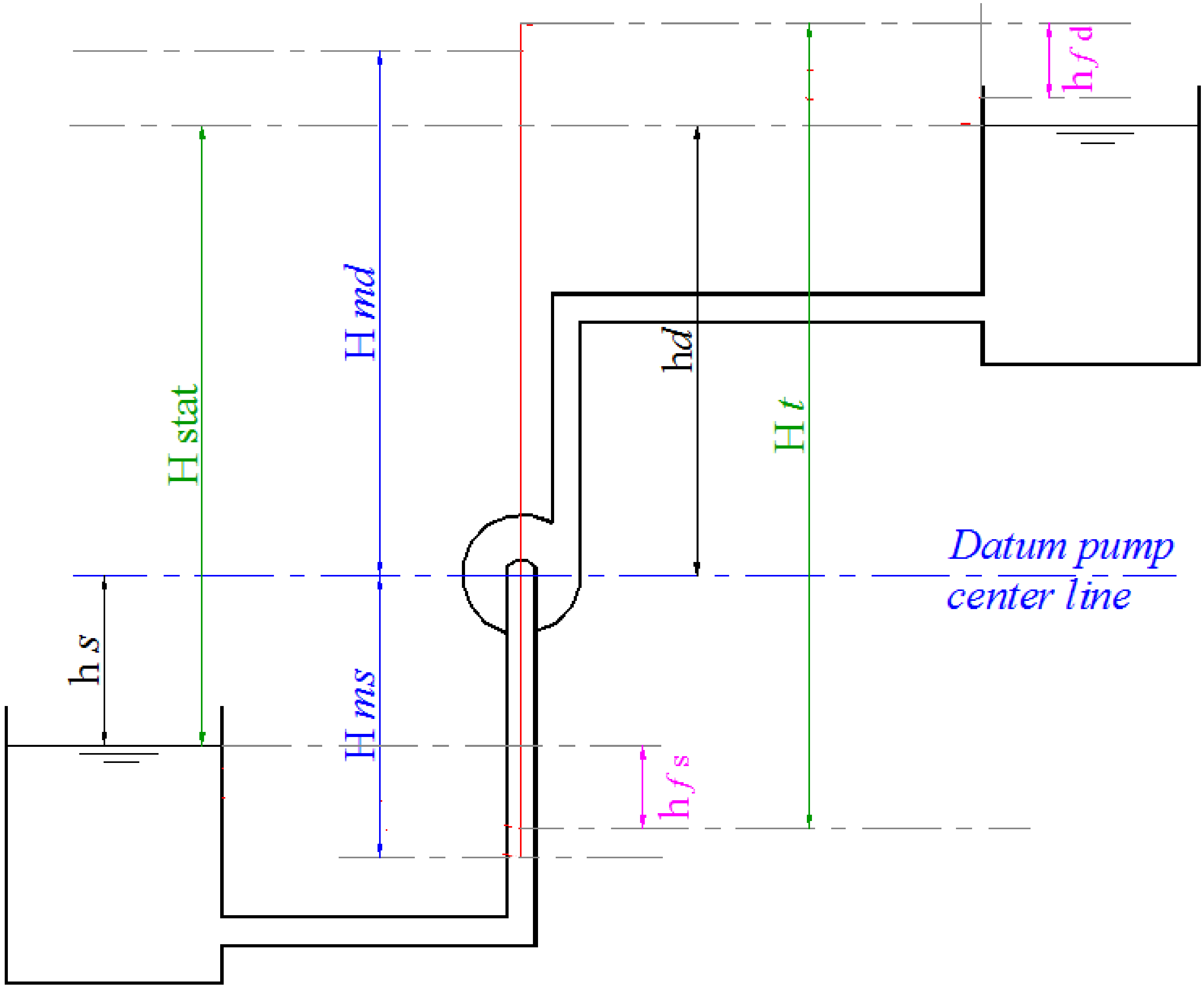
MAIN PARTS OF CENTRIFUGAL PUMPS

2.Casing

- Which is an air-tight passage surrounding the impeller
- designed to direct the liquid to the impeller and lead it away
- *Volute casing*. It is of spiral type in which the area of the flow increases gradually.



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


H stat
H md
hd
H t
h f d
Datum pump
center line
h s
H ms
h f s

The following terms can be defined

- h_s ***(suction lift)***: The difference in elevation between the suction liquid level and the centerline of the pump impeller.

- h_d ***(delivery lift)***: The difference in elevation between the discharge liquid level and the centerline of the pump impeller.

- H_{stat} ***(total static head)***: The difference (or sum) in elevation between the static discharge and the static suction heads:

$$\boxed{H_{stat}=h_d+h_s}$$

- H_{ms} ***(manometric suction head)*****:** it is the suction gage reading (if a manometer is installed just at the inlet of the pump, then H_{ms} is the height to which the water will rise in the manometer).

- H_{md} ***(manometric delivery head)*****:** it is the discharge gage reading (if a manometer is installed just at the outlet of the pump, then H_{md} is the height to which the water will rise in the manometer).

- H_m ***(manometric head)*****:** it is the increase of pressure head generated by the pump:

$$\boxed{H_m = H_{md} + H_{ms}}$$

$$H_{ms} = H_s + H_{fs} + \frac{v_s^2}{2g}$$

$$H_{md} = H_d + H_{fd} + \frac{v_d^2}{2g}$$

$$\boxed{H_m = H_{md} + H_{ms}}$$

Centrifugal Pump Performance

- Performance parameters
  1. Head (H) – the net work done on a unit weight of water by the pump
  2. Power (P) – power imparted to the water by the pump
  3. Efficiency (η)
  4. Flow rate (Q) – volume of water per unit time delivered by the pump
  5. Speed (N)
  6. Size (D)

Efficiencies of a Centrifugal Pump

Manometric efficiency

Ratio of manometric head to the energy supplied by the impeller.

Mechanical efficiency

Ratio of energy available at the impeller to the energy given to the impeller by the shaft power

Overall efficiency

Ratio of actual work done by the pump to the energy supplied to the pump

Ex 1

A centrifugal pump is required to lift 0.0125 m^3/s of water from a well with depth 30 m. If rating of the pump motor is 5 kW, work out overall efficiency of the pump.

Ex 2

A centrifugal pump having an overall efficiency of 72% delivers 0.03 m^3/s of water to a height of 20 m through a 10 cm diameter pipe 80 m long. Taking friction coefficient f=0.04, calculate the power required to run the pump.

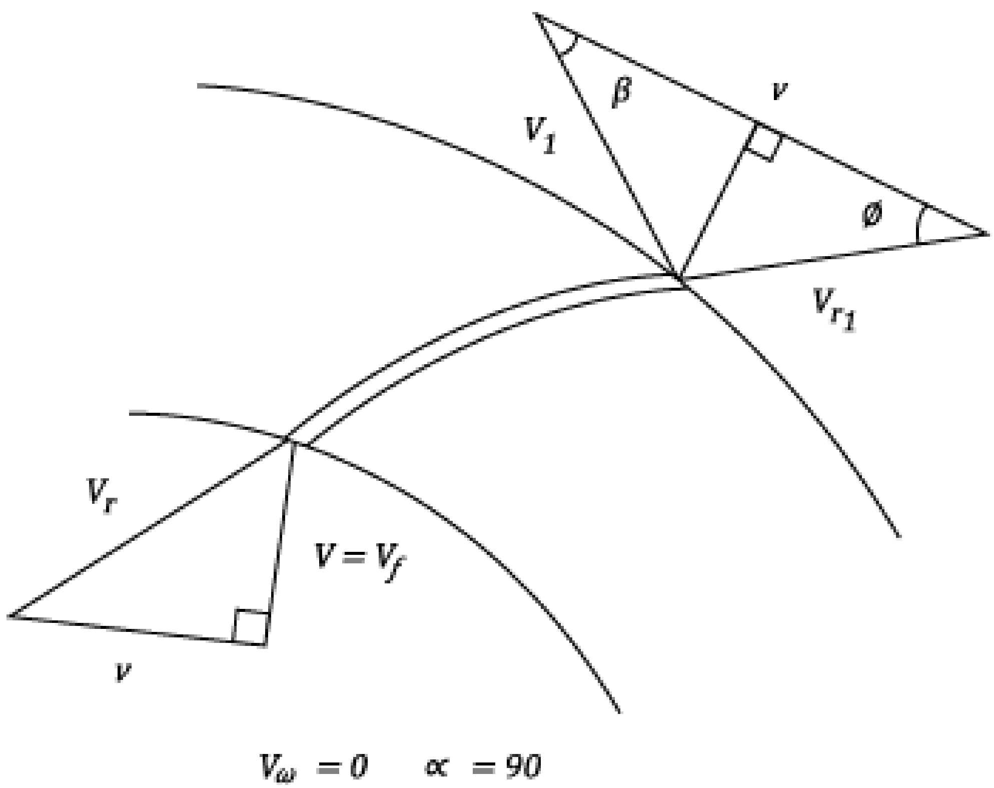
Specific Speed

- Is used to compare the performance of different pumps.
- This can be used to predict the behaviour of one pump based on tests of similar but different sized pumps

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

N – pump speed in rev/min
Q – discharge in m^3/s of a single suction impeller
H – head per stage in m

VELOCITY TRIANGLE



Ex 3

A centrifugal pump has an impeller of outer diameter 30 cm. The vane tips are radial at the outlet. For a rotative speed of 1450 rpm, calculate the net head developed. Assume manometric efficiency = 0.82

Ex 4

A centrifugal pump is to discharge 100 l/s at a speed of 1450 rpm against a head of 15 m. The impeller has an outer diameter of 25 cm with a width at the outlet of 6 cm. The manometric efficiency is 80%. Estimate the blade angle at the outlet.

Ex 5

A centrifugal pump has an impeller 0.5 m outer diameter and when running at 600 rpm discharges water at the rate of 8000 l/min against a head of 8.5 m. The water enters the impeller without whirl and shock. The inner diameter is 250 mm, and the vanes are set back at outlet at an angle of 45^0 and the area of flow which is constant from inlet to outlet of the impeller is 0.06 m^2. Determine

a) the manometric efficiency of the pump
b) The vane angle at inlet

Ex 6

Find the power required to drive a centrifugal pump which delivers 40 litres of water per second to a height of 20 m through a 150 mm diameter and 100 m long pipeline. The overall efficiency of pump is 70% and Darcy's friction factor is 0.06 for the pipeline. Assume inlet losses in suction pipe equal to 0.33 m.

Performance of Centrifugal Pumps

- The characteristics of a centrifugal pump are plotted as a set of constant speed lines for
  - Head – discharge
  - Input Power – discharge
  - Overall efficiency – discharge

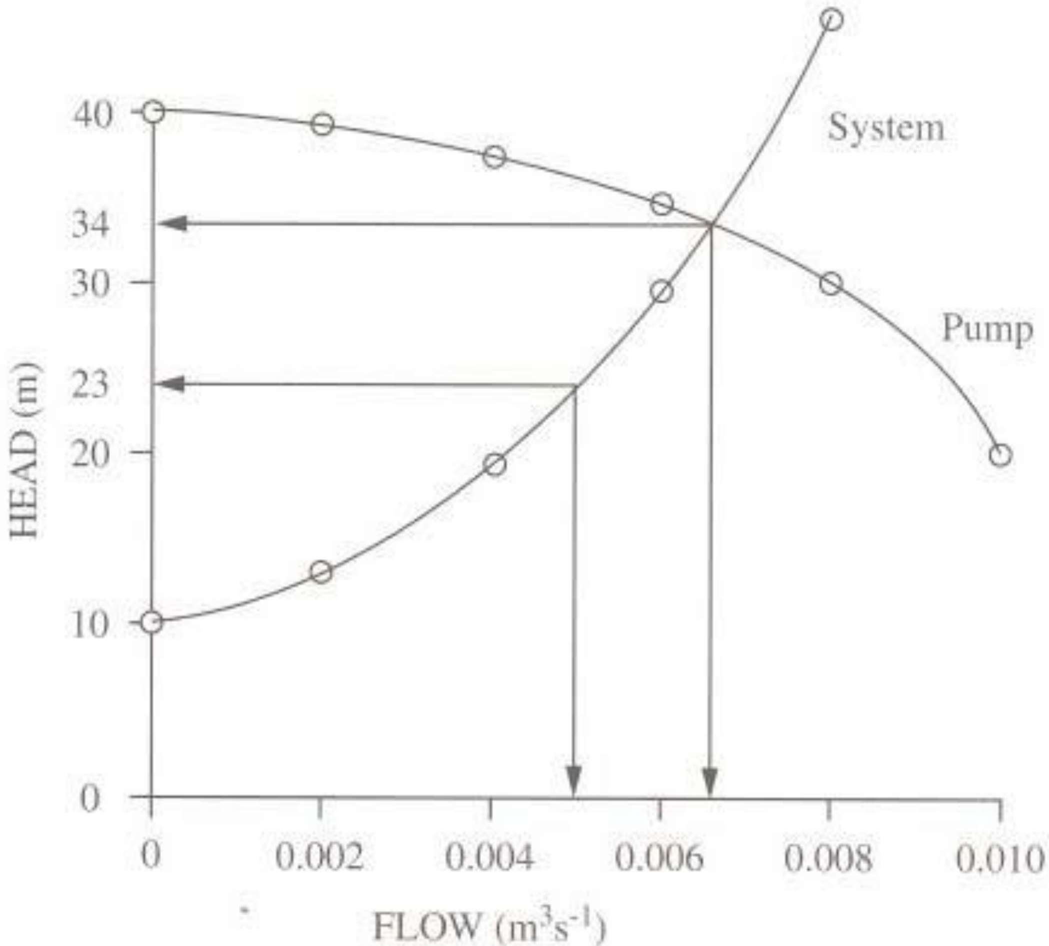
Pump Characteristic Curves

- Pump manufactures provide information on the performance of their pumps in the form of curves, commonly called pump characteristics curves (or simply pump curves).

- In pump curves the following information may be given:
  - the discharge on the x-axis,
  - the head on the left y-axis,
  - the pump power input on the right y-axis
  - the pump efficiency as a percentage

- The pump characteristic curves are very important to help select the required pump for the specified conditions.
- If the system curve is plotted on the pump curves:
- The point of intersection is called the **operating point**.
- This matching point indicates the actual working conditions, and therefore the proper pump that satisfy all required performance characteristic is selected.

PUMP CURVES

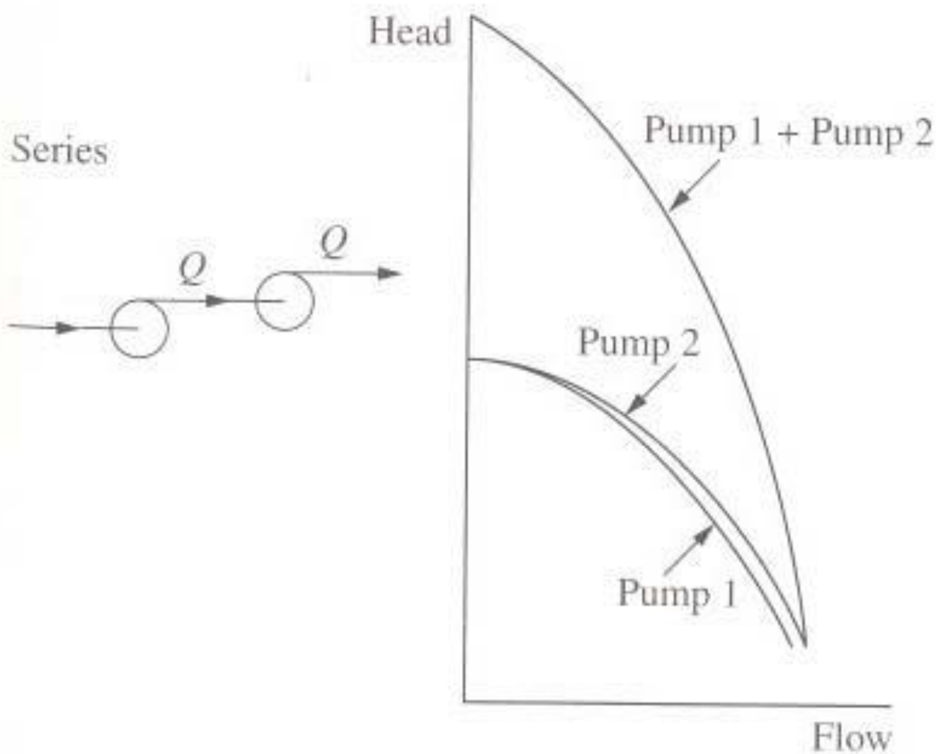


System
Pump
HEAD (m)
40
34
30
23
20
10
0
0
0.002
0.004
0.006
0.008
0.010
FLOW (m^3s^{-1})

Pumps in Series

- The manufacturer gives the pump curve for a single pump operation only.
- For pumps in series, the curve of two pumps, for example, is produced <u>by adding the heads of the two pumps at the same discharge.</u>
- Note that, all pumps in a series system must be operating simultaneously.

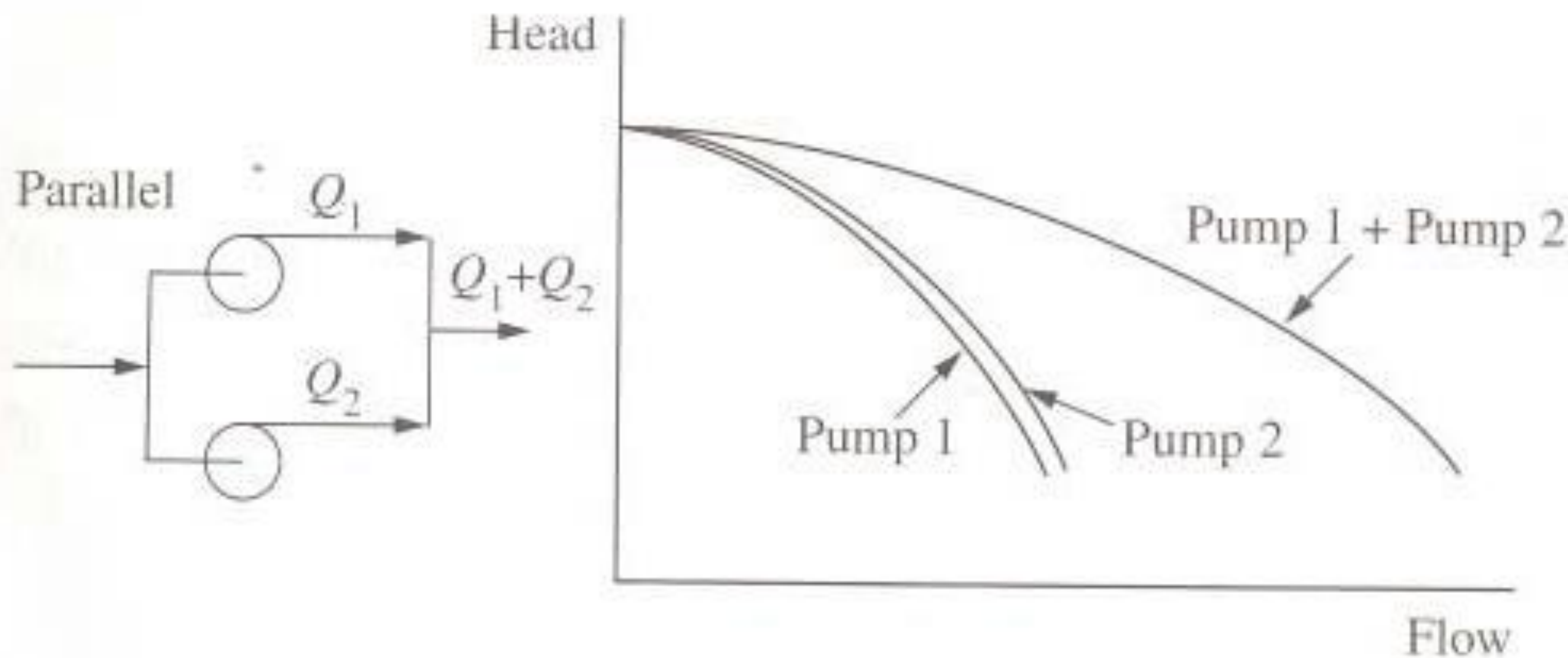
PUMPS IN SERIES



Pumps in Parallel

- The manufacturer gives the pump curve for a single pump operation only.
- If two or more pumps are in operation, the pumps curve should be calculated and drawn using the single pump curve.
- For pumps in parallel, the curve of two pumps, for example, is produced <u>by adding the discharges of the two pumps at the same head </u>(assuming identical pumps).

PUMPS IN PARALLEL



Ex 7

- The H-Q of a centrifugal pump is shown below:

H (m)	22.5	22.0	20.9	19.0	16.3	12.7	7.7	0
Q (m3/s)	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35

Ex….

- Both pumps are installed together and are required to pump water through a pipe 150 mm diameter having $\lambda = 0.02$. Calculate the heads under which pumps are working and discharge in litres per second pumped by them if:
  a) The pumps are connected in series: static lift is 65 m and the suction and the delivery pipes are 800 m long
  b) The pumps are connected in parallel: static lift is 15 m and the suction and the delivery pipes are 360 m long

Ex 8

- Two centrifugal pumps have the head and discharge characteristics as follows:

Q	0	4	8	12	16	20	24
H_{m1}	50.0	51.8	50.8	48.0	42.5	32.5	18.3
H_{m2}	46.7	45.9	44.2	40.3	34.3	26.0	17.0

Ex …….

- The pump is to be connected to a rising main which has a diameter (D) of 400 mm and a length of 137 m.The entry exit and minor head losses in the pipeline can be taken as 80D in this particular situation. The friction loss can be approximated by $h_F = \lambda LQ^2/12D^5$ with λ=0.04. The static lift is 10 m. By considering a single pump (P). And two of the pumps in series (P+P) and parallel (P//P) determine:
- the H-Q curve of the two pump combinations
- Which combination will be capable of discharging at least 0.3 m^3/s, with the ability to pump up to 0.35 m^3/s if the need arises.

CAVITATION

- Vapour forms in any liquid when the pressure in the liquid is less than the vapour pressure at the liquid temperature.
- The possibility of happening this phenomena is much greater when the liquid is in motion, particularly on the suction side of centrifugal pumps where velocities may be high and the pressure correspondingly reduced.
- Then the vapour bubbles travel with the liquid and eventually collapse with explosive force giving pressure waves of high intensity.
- This collapse is known as cavitation.