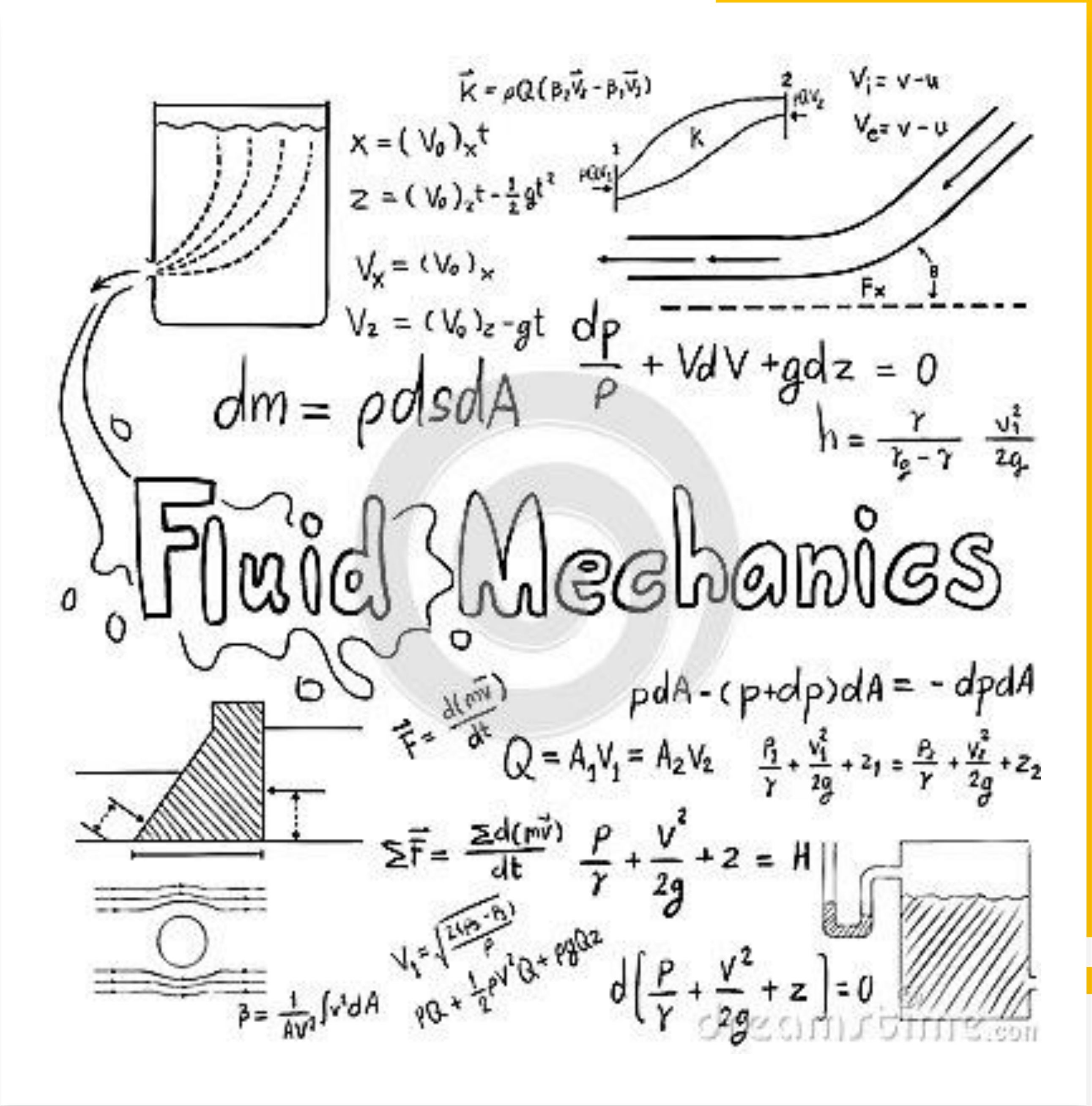
Fluid Mechanics



specific gravity

- Sometimes the density of a substance is given relative to the density of a well-known substance.

$$SG = \frac{\rho}{\rho_{H_2O}}$$

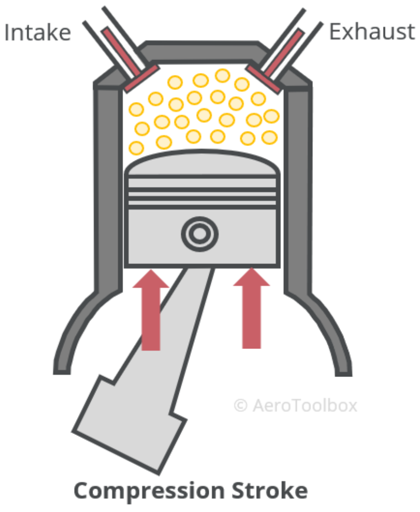
Specific gravities of some substances at 0°C

Substance	SG
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3–0.9
Gold	19.2
Bones	1.7–2.0
Ice	0.92
Air (at 1 atm)	0.0013

$$\gamma_s = \rho g$$

Specific Weight

The weight of a unit volume of a substance is called specific weight and is expressed as



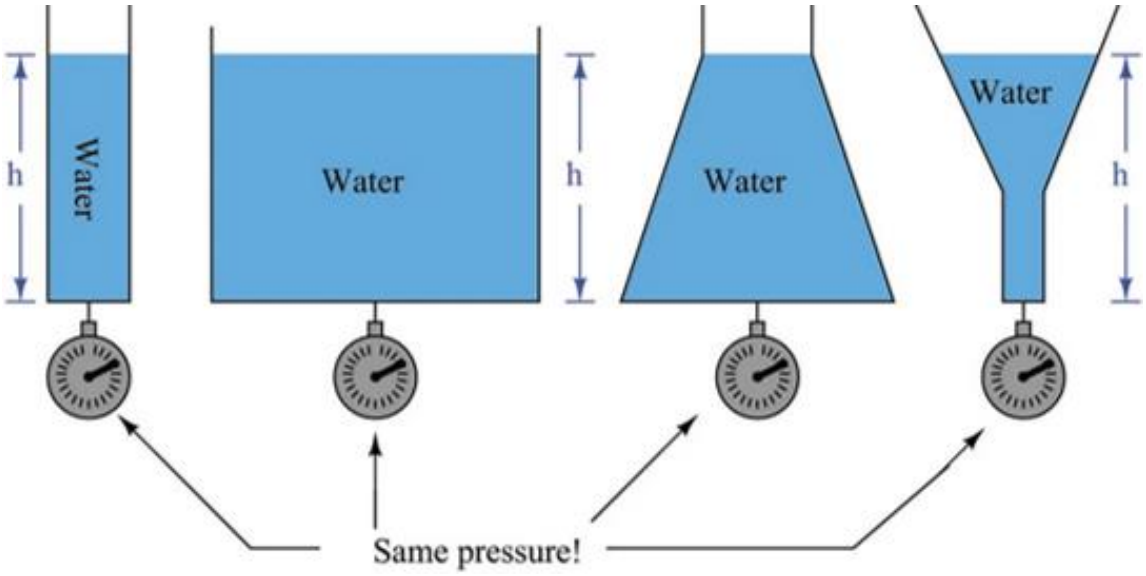
Pressure Units

- 1 Bar = 100 kPa = 14.5 psi
- The recommended pressure for air in tires ranges between **30 and 35 psi.**
- In car engine, peak cylinder pressures near TDC (where spark occurs) will be in the range of **300 psi** for engine's at light loads

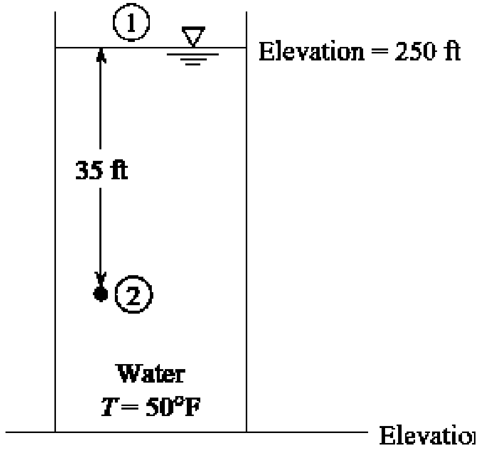
What is Hydrostatic pressure?

- The pressure that is generated by the **weight of liquid** above a measurement point, when the liquid is at rest.

$$P_h = \rho g h$$



What is the Hydrostatic Equation?



The piezometric head in a static fluid with uniform density is constant at every point.

$$\frac{p_1}{\gamma} + z_1 = \frac{p_2}{\gamma} + z_2$$

What is the Bernoulli equation?

- The assumptions to apply Bernoulli equation :
  - The flow is steady - the flow parameters does **not** change with time.
  - The flow is **not** compressible (constant density).
  - The flow is **not** viscous.

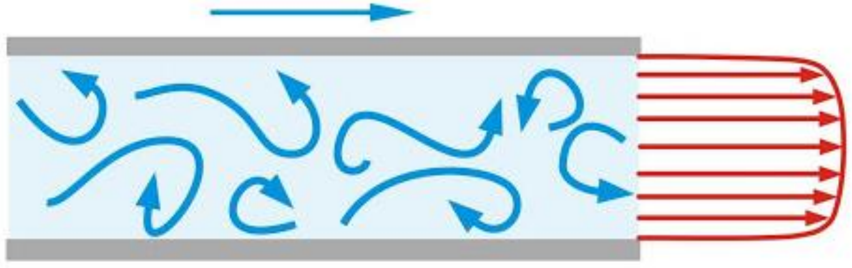
- The **total mechanical energy** of the fluid is conserved and constant.

- **Volute** in the casing of centrifugal pumps converts the velocity of fluid into pressure energy by increasing the area of flow.

$$\frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 = \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1$$

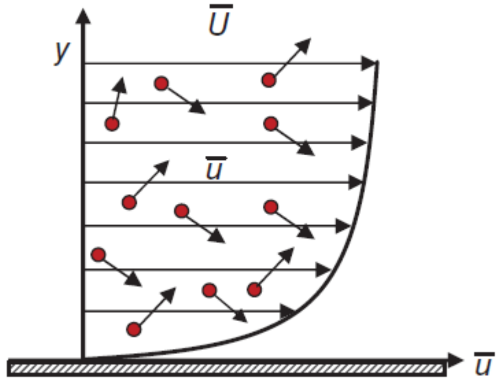
Pressure head + kinetic head + potential head = constant

What are the differences between Turbulent and laminar flow?



Turbulent flow

- is characterized by a **mixing action** throughout the flow field, and this mixing is caused by eddies of varying sizes within the flow.
- Full of **irregularities**, **eddies**, and **vortices** mixing flow.

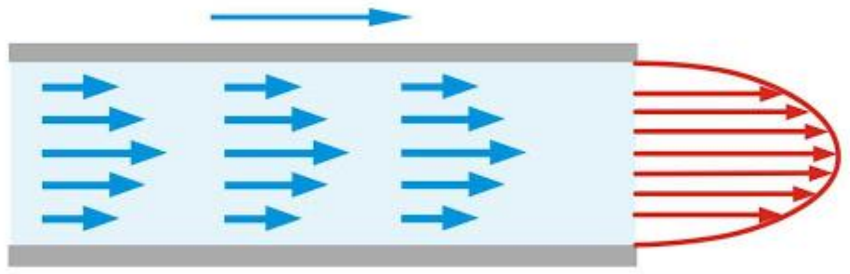


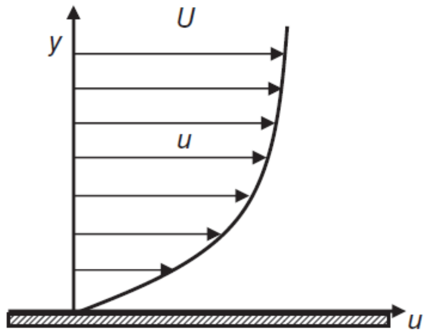
Turbulent flow near a solid boundary

What are the differences between Turbulent and laminar flow?

Laminar flow

- This flow has a very **smooth appearance**.
- No **mixing phenomena** and **eddies**.
- A typical example is the flow of honey.
- Velocity distribution is parabolic (less uniform)
- Velocity is constant with time at any given position (no fluctuation)





Laminar flow near a solid boundary

Figure 1.13 The velocity profiles

What is Reynold’s number?

1. Laminar Flow $Re < 2000$
2. Unstable Flow $2000 < Re < 4000$
3. Turblent Flow $Re > 4000$

$$Re = \frac{\rho V L}{\mu}$$

The Reynolds number (Re) is

- dimensionless quantity.
- used to **predict flow patterns** in different fluid flow situations.

What are the Friction Losses in Piping System?

- Friction losses in piping systems are normally divided into two parts:
  - **The major losses** represent the friction losses in straight pipes.
  - **The minor losses** represent the losses in various types of pipe fittings including bends, valves, filters, and flowmeters. (K is a friction factor to be obtained experimentally for every pipe fitting)

$$(h_L)_{minor} = \sum K \frac{V^2}{2g}$$

$$h_L = \frac{fLV^2}{2gD}$$

How to calculate the flow rate and the mass flow rate?

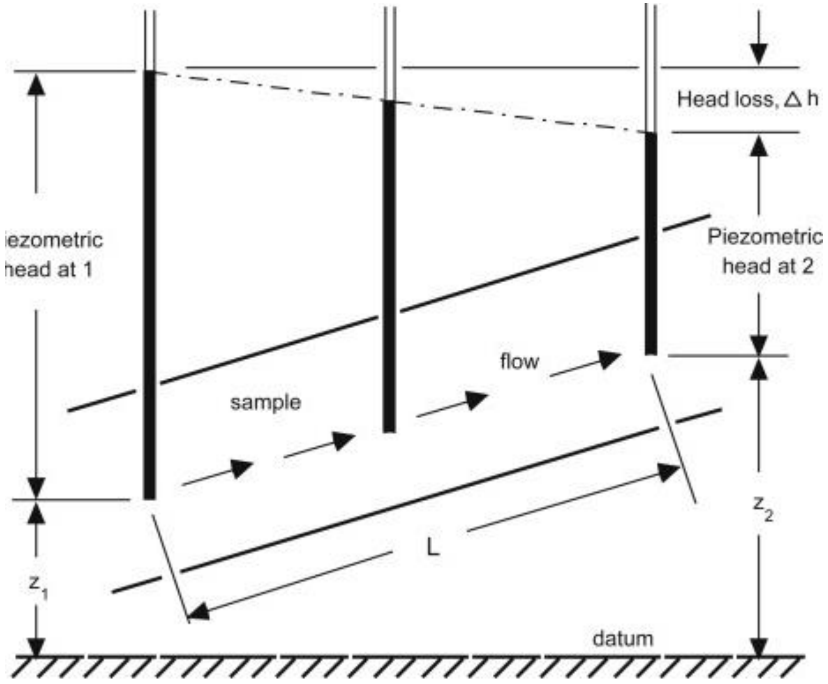
Mass flow rate equation

$$\dot{m} = \rho A \overline{V} = \rho Q$$

$$Q = VA$$

$$\text{Flow Rate } (m^3/s) = \text{Velocity } (m/s) \times \text{Area } (m^2)$$

Can the fluid move inside a pipe from a low-pressure point to a high-pressure point?



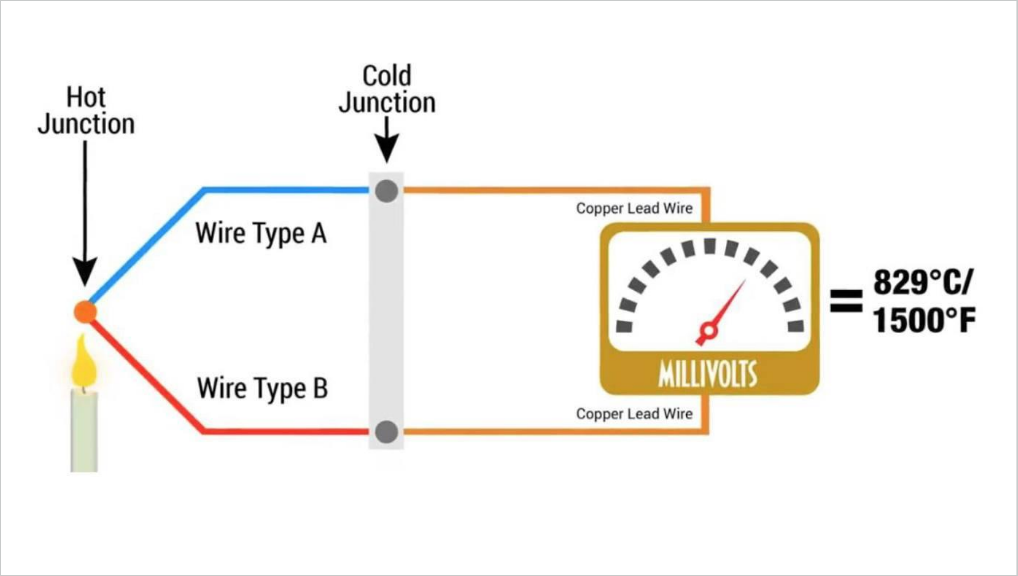
- Fluid basically flows from "higher energy level" to a "lower energy level". And yes, fluid can flow from low pressure point to high pressure point.
- **The direction in which the Total Head decreases is the direction of the flow.**

Mention 5 devices to measure temperature.

- **Thermocouple**
- **Thermistor**
- **Infrared Thermometers**
- Bi-metal thermometers
- Gas-actuated thermometer

What is Thermocouple?

- **Thermocouples** consist of two wire legs made from different metals. The wires legs are welded together at one end, creating a junction. This junction is where the temperature is measured.
- Let say one was made from copper, and the other one was made from iron.
- Then, the two metals will conduct heat differently, so the temperature gradient will be different that means the electron buildup will be different.
- And so we can connect a voltmeter to this and read a voltage difference.



What is Thermistor?

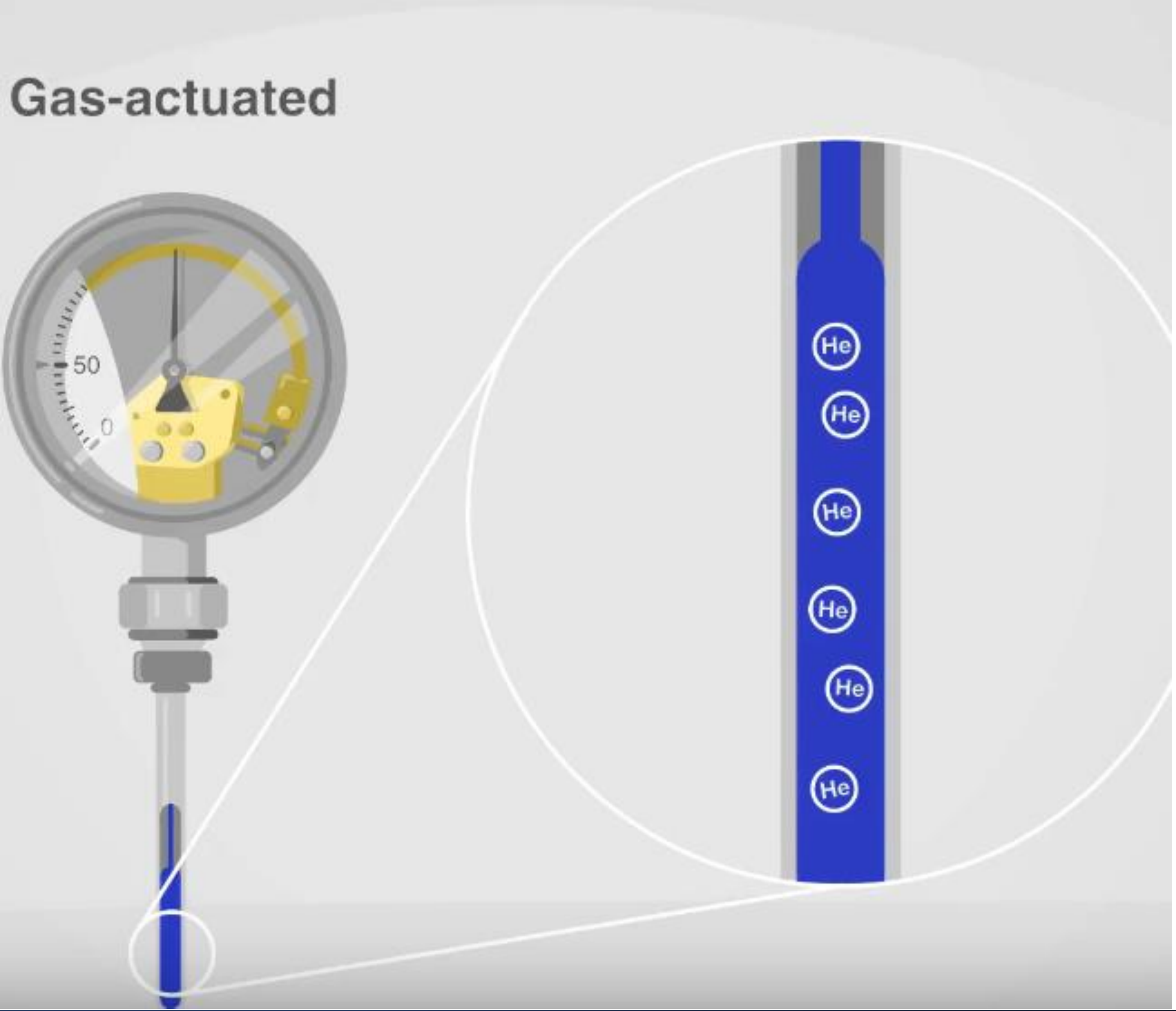
- A **thermistor** is a type of resistor whose resistance is dependent on temperature
- Most conductors will increase in resistance the hotter they get. This occurs because, as the molecules become excited, they move around a lot, so it's harder for the free electrons to get through without a collision.
- So, using a formula known as Ohm's Law, voltage is equal to current multiplied by resistance. This means that as long as we keep the current the same, a change in resistance will cause a change in voltage, and as temperature changes the resistance of a material, we can measure the voltage to tell the temperature.

What is Infrared Thermometer?

- Every object that is not in absolute zero temperature has atoms moving within it. These moving molecules emit energy in the form of **infrared radiation**.
- Infrared thermometers employ a lens to focus the infrared light emitting from the object onto a detector known as a **thermopile**.
- The **thermopile** is thermocouples connected in series or parallel. Then we can measure the voltage to measure the temperature.

What is Bi-metal thermometers?

- A bimetal thermometer measures the temperature via a spiral tube which consists of two different metals that possess different thermal expansions.
- That difference in thermal expansion rates is used to produce **deflections** that are **proportional** to changes in **temperature**.



What is gas-actuated thermometer?

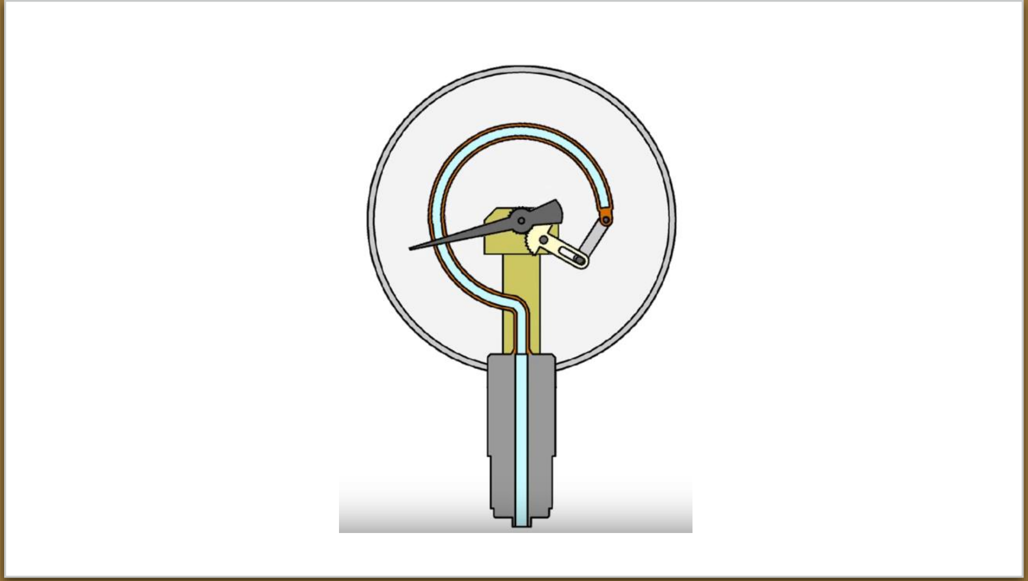
- The gas (preferably helium) expands at elevated temperatures and **deforms** the measuring tube.

Mention 3 devices to measure Pressure

- Bourdon tube pressure gauge
- Manometer
- Barometer

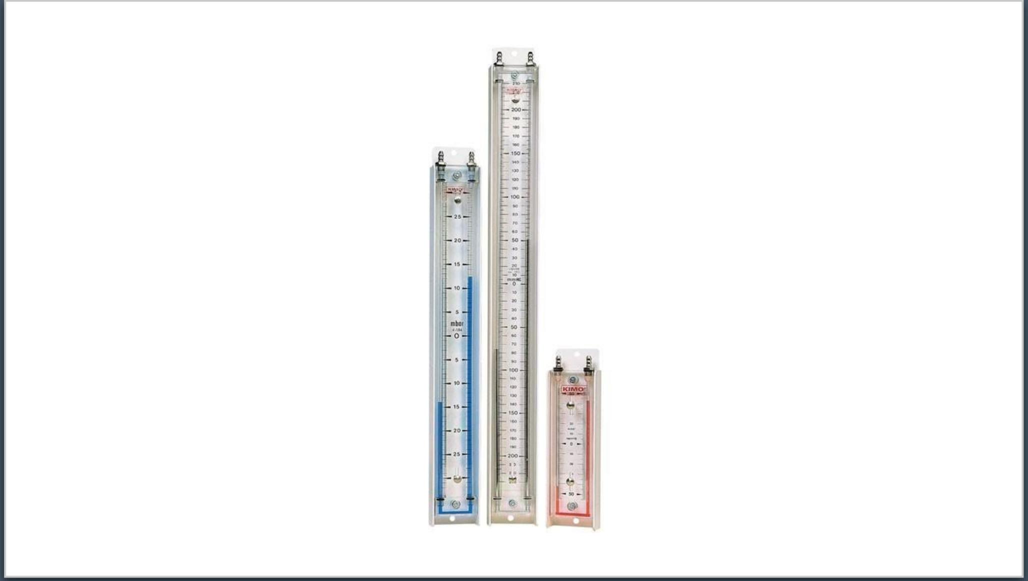
What is Bourdon tube pressure gauge?

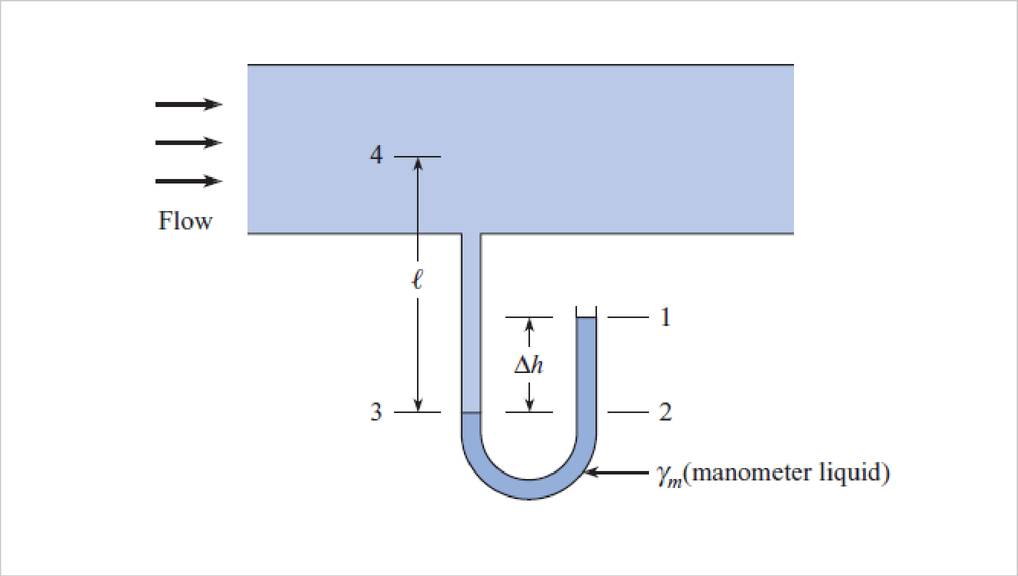
- A Bourdon-tube gage measures pressure by sensing the deflection of a coiled tube.
- The tube has an elliptical cross section and is bent into a circular arc.
- When atmospheric pressure (zero gage pressure) prevails, the tube is undeflected, and for this condition the gage pointer is calibrated to read zero pressure.
- When pressure is applied to the gage, the curved tube tends to straighten, thereby actuating the pointer to read a positive gage pressure.

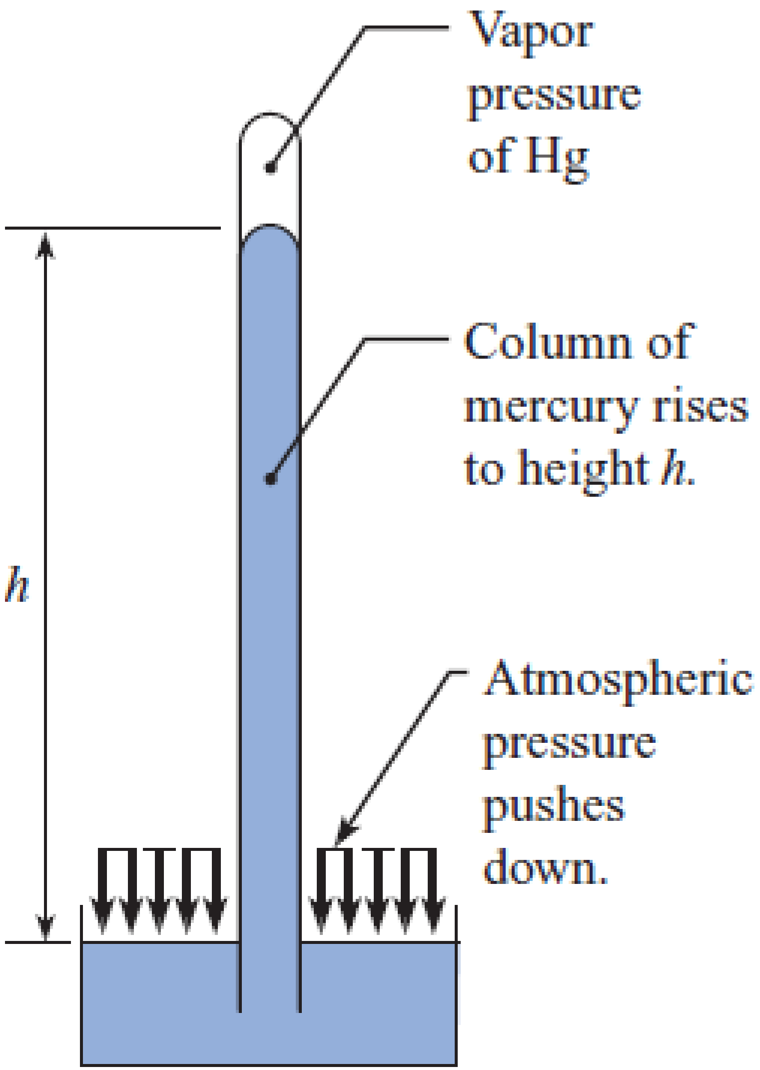


What is Manometer?

- A manometer, often shaped like the letter "U," is a device for measuring pressure by raising or lowering a column of liquid
- Positive gage pressure in the pipe pushes the manometer liquid up a height h.







What is Barometer?

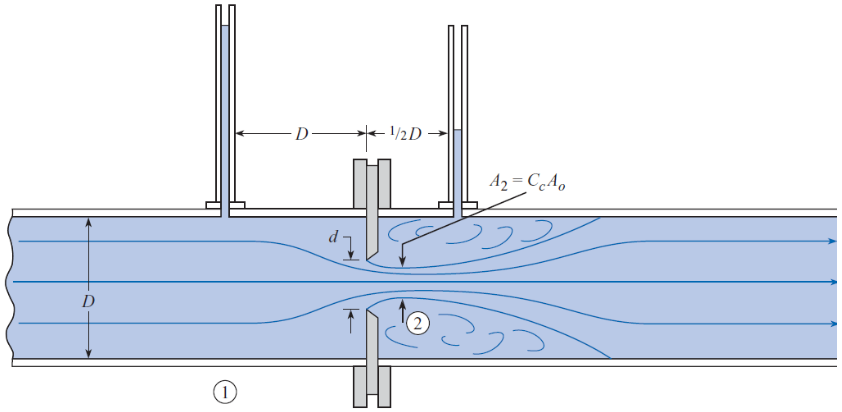
- An instrument that is used to measure atmospheric pressure is called a barometer.
- A mercury barometer is made by inverting a mercury-filled tube in a container of mercury The pressure at the top of the mercury barometer will be the vapor pressure of mercury, which is very small. Thus, atmospheric pressure will push the mercury up the tube to a height h.

Mention 3 devices to measure flow rate.

1. Venturi meter
2. Rotameter
3. Orifice meter

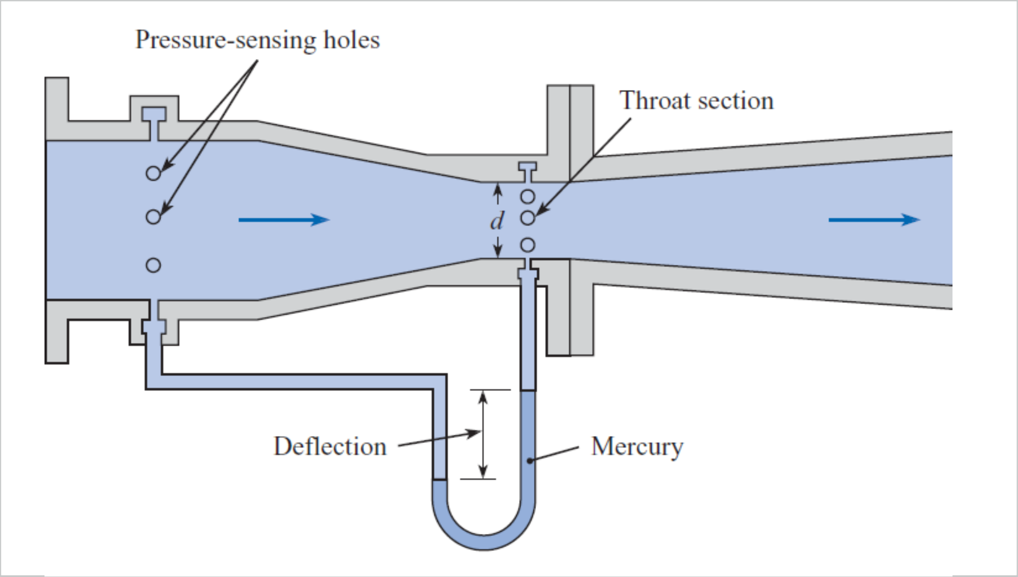
What is Orifice plate?

- An orifice meter is an instrument for measuring flow rate by making a pressure drop in the fluid due to the sudden change in the cross-sectional area.
- Flow rate is found by measuring the pressure drop across the orifice and then using an equation to calculate the appropriate flow rate.



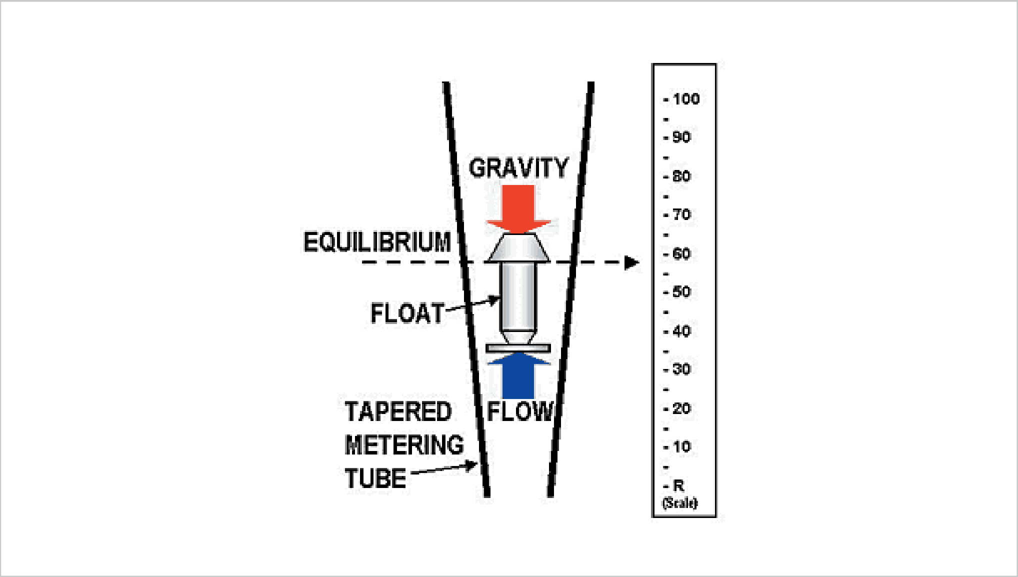
What is Venturi Meter?

- The venturi meter is an instrument for measuring flow rate by using measurements of pressure across a converging-diverging flow passage.
- The main advantage of the venturi meter as compared to the orifice meter is that the head loss for a venturi meter is much smaller.



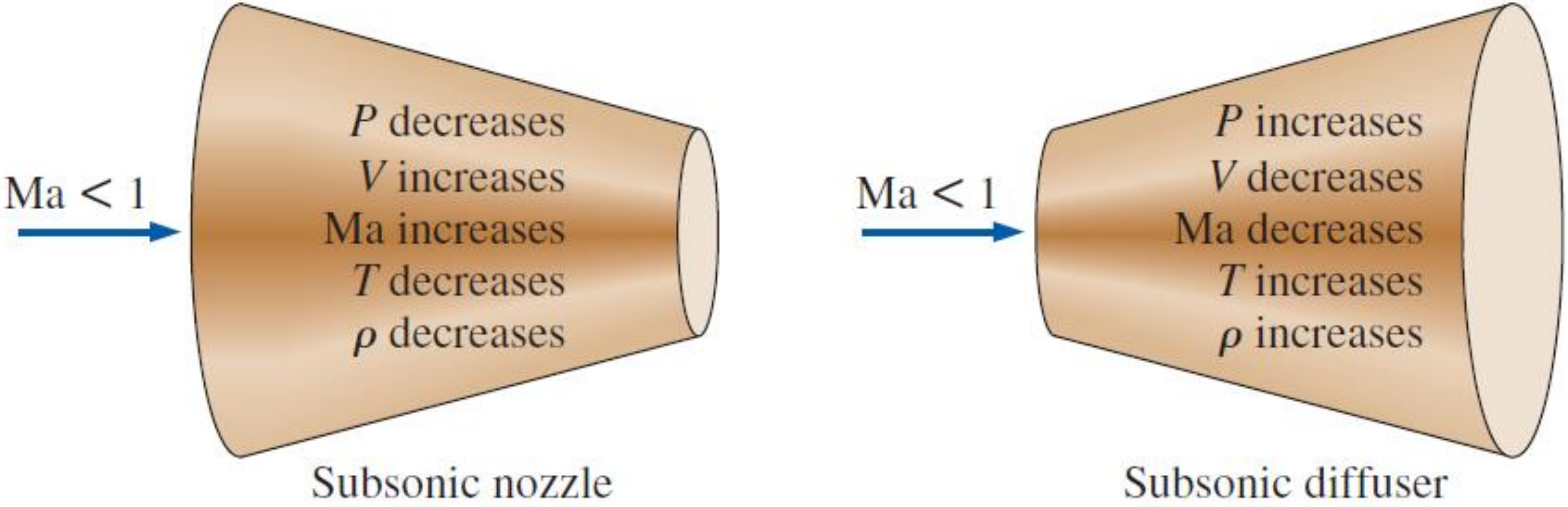
What is Rotameter?

- The rotameter is an instrument for measuring flow rate by sensing the position of an **element** that is situated in a **tapered** tube.
- The element moves up and down until it reaches the equilibrium position where both the weight and the drag forces are equal.
- The weight of the element is fixed, while the drag is changing depending on the flow rate and the cross-sectional area.
- Once the flow rate increases the element moves up, and at the same time the cross-sectional area is increasing which reduces the drag force until both forces become equal again.

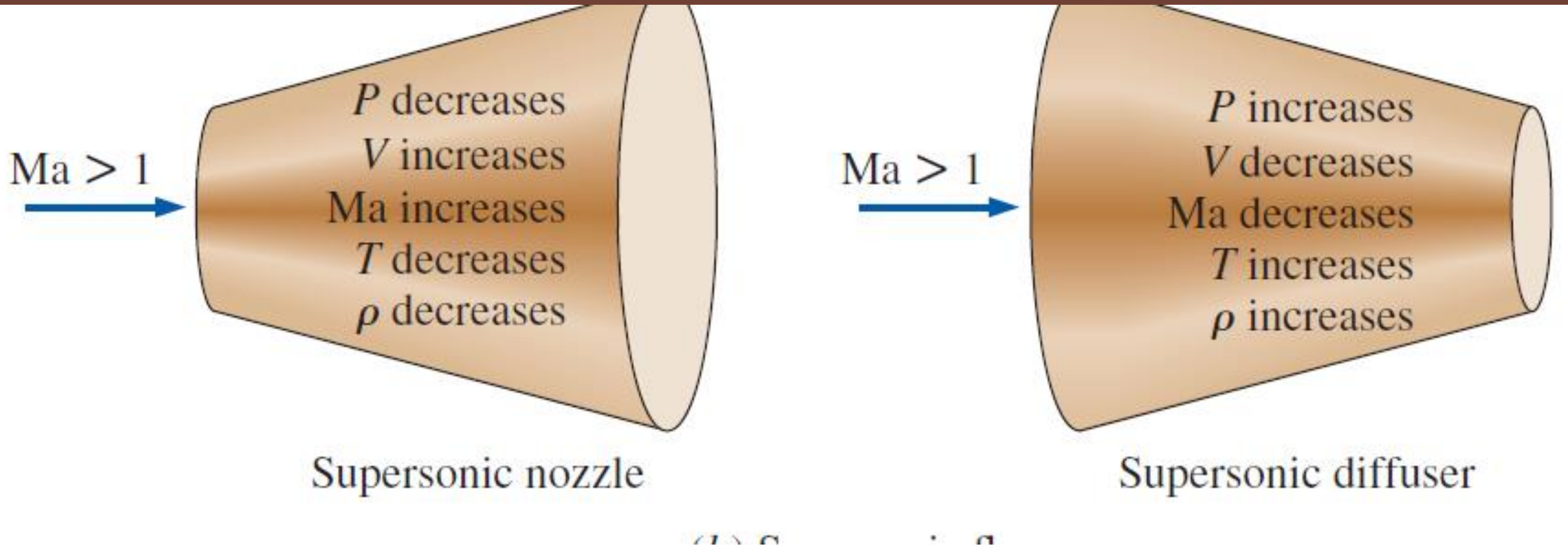


compressible flow

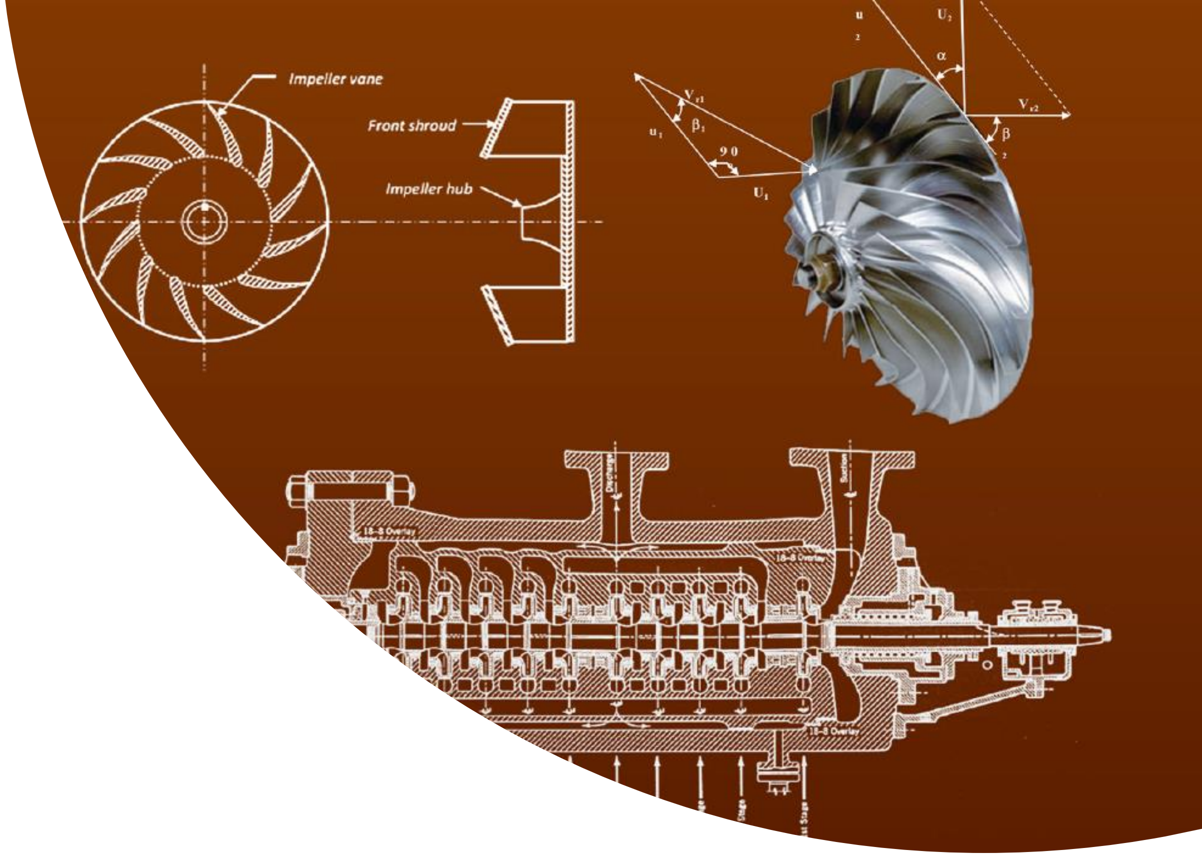
- An important parameter in the study of compressible flow is the **speed of sound** defined as the speed at which an infinitesimally small pressure wave travels through a medium.
- **Mach number** Ma is the ratio of the actual speed of the fluid to the speed of sound in the same fluid at the same state.
- The flow is called
  - Sonic when Ma = 1
  - Transonic when Ma =~ 1.
  - Subsonic when Ma<1
  - Supersonic when Ma > 1
  - Hypersonic when Ma >> 1



Subsonic flow



Supersonic flow



Pumping Machinery

Content

What are the Types of pumps?

Centrifugal pumps

- How do the centrifugal pumps work?
- Draw Pump Performance Characteristics
- The main components inside the pump
- What are the types of Losses on Pump?
- What is NPSH?
- What are the major pump problems? How to solve each one?
- How to control Flow Rate in Pumping Systems?

Displacement Pumps

How can you select a pump?

Compressors

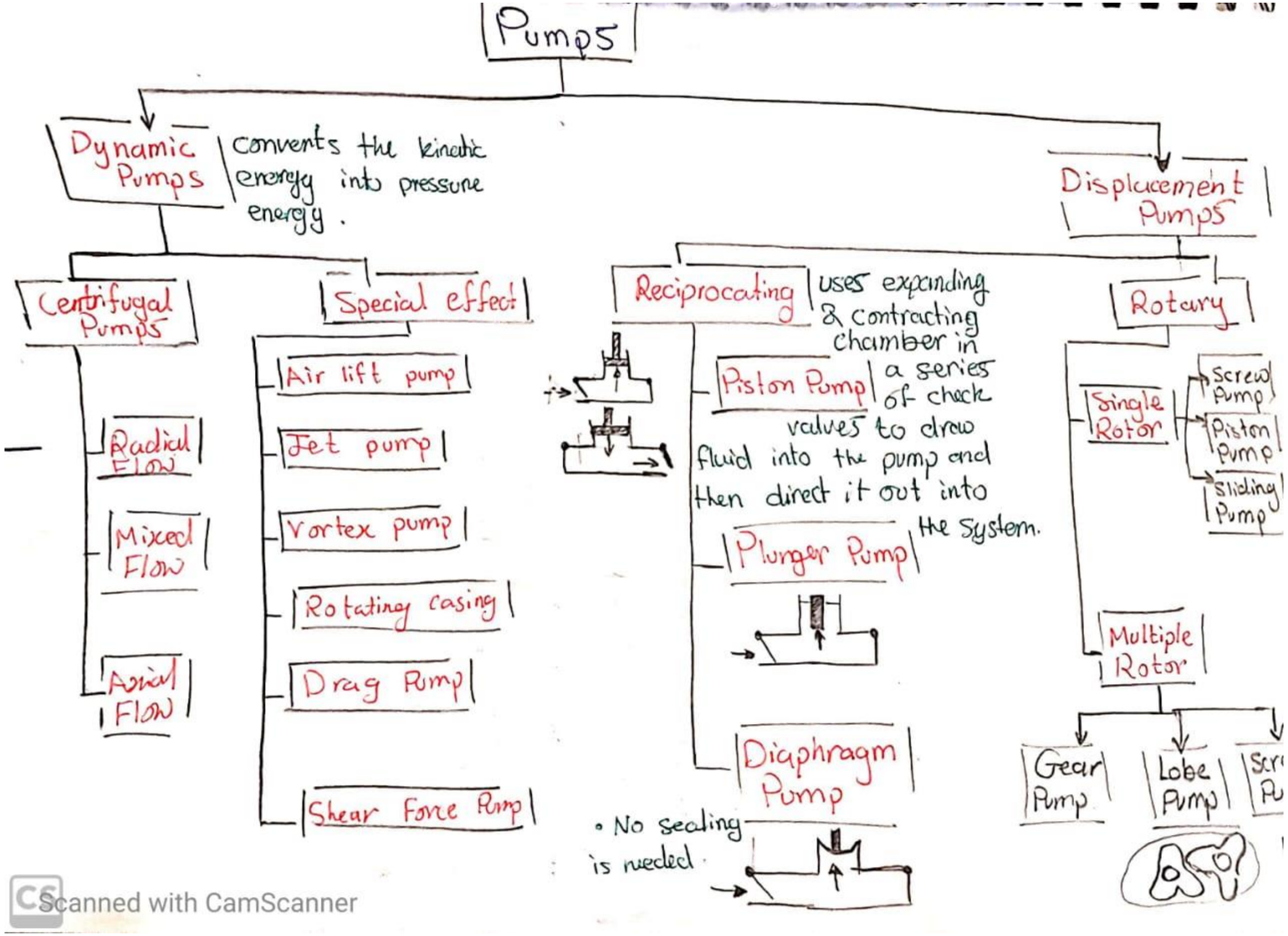
- What is the difference between the pump & compressor?
- List the main components inside the compressor?
- What are the Types of Compressors?
- Compressor Performance Characteristics
- What are the major compressor problems? How to solve each one?

Types of pumps? And the differences between them

- **Dynamic pumps:** In these pumps, the fluid velocity is increased inside the pump to values higher than the discharge velocity. Velocity reductions within or after the pump create higher pressure.

- **Displacement pumps:** In these pumps, energy is added to the fluid by the direct application of a force that moves the fluid from the low-pressure side (suction) to the high-pressure side (delivery).

Types of pumps



Additional Classifications

- **Shape of casing** : volute shape, double volute, diffuser, annular, tubular, split casing, etc.
- **Inlet geometry**: single suction, double suction, axial inlet, side inlet, top inlet, etc.
- **Layout**: the pump shaft may be horizontal, vertical, or inclined.
- **Discharge pressure or the energy consumption**: pumps are sometimes classified as low pressure, high pressure, or high energy.
- **Number of stages**: in the cases of radial and mixed-flow centrifugal pumps, they may be classified as single-stage, double-stage, or multistage.
- **Liquid handled**: the type of pumped fluid may necessitate some special design considerations. For example, gasoline pumps require special sealing system to avoid leakage in order to reduce fire hazard, and similarly for handling toxic liquids.
- **Material of pump parts:** the material used for manufacturing the impeller and pump casing may differ based on the type of pumped fluid. Special materials or coatings are used when handling corrosive liquids (such as sulfuric acid). or liquids containing solid particles.
- **Type of prime mover**: in most cases, pumps are driven by electric motors, but in some cases, they can be driven by diesel engines or steam or gas turbines.
- **Operating condition**: such as submersible pump, wet motor pump, standby pump, and auxiliary pump.

What is the equation of a specific speed?

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

- **The specific speed *Ns*** is a shape factor that helps the engineer to determine the type of pump to be used in a specific application.
- Example: What type of pump should be used to pump kerosene at a rate of 0.35 m3 /s under a head of 60 m assuming that N = 1450 rpm

Table 2.3 The specific speed range for different types of pumps

Type of pump	N_s range
Displacement pumps	<500
Radial-type centrifugal pumps	500–5000
Mixed-flow pumps	4000–10 000
Axial-flow pumps	9000–15 000

How do the centrifugal pumps work?

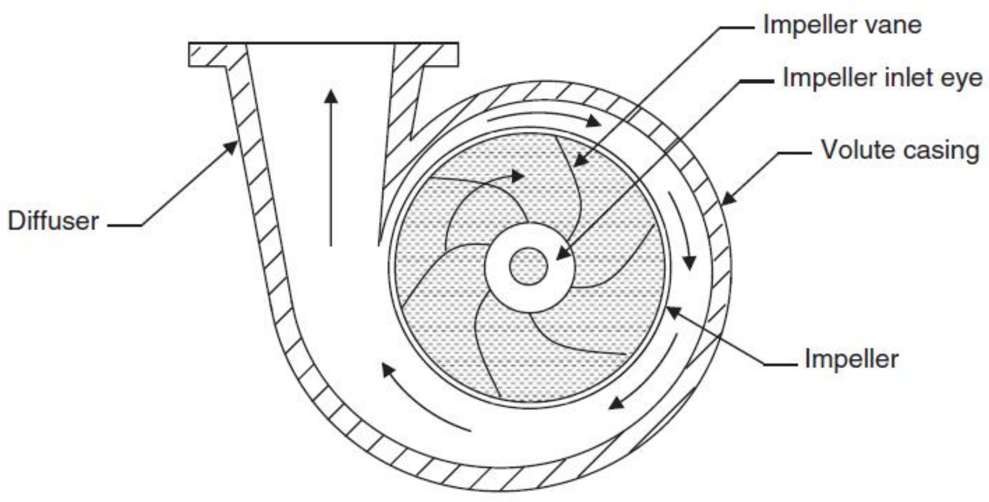
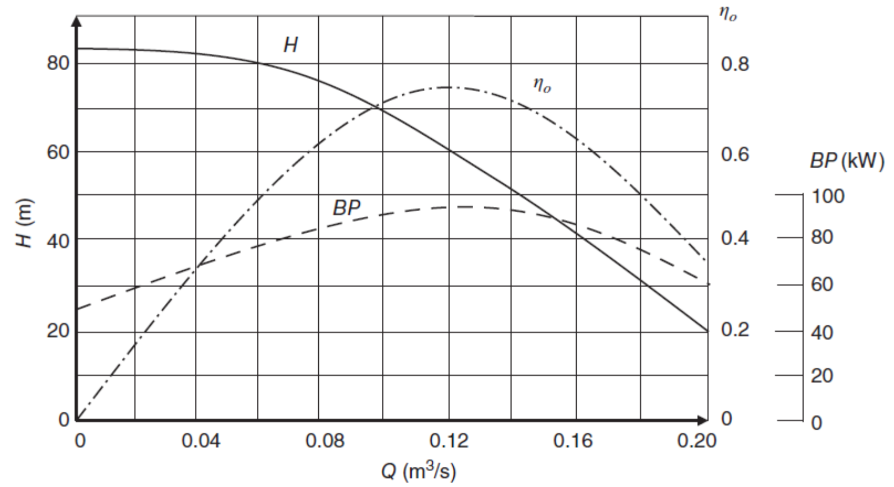


Figure 2.3 A sectional view of a radial-type centrifugal pump

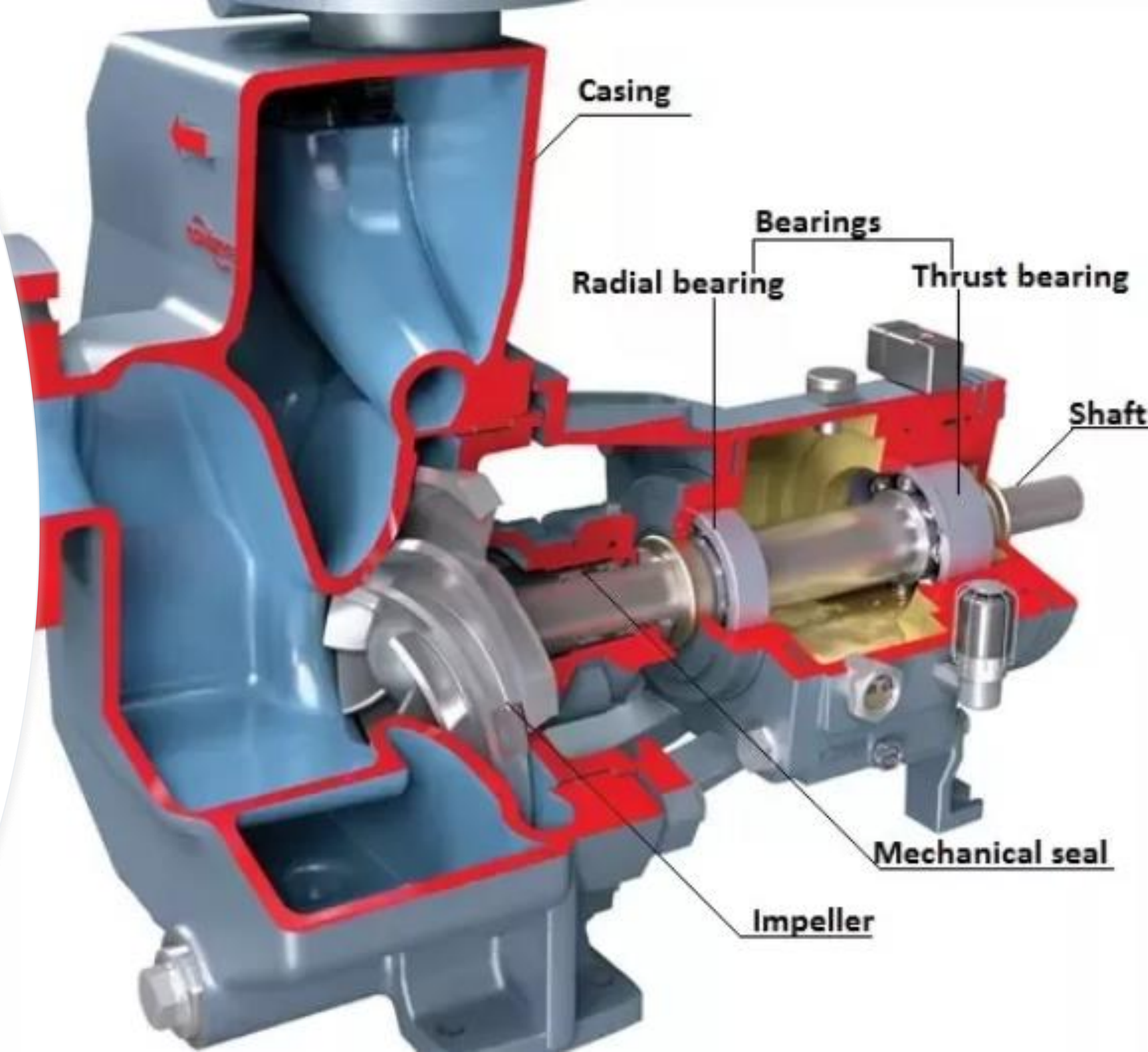
- The fluid enters the impeller axially through the inlet eye in a direction perpendicular to the page and is then forced to rotate by the impeller vanes. While rotating inside the impeller the fluid moves outward, thus gaining increase in pressure with a parallel increase in kinetic energy. The high velocity at the impeller exit is transformed to a pressure increase through the volute casing and discharge nozzle which has a diffuser shape.

Pump Performance Characteristics

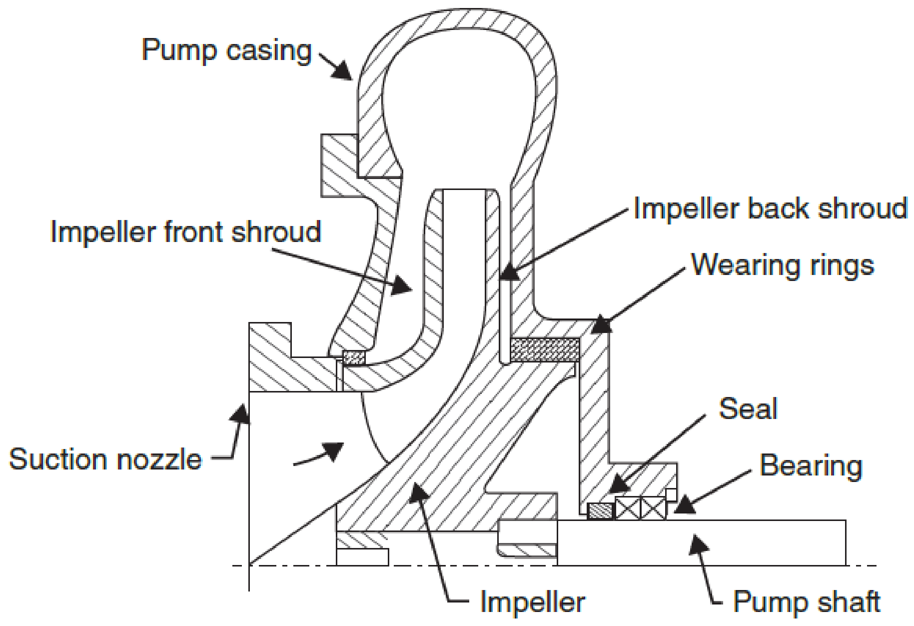
- The pump performance characteristics is a term used by engineers referring to the relationship between each of the total head developed by the pump (*H*), the pump power consumption (*BP*), the pump overall efficiency (η_o), and the pump flow rate (*Q*).
- These are usually presented graphically in terms of the three curves of *H*–*Q*, *P*–*Q*, and η_o–*Q* when the pump operates at <u>a constant speed</u> *N*, considering <u>pure water</u> as the pumped fluid.



The main components inside the pump



The main components inside the pump



1. **The pump shaft** is an essential component and is used for transferring mechanical power from the prime mover to the pump.

The main components inside the pump

2. **The pump impeller** is the component that converts the input mechanical power to fluid power through the work done on the fluid. The fluid gains higher pressure and higher kinetic energy during its course of motion through the impeller.

What are the types of pump impeller?

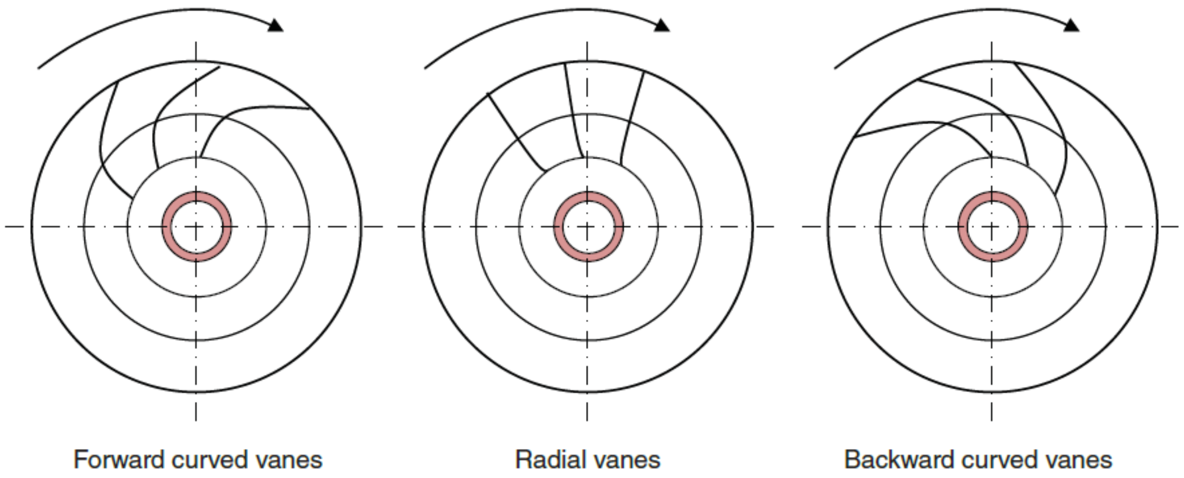
- No-shrouds impellers cannot easily get clogged and accordingly are suitable for handling liquids with suspended materials/ solids.
- By contrast, the double-shrouded impellers provide maximum support to the vanes and are widely used for pumping liquids with less suspended solids.
- The pump impeller may be single suction (suction from one side) or double suction (suction from opposite sides).

Single-shrouded impeller

Double-shrouded impeller

Impeller with no shrouds

The main components inside the pump



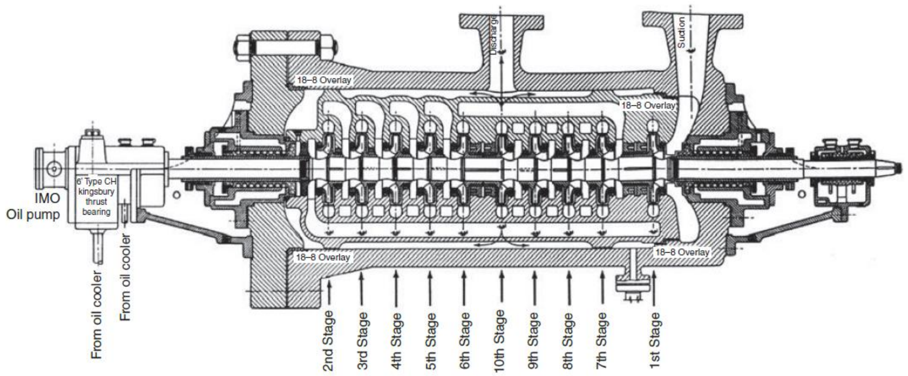
3. **The impeller vanes** are the most important elements in the pump. The work done on the fluid and the energy transfer from mechanical power to fluid power only occur because of the vanes.

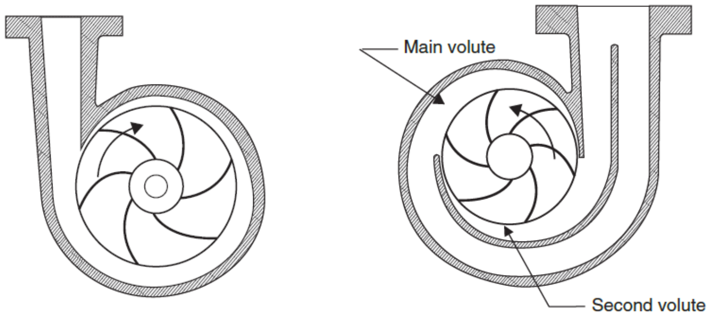
- Also, the pump performance characteristics and the overall efficiency depend mainly on the vane shape and number of vanes.

The main components inside the pump

4. The **pump casing** is an essential part of the pump which is important not only for housing the impeller(s) and sealing the system, but also for supporting the suction and delivery nozzles.

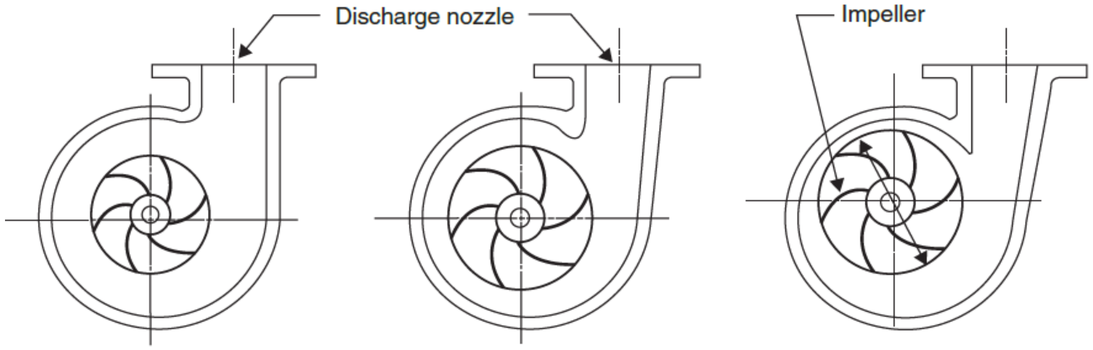
- The shapes include concentric volute, semi-concentric volute, and spiral volute.
- The casing may have a single or double volute.
- The casing used for a multistage pump (barrel casing) has a special design to enable the pumped fluid to move from one stage to another with the minimum amount of loss while maintaining compact design.





Single volute

Double volute



Concentric volute

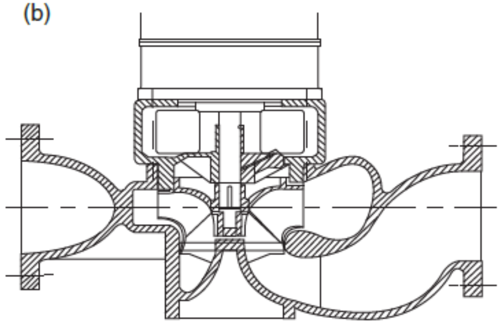
Semi-concentric volute

Spiral volute

The main components inside the pump

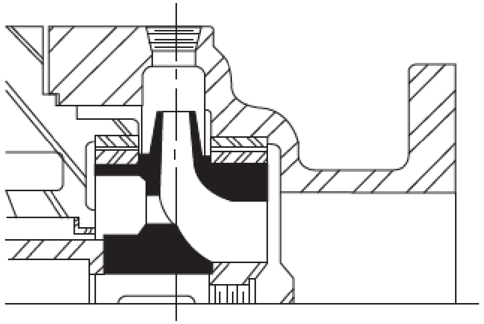
5. **The pump suction nozzle** is used to direct the fluid from the suction pipe until it enters the impeller. These nozzles may have single entry or double entry and may have an axial inlet or a side inlet. The suction nozzle may also be equipped with inlet guide vanes that are used for flow rate control.
6. **The discharge nozzle** directs the fluid from the casing to the discharge pipe. It also acts as a diffuser that converts the fluid's high velocity into pressure.

(b)

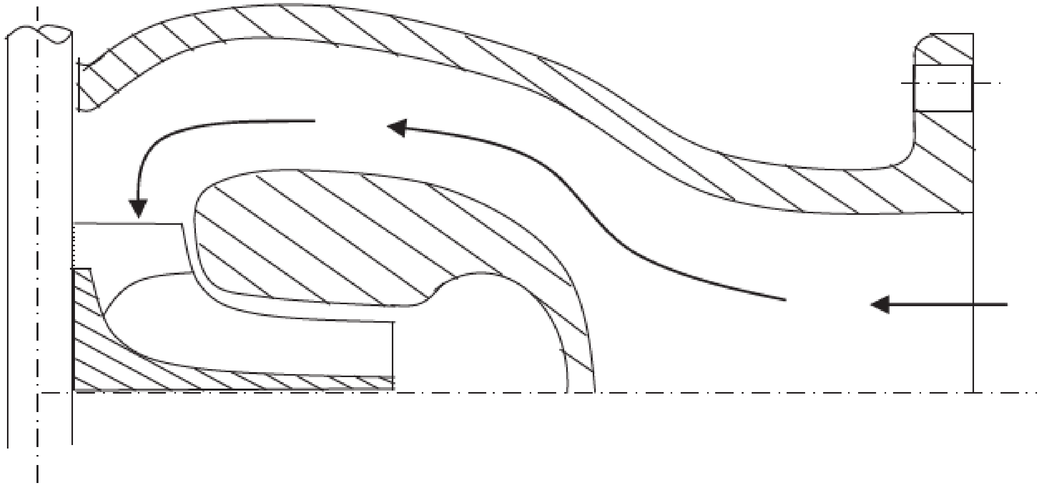


Side inlet suction nozzle

(a)



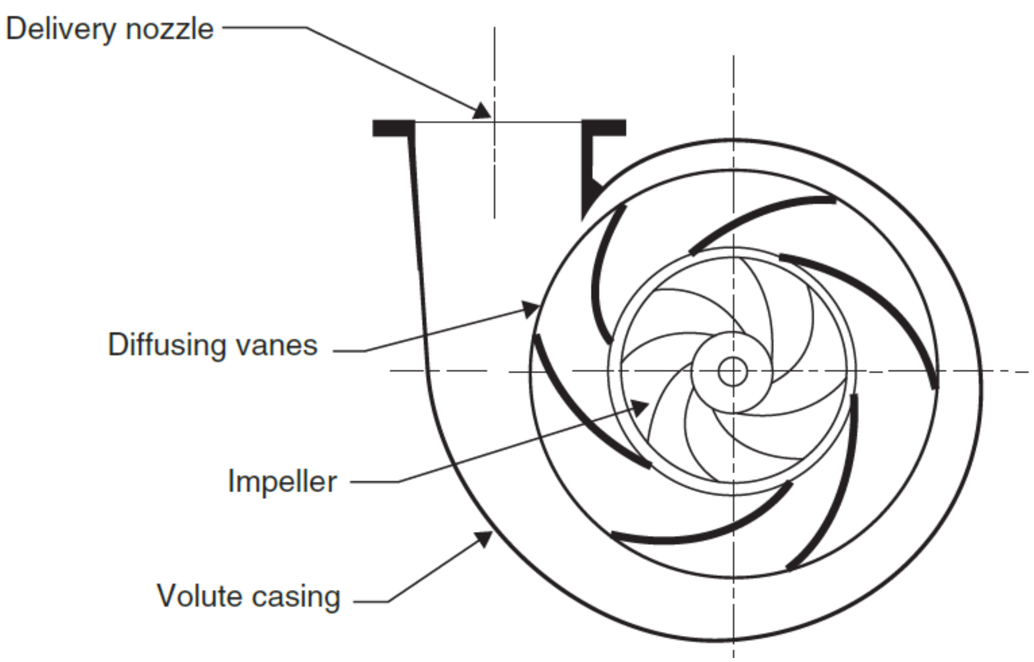
Axial inlet suction nozzle



The main components inside the pump - **Bearings**

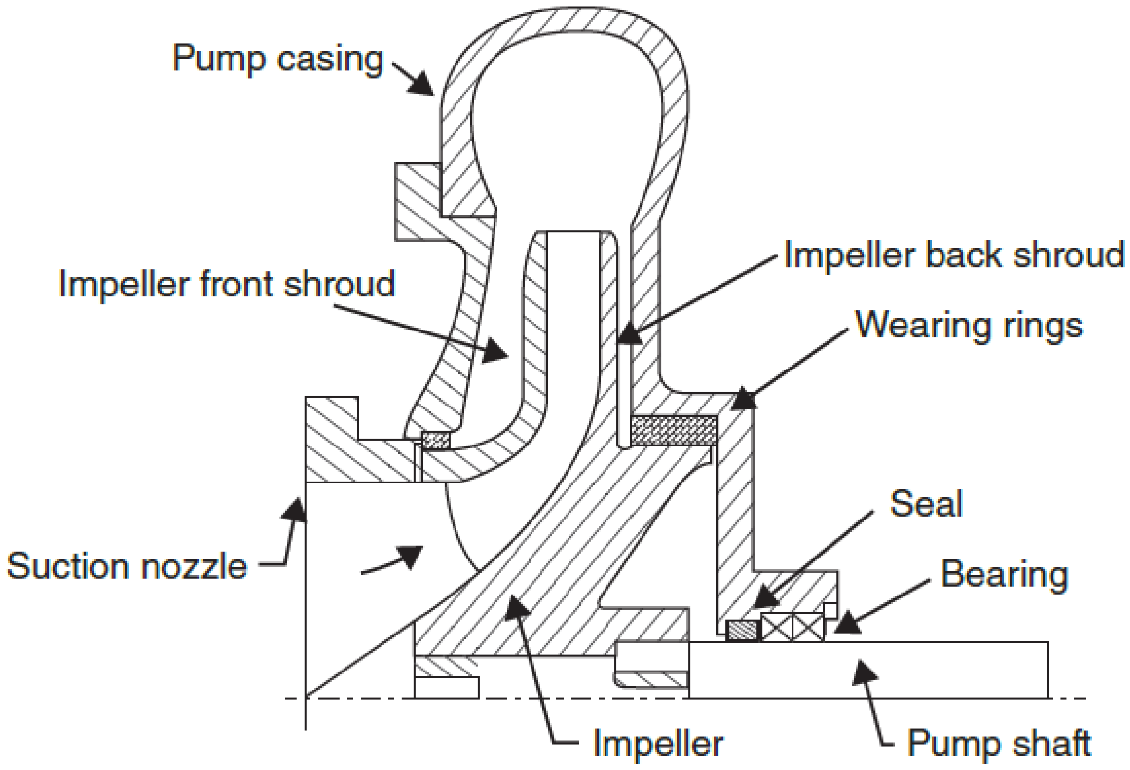
MOVER TYPE	COMMON BEARING TYPE USED
Centrifugal pumps  	• Two angular contact ball bearing. • One cylindrical roller bearing.
Centrifugal compressors  	Two radial (journal) bearings. One thrust bearing.

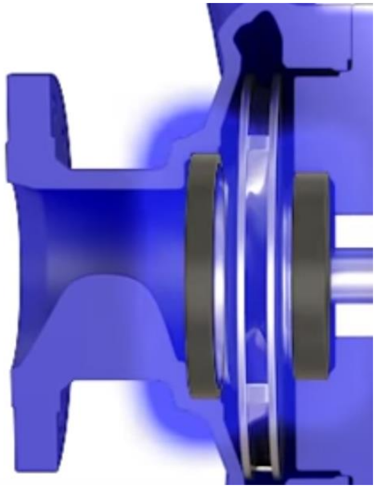
The main components inside the pump



8. The main function of **diffusing vanes** is to streamline the flow at the impeller exit and convert the high velocity into pressure. This will lead to a reduction of friction losses in the volute casing.

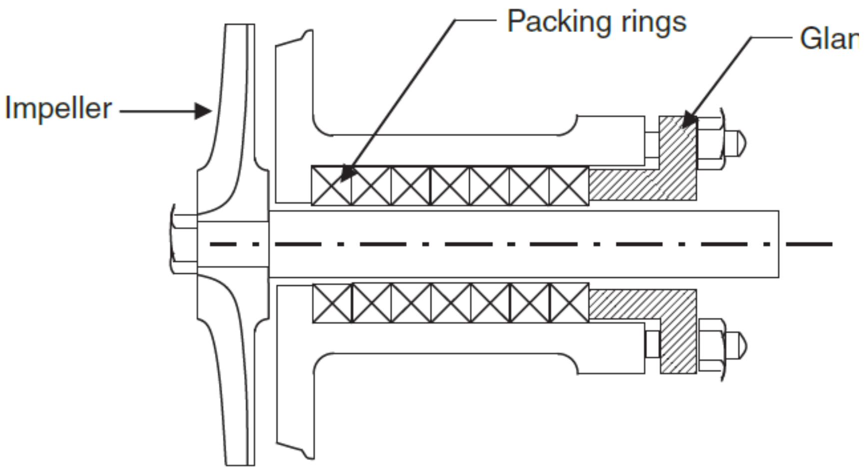
The main components inside the pump





9. **Wearing rings** are commonly used for reducing internal fluid leakage from the high-pressure side (volute casing) to the low-pressure side (suction nozzle).

The main components inside the pump

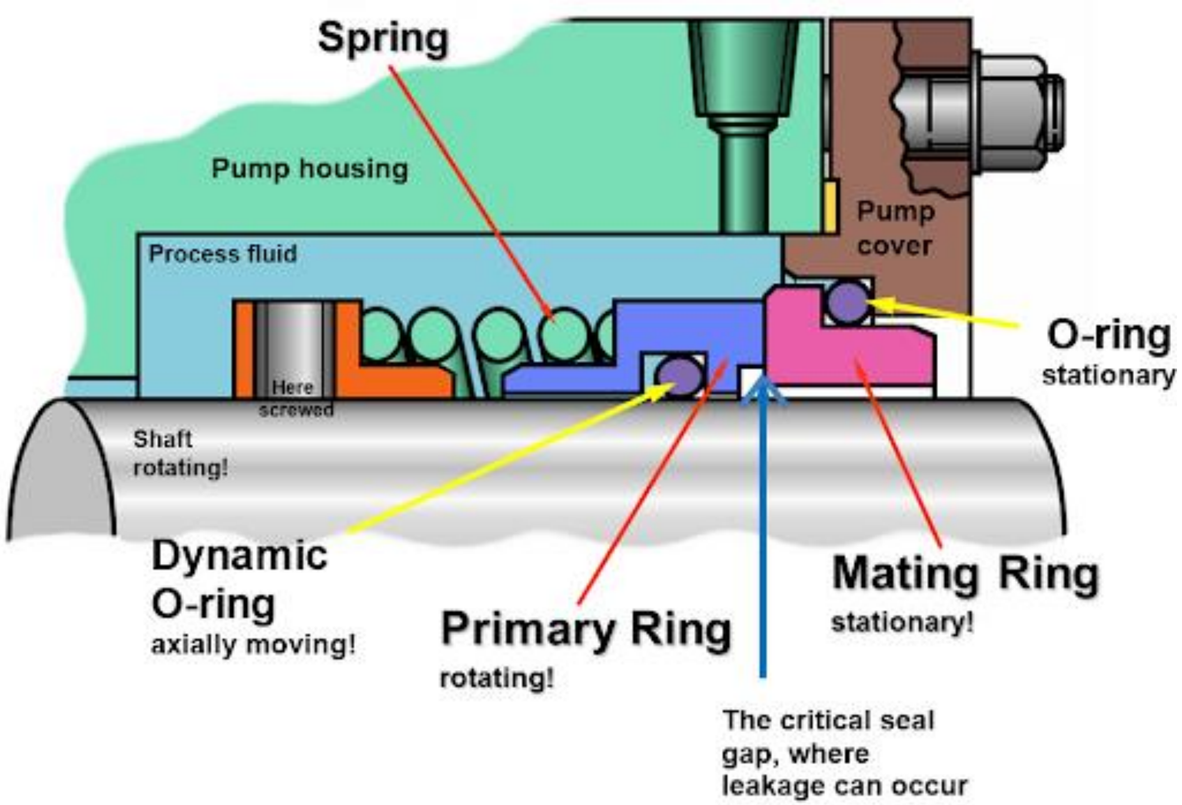


10. The seals are very important for every pump since they prevent the pumped fluid from leaking out of the pump.

- The type of seal depends on the pumped fluid.
- For example, a stuffing box with compression packing is commonly used in water pumps.
- while mechanical seals are widely used in pumps handling toxic or flammable liquids, in order to avoid fire and environmental hazards.

What is mechanical seal?

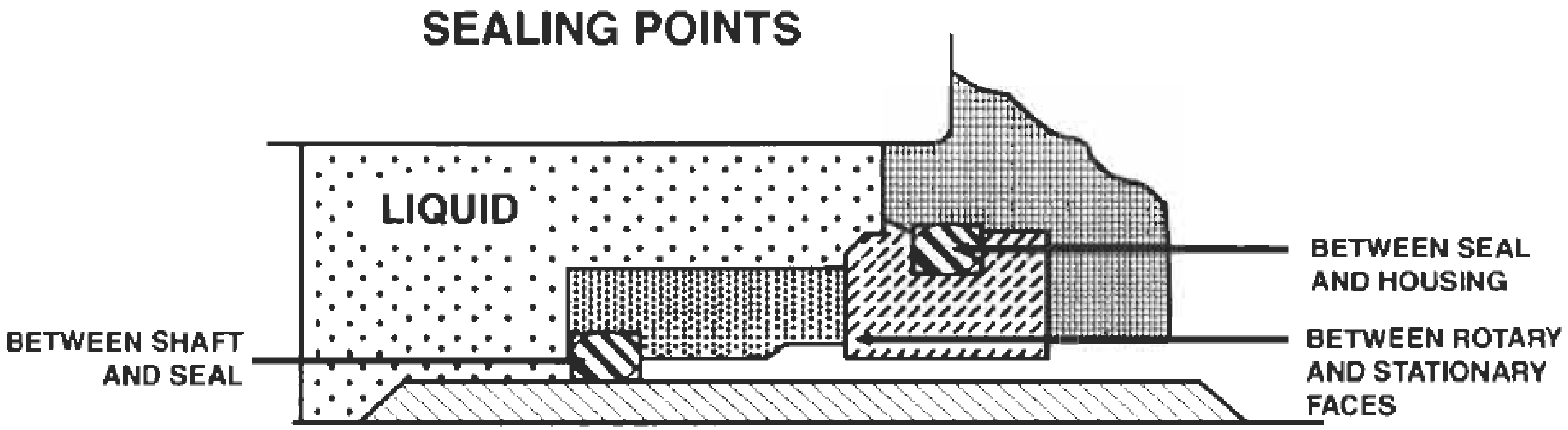
- It is a device that forms a barrier between rotary and stationary parts in the pump. The common parts in all seals are:
    1. Stationary Face.
    2. Rotary Face.
    3. O-rings.
    4. Spring.
    5. Set Screw.



What is mechanical seal?

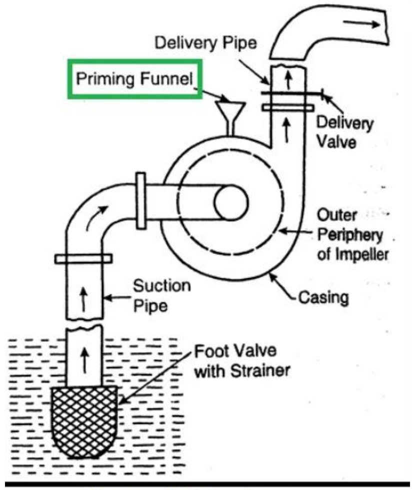
The seal must block leakage at three points:

- Between the faces (rotary and stationary) of the seal.
- Between the stationary element and the seal chamber housing of the pump.
- Between the rotary element and the shaft.

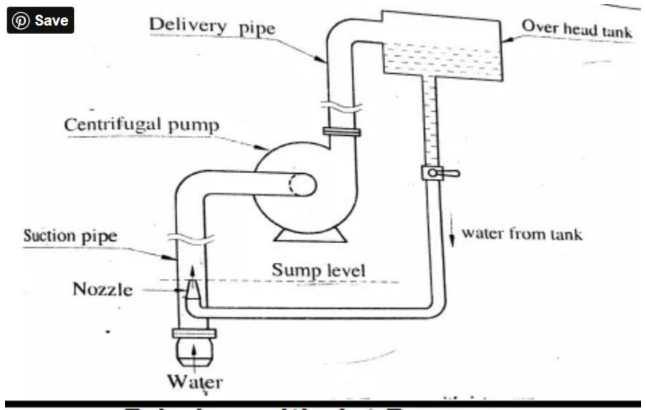


What is mechanical seal?

- The **set screw** is connected to the rotary face through the spring. It also provides for the positive and correct positioning of all rotary parts.
- As the faces wear, the **spring** extends maintaining the rotary face in contact with the stationary face.
- The liquid’s pressure in the seal chamber holds the faces together and also provides a thin film of lubrication between the faces. This lubricant is the pumped product.



Manual Priming

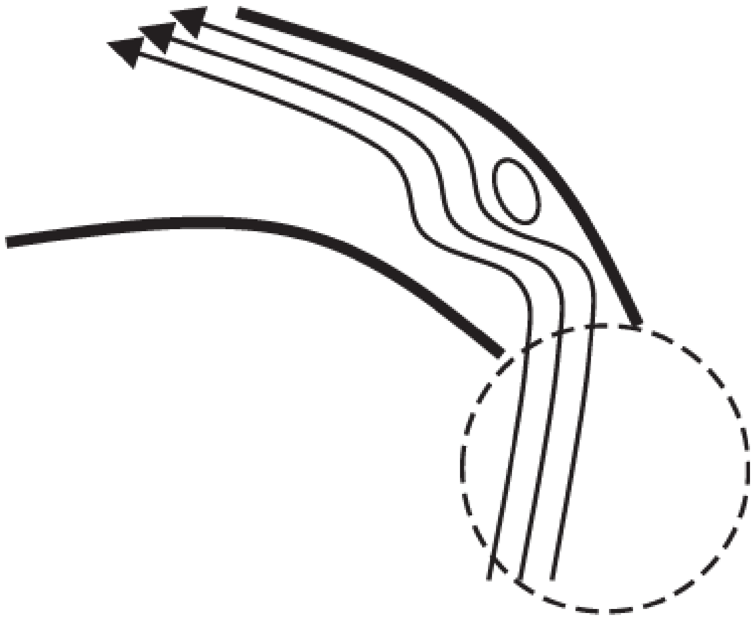


Priming with Jet Pump

Pump Priming

- Pump Priming is the process of removing air from the pump and suction line.
- Priming reduces the risk of pump damage during start-up as it prevents the pump impeller to becomes gas-bound and thus incapable of pumping the desired liquid.
- The pump would not function properly when not completely filled with liquid. Along with compromised performance, not priming the pump and allowed to run without fluid, it will **overheat** the pump system and there will be a danger of damage to critical internal pump components.

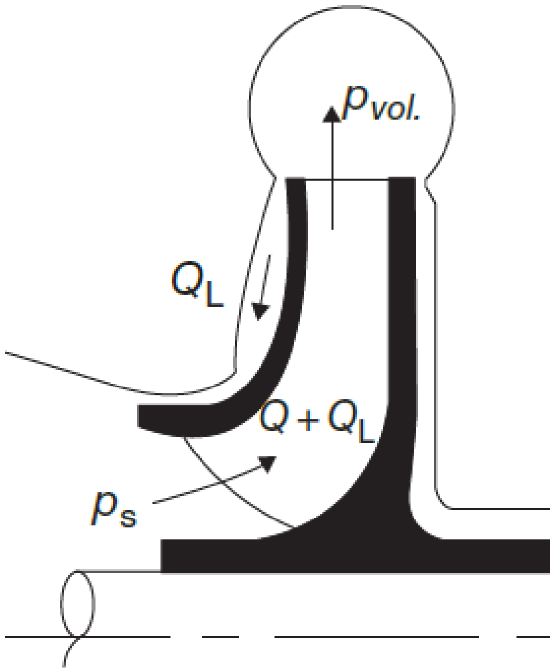
What are the types of Losses on Pump?



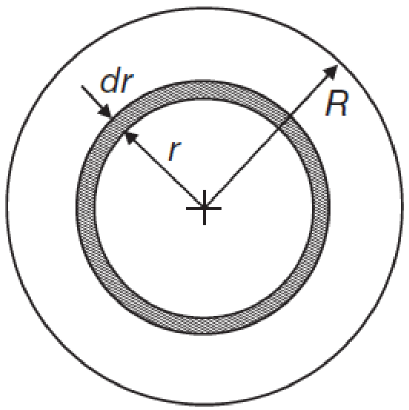
- **Hydraulic loss** is defined as the loss of head between the suction and delivery nozzles of the pump. The loss of energy due to these hydraulic losses has a direct effect on the pump overall efficiency. Hydraulic losses can be divided into:
  1. **Friction losses:** occur in various flow passages of the pump including:
     a) The suction nozzle,.
     b) The impeller flow passages
     c) The volute casing.
     d) The discharge nozzle.
  2. **Shock losses:** if the pump operates away from the operating point, the direction of flow relative velocity at vane inlet is not tangential to the vane.

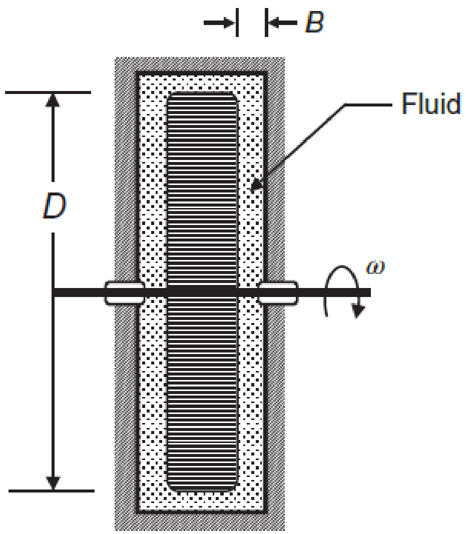
What are the types of Losses on Pump?

- **Leakage Losses:** represent the loss of energy due to the fluid leaking from the high-pressure side of the impeller to the low-pressure side:
  - Through the clearance space between the impeller and the casing
  - Through balancing chambers or the sealing system.
- Erosion (or erosion/ corrosion) causes an increase in the clearance space between the wearing rings, resulting in higher leakage.
- Replacing or maintenance of the wearing rings is essential for reducing leakage losses.



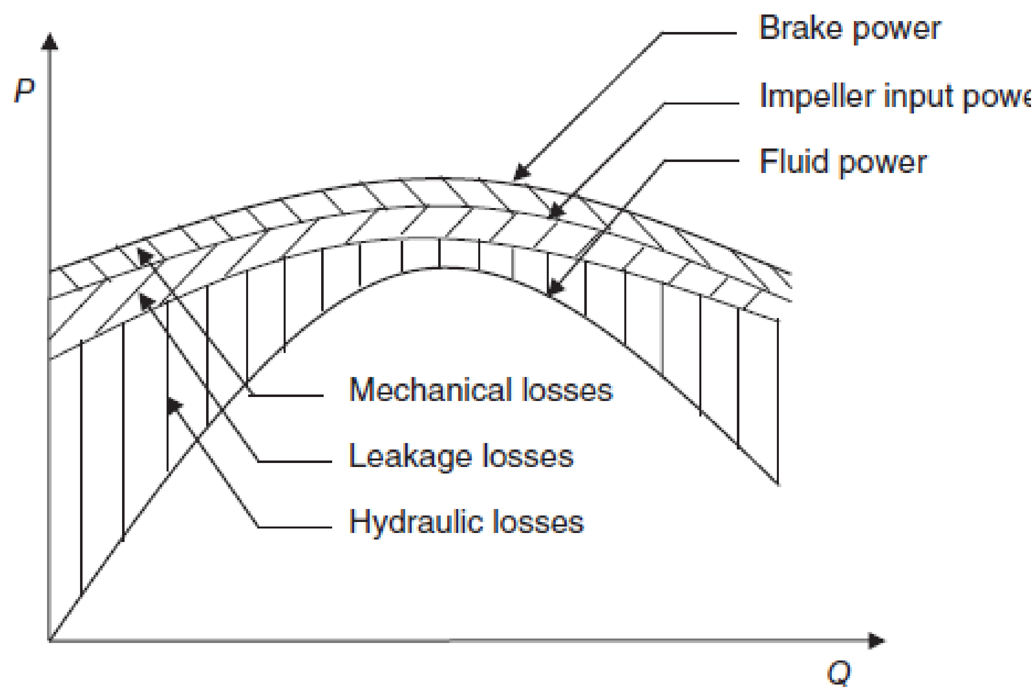
What are the types of Losses on Pump?





- **Mechanical Losses:** represent the loss of power due to friction:
  - In the bearings.
  - In the sealing systems.
  - In the fluid friction between the impeller and the casing.

What are the types of Losses on Pump?

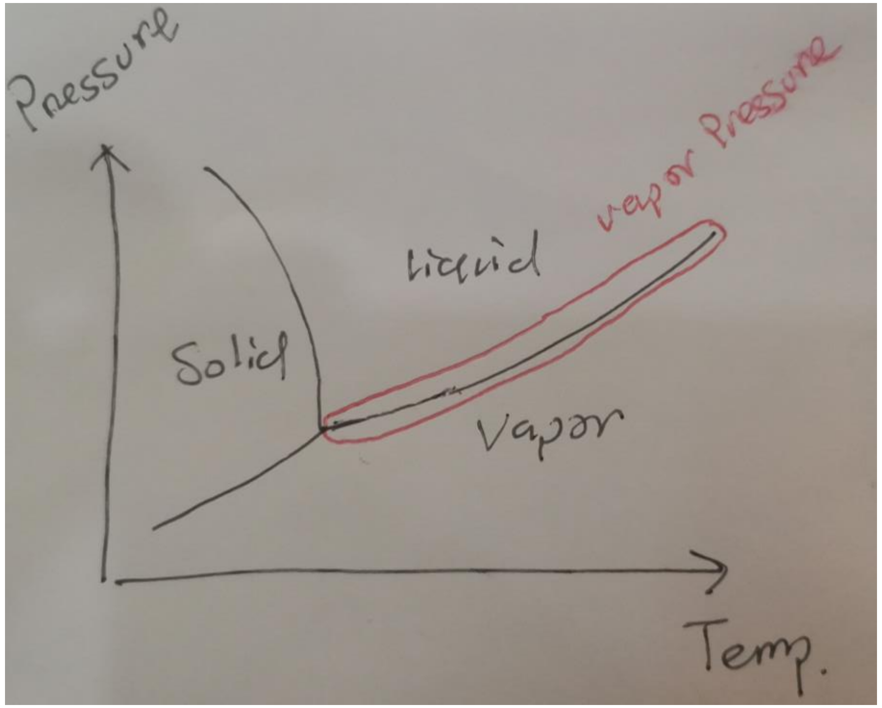


$$P_{in} = B.P. = P_{mech.} + P_L + P_{hyd.} + P_{out}$$

$$P_{in} = \frac{\gamma(Q+Q_L)H_i}{\eta_{mech.}} = \underbrace{B.P.(1-\eta_{mech.}) + \gamma Q_L H_i + P_{hyd.}}_{\text{Loss}} + \underbrace{\gamma Q H}_{\text{out}}$$

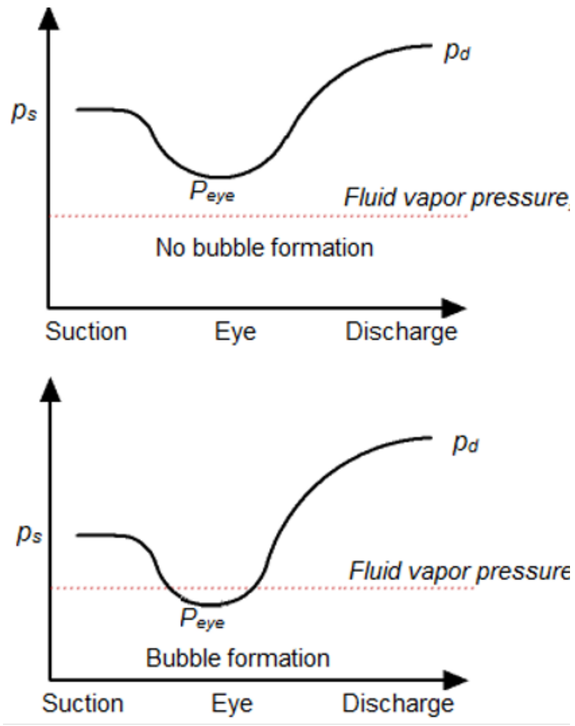
What is vapor pressure?

- The vapor pressure is a property of a substance.
- The fluid's vapor pressure is the pressure at which the liquid vaporizes at a specific temperature.
- As the temperature of a liquid increases, the vapor pressure increases.
- Figure represents the phase diagram for Water.



What is NPSH?

- Intro: There will be a pressure drop that will occur to the fluid due to the following:
    1. The friction head loss in the suction nozzle.
    2. The local pressure drop inside the impeller.
    3. The change of the velocity head.
- **NPSH** is the energy/head that the fluid has before it enters to the pump (suction side).
- This energy/this head should be sufficient to avoid any bubble formation inside the pump. This is called **NPSHR.**
- Each system, meaning all pipe, tanks and connections on the suction side of the pump , will have its own NPSH. This is called **NPSHA**.



What are the major pump problems? How to solve each one?

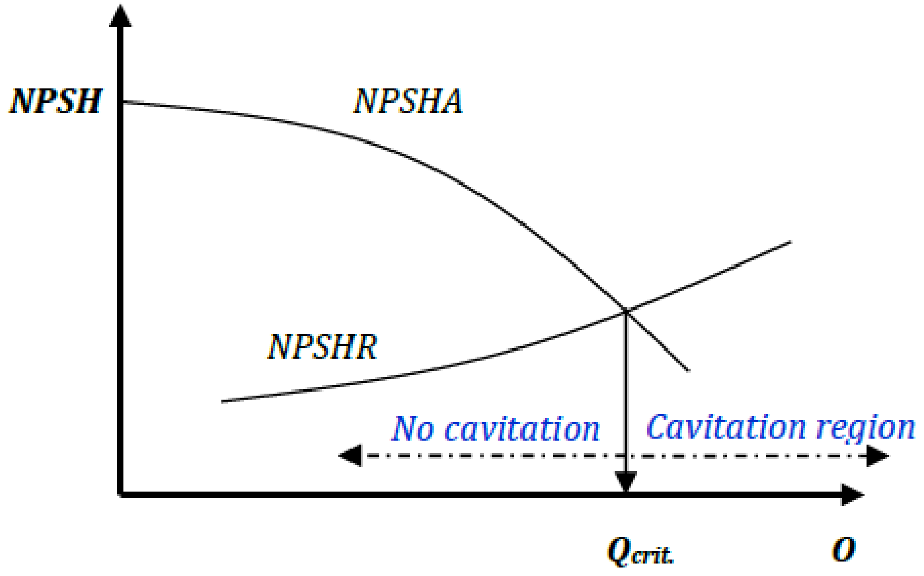
1) Cavitation.
2) Solid Particle Erosion.
3) Temperature Rise of Pumped Fluid.
4) Impeller Recirculation.
5) Increase in the unbalanced axial and radial thrusts.
6) Pump Vibration.

1.Cavitation

- **Cavitation** is bubble formation occurring inside the pump due to the pressure drop below the fluid vapor pressure.
- When the fluid pressure increases, the bubbles collapses resulting cavitation erosion on the pump components.

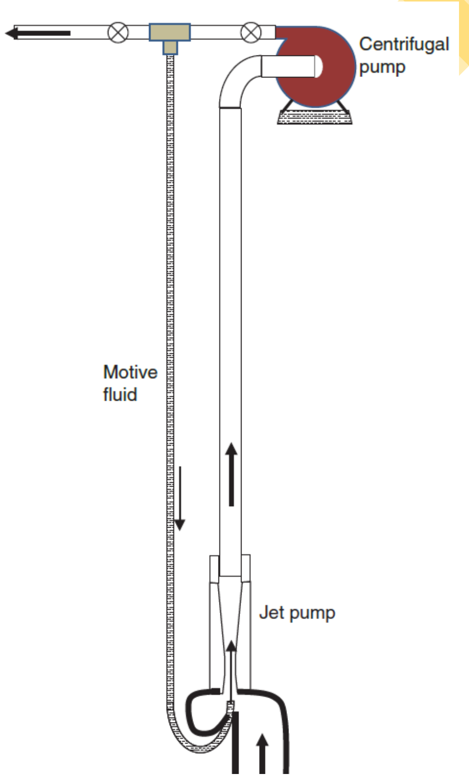
1. Cavitation

- The cavitation depend on:
  1. Flow Rate (Why? By equations)
  2. Th elevation of the pump from the tank (suction lift).



How to prevent cavitation?

1. Install the pump as close as possible to the suction reservoir - reduce the **suction lift**.
2. Use large **diameter pipes** in the suction side – reduce head losses.
3. Reduce the **number of fittings** (such as bends, elbows, valves) in the suction side to a minimum – reduce head losses.
4. Reduce **surface roughness** for all inner surfaces of pump components – reduce head losses.
5. Avoid operating the pump much lower or much higher than **its rated capacity**.
6. Reduce **vibrations** as much as possible.
7. The **jet pump** is used for increasing NPSHA. The jet pump utilizes part of the pumped fluid as a motive fluid for the jet pump.



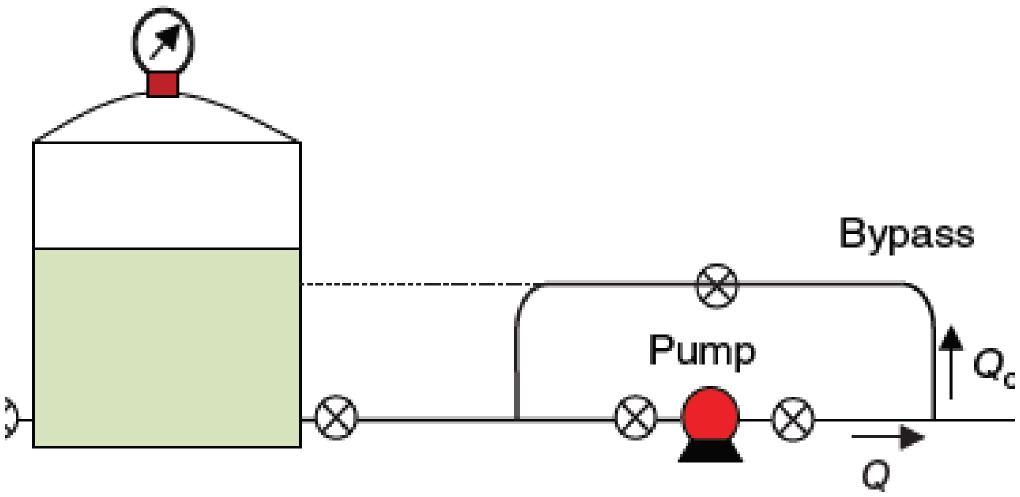
$$NPSHA = \frac{p_{atm}}{\gamma} + (z_a - z_{sn}) - h_{Ls} - \frac{p_v}{\gamma}$$

$$\sum h_L = \frac{f_s L_s V_s^2}{2gD_s} + \frac{f_d L_d V_d^2}{2gD_d} + \sum K \frac{V^2}{2g}$$

2. Solid Particle Erosion

- Erosion caused by the presence of solid particles in the pumped fluid is one of the major sources of surface damage to the impeller and casing materials.
- This damage tends to reduce the overall pump efficiency due to the increase in hydraulic losses (because of the increase of surface roughness) and increase the rate of fluid leakage (due to the increase in the gap between the wearing rings).
- One example is the pumping of **sea water** for cooling purposes.

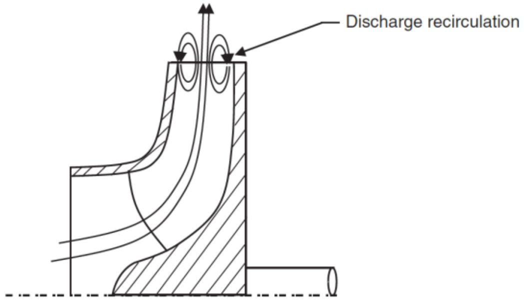
3. Temperature Rise of Pumped Fluid

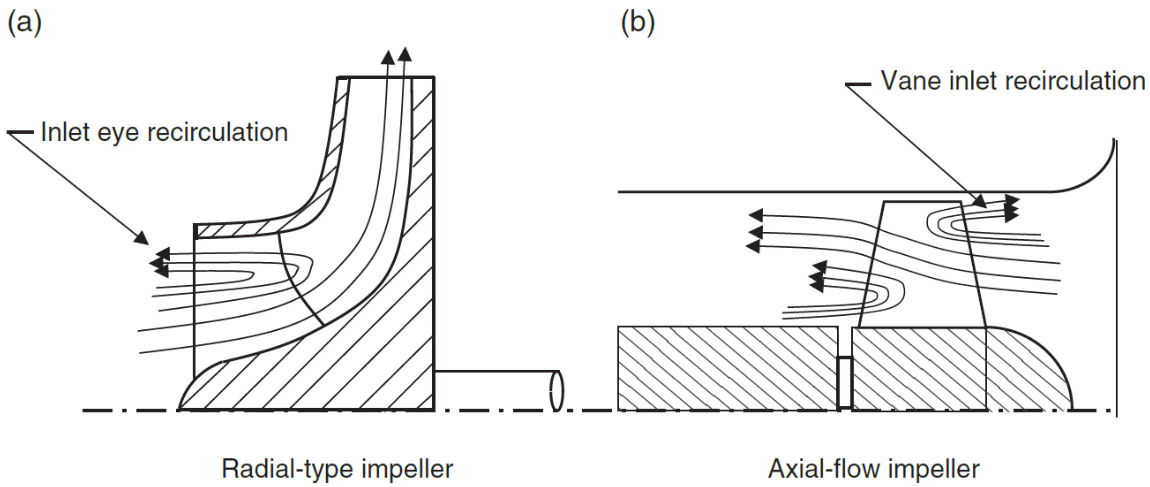


- The fluid temperature increases due to the power losses, when pumps are operated at low capacities either
  1. Using the delivery valve for controlling the flow rate.
  2. Using a bypass.
- It is recommended to have the bypass flow returned to the suction vessel rather than to the suction pipe. This will lead to a smaller increase in the fluid temperature.

4. **Impeller Recirculation** due to the Operation at Other Than the Normal Capacity

- Impeller internal recirculation is a phenomenon that takes place at the impeller inlet eye or exit section **at low flow rates.**
- This internal recirculation leads to cavitation which is completely independent of *NPSHA*.

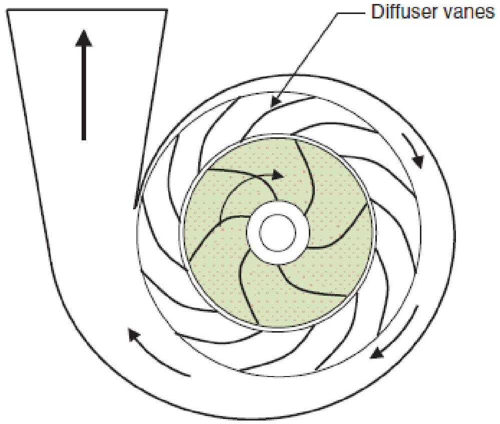


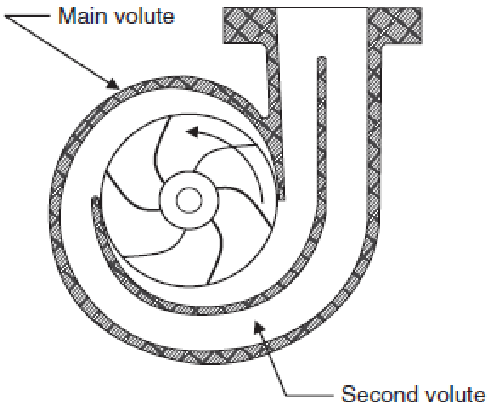


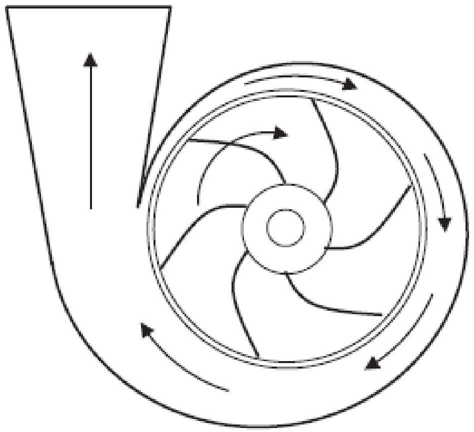
5. **Increase in the unbalanced axial and radial thrusts** due to Operation at Other Than the Normal Capacity

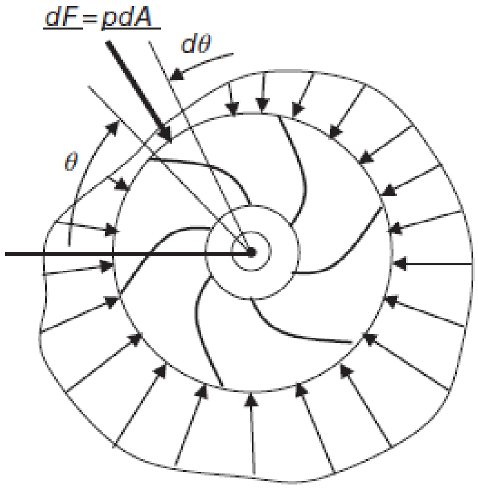
Radial Loads

- While the fluid pass through the volute, there will radial load generated.
- The solutions are:
  - Use of **Diffuser Vanes** (Reduces the radial load only at the design point).
  - Use of **Double-Volute Casing** (Reduces the radial load at any capacity).



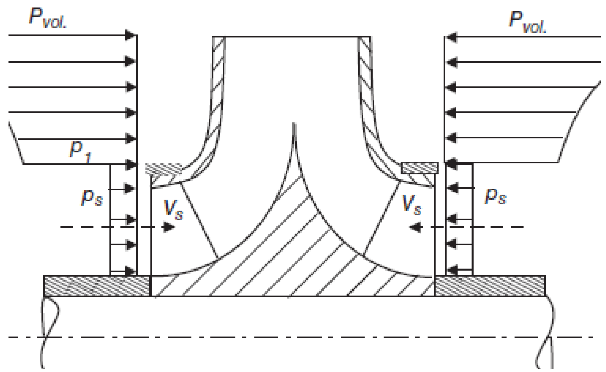


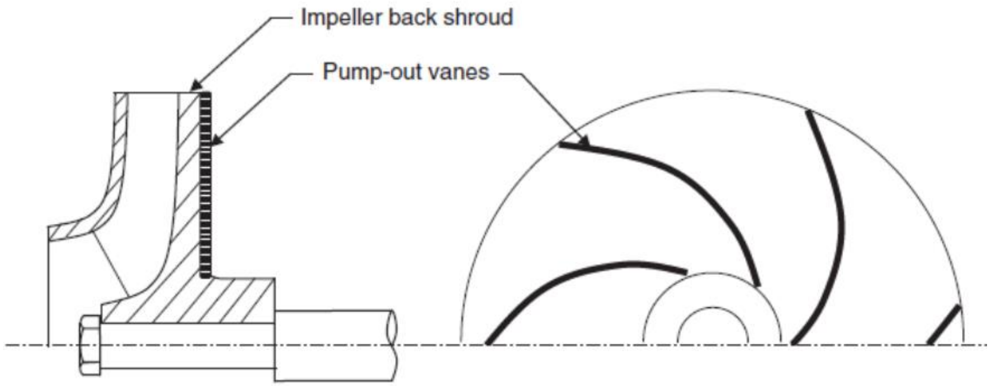


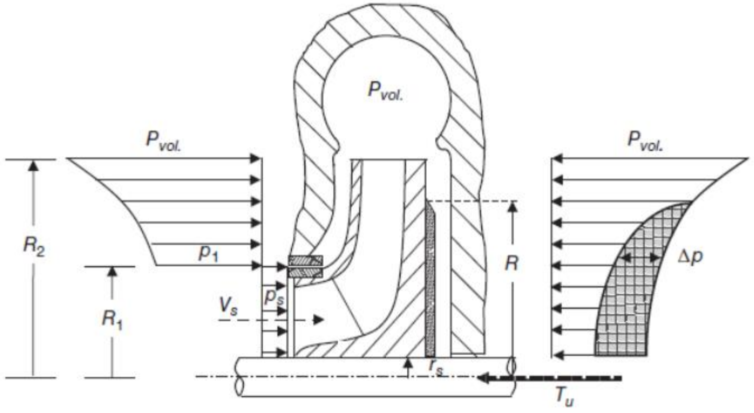


Axial Loads

- The axial load is the resultant of forces on pump impeller due to pressure differential inside the pump between the low-pressure side (suction side) and the high-pressure side (discharge side).
- The solutions are:
    1. **Thrust bearing**.
    2. **Pump-out Vanes:** The pressure reduction is mainly due to the increase of speed of rotation of the fluid entrained in the clearance space between the impeller and casing.
    3. **Double Suction Impellers**



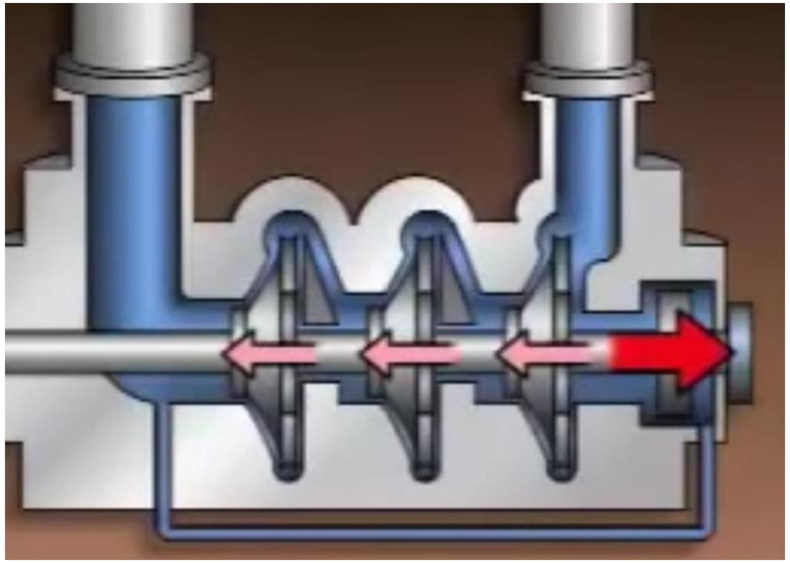


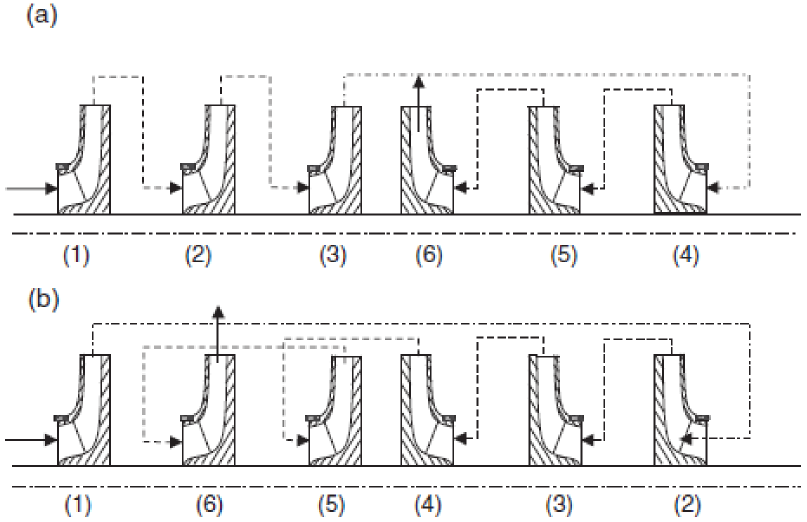


Axial Loads

The solutions are:

4. **Balancing Drum/Disk:** The area on the seal chamber side of the balance drum is subjected to the pump suction pressure. While the area on the impeller side of the balance drum is exposed to the high-pressure fluid in the pump. The difference in fluid pressure across the balance drum provides a force on the balance drum that is opposite to the direction of axial hydraulic thrust from the impellers.
5. **Opposed Impellers configuration.**





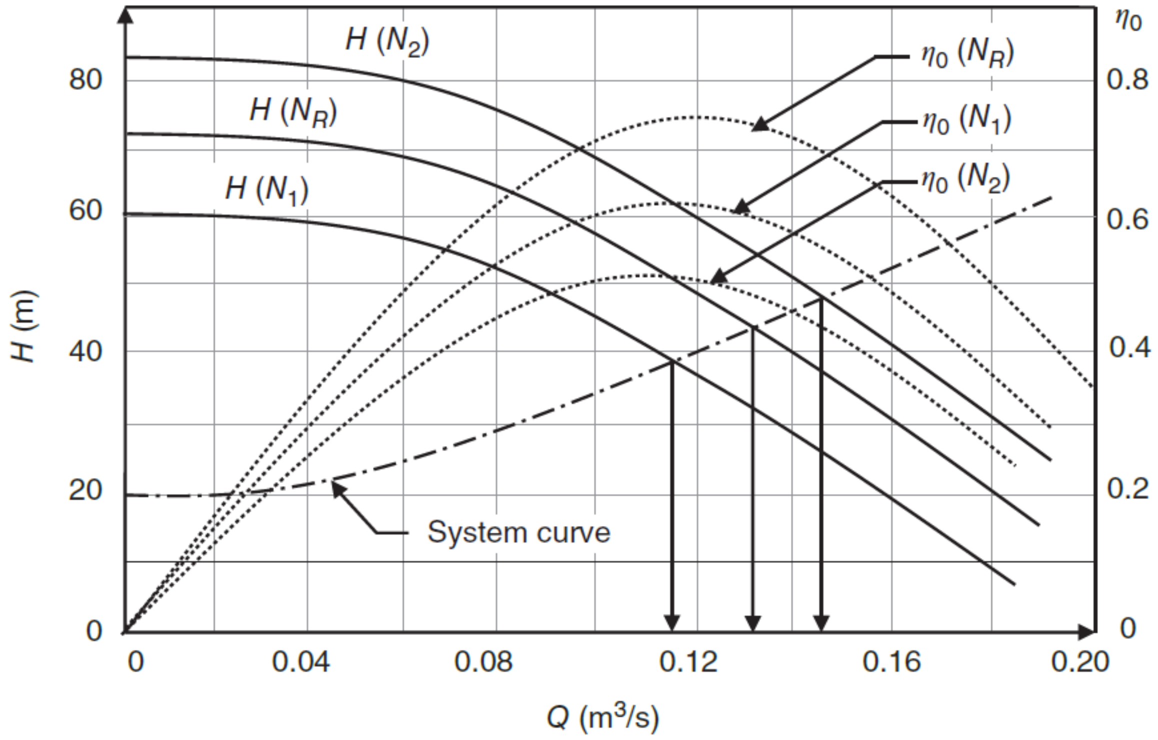
6. Pump Vibration - Major Pump Problems

1. Impeller unbalance due to **erosion/corrosion** of impeller material.
2. **Operation near shaft critical speed** (that is the theoretical angular velocity which excites the natural frequency of a shaft).
3. **Misalignment** of pump and driver shafts.
4. Faulty bearings (e.g. **worn bearings**).
5. Formation and implosion of vapor bubbles due to **cavitation**.
6. Pump operation away from its best efficiency point (BEP).
7. Vibrations from **nearby equipment**.

Flow Rate Control in Pumping Systems

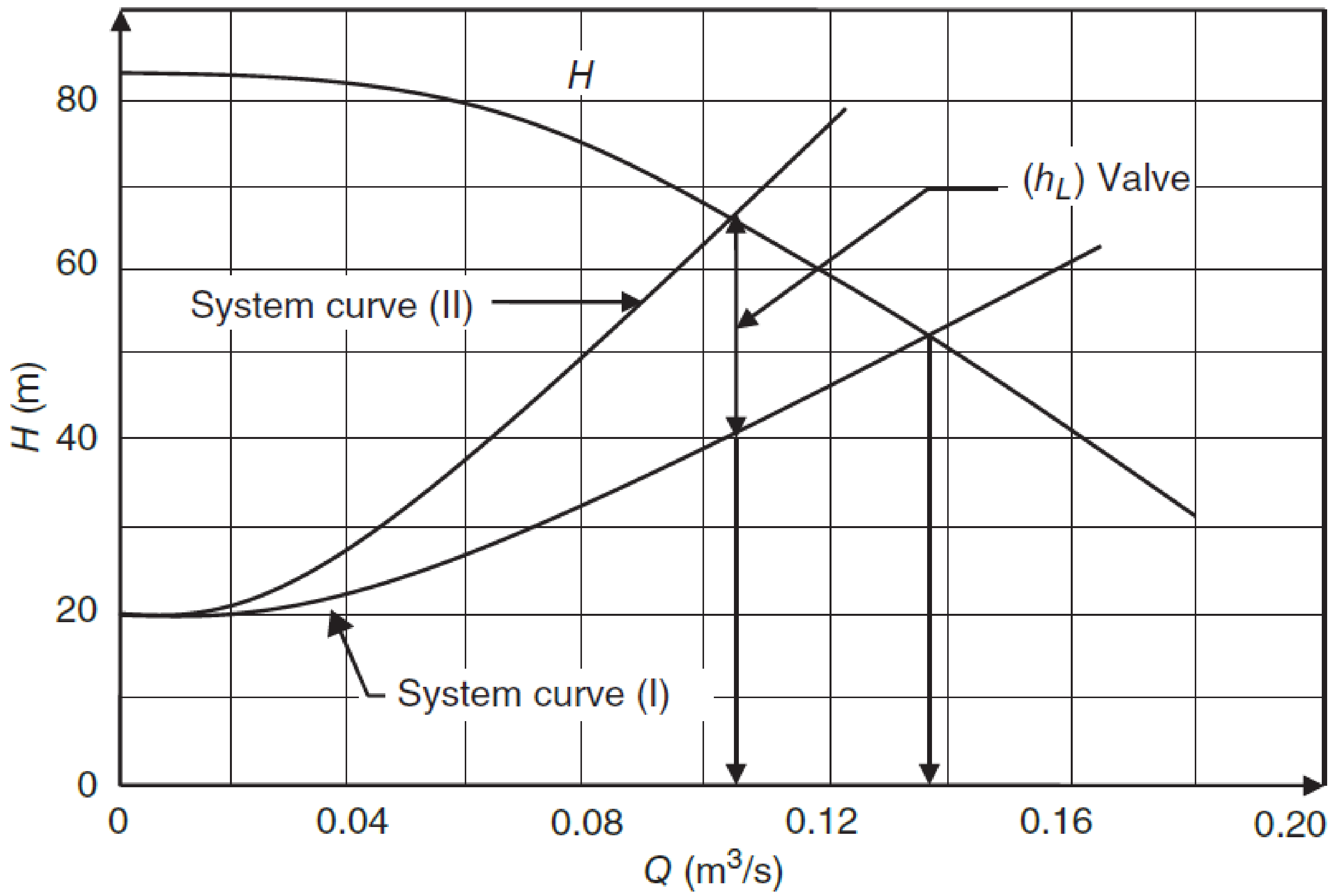
1. Speed control of the pump driver
2. Delivery valve throttling
3. Impeller trimming
4. Partial circulation of the outflow using a bypass
5. Operate the system using more than one pump
6. Use of a storage tank
7. Using Inlet Guide Vanes for Flow Rate Control

1. Speed Control of the Prime Mover



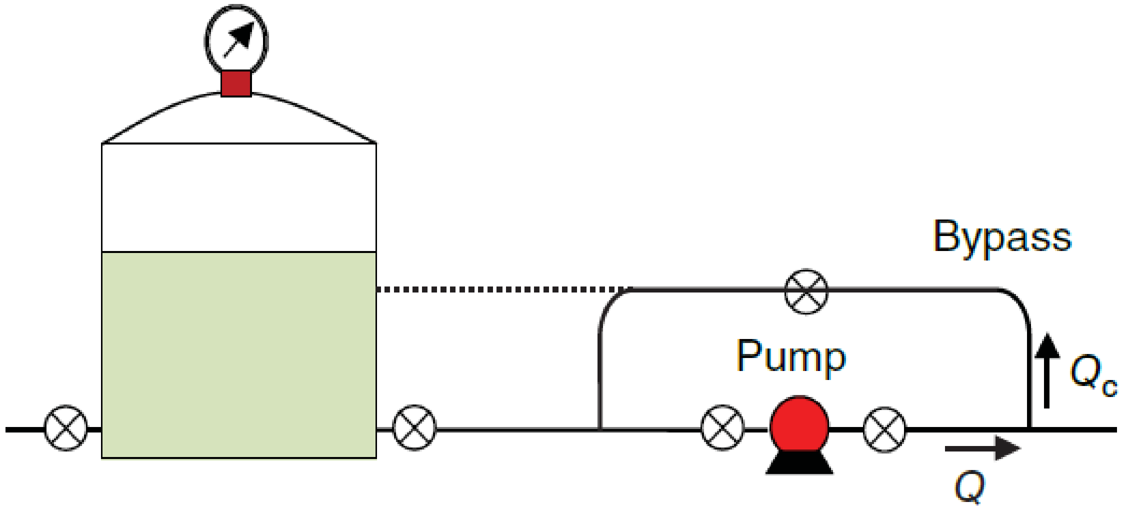
- The pumping system flow rate can be increased or decreased by driving the pump at a higher or a lower speed. However, operating the pump at speeds higher or lower than its rated speed will result in less overall efficiency.
- Moreover, electric motors with speed control are more expensive.

2. Delivery Valve Throttling



- The system flow rate can be reduced by partial closure of the delivery valve.
- Although this is the cheapest and most common method for flow rate control, it is accompanied by a large amount of energy loss, which can be as high as 50% or more of the pump output power.

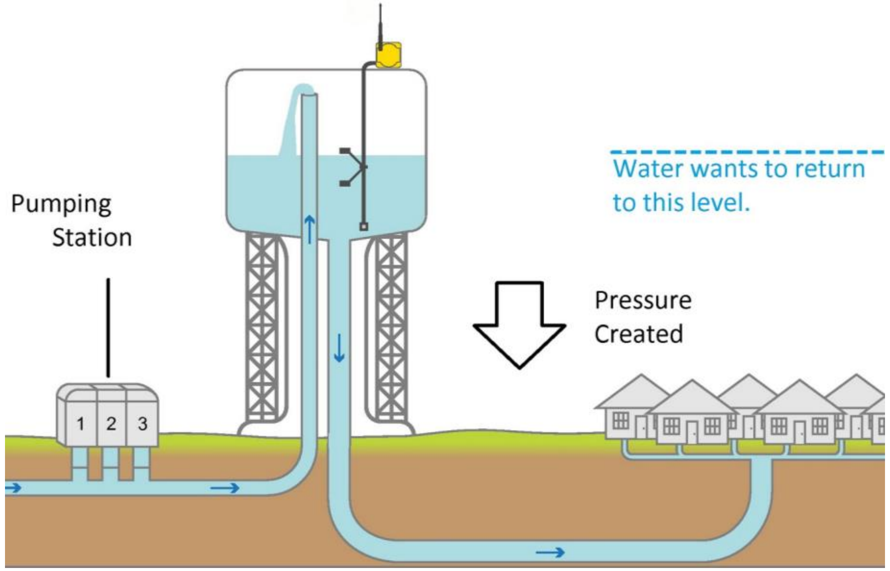
3. Using Bypass for Flow Rate Control



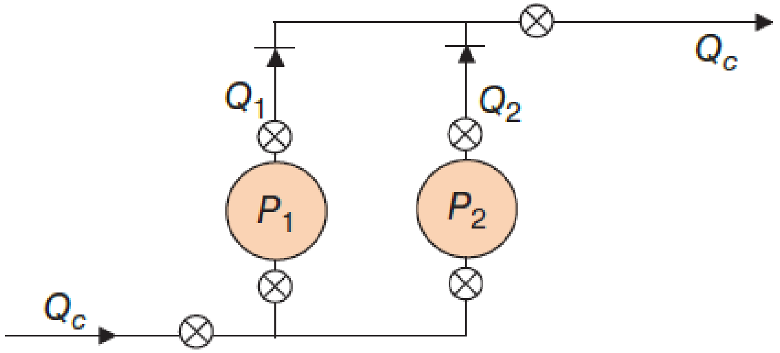
- In this method, part of the pump outflow is circulated back to the suction pipe or to the suction reservoir.
- The main advantages of this method are its low cost and simplicity.
- The disadvantages include:
    - The high-power loss in fluid friction.
    - The temperature increase of the circulated flow.

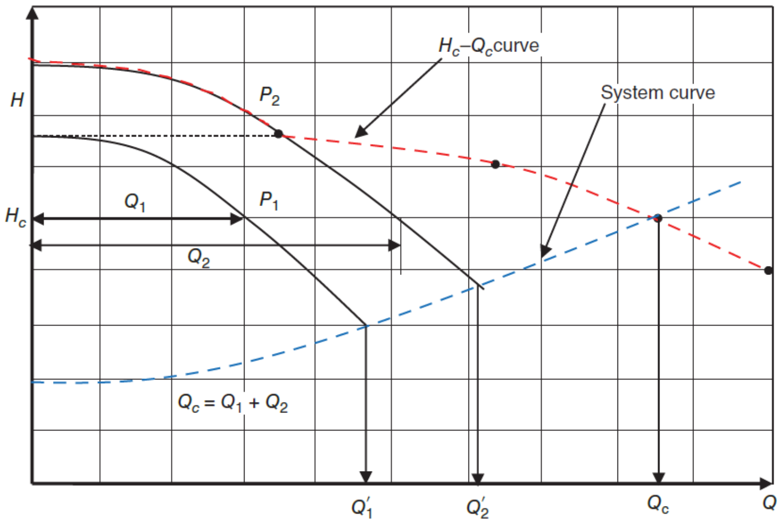
4. Use of a Storage Tank

- Sometimes the system demand temporarily exceeds the normal capacity of the pumping station (e.g. in a city water network). In this case, a water tower can be a good solution.
- Used for emergences.



5. Flow Rate Control by Operating Pumps in Parallel or in Series

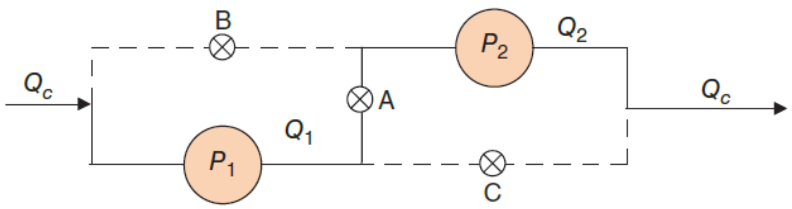


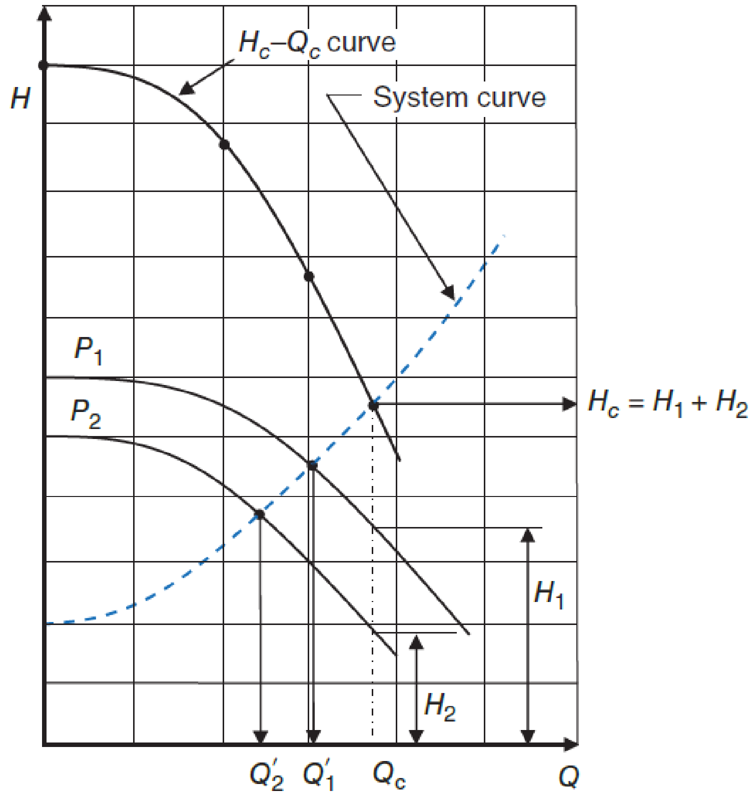


Pumps in series **vs** Pumps in parallel

Parallel Operation

- Identical or different pumps may be connected in parallel in order to **increase the volume flow rate** through a piping system.
- Qc =Q1 +Q2 (Theoretically)
- Hc =H1 =H2
- The system is analogous to the operation of two batteries connected in parallel. The flow rate is similar to the current and the total head developed is similar to the potential difference.





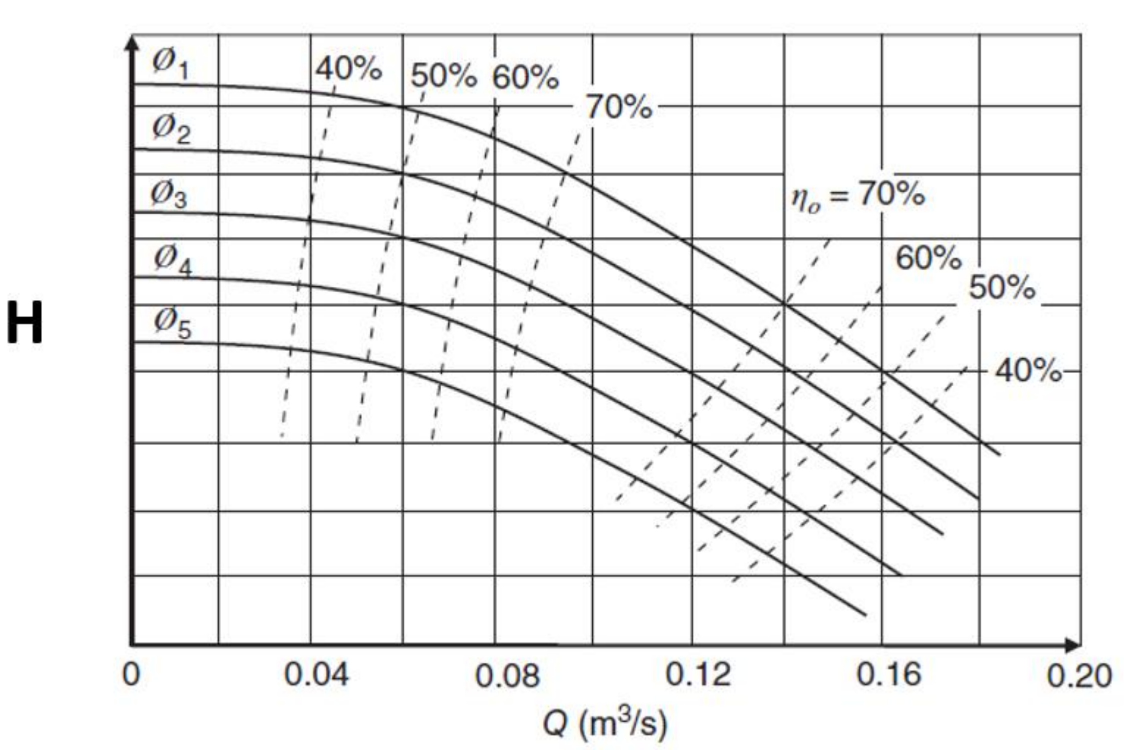
Pumps in series **vs** Pumps in parallel

Series Operation

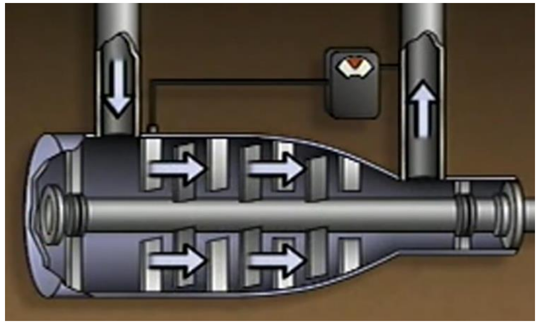
- Consider the two different pumps P1 and P2 connected in series, as shown in the figure. The combined H–Q curve (Hc–Qc) for the two pumps can be plotted using the equations
- Qc =Q1 =Q2
- Hc =H1 +H2 (Theoretically)

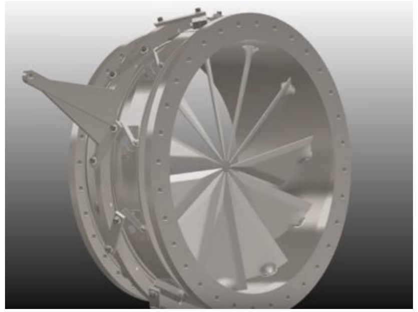
6. Impeller Trimming

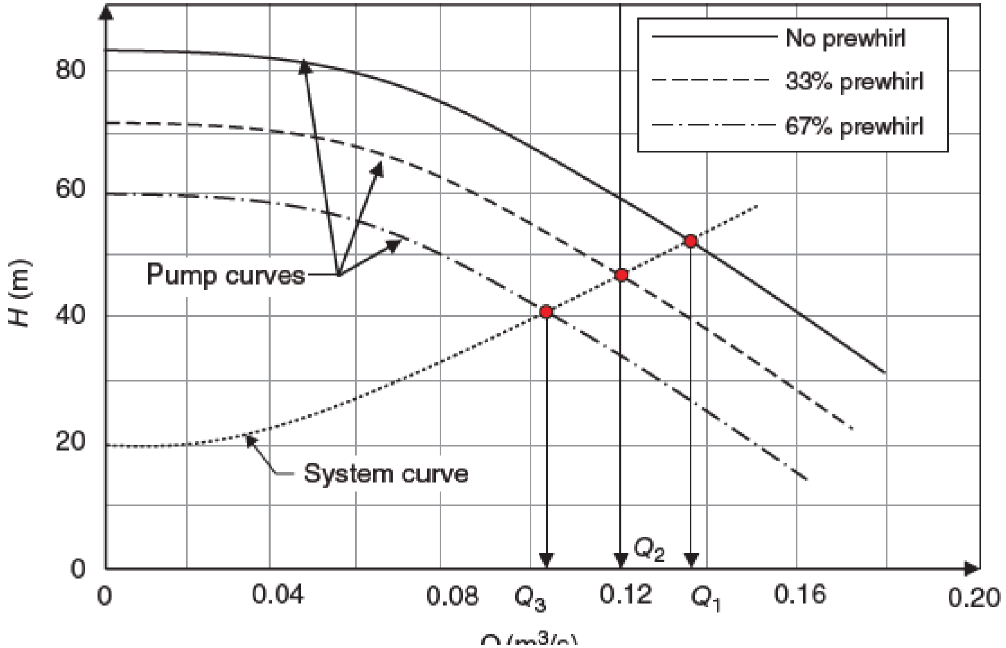
- In this method, the impeller outer diameter is reduced by **machining** in order to **decrease the pump flow rate** when operating in a given system. The amount of reduction in the impeller diameter is normally small (10–20%) and should not affect the hydraulic performance of other parts.



φ1 > φ5





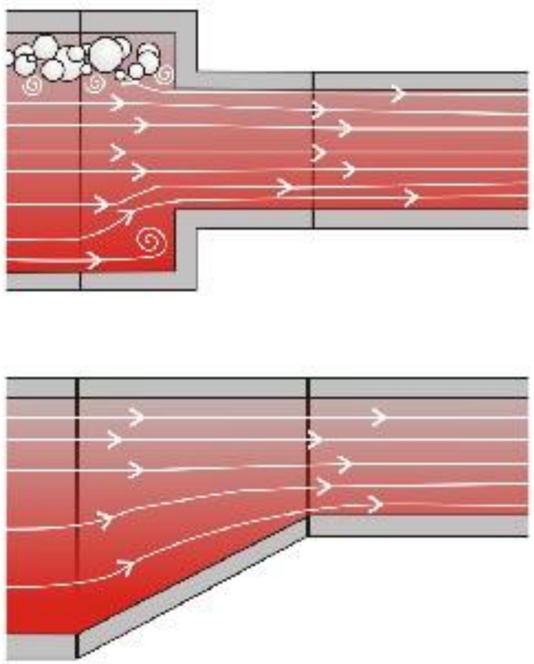


7. Using Inlet Guide Vanes for Flow Rate Control

- The use of inlet guide vanes for flow rate control is common in fans and compressors and also in axial flow pumps but less common in radial-type centrifugal pumps.
- The idea is to have a set of guide vanes upstream of the impeller (close to the impeller inlet) to create **prewhirl** before the vane inlet.

Why eccentric reducer is used at pump suction?

- **Eccentric reducer**. **Eccentric reducers** are **used** at the **suction** side of **pumps** to ensure air does not accumulate in the pipe. The gradual accumulation of air in a concentric **reducer** could result in a large bubble that could eventually cause the **pump** to stall or cause cavitation when drawn into the **pump**.



Eccentric reducers eliminate air/vapour pockets and minimize friction

Displacement Pumps

- In these pumps, energy is added to the fluid by the direct application of a force that moves the fluid from the low-pressure side (suction side) to the high-pressure side (delivery side).
- For applications in which a **small flow rate** is required to be supplied at **high pressure**, the use of displacement pumps becomes unavoidable.
- They also maintain sufficiently high efficiency when operating at flow rates lower or higher than their normal capacities.
- The specific speed range for displacement pumps (Ns < 500) is the lowest of all types of pumps because of the low flow rate and high head characteristics.

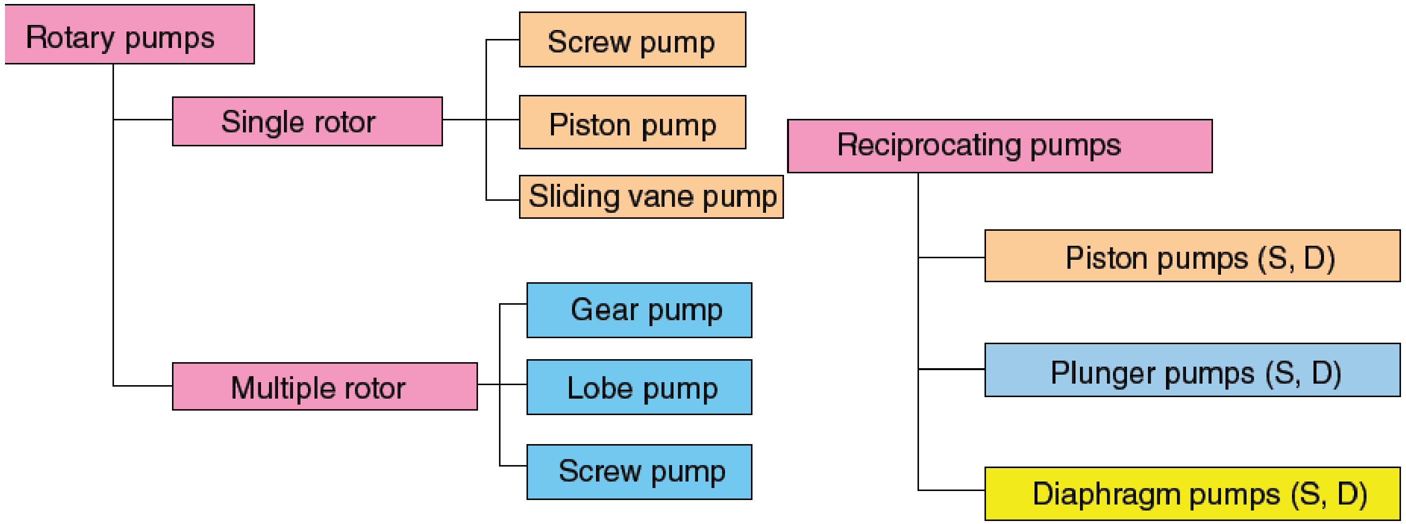
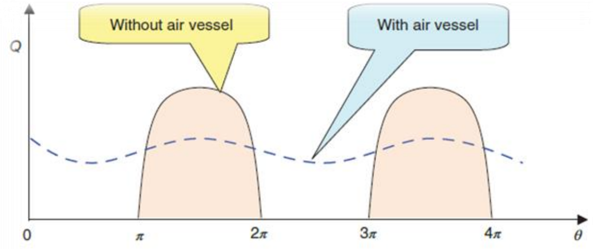
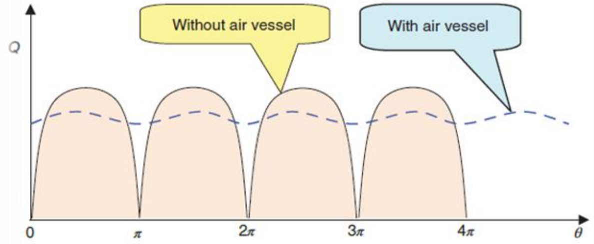


Figure 7.1 Classification of reciprocating and rotary displacement pumps

Reciprocating Pumps

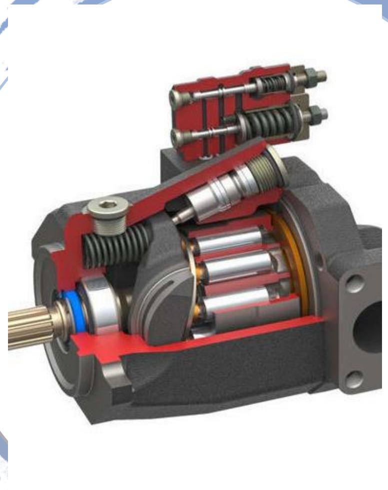


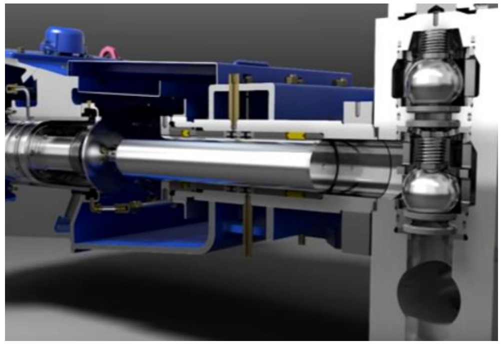
igure 7.11a Flow rate fluctuations for a single-cylinder single-acting piston pump.

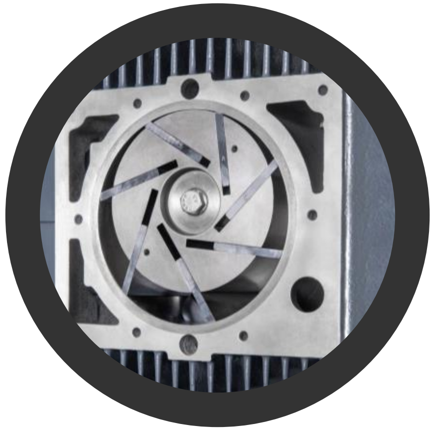


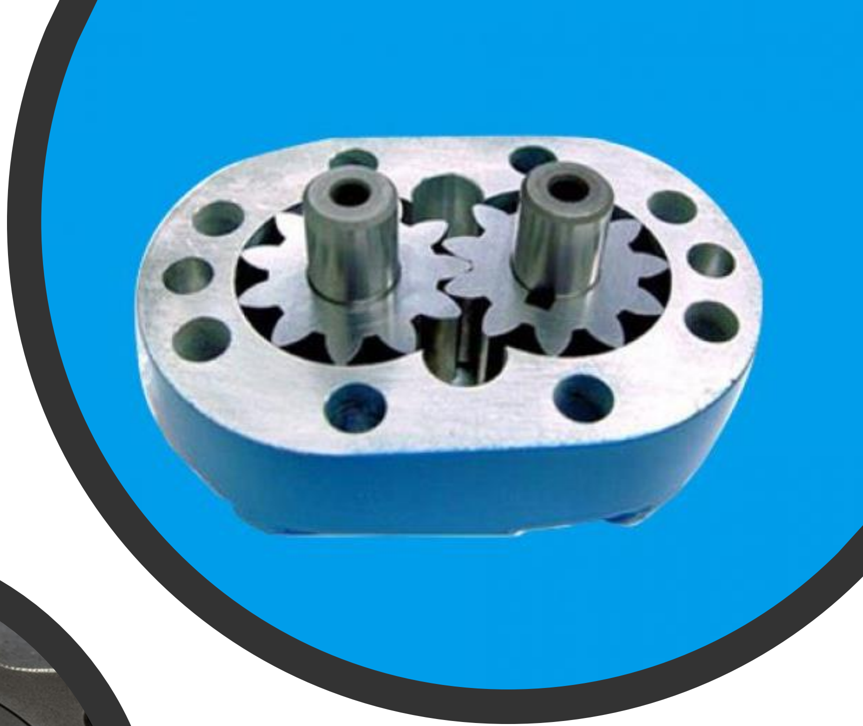
gure 7.11b Flow rate fluctuations for a single-cylinder double-acting piston pump

- These pumps are used in many industrial applications such as pumping heavy petroleum products in pipelines and chemical industries.
- **Diaphragm pumps** are operated either mechanically or pneumatically. They can handle highly viscous fluids, fluids with a high percentage of solid contents and corrosive or abrasive fluids (concrete, acids, and other chemicals).
- The flow delivered by a reciprocating pump is always **fluctuating** in a periodic fashion, thus creating pressure pulsation.



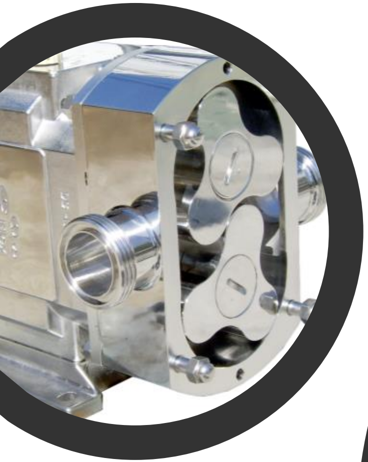


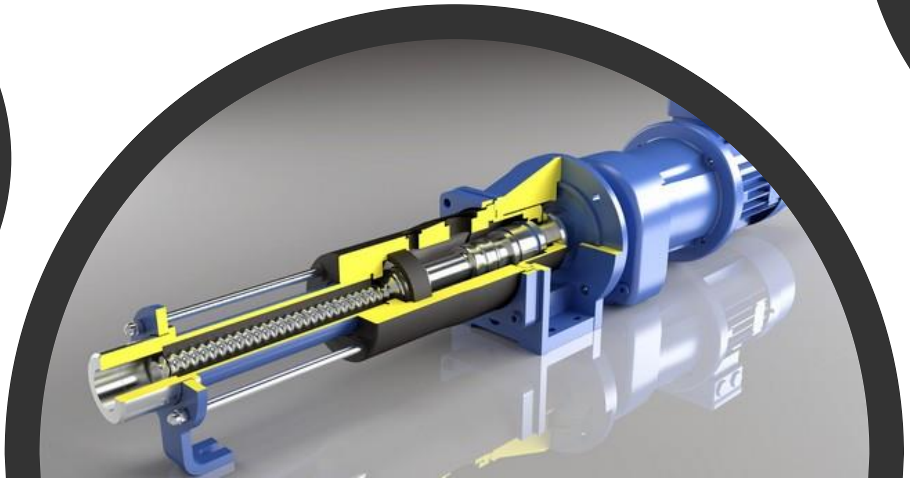




Rotary Pumps

- In comparison with reciprocating pumps, rotary pumps produce much less fluctuation in the flow rate, and they can operate at much higher speeds.
- Rotary pumps are also used as fluid meters since the volume of liquid supplied depends mainly on the number of revolutions of the driving shaft.





How can you select a pump?

TYPE OF PUMPED FLUID.

OPERATING CONDITIONS.

RELIABILITY AND MAINTAINABILITY.

INITIAL AND OPERATING COST.

Selection Based on Type of Pumped Fluid

The fluid properties of direct relevance to pump selection are the following:

1. Fluid viscosity and density
2. Fluid chemical activity (corrosiveness)
3. Flammability or toxicity of the pumped fluid
4. Presence of solid particles in the fluid (e.g. sea water, crude oil, etc.)
5. Presence of gas contents (e.g. natural gas in oil production facilities)
6. The fluid vapor pressure and its variation during normal operation.

Selection Based on Operating Condition

1. Location of the pump/pump station relative to the fluid in the suction reservoir.
2. Diameter, length, and surface roughness of all pipes
3. Type of all pipe fittings (valves, bends, filters, flowmeters, etc.)
4. Normal operating temperature of the pumped fluid.
5. Type and characteristics of the prime mover (simple induction motor, variable speed motor, diesel engine, steam turbine, etc.)
6. Methods of flow rate control (valve throttling, inlet guide vanes, speed of prime mover, etc.)
7. Mode of pumping system operation (continuous, intermittent, etc.)

Selection Based on Reliability and Maintainability

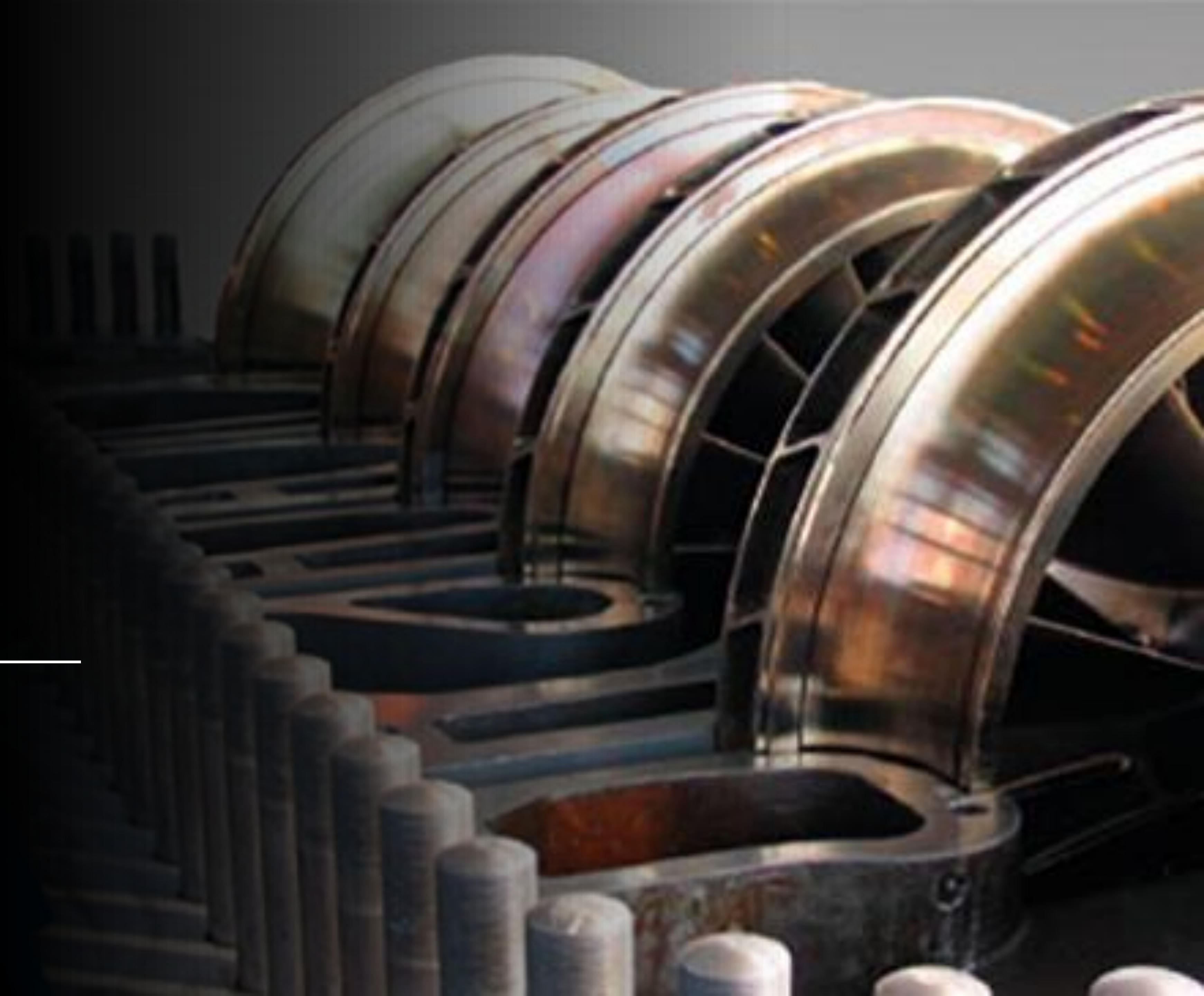
In some applications, the pump reliability becomes the most important factor in the pump selection process.

- Multistage submersible pumps
- The pumps used in aircrafts, rockets, and spacecraft

Selection Based on Initial and Operating Cost

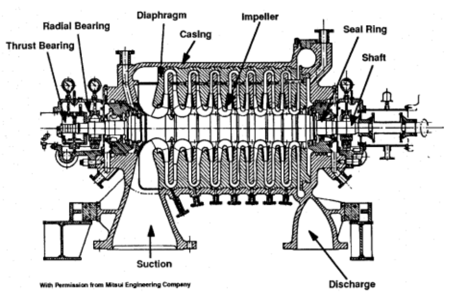
- The direct cost of operation per year depends on:
  - The initial cost of equipment and installation.
  - The cost of power.
  - The cost of maintenance.
  - The cost of labor including periodic technical inspection.

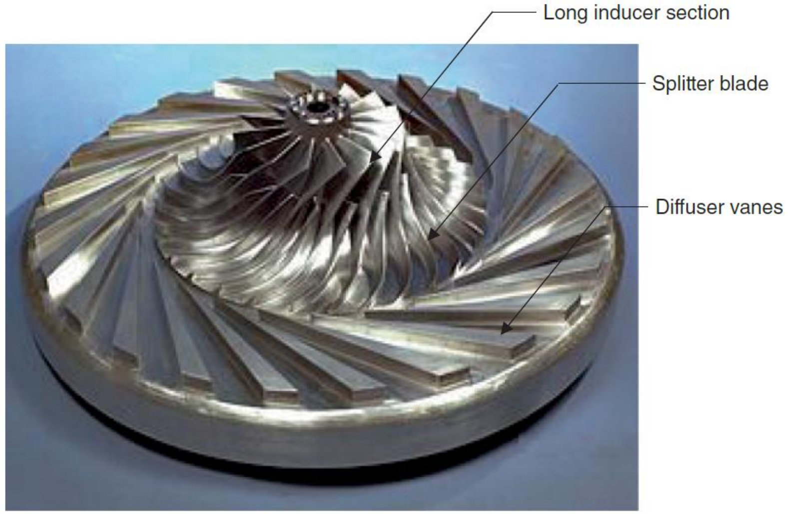
Compressors



What is the difference between the pump & compressor?

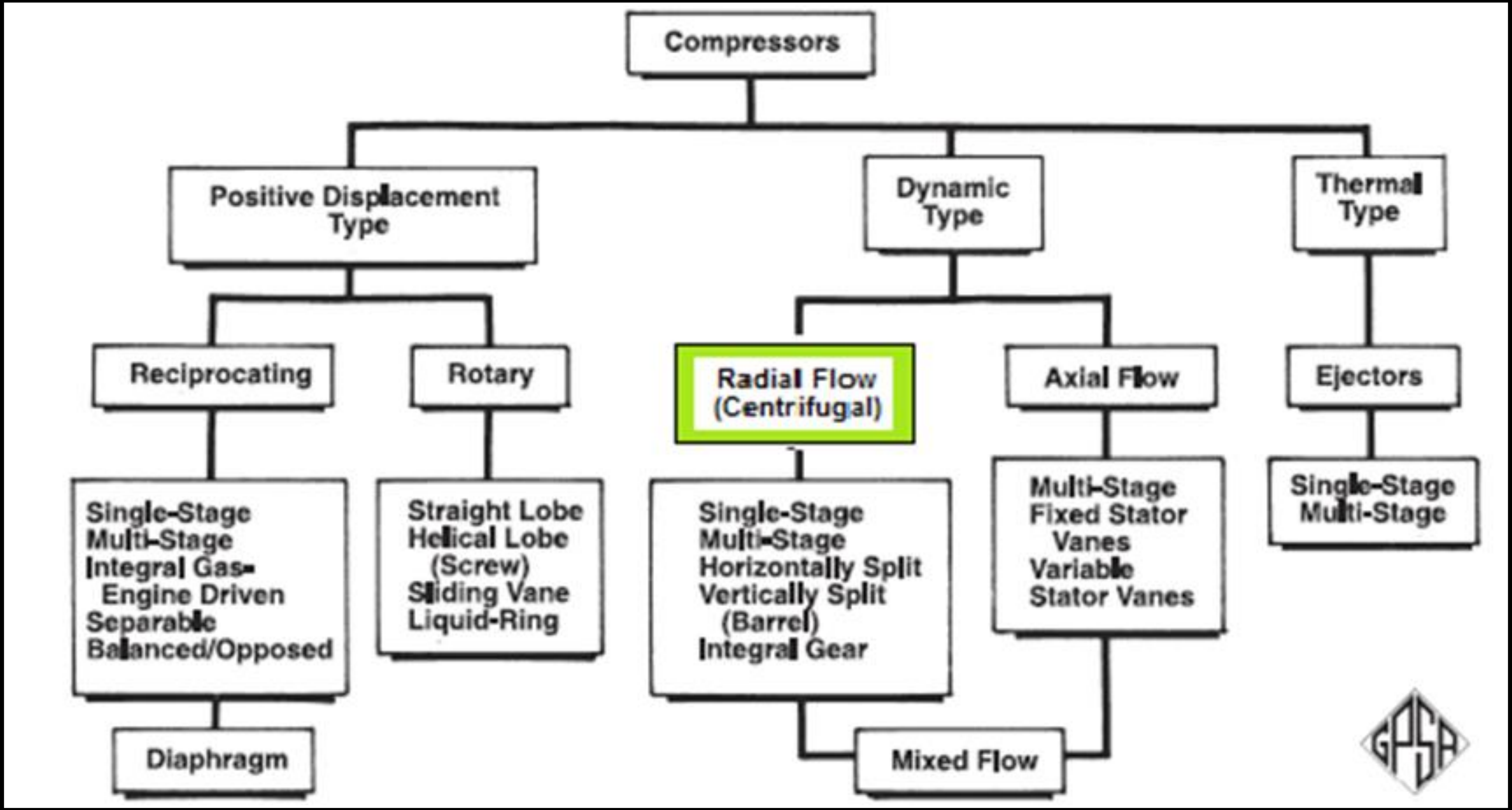
In term of	Pumps	Compressors
1. Solid Particles	Pumps can handle liquids that may contain some solid particles (such as river water, sea water, or crude oil).	Compressors are very sensitive to the presence of solid particles in the gas. Due to the high speeds inside the compressor, solid particles impacting the impeller vanes create severe erosion.
2. Thickness of the impeller vanes	Thick (because of the liquid density)	Thin (because of the gas density)
3. Speed Ranges	Low speed, example: 1600 RPM	High speed, example: 16,000 RPM
4. Sealing System	Packing Seal, Mechanical seal.	More advance sealing system such as oil lubricated seal, dry gas seal, and carbon ring seal. (because of the low gas viscosity)
5. Inducer in impeller?	No	Yes, used to reduce the hydraulic losses.
6. Temperature Change?	No	Yes (PV= mRT)
7. Cavitation	Liquids can cavitate and damage the pump internal parts.	Gases cannot cavitate.
8. Flow Type	Incompressible Flow	Compressible Flow
9. What happen in case of using different fluid?	A pump cannot compress a gas, the impeller will just spin in the air inside the pump housing.	A compressor cannot pump a liquid (it might, for a little while, but it would eventually fail).





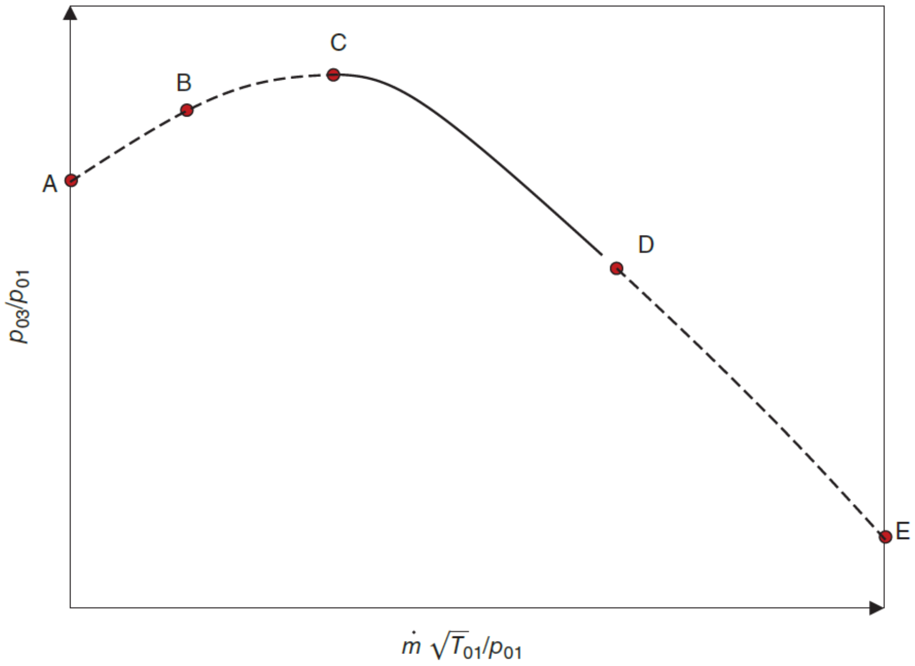
List the main components inside the compressor?

- The main components of the centrifugal compressor are much the same as those for a pump; however, the compressor impeller vanes have an **inducer** section.
- The main function of the inducer is to reduce the hydraulic losses (friction and shock losses).
- The figure shows a large number of vanes in comparison with a pump impeller. This is mainly to reduce the relative circulation in the channel between the vanes due to the high speed of rotation.



Types of Compressors

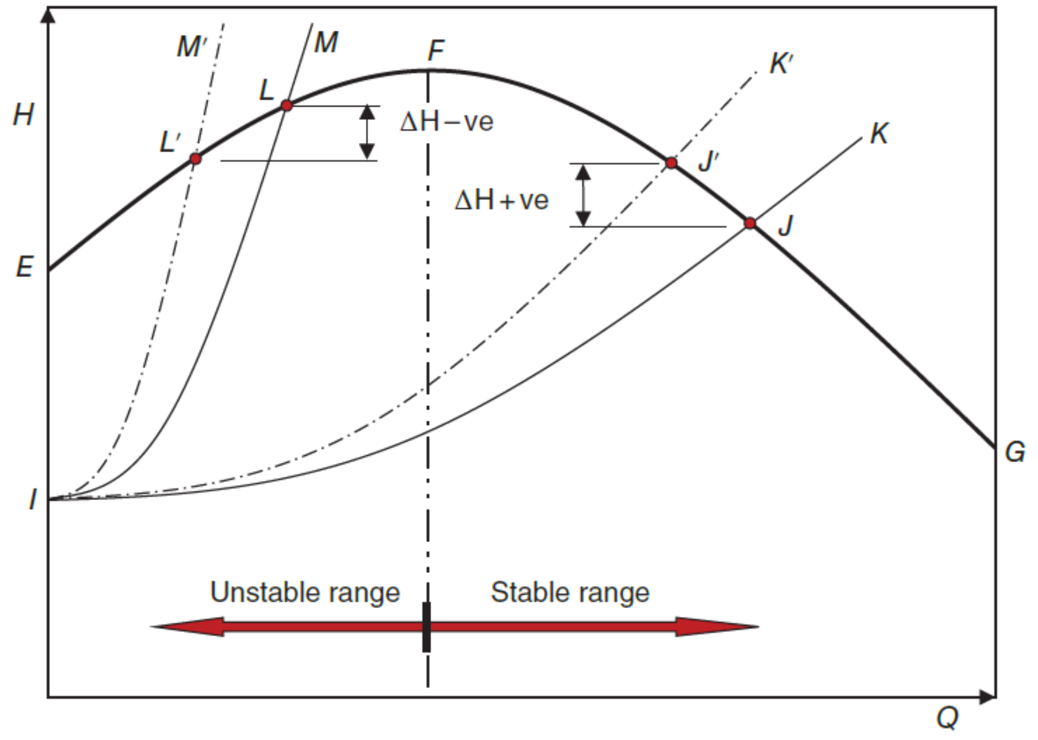
Compressor Performance Characteristics



- The compressor performance is normally presented in terms of three curves representing the variation of each of the stagnation pressure ratio ($p03/p01$) and the overall efficiency (ηo) with the mass flow rate (m•**)** when operating at a constant speed.
- Instead of using the head as the y-axis, the ratio b/w the compressor discharge pressure and the impeller inlet eye pressure is used here.
- Point A in represents the shut- off condition when the delivery valve is fully closed.
- The region between points A and C is an unstable region due to compressor surge, and point D is a choking point at which any of the compressor flow passages is choked.
- So the dotted lines AC and DE represent regions of unsafe and unavailable operating conditions, respectively.

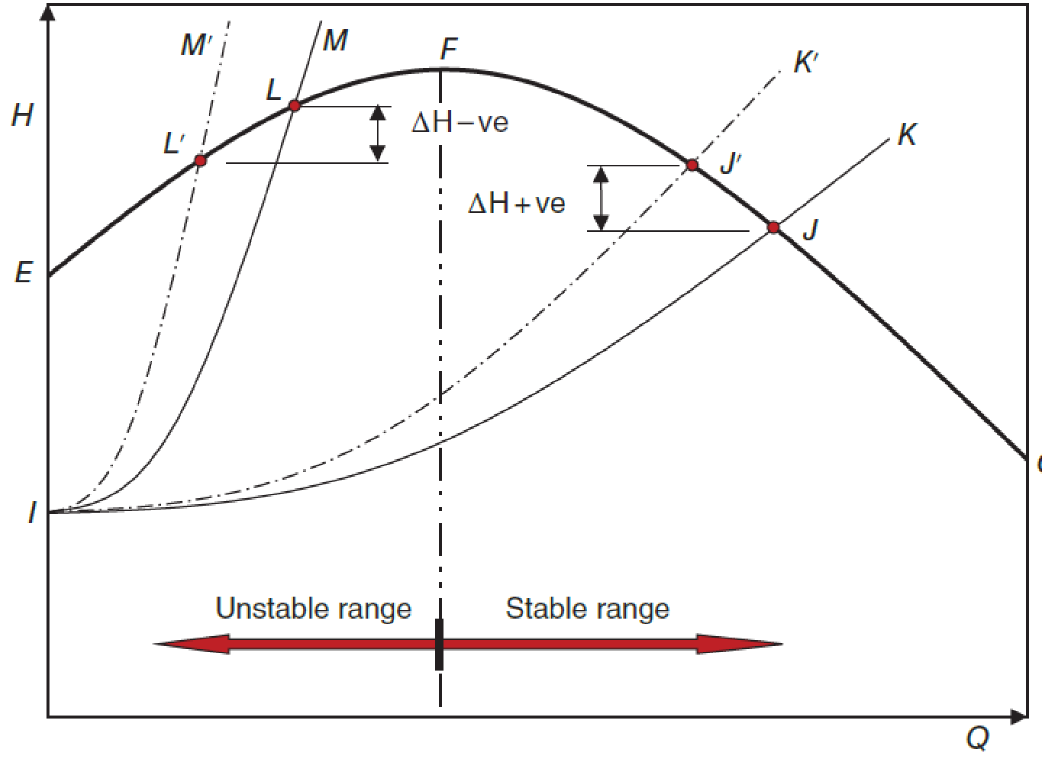
What is Compressor Surge?

- Compressor surge refers to unstable performance resulting in flow rate and pressure fluctuations that may lead to The effect of Compressor Surge:
  - Flow Reversal
  - Compressor vibration.
  - Failure of the seal or the thrust bearing, or even the impellers.
- The flow rate unsteadiness in this system may result from different sources such as a change in system resistance due to obstruction in the discharge side.

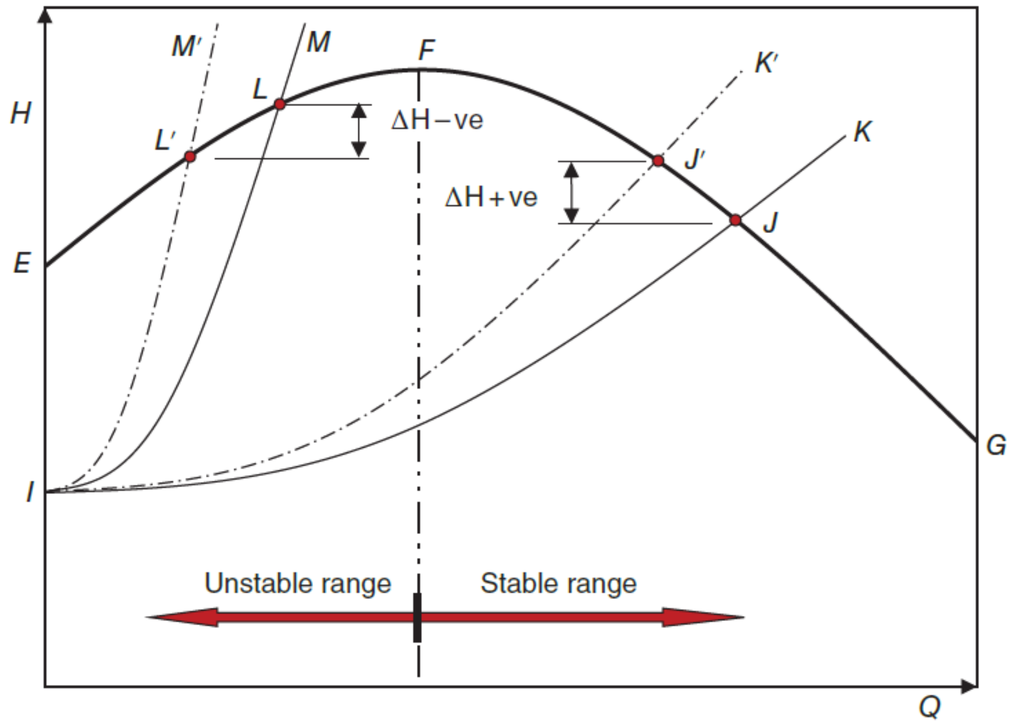


Case 1

- Suppose that the partial valve closure at C causes the point of operation to move to point J’ and the system curve changes momentarily to I’J’K’. The compressor response to additional resistance of the system is an increase in the pump head and a reduction in the flow rate *Q*. As soon as the system returns to normal characteristic IK, the flow rate increases (since Δ*H* is positive) and the point of operation moves back to J.



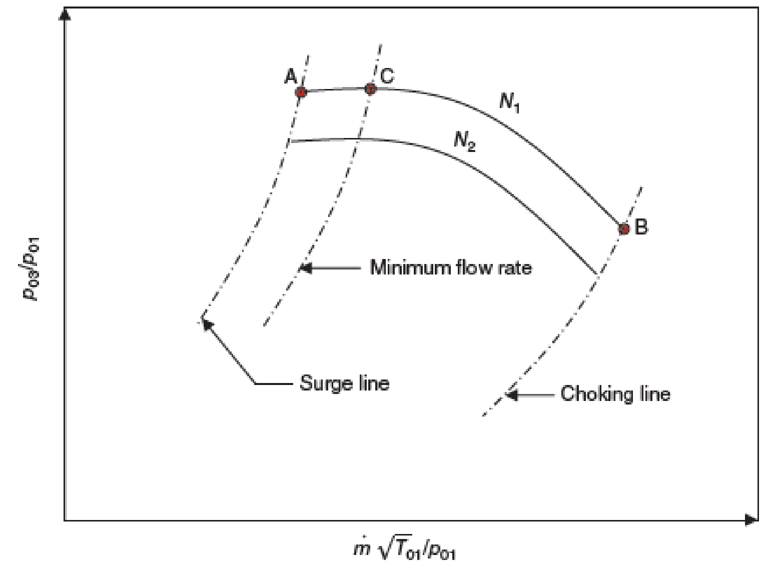
Case 2



- Let us now suppose that the system curve is ILM, and the point of normal operation is L. A similar unsteadiness will cause the system curve to change to A'L'M'. The pump response is now a reduction of *Q* and *H* (Δ*H* is now negative). This results in having the head developed by the pump less than the delivery pressure which causes the flow rate to decrease further. The process continues until reaching point E, and the non-return valve closes to prevent reverse flow. Now the back pressure clears off and the difference between *HE* and *HI* causes the flow rate to increase again and the process to be repeated.

How to prevent Compressor Surge?

- In order to protect the compressor against surge, a minimum flow rate must be maintained so that the point of operation continues to be on the right side of the surge line.
- The commonly used method is recycling part of the discharge through a controlled bypass.
- When the flow rate reaches the set value *m• C*, the flow controller (FC) actuates the bypass control valve to circulate part of the discharge back to the compressor suction side. That leads to a reduction in the discharge pressure, resulting in an increase in the flow rate.
- Other methods are used such as variable speed drivers and using inlet guide vanes.



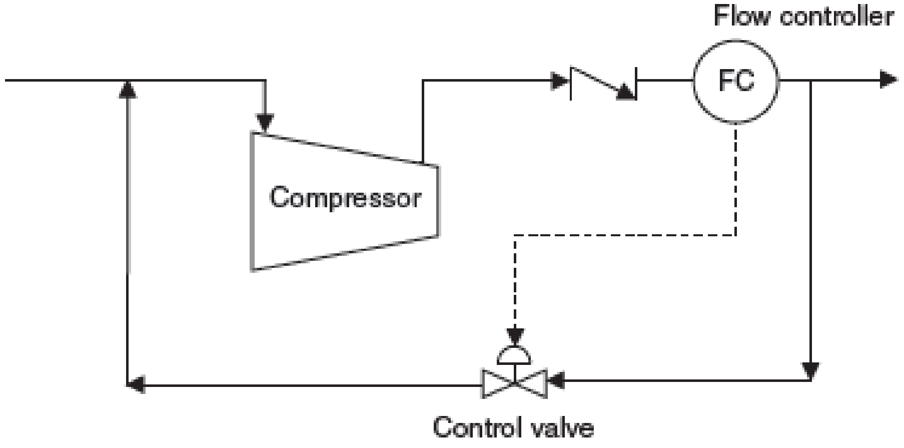
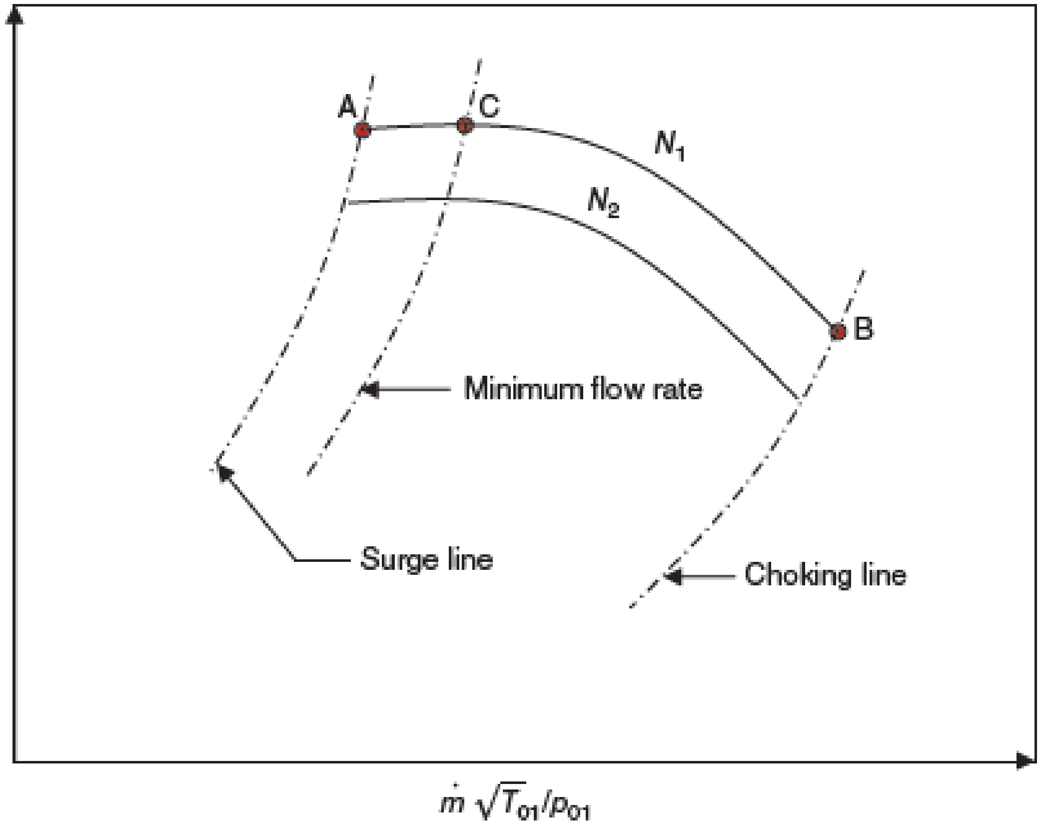


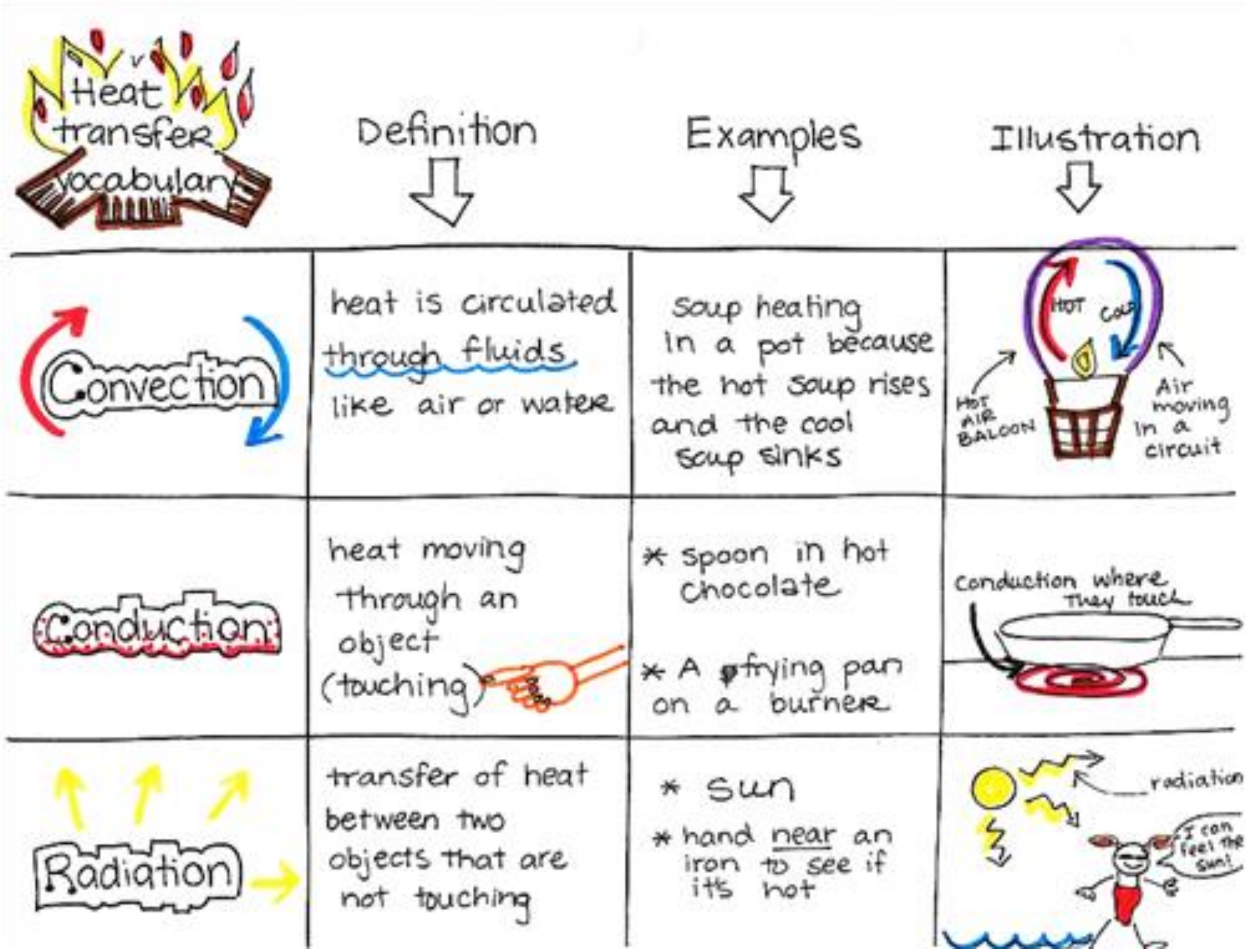
Figure 8.32 Typical Surge control system using a bypass

Choke Phenomena (stonewalling)

- Choking occurs when the compressor is operating at low discharge pressure and very high flowrates. These high flowrates at compressor choke point are the max. that the compressor can push through. Any further decrease in the outlet resistance will not lead to increase in compressor output.
- The efficiency and the head will go down after the choking line.
- Prolonged operation of a compressor at its choke point can lead to damaging the compressor parts.



Heat Transfer



What is conduction?

- Conduction is the energy transfer from the **more energetic** to the **less energetic** particles of a substance due to **interactions between the particles**.
- Conduction happens in all phases (gas, liquid, solid).
- At steady state, the rate of heat transfer depends on
  - The type of the material.
  - The temperature difference.

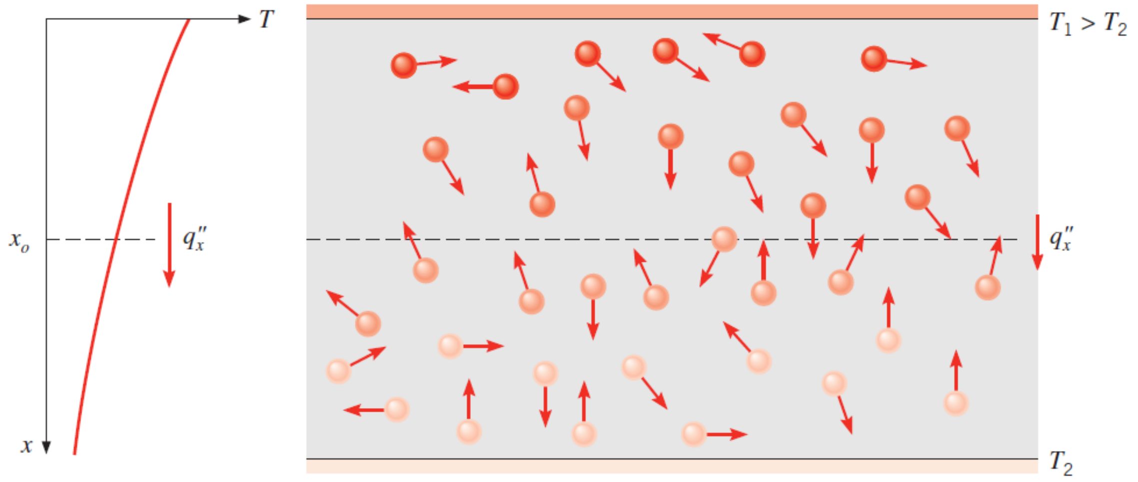
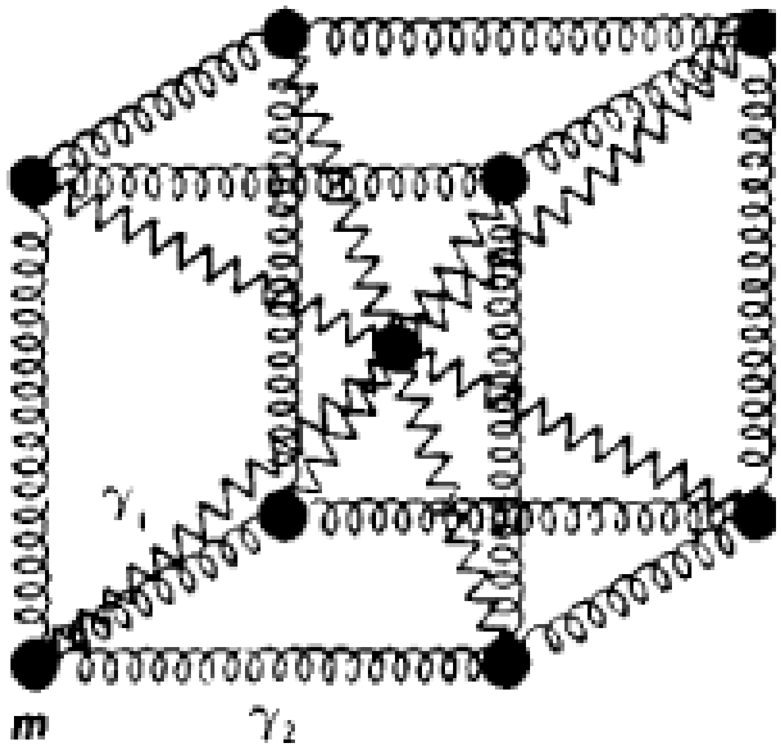


FIGURE 1.2 Association of conduction heat transfer with diffusion of energy due to molecular activity.

What is conduction?

- In solids, conduction may be attributed to atomic activity in the form of **lattice vibrations**.
- Example of conduction heat transfer: The exposed end of a metal spoon suddenly immersed in a cup of hot coffee is eventually warmed due to the conduction of energy through the spoon.

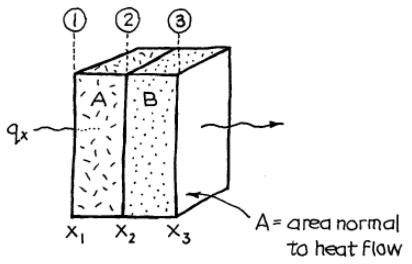


What is the conduction equation?

Fourier's law

- k is the thermal conductivity
- The minus sign tells that heat flows from regions of higher to lower temperature.

$$\dot{q}_x = -\frac{A}{\frac{x_2 - x_1}{k_A} + \frac{x_3 - x_2}{k_B}}(T_3 - T_1)$$



$$\dot{q}_x = -kA\frac{dT}{dx} \qquad \left[\frac{\mathrm{J}}{\mathrm{s}} = \mathrm{W}\right]$$

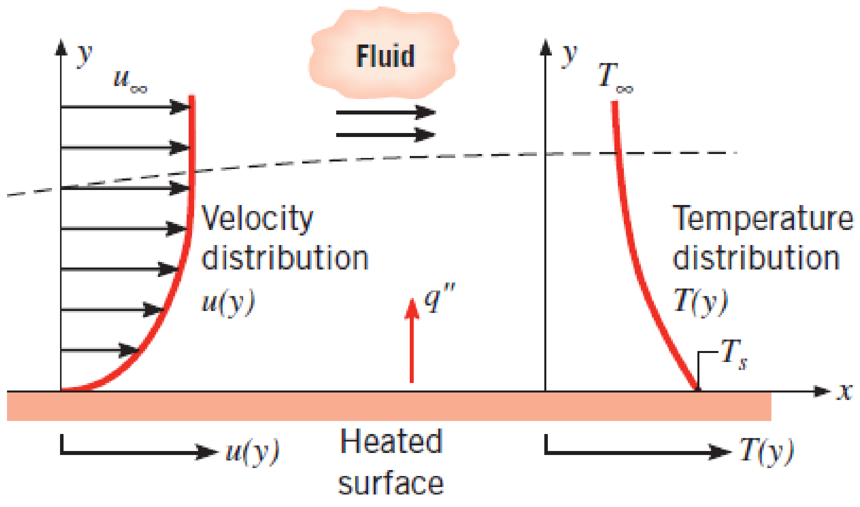
Define the thermal conductivity and what are the factors that affect it?

- The thermal conductivity of a material is a measure of its ability to conduct heat.
- Heat transfer occurs at a lower rate in materials of low thermal conductivity than in materials of high thermal conductivity.
- Influencing factors
  - Temperature
  - Chemical phase

Table 9.1 Short table of thermal conductivities for materials at room temperature[a]

Material	k, W/m K	Material	k, W/m K
Gases		Solids	
SO_2	0.009	Styrofoam	0.036
CO_2, H_2	0.018	Corrugated cardboard	0.064
H_2O	0.025	Paper	0.13
Air	0.026	Sand, dry	0.33
Liquids		Glass	0.35–1.3
Gasoline	0.13	Ice	2.2
Ethanol	0.18	Lead	34
Water	0.61	Steel	45
Mercury	8.4	Aluminum	204
Sodium	85	Copper	380

The thermal conductivity



What is convection?

- Convection refers to heat transfer that will occur between a **surface** and a **moving fluid** when the two are at different temperatures.
- When a fluid is heated and then travels away from the source, it carries the thermal energy along.
- This heat transfer is due to the combined effects of **conduction** and **bulk fluid motion**.
- The contribution due to **conduction** dominates near the surface where the fluid velocity is low.

What is convection equation?

$$q'' = h(T_\infty - T_s)$$

Newton's Law of Cooling

- h (W/m2.K): the convection heat transfer coefficient, which is a function of:
  1. Fluid velocity.
  2. Flow viscosity.
  3. Fluid density.
  4. Fluid thermal conductivity.

TABLE 1.1 Typical values of the convection heat transfer coefficient

Process	h ($W/m^2 \cdot K$)
Free convection	
Gases	2–25
Liquids	50–1000
Forced convection	
Gases	25–250
Liquids	100–20,000
Convection with phase change	
Boiling or condensation	2500–100,000

What are the convection types?

1- Forced Convection

- We speak of forced convection when the flow is caused by external means, such as by a fan, a pump, or atmospheric winds.

What are the convection types?

2- Free/Natural Convection

- For free convection, the flow is induced by buoyancy forces, which are due to density differences caused by temperature variations in the fluid.
- Free convection distributes the poisonous products of combustion during fires.

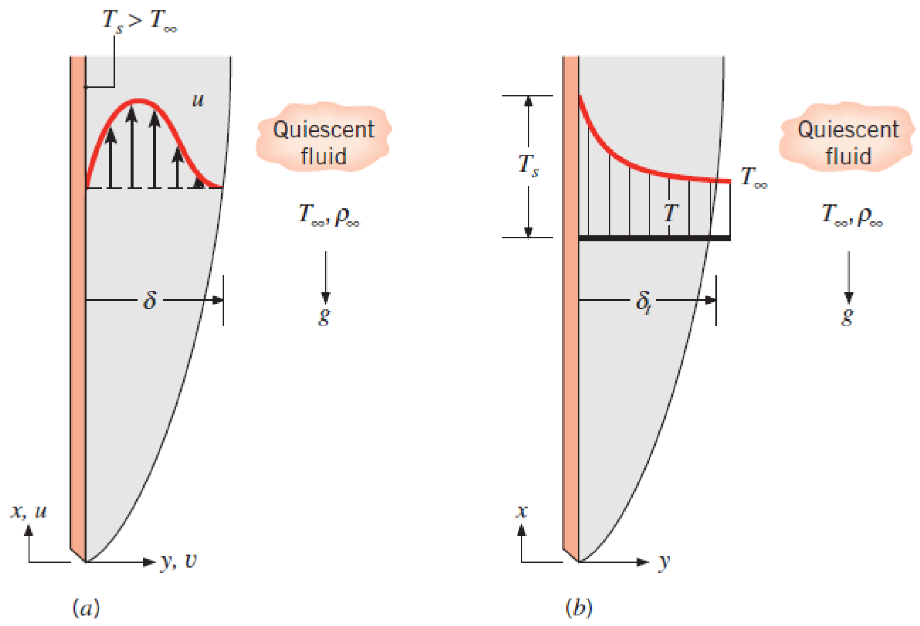


FIGURE 9.3 Boundary layer development on a heated vertical plate: (a) Velocity boundary layer. (b) Thermal boundary layer.

Draw the **velocity** distribution of external flow on the plate

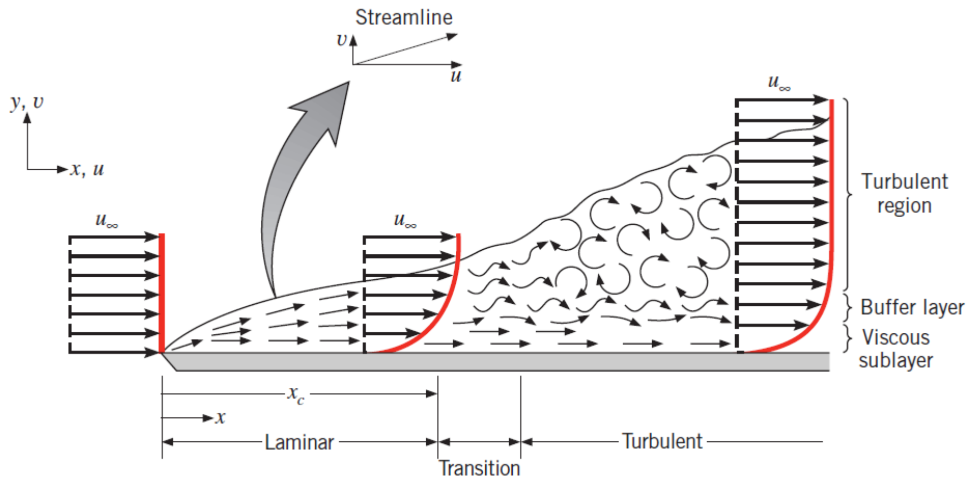
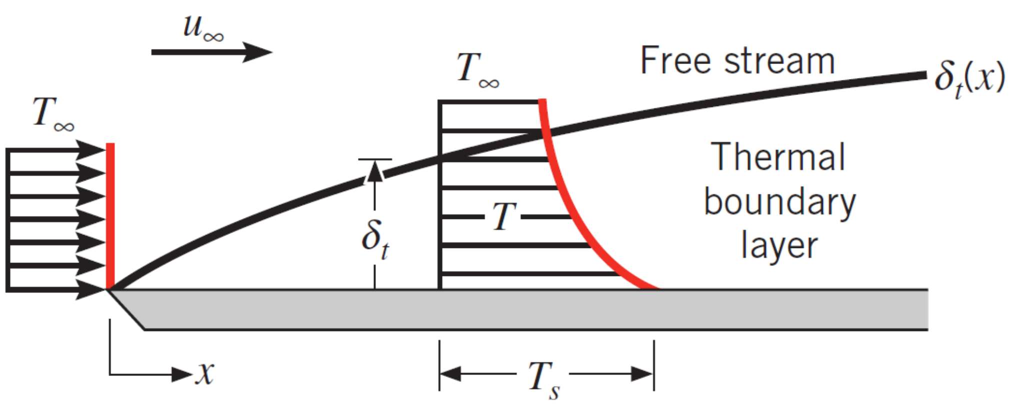


FIGURE 6.6 Velocity boundary layer development on a flat plate.

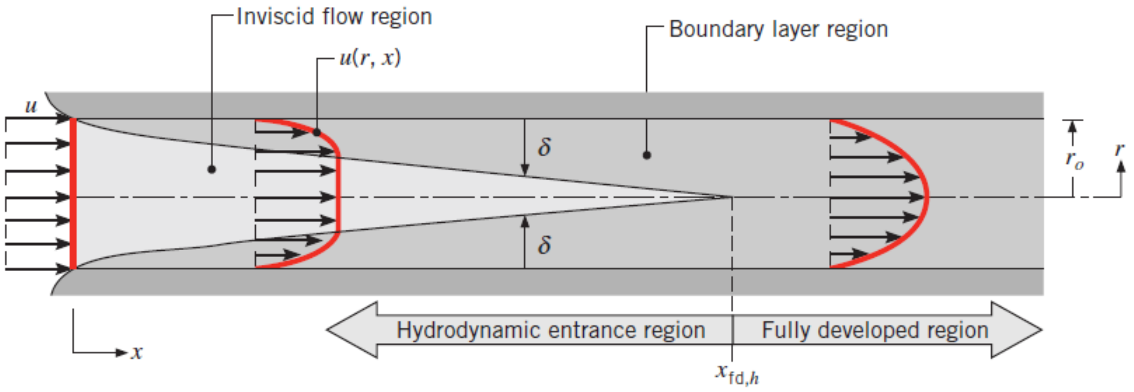
- A consequence of the fluid–surface interaction is the development of a region in the fluid through which the velocity varies from zero at the surface to a finite value u∞ associated with the flow.
- This region of the fluid is known as the velocity, boundary layer.
- When fluid particles make contact with the surface, their velocity is reduced significantly relative to the fluid velocity upstream of the plate due to **shear stresses** acting in planes.
- These particles then act to retard the motion of particles in the adjoining fluid layer, which act to retard the motion of particles in the next layer, and so on until, at a distance y = S from the surface, the effect becomes negligible.

Draw **Thermal** boundary layer development on an isothermal flat plate.



- If the surface and flow temperatures differ, there will be a region of the fluid through which the temperature varies from Ts at y = 0 to T∞ in the outer flow.
- This region, called the **thermal boundary layer.**

Draw the **velocity & Thermal** distribution of internal flow in pipes



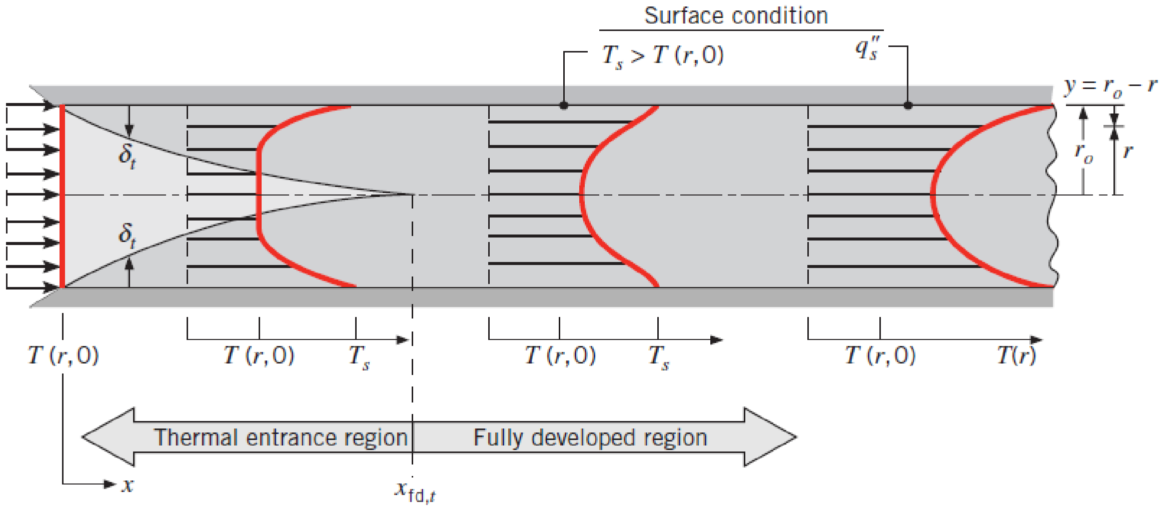


FIGURE 8.4 Thermal boundary layer development in a heated circular tube.