# Lecture
# on

## Fluid Mechanics I

### Prepared by

**Anisul Islam**
Lecturer
Department of ME, UGV

# BASIC COURSE INFORMATION

| Course Title | Fluid Mechanics I |
|---|---|
| Course Code | ME 0715-3121 |
| Credits | 03 |
| CIE Marks | 90 |
| SEE Marks | 60 |
| Exam Hours | 2 hours (Mid Exam)<br>3 hours (Semester Final Exam) |
| Level | $5^{th}$ Semester |

| | |
|---|---|
| CLO1 | After Completing this Course a Student will be able to **Understand** fluid Properties, Fluid Pressure |
| CLO2 | After Completing this Course a Student will be able to **Explain** Velocity and Head loss, Pipe friction, Pump Functioning |
| CLO3 | After Completing this Course a Student will be able to **Apply** the concepts of  Fluid Properties, Statistics and Dynamics. |
| CLO4 | After Completing this Course a Student will be able to **Analyze** Complex problems on Fluid flow, Pump Selection |
| CLO5 | After Completing this Course a Student will be able to **Calculate**  and **Evaluate** losses on pipes, Pipe design, Pump efficiency |

# Reference Books:

- Fluid Mechanics- Frank M. White
- Fluid Mechanics & Hydraulic Machines- Dr. R. K. Bansal
- A Textbook of Hydraulics, Fluid Mechanics & Hydraulic Machines- R.S Khurmi
- Fluid Mechanics and Hydraulic Machines: Problems and Solutions|| by K Subram

| S. L | Content of Course | Hrs | CLOs |
|---|---|---|---|
| 1 | Fluid Properties, Fluid Types, Newtons Law of Viscosity, Surface Tension , Capillary Action, Problem Solving | 4 | CLO 1, CLO 3 |
| 2 | Fluid Pressure, Atmospheric, Gauge , Vacuum Pressure, Pitot Tube, Stagnation Pressure, Piezometric Tube, Manometer, Types of Manometer, Problem Solving on Fluid Pressure | 06 | CLO 1, CLO 3 |
| 3 | Fluid flow Through Pipes | 06 | CLO 2, CLO 4, CLO 5 |
| 4 | Fluid Dynamics | 08 | CLO 3, CLO 4 |
| 5 | Pumps, Types of Pumps, Centrifugal and Reciprocating Pump, Problem Solving on Pumps | 08 | CLO 2, CLO 4, CLO 5 |

## ASSESSMENT PATTERN
## CIE- Continuous Internal Evaluation (90 Marks)

| Bloom's CategoryMarks (out of 90) | Tests (45) | Assignments (10) | Class Test (20) | Quiz (5) | External Participation in Curricular/Co-CurricularActivities (10) |
|---|---|---|---|---|---|
| **Remember** | 5 | | 10 | 05 | |
| **Understand** | 5 | 05 | 10 | | |
| **Apply** | 10 | | | | **10** |
| **Analyze** | 15 | | | | |
| **Evaluate** | 10 | | | | |
| **Create** | | **05** | | | |

# SEE- Semester End Examination (60 Marks)

| Bloom's Category | Test |
|---|---|
| Remember | 10 |
| Understand | 10 |
| Apply | 10 |
| Analyze | 10 |
| Evaluate | 10 |
| Create | 10 |

| | Course Plan Specifying Content, CLOs, Teaching Learning Strategy and Assessment Strategy | | | |
|---|---|---|---|---|
| | | | | |
| Week | Topics | Teaching Learning Strategy | Assessment Strategy | Corresponding CLOs |
| 1 | Fluid Properties ( Density, Specific Weight, Specific Volume, Specific Gravity) | Lecture, Oral Presentation, PPT | Quiz, Written exam | CLO 1, CLO 3 |
| 2 | Fluid Types, Newtons Law of Viscosity, Surface Tension , Capillary Action, Problem Solving | Lecture, Oral Presentation, PPT | Quiz, Written exam | CLO 1, CLO 3 |
| 3 | Fluid Pressure, Atmospheric, Gauge , Vacuum Pressure, Pitot Tube, Stagnation Pressure, Piezometric Tube | Lecture, Oral Presentation, PPT | Quiz, Written exam, CT | CLO 1, CLO 3 |
| 4 | Manometer, types of Manometer | Lecture, Oral Presentation, PPT | Quiz, Written exam, CT | CLO 1, CLO 3 |

| | Course Plan Specifying Content, CLOs, Teaching Learning Strategy and Assessment Strategy | | | |
|---|---|---|---|---|
| | | | | |
| Week | Topics | Teaching Learning Strategy | Written exam | Corresponding CLOs |
| 5 | Problem Solving on Manometer | Lecture, Oral Presentation, Video Presentation, PPT | Assignment, Written exam, Quiz CT | CLO 1, CLO 3 |
| 6 | Fluid flow Through Pipes | Lecture, Oral Presentation, PPT | Assignment, Quiz, Written exam, CT | CLO 2, CLO 4, CLO 5 |
| 7 | Fluid flow Through Pipes | Lecture, Oral Presentation, Video Presentation, PPT | Assignment, Quiz, Written exam, CT | CLO 2, CLO 4, CLO 5 |

| | **Course Plan Specifying Content, CLOs, Teaching Learning Strategy and Assessment Strategy** | | | |
|---|---|---|---|---|
| | | | | |
| Week | Topics | Teaching Learning Strategy | Assessment Strategy | Corresponding CLOs |
| 8 | Fluid Flow Through Pipes | Lecture, Oral Presentation, PPT | Quiz, Written exam, Assignment, CT | CLO 2, CLO 4, CLO 5 |
| 9 | Fluid Dynamics | Lecture, Oral Presentation, Video Presentation, PPT | Quiz, Written exam, Assignment, CT | CLO 3, CLO 4 |
| 10 | Fluid Dynamics | Lecture, Oral Presentation, PPT | Assignment, Quiz, Written exam | CLO 3, CLO 4 |

| | Course Plan Specifying Content, CLOs, Teaching Learning Strategy and Assessment Strategy | | | |
|---|---|---|---|---|
| | | | | |
| Week | Topics | Teaching Learning Strategy | Assessment Strategy | Corresponding CLOs |
| 11 | Fluid Dynamics Problem Solving | Lecture, Oral Presentation, PPT | Assignment, Quiz, Written exam, CT | CLO 3, CLO 4 |
| 12 | Fluid Dynamics Problem Solving | Lecture, Oral Presentation, PPT | Quiz, Written exam, CT | CLO 3, CLO 4 |
| 13 | Pumps, Types of Pumps, Centrifugal and Reciprocating Pump, Problem Solving on Pumps | Lecture, Oral Presentation, Video Presentation, PPT | Assignment, Quiz, Written exam, CT | CLO 2, CLO 4, CLO 5 |
| 14 | Pumps, Types of Pumps, Centrifugal and Reciprocating Pump, Problem Solving on Pumps | Lecture, Oral Presentation, Video Presentation, PPT | Quiz, Written exam | CLO 2, CLO 4, CLO 5 |
| 15 | Pumps, Types of Pumps, Centrifugal and Reciprocating Pump, Problem Solving on Pumps | Lecture, Oral Presentation, Video Presentation, PPT | Assignment, Quiz, Written exam, CT | CLO 2, CLO 4, CLO 5 |
| 16 | Pumps, Types of Pumps, Centrifugal and Reciprocating Pump, Problem Solving on Pumps | Lecture, Oral Presentation, Video Presentation, PPT | Assignment, Quiz, Written exam, CT | CLO 2, CLO 4, CLO 5 |
| 17 | Review Class on Problem solving | Group discussion | | |

# Week -1

**Lecture**

**on**

**Fluid Properties**

# WHAT IS FLUID?

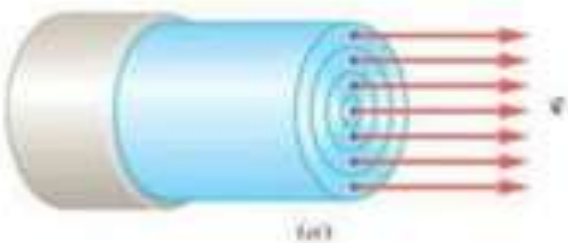
- A fluid is a substance that continually deforms (flows) under an applied shear stress or in simpler terms, a fluid is a substance which cannot resist any shear force applied to it.

## 2. Types of Fluids

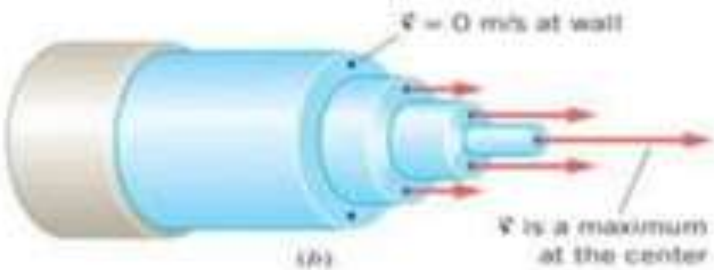
- Fluids can be classified into five basic types. They are:
- Ideal Fluid
- Real Fluid
- Pseudo-plastic Fluid
- Newtonian Fluid
- Non-Newtonian Fluid

## 2.1 IDEAL FLUID

- An Ideal Fluid is a fluid that has no viscosity.
- It is incompressible in nature.
- Practically, no ideal fluid exists.



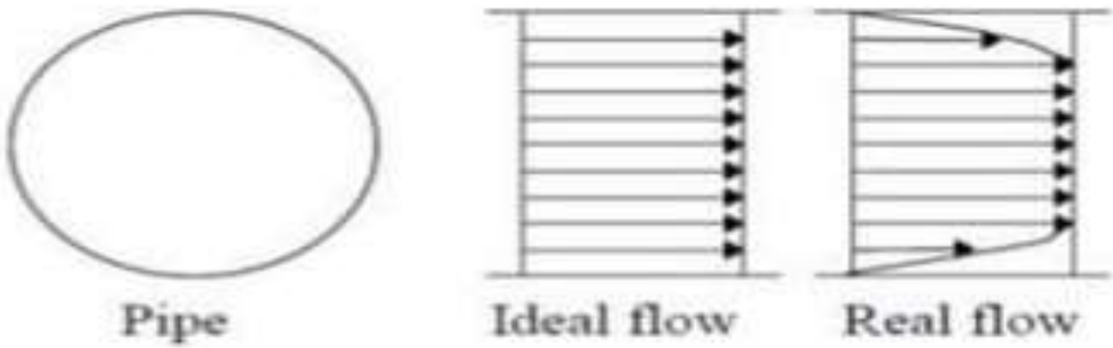

Flow of an ideal fluid.




**Flow of a viscous fluid.**

## 2.2 Real Fluid

- Real fluids are compressible in nature. They have some viscosity.
- Real fluids implies friction effects.
- Examples: Kerosene, Petrol, Castor oil




Velocity distribution of pipe flow

# Newton's Law of Viscosity

Newton's law of viscosity is states that the time rate of deformation of fluid is directly proportional to the shear stress applied on it.

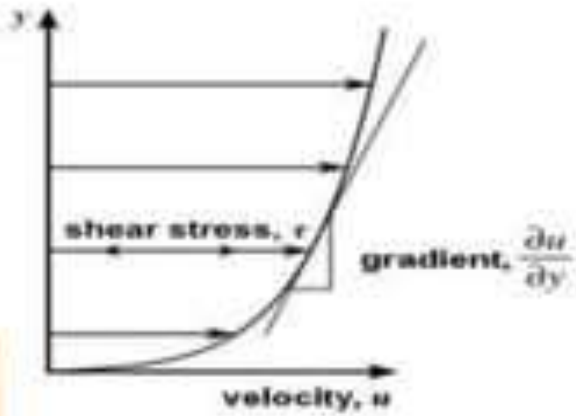
**Shear stress ∝ time rate of deformation**

**T=F/A ∝ de/dt**

**F/A ∝ du/dy** { time rate deformation is velocity gradient for fluid}

**F/A = μ (du/dy)**

where **F/A** = Shear stress
**μ** = Dynamic viscosity
**du/dy** = velocity gradient




Viscosity, $\tau = \mu \frac{du}{dy}$

Where,

$\mu$ = Dynamic viscosity

$\tau$ = Shear stress = F/A

$\frac{du}{dy}$ = Rate of shear deformation

**Newtonian Fluid:-**

The fluid which obey's the Newton's law of viscosity is called Newtonian fluid.

Newtonian fluid have constant viscosity and it does not depend upon the shear stress applied on it.

Example of Newtonian fluid: Air, water, Kerosene etc types of fluid

**Non-Newtonian Fluid:-**

The fluid which does not follow the Newton's law of viscosity and relationship is depend upon all the three quantity i.e. shear stress, viscosity and velocity gradient.

Example of non-Newtonian fluid: Blood, Paint, butter, ink etc types of fluid

The general equation for the non-Newtonian fluid is given by:-

$$\tau = A\,(du/dy)^n + B$$

## 2.4 Newtonian fluid

- Fluids that obey Newton's law of viscosity are known as Newtonian Fluids. For a Newtonian fluid, viscosity is entirely dependent upon the temperature and pressure of the fluid.
- Examples: water, air, emulsions

Different types of Emulsions

# 2.5 Non-Newtonian Fluids

- Fluids that do not obey Newton's law of viscosity are non-Newtonian fluids.
- Examples: Flubber, Oobleck (suspension of starch in water), Pastes, Gels & Polymer solutions.

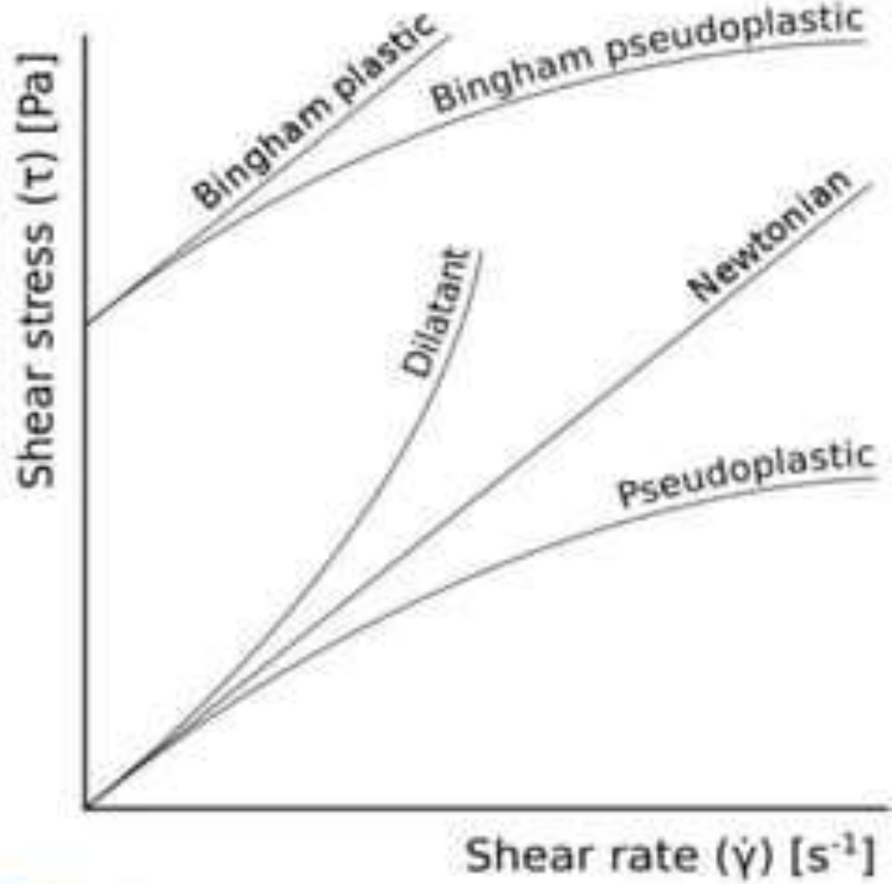
Flubber

# Types of fluid (non-Newtonian fluid)

## A.Dilatant Fluid

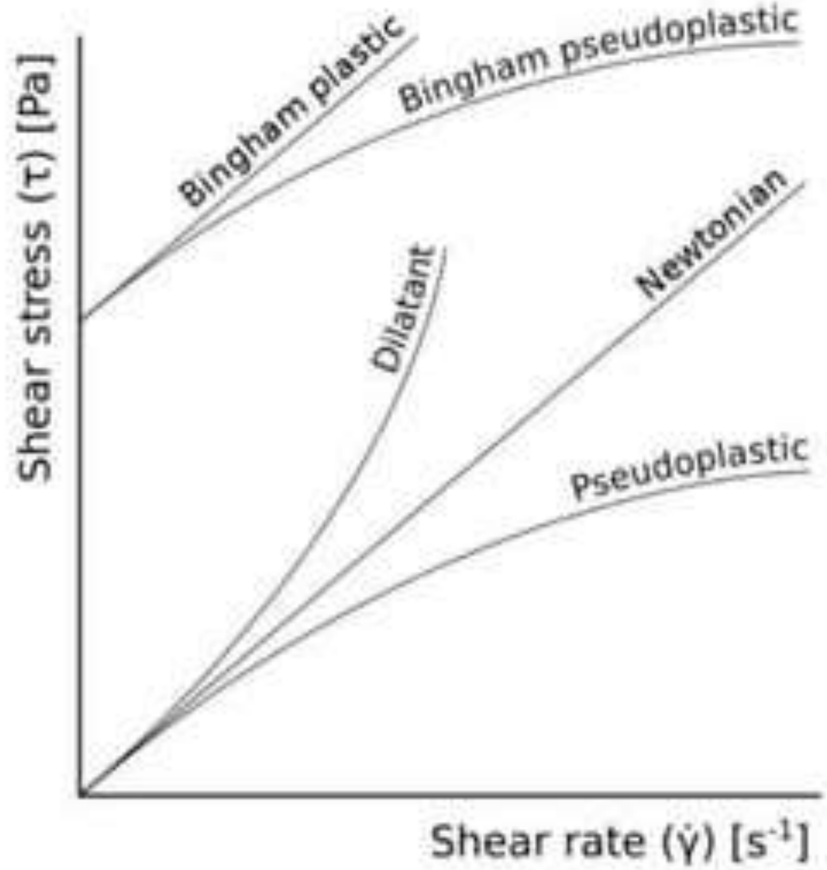
The non-Newtonian fluid which having value of B = 0 and the value of n is greater than 1 in general equation, so the graph is gradually increased.

**Example of Dilatant fluid:** Butter and Quick sand etc types of fluid



## B.Pseudoplastic Fluid

The non-Newtonian fluid which having value of B = 0 and the value of n is less than 1 in general equation, so the graph is gradually decreased.



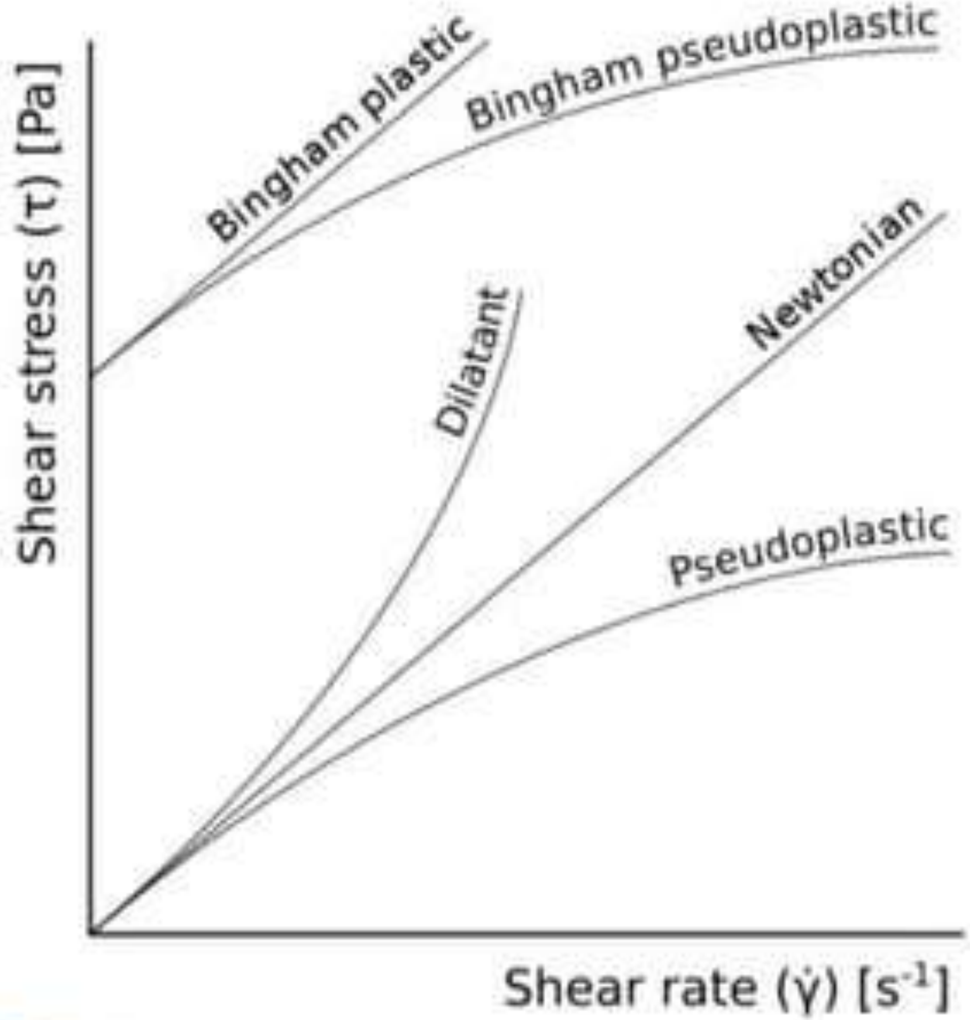

**Example of Pseudoplastic fluid:**

Blood, rubber and paints etc types of fluid

## C.Bingham Plastic

The non-Newtonian fluid which having value of B = ty and n = 1, because it having starting value of B is greater than 0, so its viscosity gradient is increased from that point.

**Example of Bingham plastic** is sewage slug, drilling mud



# Week -2

**Lecture**

**on**

**Fluid Properties**

# Fluid Properties: Density, Viscosity, and Surface Tension

## Density

Density measures the mass of a fluid per unit volume. It plays a crucial role in buoyancy and determining how a fluid responds to external forces.

## Viscosity

Viscosity represents a fluid's resistance to flow. It impacts the speed of flow, energy losses, and the formation of boundary layers.

## Surface Tension

Surface tension arises from cohesive forces within a liquid, creating a thin film at its surface. It influences droplet formation, capillary action, and the behavior of bubbles.

# FLUID PROPERTIES

- Properties are certain measurable characteristics that can be quantified, with the help of property we can identify fluid.

1. Density or Mass density
2. Specific weight or Weight density
3. Specific gravity
4. Compressibility
5. Viscosity
6. Surface Tension
7. Capillarity
8. Vapour Pressure

# 1. Density or Mass density

- Density is defined as the ratio of the mass of mass per unit volume and its SI unit is ($kg/m^3$).
- Density basically represent the number of molecules of a fluid in a given volume, so more number of molecules more is the mass and heavier is the fluid.
- Hence density can also be define as the representative of heaviness of the fluid.

$$\rho = \frac{\text{Mass (kg)}}{\text{Volume (m}^3\text{)}}$$

$$\rho_{(Solid)} > \rho_{(Liquid)} > \rho_{(Gas)}$$

$\rho_{Water} = 1000\ kg/m^3$ (at $4^0C$)
$\rho_{Air} = 1.2\ kg/m^3$ (at $0^0C$ and 1 bar)

<u>Note</u> : Density will increases with increase in Pressure .

## 2. Specific weight or Weight density

- Specific weight is defined as the weight of the fluid per unit volume and its SI unit is ($N/m^3$).

- It basically represent the force exerted by fluid due to gravity in a given volume.

$$w = \frac{\text{Weight [ mass (kg) x gravity } (m/s^2) \text{ ]}}{\text{Volume } (m^3)} = \rho \cdot g \ \ (N/m3)$$

- Weight of a fluid of a given volume is

$$W = \text{Sp. Weight * Volume} = \rho \cdot g \cdot v \ \ (N)$$

Note : Density is an absolute quantity with respect to location where as specific weight is a variable quantity with respect to location.

# 3. Specific Gravity

- Specific gravity is define as the ratio of the density of the fluid to the density of standard fluid.

- Standard fluid in case of liquid is taken as water where as in case of gases is taken as air .

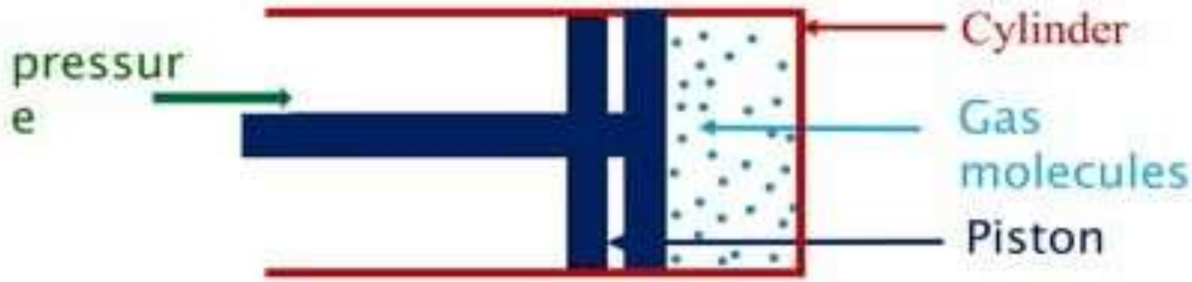
$$s = \frac{\rho_{(Fluid)}}{\rho_{(Standard\ Fluid)}} = \text{Dimensionless}$$

- Specific gravity basically shows which fluid are heavier then water or air and which fluid are lighter then water or air.
- Example : s = 1 ……………..For Water
  s = 0.760……... Fluid is lighter then water
  s = 13.6………..Fluid is heavier then water

# 4. Compressibility

- If there is a change in volume or density of fluid with respect to pressure applied such fluid called as compressible fluid.

- Example:




- With increase in pressure variation of volume of gas is large hence gases are compressible.

# Properties of Fluids

Example 1.

*Calculate the specific weight, density and specific gravity of one liter of a liquid which weighs 7 N.*

**Solution.** Given :

$$\text{Volume} = 1 \text{ litre} = \frac{1}{1000} \text{ m}^3 \quad \left(\because \ 1 \text{ litre} = \frac{1}{1000} \text{ m}^3 \text{ or } 1 \text{ litre} = 1000 \text{ cm}^3\right)$$

$$\text{Weight} = 7 \text{ N}$$

(*i*) Specific weight ($w$)

$$= \frac{\text{Weight}}{\text{Volume}} = \frac{7 \text{ N}}{\left(\frac{1}{1000}\right) \text{m}^3} = 7000 \text{ N/m}^3. \text{ Ans.}$$

(*ii*) Density ($\rho$)

$$= \frac{w}{g} = \frac{7000}{9.81} \text{ kg/m}^3 = 713.5 \text{ kg/m}^3. \text{ Ans.}$$

(*iii*) Specific gravity

$$= \frac{\text{Density of liquid}}{\text{Density of water}} = \frac{713.5}{1000} \quad \{\because \ \text{Density of water} = 1000 \text{ kg/m}^3\}$$

$$= 0.7135. \text{ Ans.}$$

Example 2. *Calculate the density, specific weight and weight of one liter of petrol of specific gravity = 0.7*

**Solution.** Given : Volume = 1 litre = $1 \times 1000 \text{ cm}^3 = \frac{1000}{10^6} \text{ m}^3 = 0.001 \text{ m}^3$

Sp. gravity $S = 0.7$

*(i) Density* ($\rho$)

*Density* ($\rho$) $= S \times 1000 \text{ kg/m}^3 = 0.7 \times 1000 =$ **700 kg/m³. Ans.**

*(ii) Specific weight* ($w$)

$$w = \rho \times g = 700 \times 9.81 \text{ N/m}^3 = \mathbf{6867 \text{ N/m}^3}$$ **Ans.**

*(iii) Weight* ($W$)

We know that specific weight $= \frac{\text{Weight}}{\text{Volume}}$

or $$w = \frac{W}{0.001} \text{ or } 6867 = \frac{W}{0.001}$$

$\therefore$ $$W = 6867 \times 0.001 = \mathbf{6.867 \text{ N}}$$ **Ans.**

# 5. Viscosity

- Viscosity is define as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid.

- Consider two layer of a fluid , a distance 'dy' apart, move one over the another at a different velocity, say 'u' and 'u+du' as show in fig.1 :

- The viscosity together with relative velocity causes a shear stress acting between the fluid.

- This shear stress is proportional to the rate of change of velocity with respect 'y' which is distance from boundary.

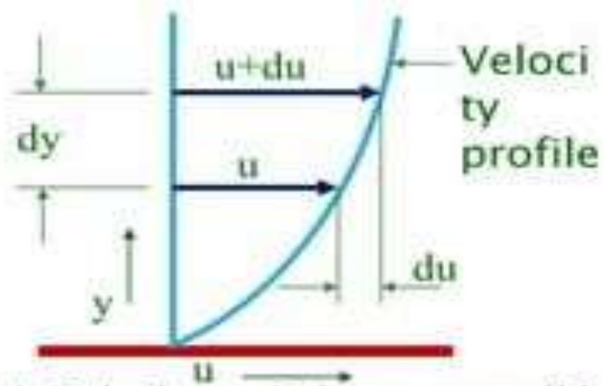



Fig.1: Velocity variation near a solid boundary

# 5. Viscosity

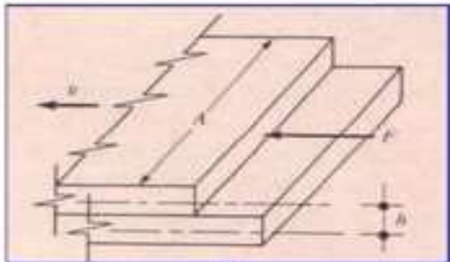
❖ Variation of Viscosity with Temperature :

- In case of liquid with increase in temperature of liquid viscosity decreases because the main reason of viscosity is molecular bonding and with increases in temperature molecular bonding brake down and viscosity decreases.

- Where as in case of gases the main reason of viscosity is the molecular collision and with increase in temperature molecular collision increases which act as resistance to flow hence viscosity increases.

## 3.2.1 Dynamic Viscosity

- The Dynamic (shear) viscosity of a fluid expresses its resistance to shearing flows, where adjacent layers move parallel to each other with different speeds.



A thin layer of fluid

Let
-A = the horizontal area of each layer
-h = the vertical distance between their centerlines
-F = internal shear force

The top layer is acted upon by F

The top layer will move with a velocity, v relative to the bottom layer

$$F = \mu A \frac{u}{y}.$$

μ = Dynamic Viscosity

## 3.2.2 Kynematic Viscosity

- The kinematic viscosity (also called "momentum diffusivity") is the ratio of the dynamic viscosity $\mu$ to the density of the fluid $\rho$.

$$\nu = \frac{\mu}{\rho}$$

| | |
|---|---|
| $\nu$ | = kinematic viscosity, $m^2/s$ |
| $\mu$ | = Dynamic viscosity, $N.s/m^2$ or Pa.s |
| $\rho$ | = Density of fluid, $kg/m^3$ |

## Example 4

Calculate the dynamic viscosity of an oil, which is used for lubrication between a square plate of size 0.8 m x 0.8 m and an inclined plane with angle of inclination 30° as shown in Fig. 1.4. The weight of the square plate is 300 N and it slides down the inclined plane with a uniform velocity of 0.3 m/s. The thickness of oil film is 1.5 mm.

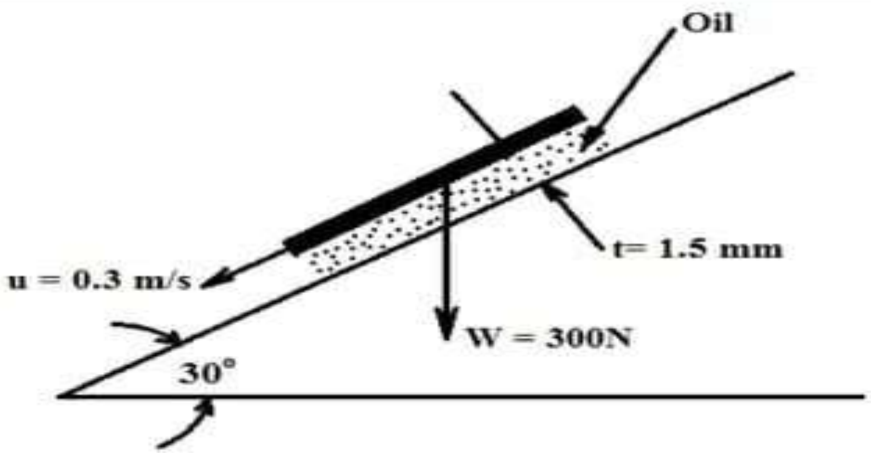



Fig.1.4

**Solution.** Given :

Area of plate, $A = 0.8 \times 0.8 = 0.64 \text{ m}^2$

Angle of plane, $\theta = 30°$

Weight of plate, $W = 300 \text{ N}$

Velocity of plate, $u = 0.3 \text{ m/s}$

Thickness of oil film, $t = dy = 1.5 \text{ mm} = 1.5 \times 10^{-3} \text{ m}$

Let the viscosity of fluid between plate and inclined plane is $\mu$.

Component of weight $W$, along the plane $= W \cos 60° = 300 \cos 60° = 150 \text{ N}$

Thus the shear force, $F$, on the bottom surface of the plate $= 150$ N

and shear stress, $$\tau = \frac{F}{\text{Area}} = \frac{150}{0.64} \text{ N/m}^2$$

Now using equation (1.2), we have

$$\tau = \mu \frac{du}{dy}$$

where $du$ = change of velocity $= u - 0 = u = 0.3$ m/s

$$dy = t = 1.5 \times 10^{-3} \text{ m}$$

$$\therefore \quad \frac{150}{0.64} = \mu \frac{0.3}{1.5 \times 10^{-3}}$$

$$\therefore \quad \mu = \frac{150 \times 1.5 \times 10^{-3}}{0.64 \times 0.3} = 1.17 \text{ N s/m}^2 = 1.17 \times 10 = \mathbf{11.7 \text{ poise}}.$$ **Ans.**

## Example 5

The space between two square flat parallel plates is filled with oil. Each side of the plate is 60 cm. The thickness of the oil film is 12.5 mm. The upper plate, which moves at 2.5 metre per sec requires a force of 98.1 N to maintain the speed.
Determine : ·
i. the dynamic viscosity of the oil, and
ii. the kinematic viscosity of the oil if the specific gravity of the oil is 0.95.

**Solution.** Given:
Each side of a square plate = 60 cm = 0.6 m
Area $A = 0.6 \times 0.6 = 0.36\ m^2$
Thickness of oil film $dy = 12.5\ mm = 12.5 \times 10^{-3}\ m$
Velocity of upper plate $u = 2.5\ m/s$

P SATISHKUMAR

∴ Change of velocity between plates, $du = 2.5$ m/sec

Force required on upper plate, $F = 98.1$ N

∴ Shear stress, $$\tau = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} = \frac{98.1\text{ N}}{0.36\text{ m}^2}$$

(*i*) Let $\mu$ = Dynamic viscosity of oil

Using equation (1.2), $$\tau = \mu \frac{du}{dy} \text{ or } \frac{98.1}{0.36} = \mu \times \frac{2.5}{12.5 \times 10^{-3}}$$

∴ $$\mu = \frac{98.1}{0.36} \times \frac{12.5 \times 10^{-3}}{2.5} = 1.3635 \frac{\text{Ns}}{\text{m}^2} \quad \textbf{Ans.}$$

(*ii*) Sp. gr. of oil, S = 0.95

Let $\nu$ = kinematic viscosity of oil

Using equation (1.1 A),

Mass density of oil, $$\rho = S \times 1000 = 0.95 \times 1000 = 950 \text{ kg/m}^3$$

Using the relation, $\nu = \frac{\mu}{\rho}$, we get $$\nu = \frac{1.3635\left(\frac{\text{Ns}}{\text{m}^2}\right)}{950} = .001435 \text{ m}^2\text{/sec} \quad \textbf{Ans.}$$

# 6. Surface Tension

- **Cohesion**

  It is a intermolecular force of attraction between molecule of same nature

  Example: water & water, Hg & Hg , etc.

- **Adhesion**

  It is a intermolecular force of attraction between molecule of Different nature.

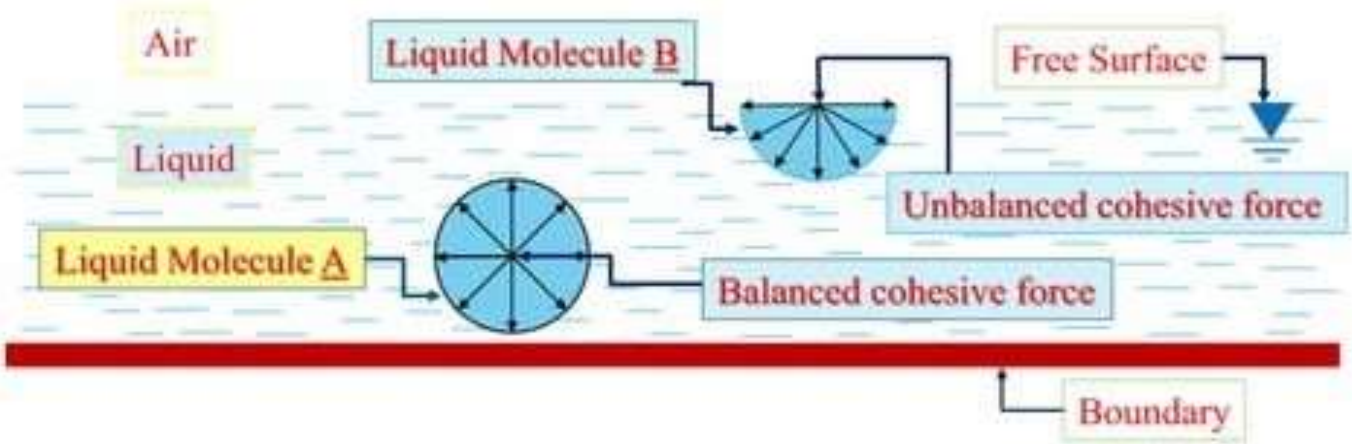
  Example: water & glass , Hg and glass , etc.

<u>Note:</u> Cohesion and Adhesion depends upon the nature of surface in contact.

Example:

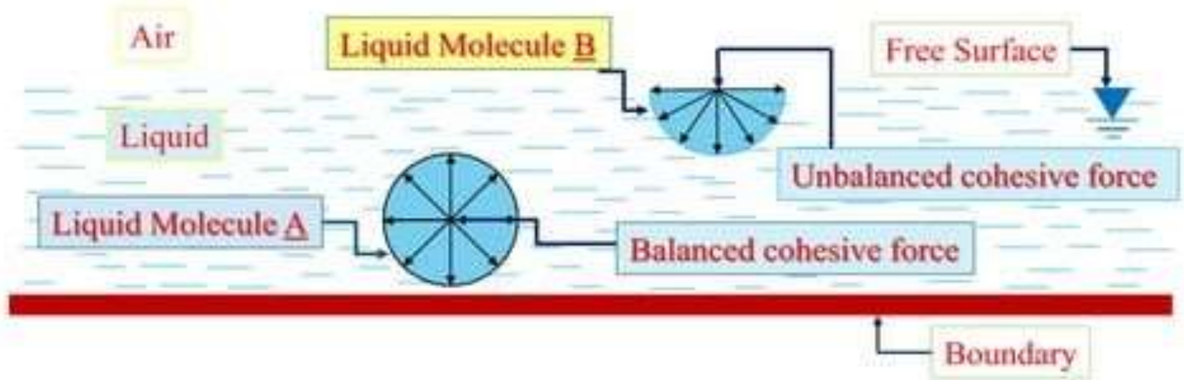
1. Water in glass Shows adhesion more
2. Mercury in glass shows cohesion more
3. Water on plastic sheet will shows cohesion more

# 6. Surface Tension



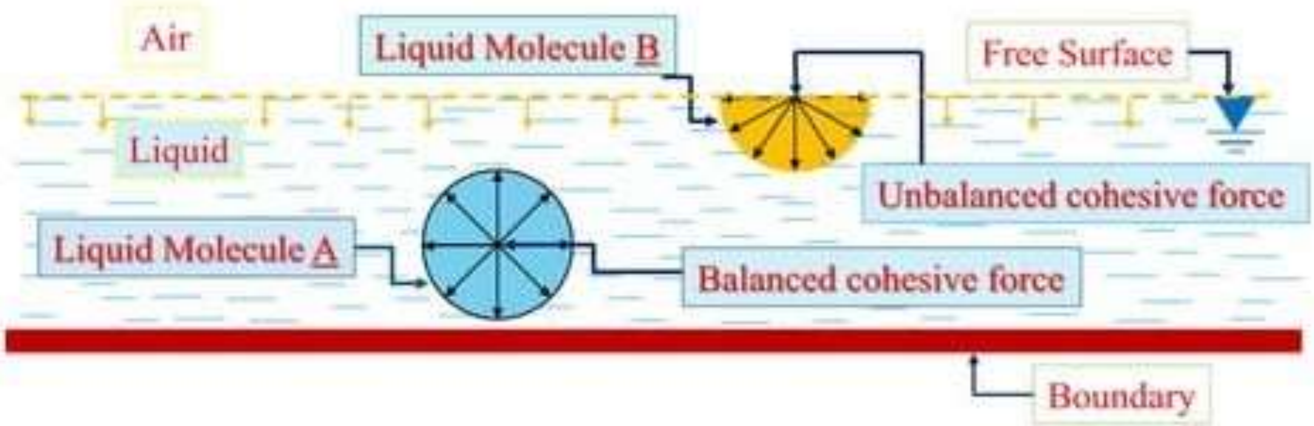

- Let us consider a molecule of liquid 'A' which is under the surface of a liquid, due to the cohesive forces molecule 'A' is attracted in all direction equally by surrounding molecules of liquid, thus resultant forces acting on the molecule 'A' is zero.

# 6. Surface Tension




- Let us consider a molecule of liquid 'B' which is situated on the free surface of liquid, due to cohesive force this liquid molecule is under the action of downward force.

# 6. Surface Tension




- There are large number of molecules on free surface and all the molecules are under downward pull due to this there appears to be a membrane on surface of liquid which can bear small load, this property known as Surface Tension.

# 6. Surface Tension

- Surface tension is define as the **tensile force** acting on the surface of liquid in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrane under tension.
- Surface tension is also given as the force acting per length over which surface tension acting. Mathematically,

$$\text{Surface Tension} = \frac{\text{Surface tension force}}{\text{Length over which surface tension acting (Perimeter of contact surface)}}$$

Fig.2: Water striders can walk on water because of the surface tension of water

# 6. Surface Tension

- Mathematically,

$$\sigma = \frac{Fs}{L} \left(\frac{N}{m}\right)$$

Note :

- Liquid droplet take the shape of sphere due to surface tension because drop tries to minimize its surface area and mathematically sphere has the minimum surface area.
- Detergent are used while washing cloth to reduce surface tension so that dirt particles can come out.

## 7. Capillarity

- Capillarity is the define a phenomenon of **rise or fall** of liquid surface when small diameter glass tube is inserted vertically in liquid relative to the adjacent general level of liquid.

- The rise of liquid surface is known as capillary rise as shown in figure no 3.

- Capillary rise occurs due to adhesion.

Example: Water in glass tube.

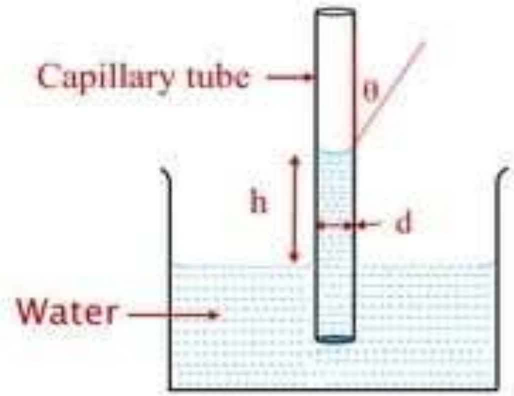



Fig.3: Capillary Rise

# 7. Capillarity

- If the capillary tube is dipped in mercury, the level of mercury in the tube will be lower then the general level of the outside liquid as shown in figure No. 4.

- Capillary fall occurs due to cohesion.

- Capillary rise or fall (h) can be calculated by following formula:

$$h = \frac{4\sigma \cos\theta}{\rho * g * d}$$

Where,

θ :Angle of contact between liquid & capillary tube

d :Diameter of capillary tube

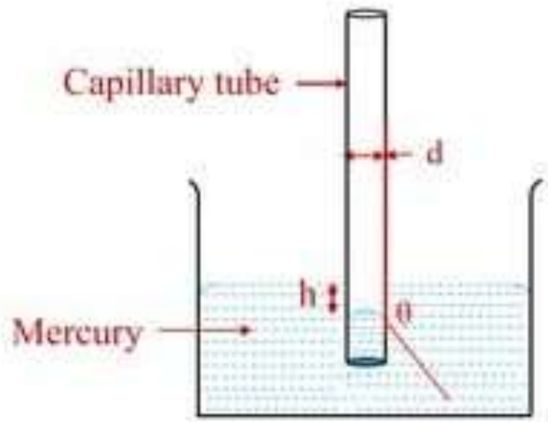



Fig.4: Capillary fall

# 8. Vapour Pressure

- A change from the liquid state to the gaseous state is knows as vaporization.
- The vaporization ( which depends upon the pressure and temperature) occurs because of continuous escaping of the molecules through the free surface.
- Let us consider a closed vessel which is partially filled with liquid ( Say water) as shown in fig.
- The molecules on the free surface of the liquid are in highly excited state and by taking energy from molecules beneath it, this molecules evaporate.

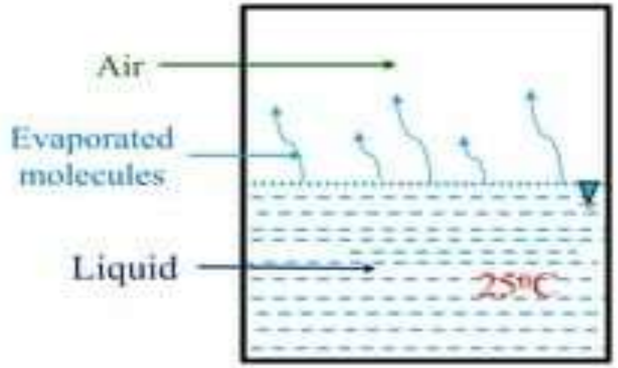



Fig.5: closed vessel

# 8. Vapour Pressure

- The air above the free surface of liquid can absorb the vapour molecules up to the certain limit known as saturation.
- Once saturation is reached, the number of vapour molecules evaporated from the free surface of liquid become equal to number of vapor molecules condensed back to the liquid.
- The pressure exerted by the liquid molecules over the free surface of liquid under saturation condition at given temperature is known as saturation vapour pressure or **Vapour pressure.**

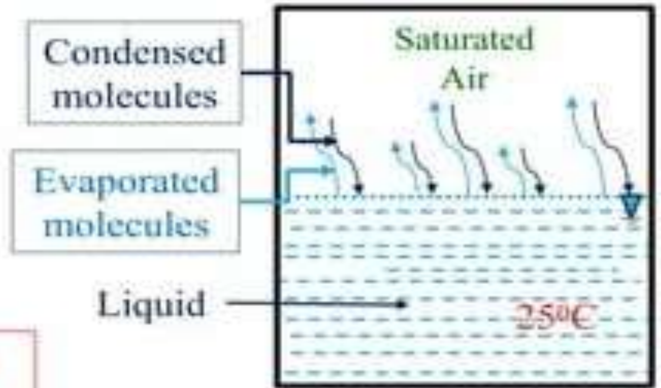



Fig.6: closed vessel

Note : With increase in temperature vapour pressure increases

# Week -3

## Lecture
## on
## Fluid Pressure

# Fluid Pressure

**Hydrostatic pressure** is the **pressure** that is exerted by a fluid at equilibrium at a given point within the fluid, due to the force of gravity.

**Hydrostatic Law:** It states that the intensity of pressure or the rate of increase of pressure in a vertical direction must be equal to the specific weight of fluid at that point.

**Unit:**

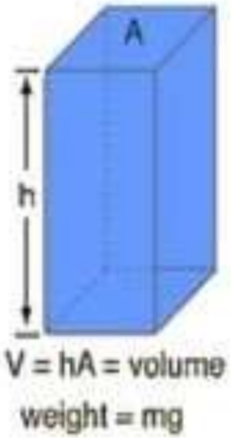
$N/m^2$ or Pascal

Density = Mass/Volume

OR

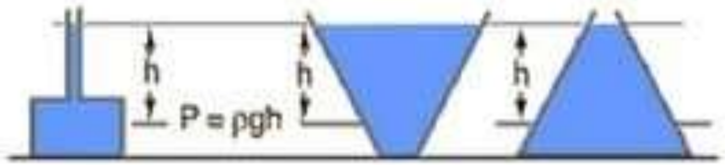
Mass = Density x Volume

= $\rho V$

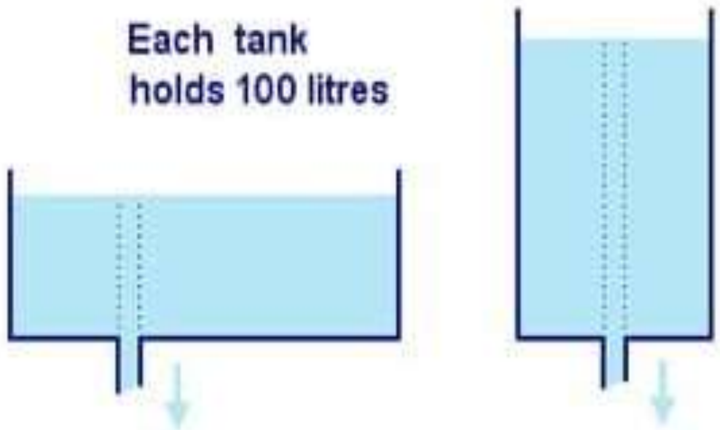


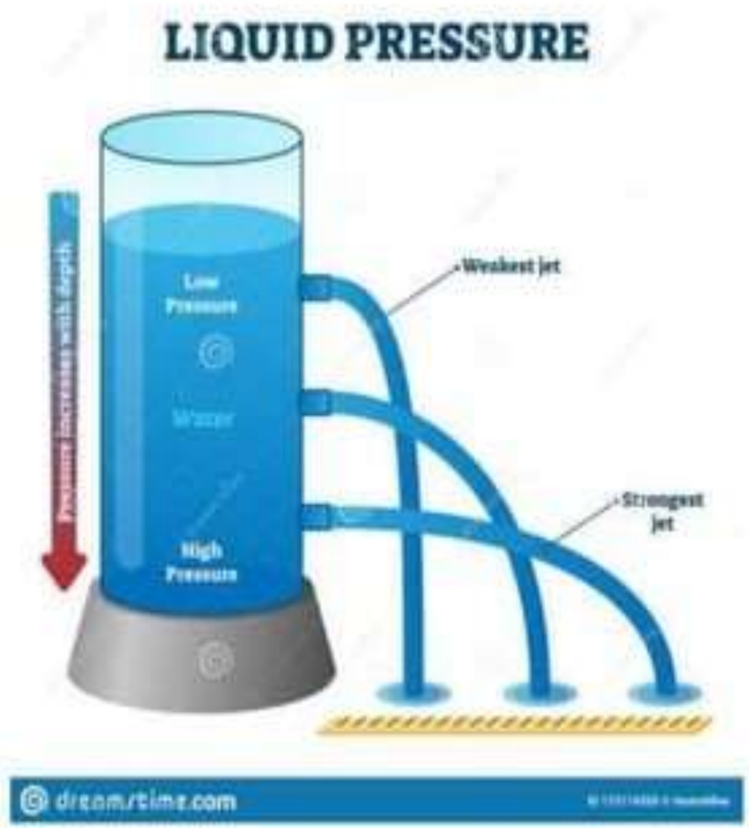

Static fluid pressure does not depend on the shape, total mass, or surface area of the liquid.

$$\text{Pressure} = \frac{\text{weight}}{\text{area}} = \frac{mg}{A} = \frac{\rho V g}{A} = \rho g h$$



## Pressure variation in a Fluid at Rest



# Types of Pressure

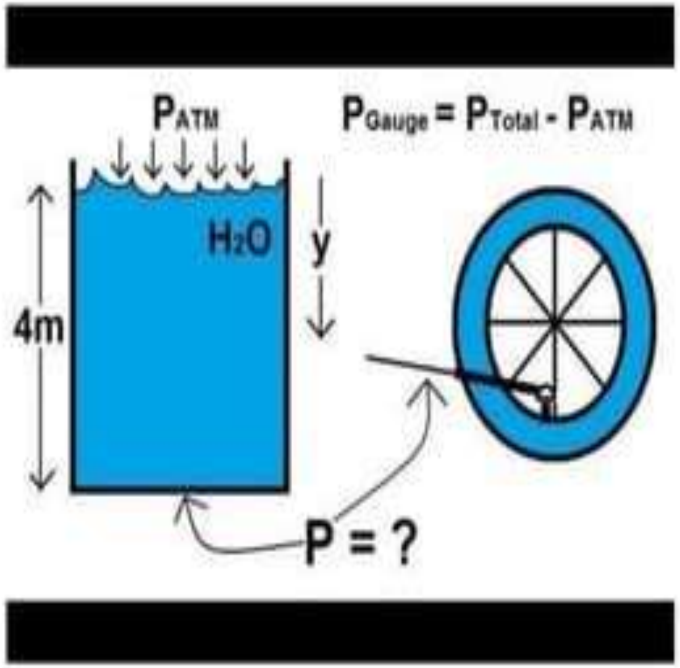
1. Gauge Pressure
2. Vacuum Pressure → Negative Gauge Pressure
3. Atmospheric Pressure → 101.325 kPa or
   1 bar or
   14.696 psi

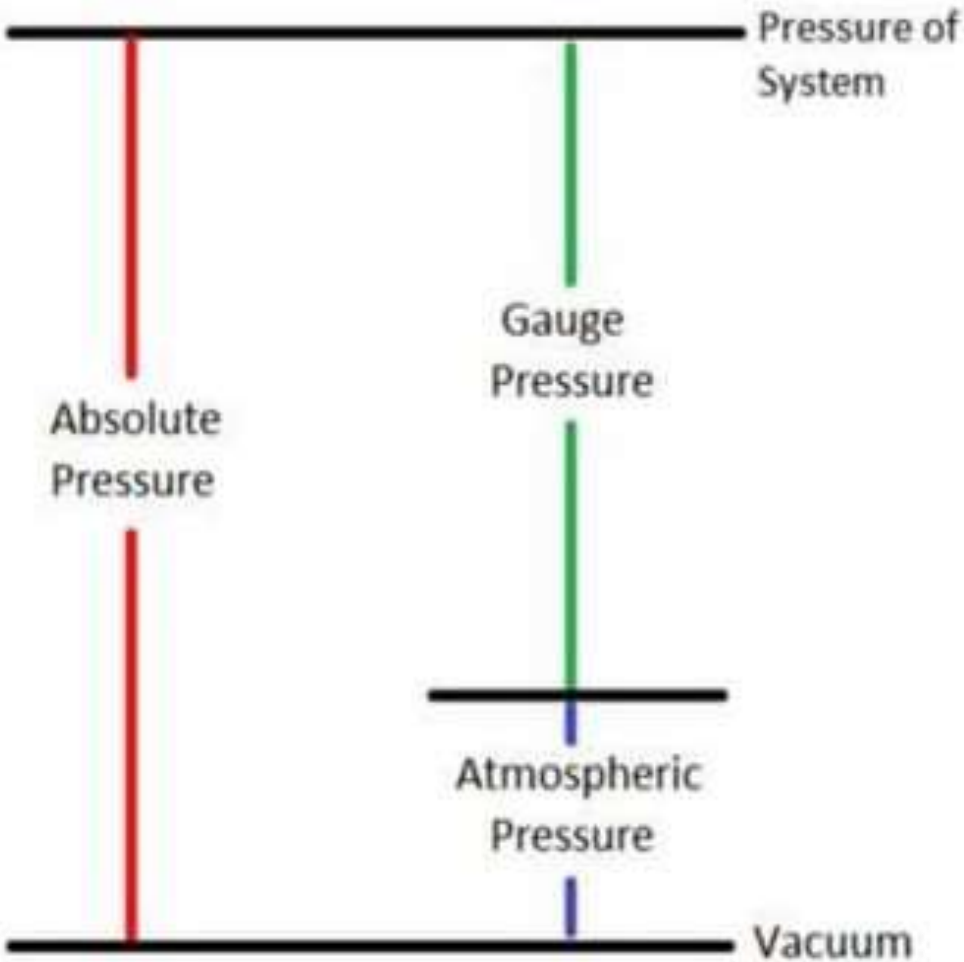
4. Absolute Pressure:

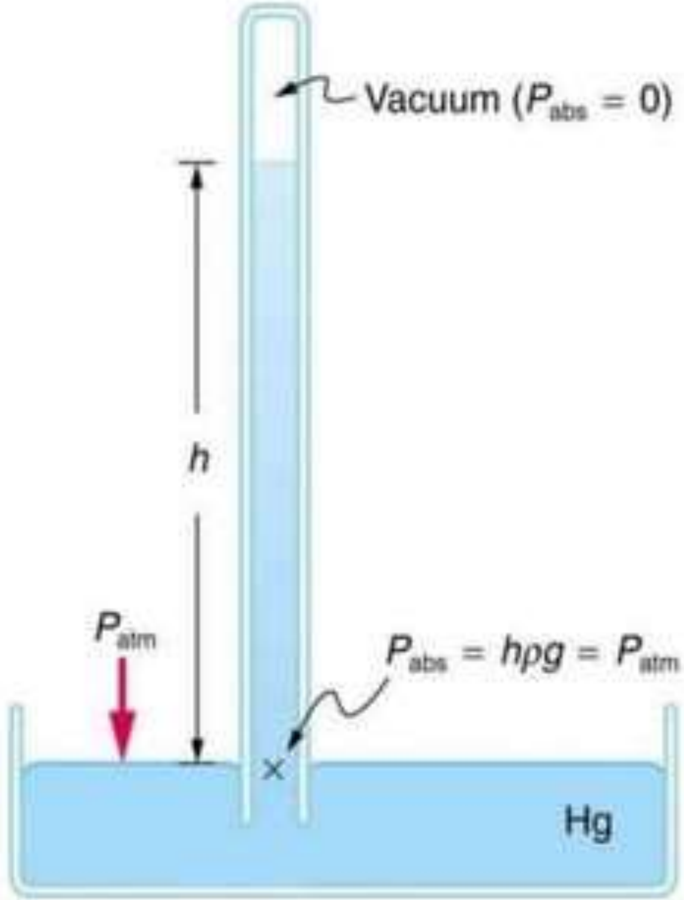
= Gauge Pressure + Atmospheric Pressure

OR

= Atmospheric Pressure – Vacuum Pressure




Pressure of System
Gauge Pressure
Absolute Pressure
Atmospheric Pressure
Vacuum


Vacuum ($P_{abs}$ = 0)
h
$P_{atm}$
$P_{abs} = h\rho g = P_{atm}$
Hg

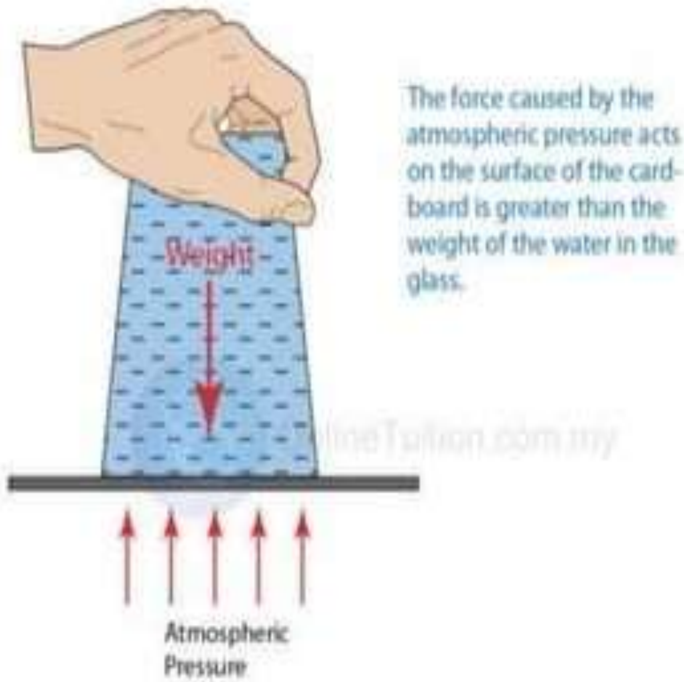
# Total Pressure

Total Pressure or Absolute Pressure is sum of Atmospheric Pressure and Fluid Pressure

$P_{total} = P_{atm} + \rho gh$

Atmospheric Pressure at the surface of the Earth stays relatively constant.

The value of the atmospheric pressure at the surface of the Earth, $P_{atm} = 1.01 \times 10^5$ Pa

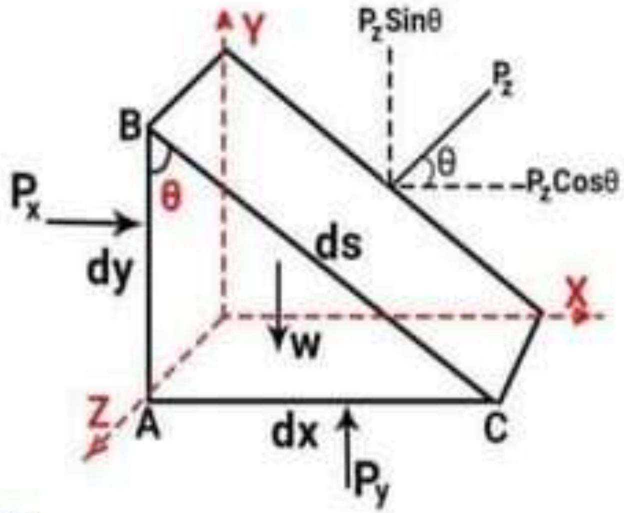


# Pascal's Law

Pascal's law states that the intensity of pressure at a point in a static fluid is equal in all the directions (x, y and z directions).

OR

The intensity of pressure at any point in a liquid at r same in all directions. i.e., $P_x = P_y = P_z$




This can be derived from

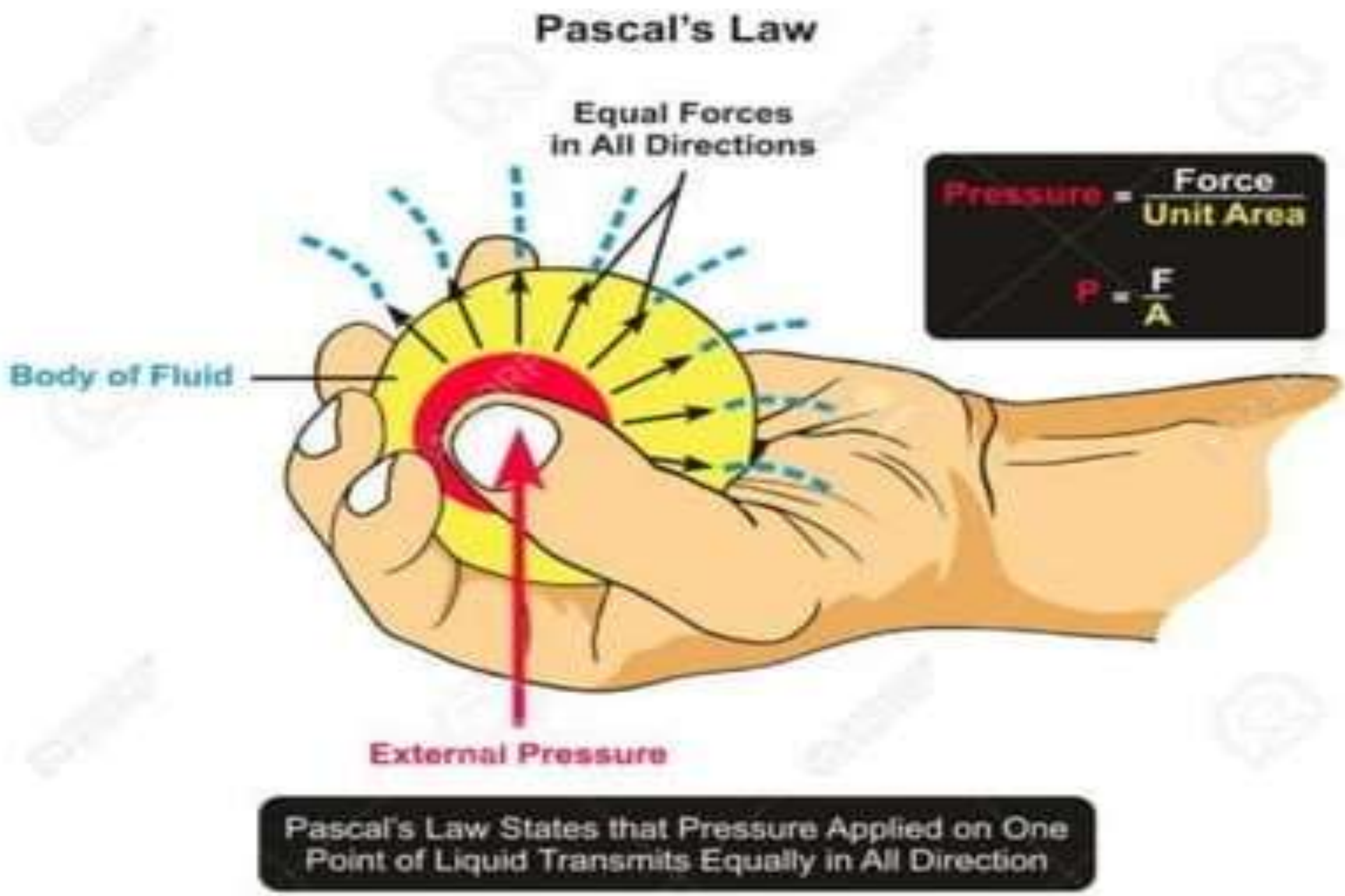
$\Sigma X = 0$

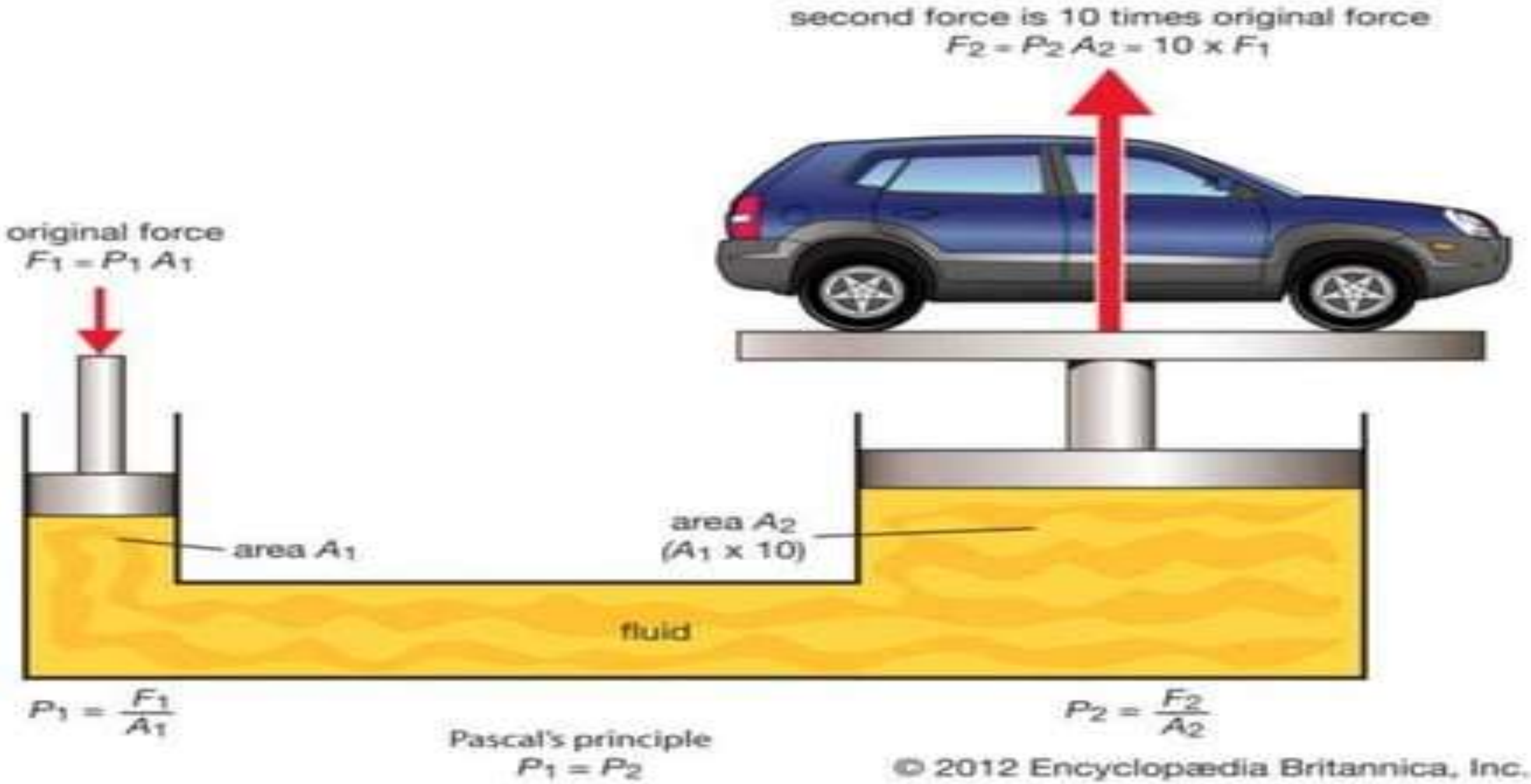
(consider Px and Pz cosθ)

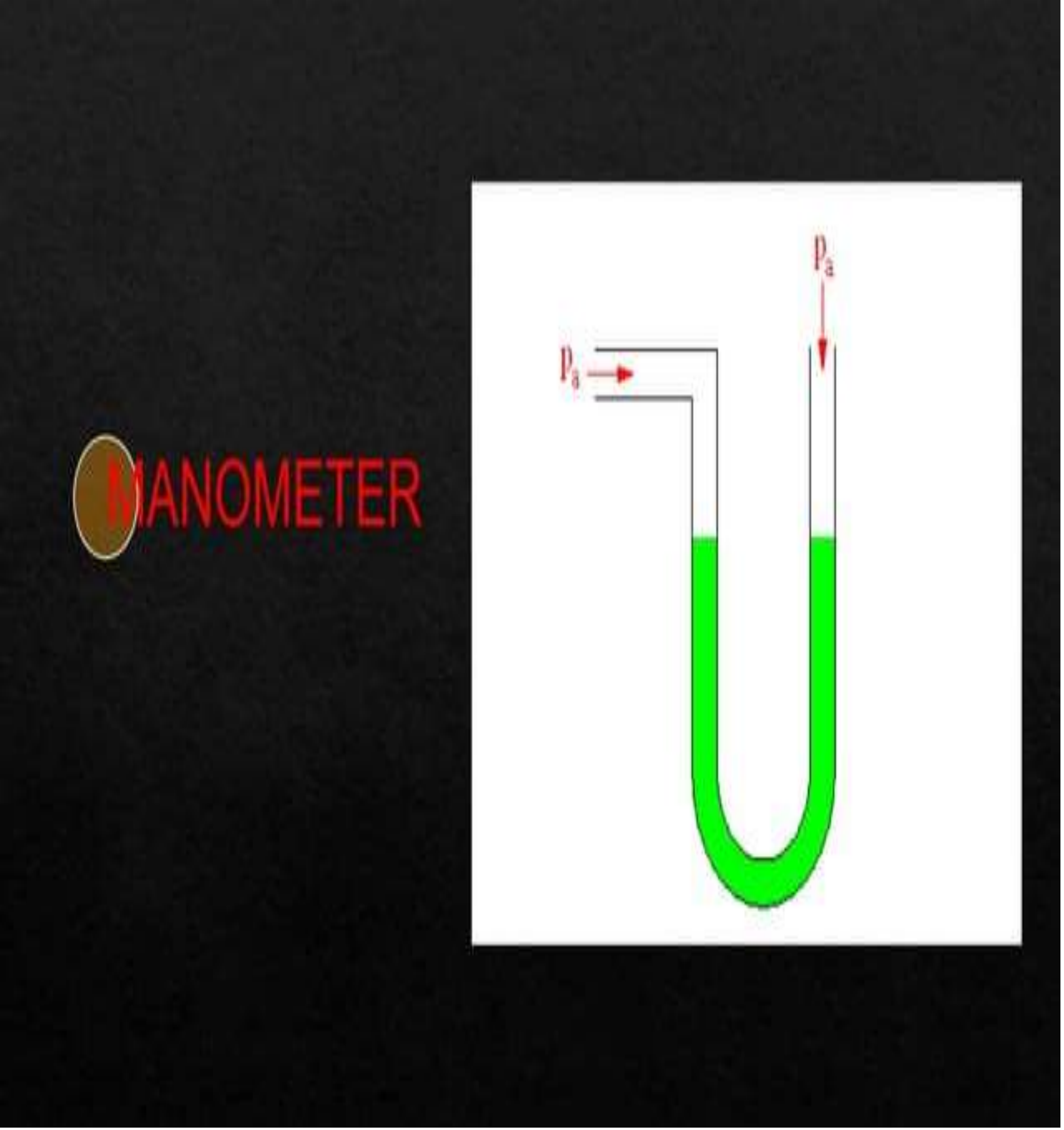
and

$\Sigma Y = 0$

(consider weight of fluid in addition to Py and Pz sinθ)


Pascal's Law
Equal Forces
in All Directions
Pressure = Force / Unit Area
P = F / A
Body of Fluid
External Pressure
Pascal's Law States that Pressure Applied on One
Point of Liquid Transmits Equally in All Direction


second force is 10 times original force
$F_2 = P_2 A_2 = 10 \times F_1$
original force
$F_1 = P_1 A_1$
area $A_1$
area $A_2$
($A_1 \times 10$)
fluid
$P_1 = \frac{F_1}{A_1}$
$P_2 = \frac{F_2}{A_2}$
Pascal's principle
$P_1 = P_2$
© 2012 Encyclopædia Britannica, Inc.




# Week -4

## Lecture on Manometer

# MANOMETER

A manometer is a device for measuring fluid pressure consisting of a bent tube containing one or more liquids of different densities.

A known pressure (which may be atmospheric) is applied to one end of the manometer tube and the unknown pressure (to be determined) is applied to the other end.

Differential pressure manometer measures only the difference between the two pressures.

# Classification of Manometers :

## Simple manometer:

- Piezometer
- U-tube manometer
- Single column manometer
- Vertical single column manometer
- Inclined single column manometer

## Differential manometer :

- U-tube differential manometer
- Inverted U-tube differential manometer

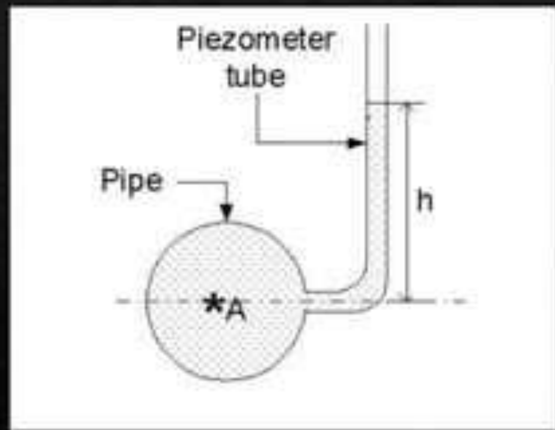
# PIEZOMETER

A piezometer is the simplest form of the manometer. It measures gauge pressure only.

The pressure at any point in the liquid is indicated by the height of the liquid in the tube above that point, which can read on the calibrated scale on glass tube.

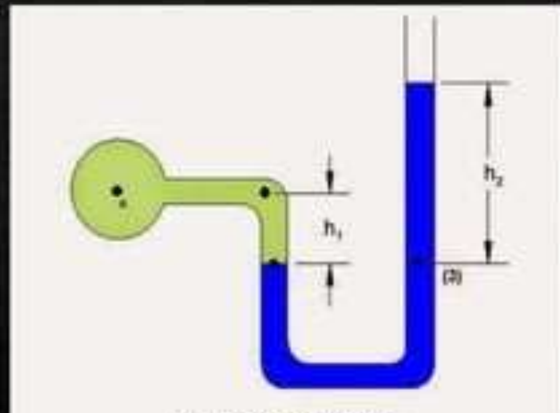
The pressure at point A is given by: $p = \rho g h = wh$

$\therefore h = p\ \rho g$ *piezometric head*



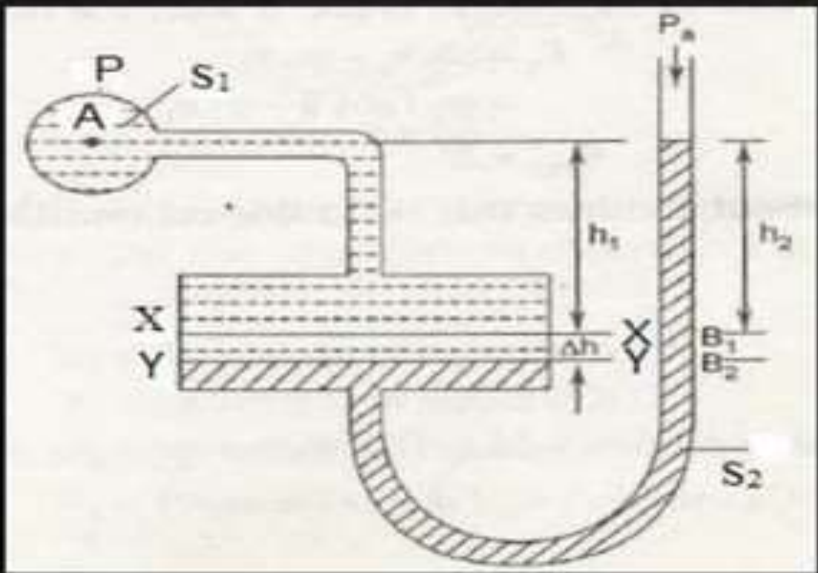
# U-TUBE MANOMETER

- Simplest manometer.
- Used in the measurement of liquid or gas pressure.
- Both legs have same area.
- Manometric fluid of known specific gravity is used.
- Mercury is generally used as fluid.

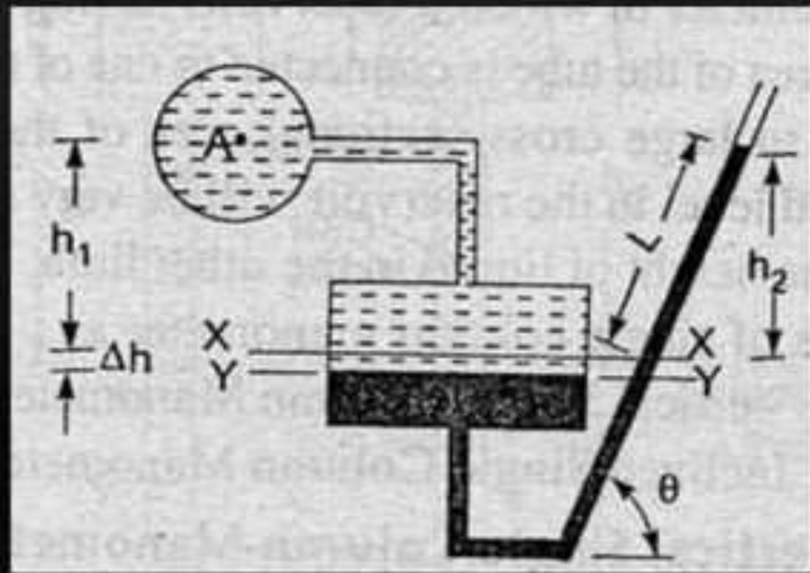


U - Tube Manometer

## VERTICAL SINGLE COLUMN MANOMETER



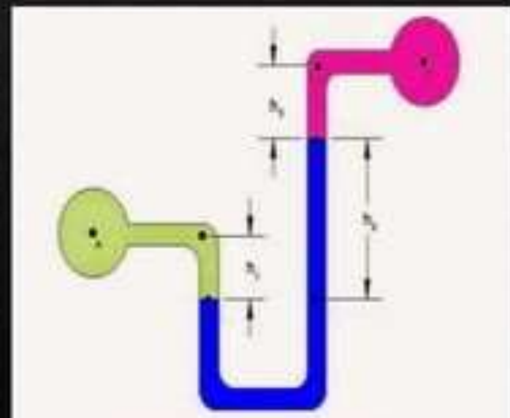

## INCLINED SINGLE COLUMN MANOMETER



# U TUBE DIFFERENTIAL MANOMETER

Differential U-tube manometer is extremely similar to the U-tube manometer as we tend to mentioned on top of. Here one open Location (which was thought-about as atmospheric Location in U-Tube manometer ) is connected to a different pressure Location i.e This manometer is largely used to observe the differences between to totally different points otherwise you will say we tend to calculate the difference.

Pressure distinction between A and B

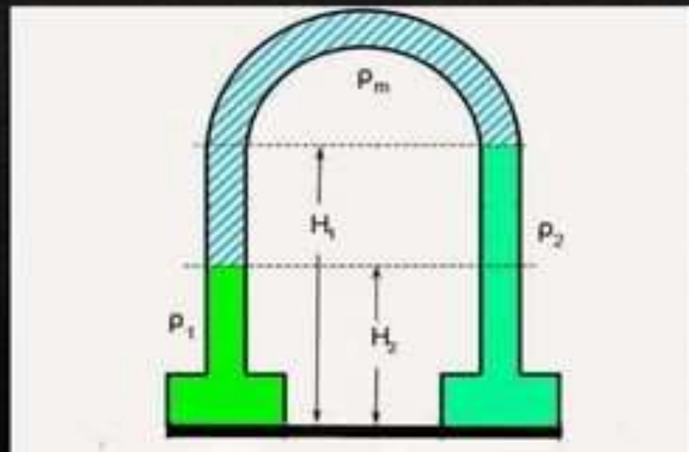


Differential U - Tube Manometer

# Inverted U-Tube Manometer

Inverted U-Tube manometer is employed for the measuring of tiny pressure differences in liquids. It consists of associate inverted U – Tube containing a light-weight liquid. this is often used to observe the differences of low pressures between 2points wherever higher accuracy is needed. It typically consists of associate air cock at prime of Mano-metric Liquid kind

Inverted U-tube differential manometer are used for mensuration the vacuum pressure. Inverted U-tube differential manometer can have one inverted U-tube contained with light-weight liquid.



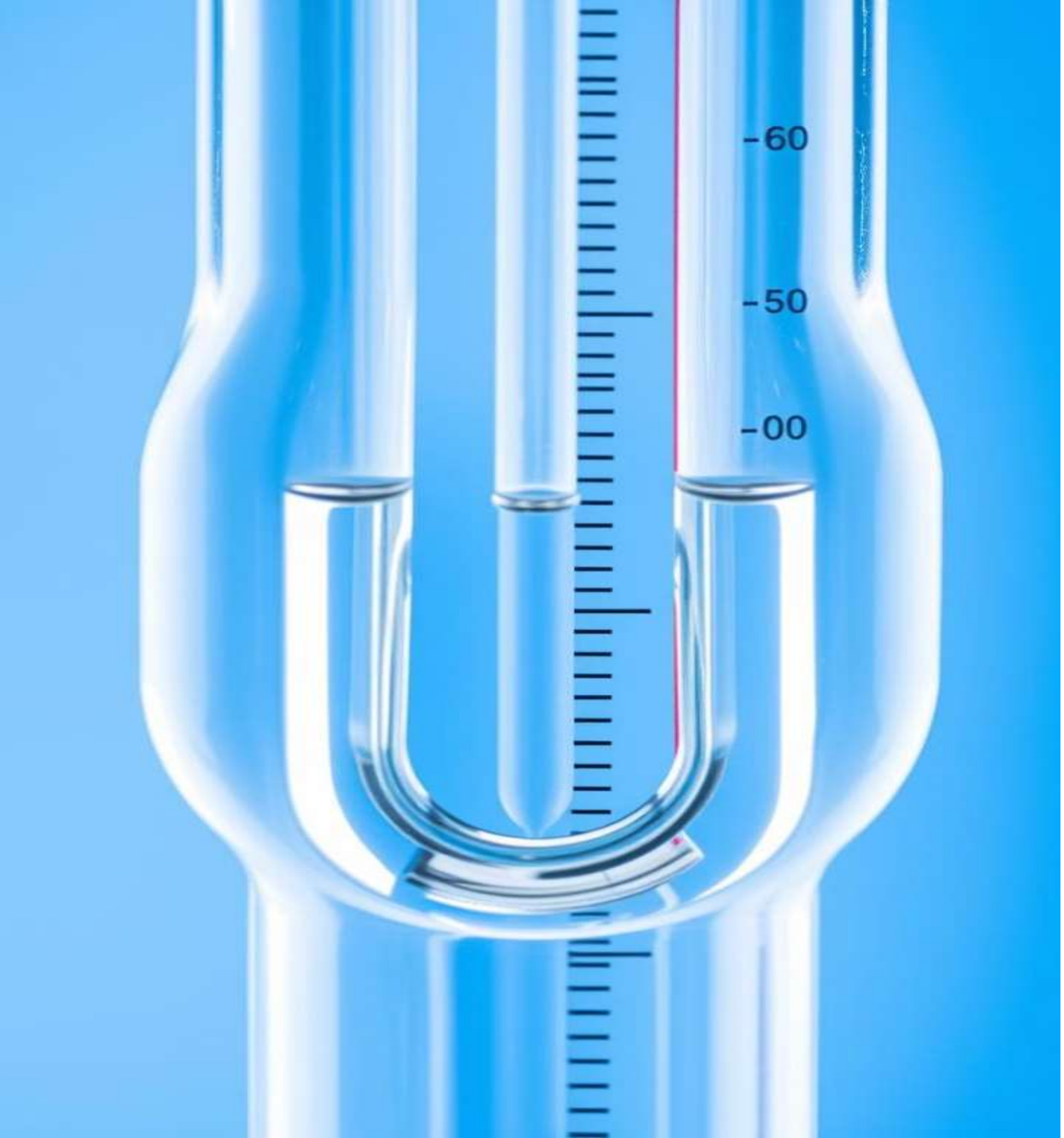
Inverted U tube Manometer

# Applications of Manometer

Liquid manometers, because of inherent accuracy and simplicity, have applications in every industry and laboratory. They are unique in being both basic pressure measurement instruments and standards for calibration of other instruments.

In addition to straight pressure and vacuum measurement, other process variables that are a function of pressure can be readily measured with a manometer.

Common applications are flow, filter pressure drop, meter calibrations, leak testing and tank liquid level.




# Week -5

**Lecture**

**on**

**Manometer Equation**

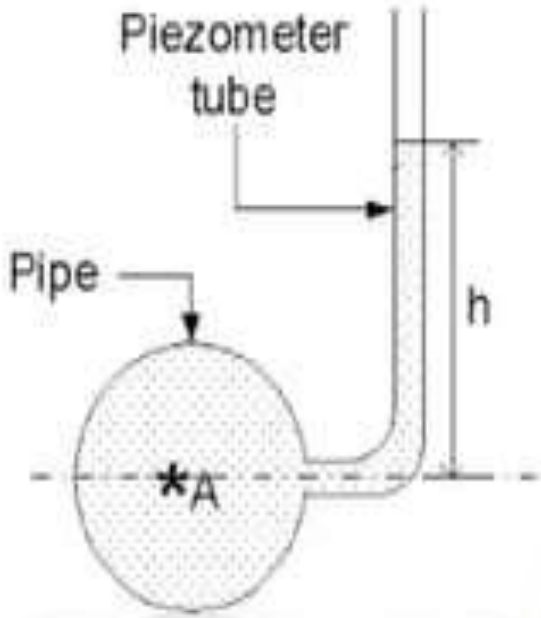
**&**

**Problem Solving**

# 1. Piezometer :

A piezometer is the simplest form of the manometer. It measures gauge pressure only.

The pressure at any point in the liquid is indicated by the height of the liquid in the tube above that point, which can read on the calibrated scale on glass tube.




The pressure at point A is given by;

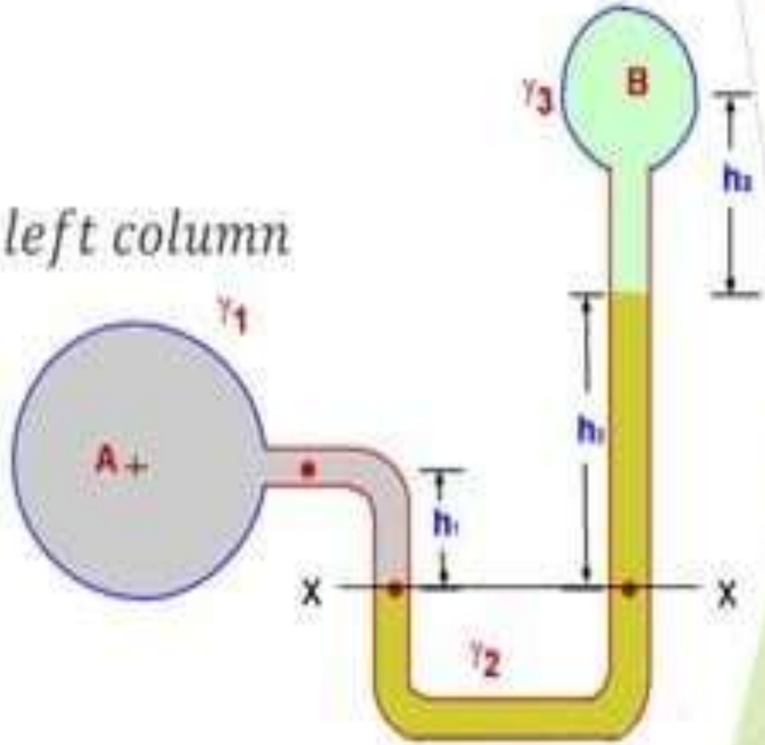
$$p = \rho g h = wh$$

$$\therefore h = \frac{p}{\rho g} \ \textit{piezometric head}$$

# 2. U-tube Manometer

:

It can be measure large pressure or vacuum pressure and gas pressure.




$\therefore Pressure\ at\ XX\ in\ left\ column$

$= Pressure\ at\ XX\ in\ left\ column$

$\therefore p + \rho_1 g h_1 = \rho_2 g h_2$

$\therefore p = \rho_2 g h_2 - \rho_1 g h_1$

$Now, p = \rho g h, h\ head\ in\ terms\ of\ water\ column,$

$\rho g h = \rho_2 g h_2 - \rho_1 g h_1$

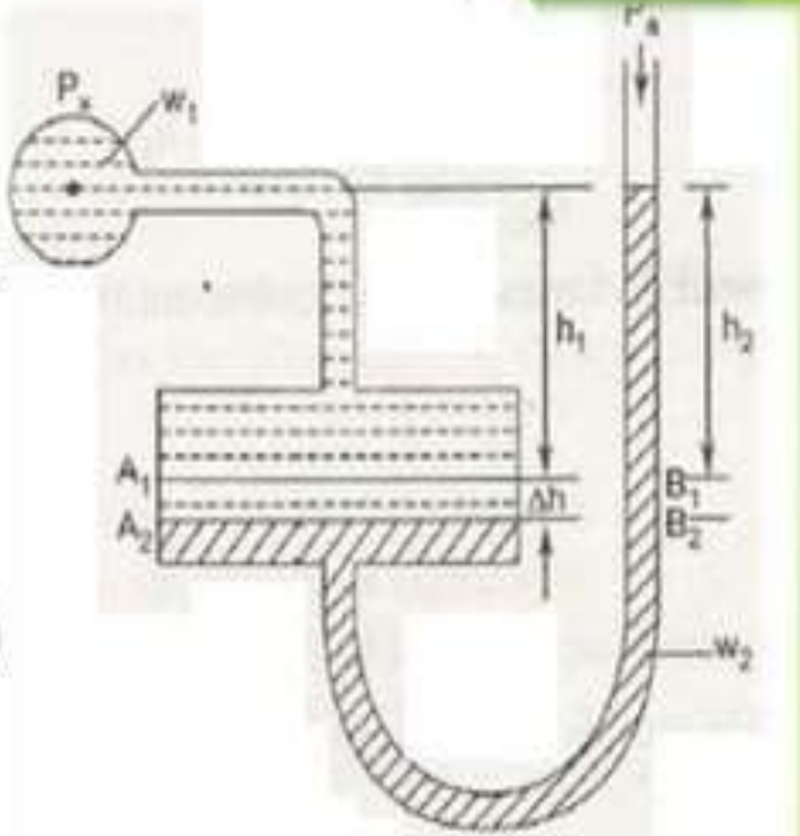
$\therefore h = \frac{\rho_2}{\rho} h_2 - \frac{\rho_1}{\rho} h_1$

$\therefore h = s_2 h_2 - s_1 h_1$

# 3. Single column Manometer :

## (A) Vertical single column manometer

One of the limbs in double column manometer is converted into a reservoir having large cross sectional area (about 100 times) with respect to the other limb.




$\therefore$ *Volume of heavy liquid fall in reservoir*
$=$ *Volume of heavy liquid rise in right column*

$$\therefore A \times \Delta h = a \times h_2 \rightarrow \Delta h = \frac{a \times h_2}{A}$$

Pressure in left col. = pressure in right col.

$$\therefore p = \frac{ah_2}{A}[\rho_2 g - \rho_1 g] + \rho_2 g h_2 - \rho_1 g h_1 \text{............(i)}$$

$$\therefore p = \rho_2 g h_2 - \rho_1 g h_1$$

# (B) Vertical single column manometer

It is modified of vertical column manometer. This manometer is useful for the measurement of small pressure.

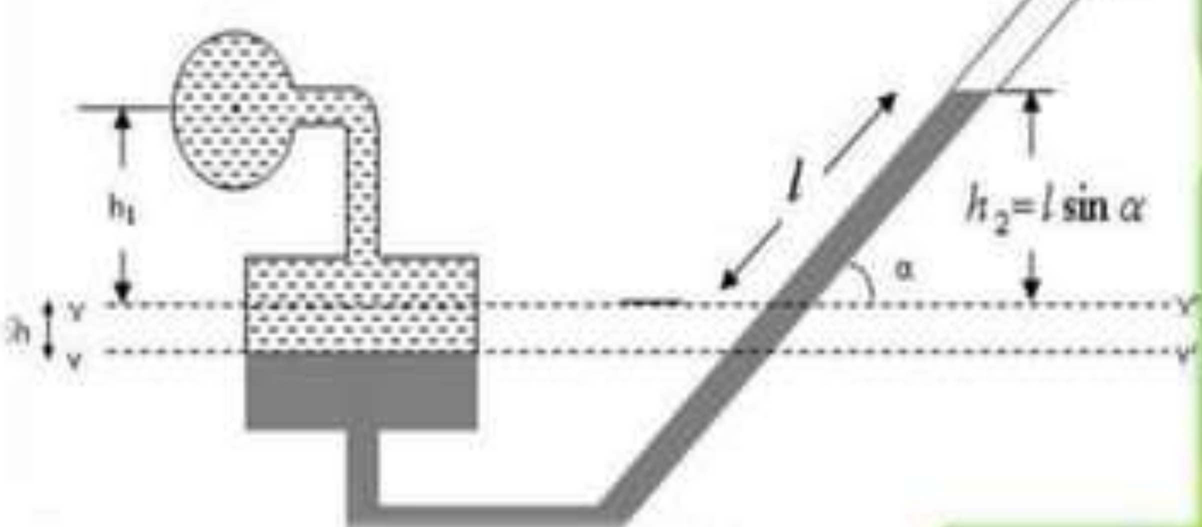
Here, $height\ h_2 = l\ sin\theta\ and\ putting\ in\ above\ eq.(i);$

$$\therefore p = \frac{al\ sin\theta}{A}[\rho_2 g - \rho_1 g] + \rho_2 g l sin\theta - \rho_1 g h_1$$

$since, a \ll A, neglecting\ first\ term;$

$$\therefore p = \rho_2 g l sin\theta - \rho_1 g h_1$$

$$\therefore h = s_2 l sin\theta - s_1 h_1$$



# 5. Inverted U-tube differential manometer

It is used for low pressure difference.

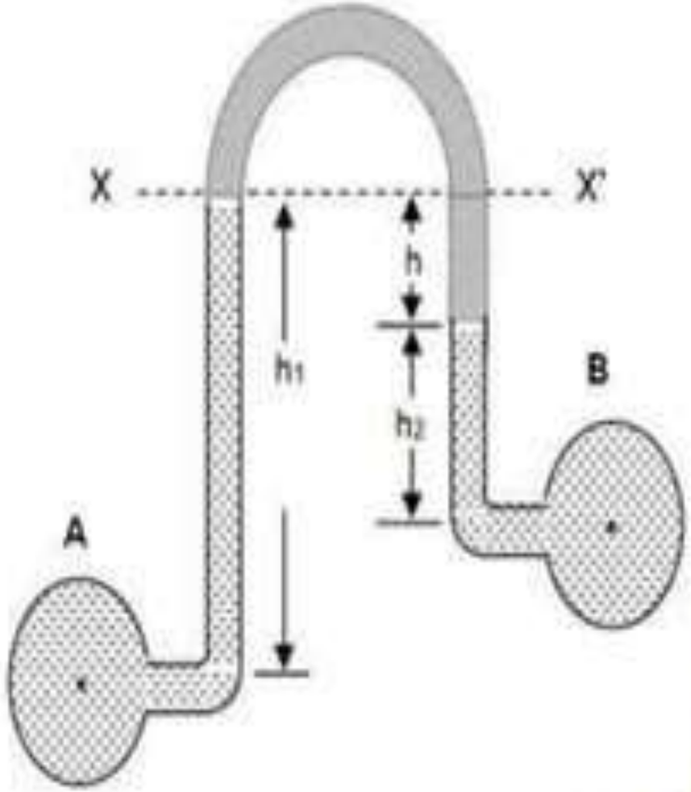
Left limb eq : $h_A - h_1 S_1$........................(i)

Right limb eq : $h_B - h_2 S_2 - hS$............(ii)

* Pressure is same at the datum line :

$$h_A + h_1 S_1 = h_B - h_2 S_2 - hS$$

$$h_A - h_B = h_1 S_1 - h_2 S_2 - hS$$



# U-tube Manometer

**Problem 2.9** *The right limb of a simple U-tube manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe in which a fluid of sp. gr. 0.9 is flowing. The centre of the pipe is 12 cm below the level of mercury in the right limb. Find the pressure of fluid in the pipe if the difference of mercury level in the two limbs is 20 cm.*

**Solution.** Given :

Sp. gr. of fluid, $S_1 = 0.9$

∴ Density of fluid, $\rho_1 = S_1 \times 1000 = 0.9 \times 1000 = 900 \text{ kg/m}^3$

Sp. gr. of mercury, $S_2 = 13.6$

∴ Density of mercury, $\rho_2 = 13.6 \times 1000 \text{ kg/m}^3$

Difference of mercury level, $h_2 = 20 \text{ cm} = 0.2 \text{ m}$

Height of fluid from $A$-$A$, $h_1 = 20 - 12 = 8 \text{ cm} = 0.08 \text{ m}$

Let $p$ = Pressure of fluid in pipe

Equating the pressure above $A$-$A$, we get

$$p + \rho_1 g h_1 = \rho_2 g h_2$$

or $$p + 900 \times 9.81 \times 0.08 = 13.6 \times 1000 \times 9.81 \times .2$$

$$p = 13.6 \times 1000 \times 9.81 \times .2 - 900 \times 9.81 \times 0.08$$

$$= 26683 - 706 = 25977 \text{ N/m}^2 = \mathbf{2.597 \text{ N/cm}^2}. \textbf{ Ans.}$$

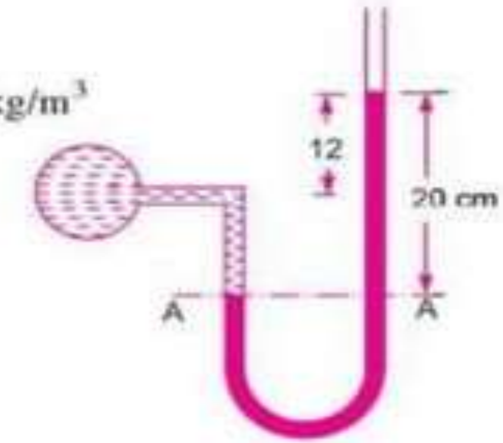



Fig. 2.10

# U-tube Manometer

**Problem 2.10** *A simple U-tube manometer containing mercury is connected to a pipe in which a fluid of sp. gr. 0.8 and having vacuum pressure is flowing. The other end of the manometer is open to atmosphere. Find the vacuum pressure in pipe, if the difference of mercury level in the two limbs is 40 cm and the height of fluid in the left from the centre of pipe is 15 cm below.*

**Solution.** Given :

| | |
|---|---|
| Sp. gr. of fluid, | $S_1 = 0.8$ |
| Sp. gr. of mercury, | $S_2 = 13.6$ |
| Density of fluid, | $\rho_1 = 800$ |
| Density of mercury, | $\rho_2 = 13.6 \times 1000$ |

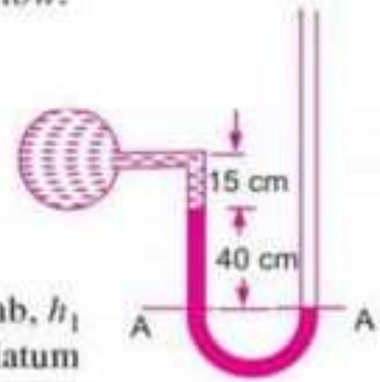


Fig. 2.11

Difference of mercury level, $h_2 = 40$ cm $= 0.4$ m. Height of liquid in left limb, $h_1 = 15$ cm $= 0.15$ m. Let the pressure in pipe $= p$. Equating pressure above datum line $A$-$A$, we get

$$\boxed{\rho_2 g h_2 + \rho_1 g h_1 + p = 0}$$

$$\therefore \quad p = -[\rho_2 g h_2 + \rho_1 g h_1]$$

$$= -[13.6 \times 1000 \times 9.81 \times 0.4 + 800 \times 9.81 \times 0.15]$$

$$= -[53366.4 + 1177.2] = -54543.6 \text{ N/m}^2 = \mathbf{-5.454\ N/cm^2}.\ \textbf{Ans.}$$

**Problem 2.14** *A single column manometer is connected to a pipe containing a liquid of sp. gr. 0.9 as shown in Fig. 2.17. Find the pressure in the pipe if the area of the reservoir is 100 times the area of the tube for the manometer reading shown in Fig. 2.17. The specific gravity of mercury is 13.6.*

**Solution.** Given :

Sp. gr. of liquid in pipe, $S_1 = 0.9$

∴ Density $\rho_1 = 900 \text{ kg/m}^3$

Sp. gr. of heavy liquid, $S_2 = 13.6$

Density, $\rho_2 = 13.6 \times 1000$

$$\frac{\text{Area of reservoir}}{\text{Area of right limb}} = \frac{A}{a} = 100$$

Height of liquid, $h_1 = 20 \text{ cm} = 0.2 \text{ m}$

Rise of mercury in right limb,

$h_2 = 40 \text{ cm} = 0.4 \text{ m}$

Let $p_A$ = Pressure in pipe

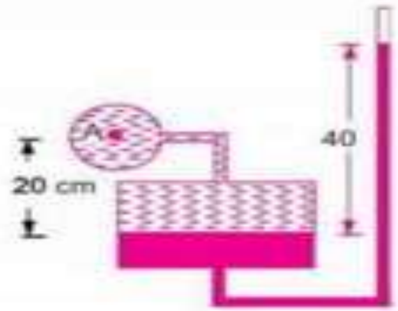



Fig. 2.17

Using equation (2.9), we get

$$p_A = \frac{a}{A} h_2[\rho_2 g - \rho_1 g] + h_2\rho_2 g - h_1\rho_1 g$$

$$= \frac{1}{100} \times 0.4[13.6 \times 1000 \times 9.81 - 900 \times 9.81] + 0.4 \times 13.6 \times 1000 \times 9.81 - 0.2 \times 900 \times 9.81$$

$$= \frac{0.4}{100}[133416 - 8829] + 53366.4 - 1765.8$$

$= 533.664 + 53366.4 - 1765.8 \text{ N/m}^2 = 52134 \text{ N/m}^2 =$ **5.21 N/cm². Ans.**

**Problem 2.17** *A differential manometer is connected at the two points A and B as shown in Fig. 2.20. At B air pressure is 9.81 N/cm² (abs), find the absolute pressure at A.*

**Solution.** Given :

Air pressure at $B = 9.81 \text{ N/cm}^2$

or $p_B = 9.81 \times 10^4 \text{ N/m}^2$

Density of oil $= 0.9 \times 1000 = 900 \text{ kg/m}^3$

Density of mercury $= 13.6 \times 1000 \text{ kg/m}^3$

Let the pressure at $A$ is $p_A$

Taking datum line at $X$-$X$

Pressure above $X$-$X$ in the right limb

$$= 1000 \times 9.81 \times 0.6 + p_B$$
$$= 5886 + 98100 = 103986$$

Pressure above $X$-$X$ in the left limb

$$= 13.6 \times 1000 \times 9.81 \times 0.1 + 900 \times 9.81 \times 0.2 + p_A$$
$$= 13341.6 + 1765.8 + p_A$$

Equating the two pressure heads

$$103986 = 13341.6 + 1765.8 + p_A$$

$\therefore$ $p_A = 103986 - 15107.4 = 88876.8$

$\therefore$ $p_A = 88876.8 \text{ N/m}^2 = \dfrac{88876.8 \text{ N}}{10000 \text{ cm}^2} = 8.887 \dfrac{\text{N}}{\text{cm}^2}$.

$\therefore$ Absolute pressure at $A =$ **8.887 N/cm². Ans.**

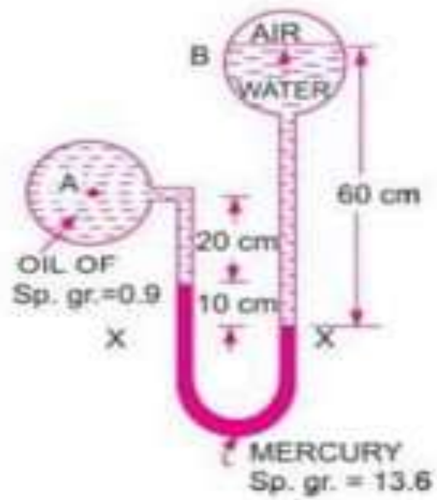



**Fig. 2.20**

**Problem 2.19** *In Fig. 2.23, an inverted differential manometer is connected to two pipes A and B which convey water. The fluid in manometer is oil of sp. gr. 0.8. For the manometer readings shown in the figure, find the pressure difference between A and B.*

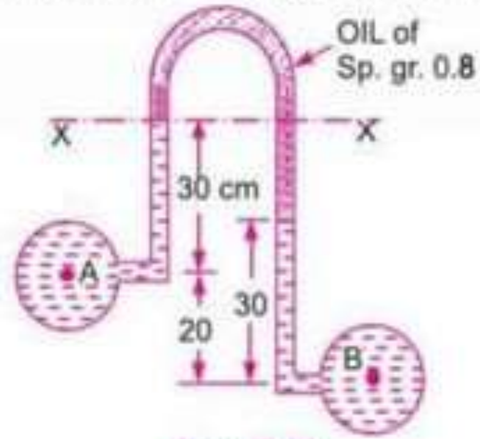


Fig. 2.23

**Solution.** Given :

Sp. gr. of oil $= 0.8 \quad \therefore \quad \rho_s = 800 \text{ kg/m}^3$

Difference of oil in the two limbs

$= (30 + 20) - 30 = 20 \text{ cm}$

Taking datum line at *X-X*

Pressure in the left limb below *X-X*

$= p_A - 1000 \times 9.81 \times 0$

$= p_A - 2943$

Pressure in the right limb below *X-X*

$= p_B - 1000 \times 9.81 \times 0.3 - 800 \times 9.81 \times 0.2$

$= p_B - 2943 - 1569.6 = p_B - 4512.6$

Equating the two pressure $p_A - 2943 = p_B - 4512.6$

$\therefore \quad p_B - p_A = 4512.6 - 2943 = \mathbf{1569.6 \ N/m^2}$. **Ans.**

**Problem 2.6** *An open tank contains water upto a depth of 2 m and above it an oil of sp. gr. 0.9 for a depth of 1 m. Find the pressure intensity (i) at the interface of the two liquids, and (ii) at the bottom of the tank.*

**Solution.** Given :

Height of water, $Z_1 = 2$ m

Height of oil, $Z_2 = 1$ m

Sp. gr. of oil, $S_0 = 0.9$

Density of water, $\rho_1 = 1000$ kg/m$^3$

Density of oil, $\rho_2 =$ Sp. gr. of oil $\times$ Density of water $= 0.9 \times 1000 = 900$ kg/m$^3$

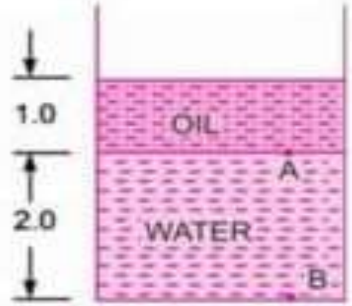


Fig. 2.4

Pressure intensity at any point is given by

$$p = \rho \times g \times Z.$$

(*i*) At interface, *i.e.*, at *A*

$$p = \rho_2 \times g \times 1.0$$
$$= 900 \times 9.81 \times 1.0$$
$$= 8829 \frac{\text{N}}{\text{m}^2} = \frac{8829}{10^4} = \mathbf{0.8829\ N/cm^2.\ Ans.}$$

(*ii*) At the bottom, *i.e.*, at *B*

$$p = \rho_2 \times gZ_2 + \rho_1 \times g \times Z_1 = 900 \times 9.81 \times 1.0 + 1000 \times 9.81 \times 2.0$$
$$= 8829 + 19620 = 28449 \text{ N/m}^2 = \frac{28449}{10^4} \text{ N/cm}^2 = \mathbf{2.8449\ N/cm^2.\ Ans.}$$

**Problem 2.1** *A hydraulic press has a ram of 30 cm diameter and a plunger of 4.5 cm diameter. Find the weight lifted by the hydraulic press when the force applied at the plunger is 500 N.*

**Solution.** Given :

Dia. of ram, $D = 30 \text{ cm} = 0.3 \text{ m}$

Dia. of plunger, $d = 4.5 \text{ cm} = 0.045 \text{ m}$

Force on plunger, $F = 500 \text{ N}$

Find weight lifted $= W$

Area of ram, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (0.3)^2 = 0.07068 \text{ m}^2$

Area of plunger, $a = \frac{\pi}{4} d^2 = \frac{\pi}{4} (0.045)^2 = .00159 \text{ m}^2$

Pressure intensity due to plunger

$$= \frac{\text{Force on plunger}}{\text{Area of plunger}} = \frac{F}{a} = \frac{500}{.00159} \text{ N/m}^2.$$

Fig. 2.3

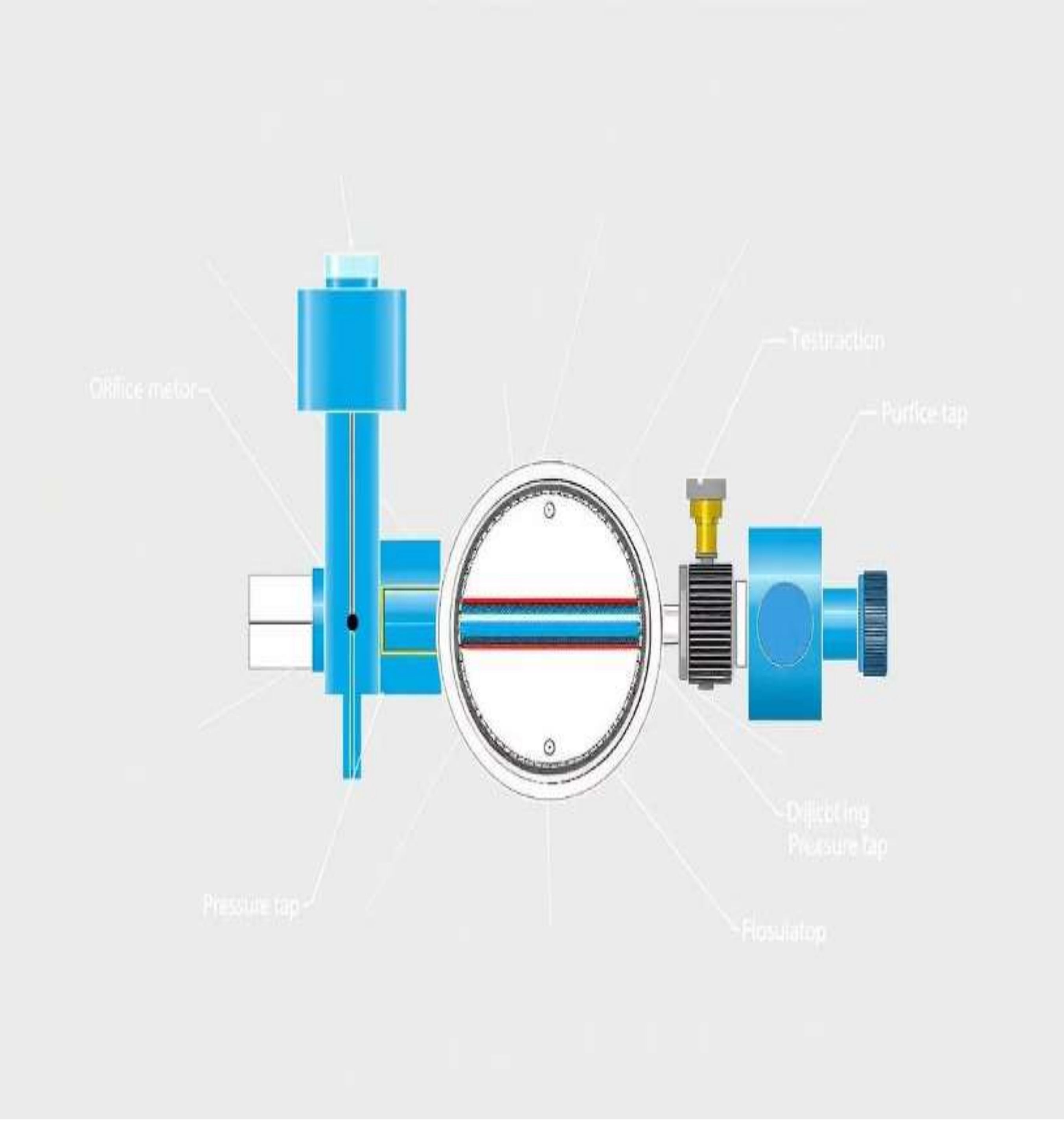
Due to Pascal's law, the intensity of pressure will be equally transmitted in all directions. Hence the pressure intensity at the ram

$$= \frac{500}{.00159} = 314465.4 \text{ N/m}^2$$

But pressure intensity at ram $= \frac{\text{Weight}}{\text{Area of ram}} = \frac{W}{A} = \frac{W}{.07068} \text{ N/m}^2$

$$\frac{W}{.07068} = 314465.4$$

$\therefore$ Weight $= 314465.4 \times .07068 = 22222 \text{ N} = \mathbf{22.222 \text{ kN}}$. **Ans.**

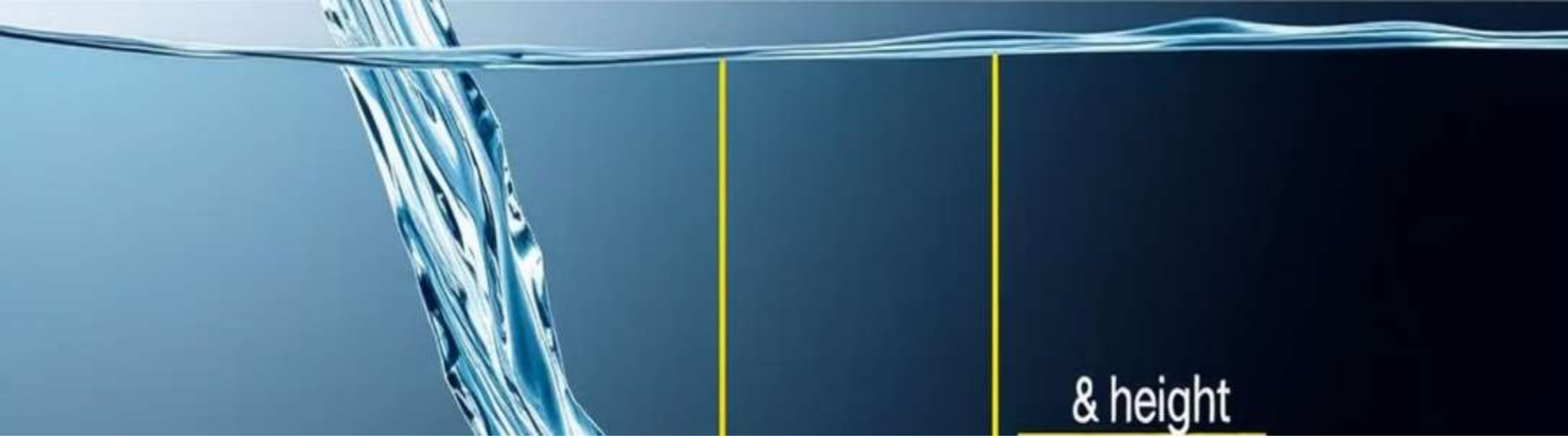



# Week -6

**Lecture**

**on**

**Bernoulli Equation**




# Bernoulli's Principle and Its Applications

1

### Conservation of Energy

Bernoulli's principle is a statement of energy conservation for an ideal fluid. It relates pressure, velocity, and height along a streamline.

2

### Applications

Bernoulli's principle is applied in numerous applications, including including aircraft lift generation, venturi meters, and fluid pumps. pumps.

# Bernoulli's Equation

Theory - Introduction

*Daniel Bernoulli*
(1700 – 1782)

**Bernoulli's principle** states that an increase in the speed of a fluid , decrease in pressure.

The principle is named after *Daniel Bernoulli* who published it in his book *Hydrodynamica* in 1738.

*Leonhard Euler* who derived **Bernoulli's equation** in its usual form in 1752.

*Leonhard Euler*
(1707 - 1783)

# Bernoulli's Principle

## Theory - Statement

The total mechanical energy of the moving fluid comprising the gravitational potential energy of elevation, the energy associated with the fluid pressure and the kinetic energy of the fluid motion, remains constant.

Mathematical form:

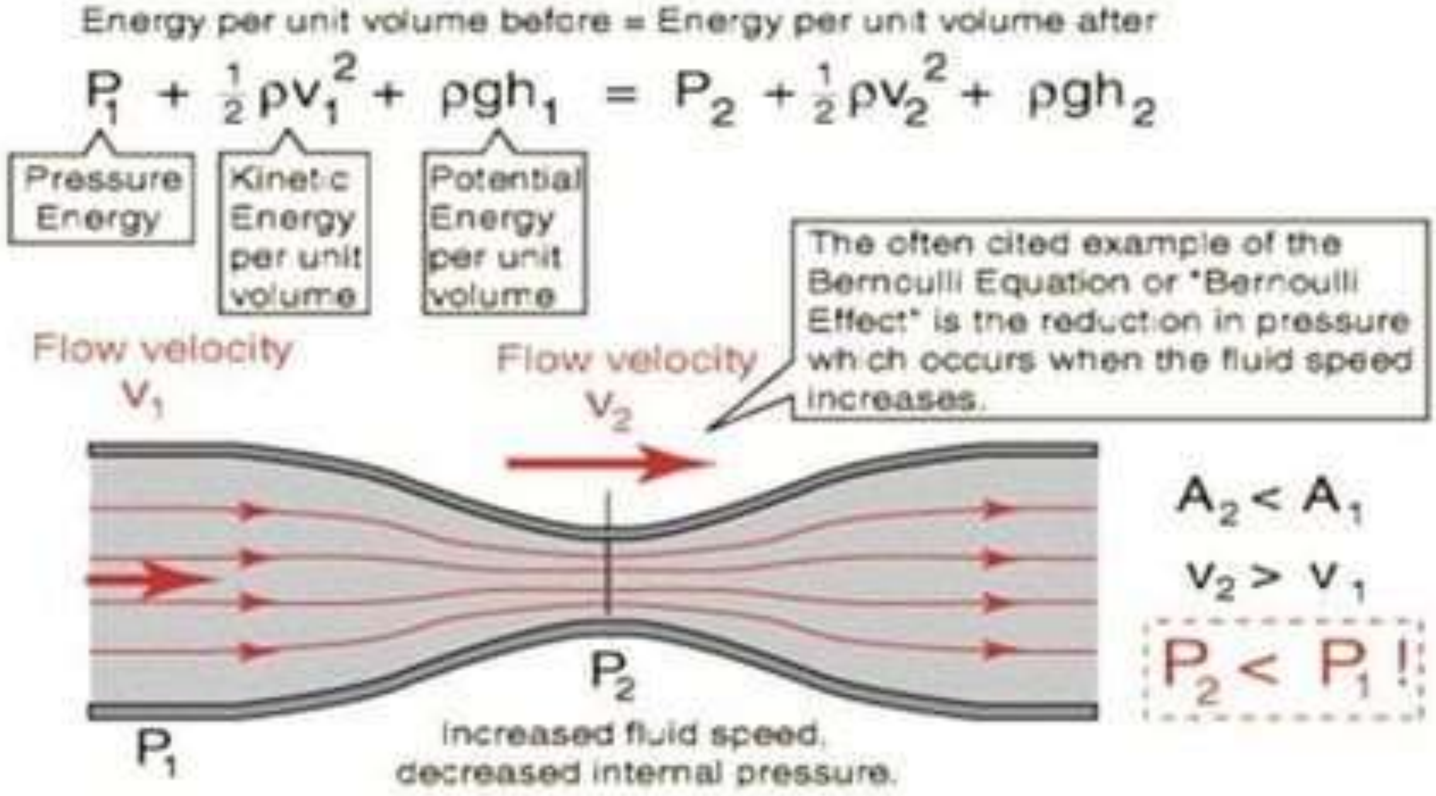
$$P + \frac{1}{2}mv^2 + mgh = \text{constant}$$

pressure ⟷ velocity ⟷ height

Applicable :

- Incompressible
- Steady
- Non viscous

# WHAT IS BERNOULLI EQUATION ?

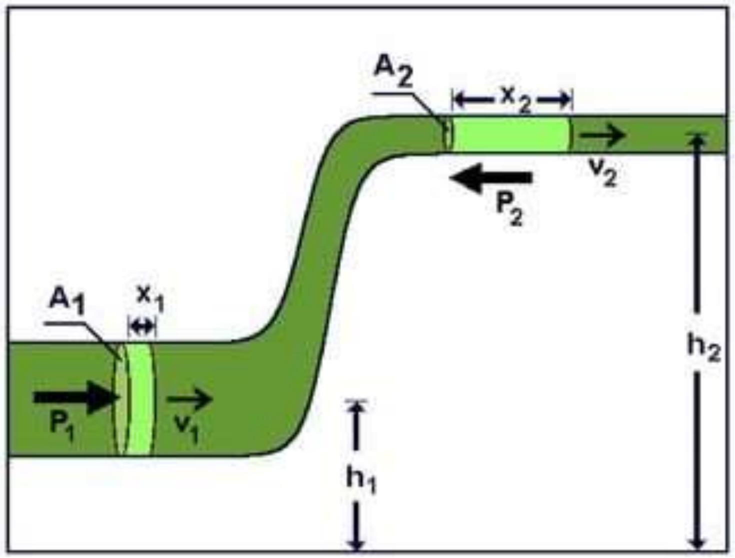


# Bernoulli's Equation

## Explanation

Consider the following diagram where water flows from left to right in a pipe that changes both area and height.

When fluid move upward, the water will be gaining gravitational potential energy $U_g$ as well as kinetic energy $K$.



# Derivation

## Work done on the fluid:

$$W_1 = F_1\, \Delta x_1$$

As

$$P = \frac{F}{A}$$

$$F = PA$$

Then

$$W_1 = P_1\, A_1\, \Delta x_1$$

In terms of velocity

$$V_1 = \frac{\Delta x_1}{t}$$

$$\Delta x_1 = V_1\, t$$

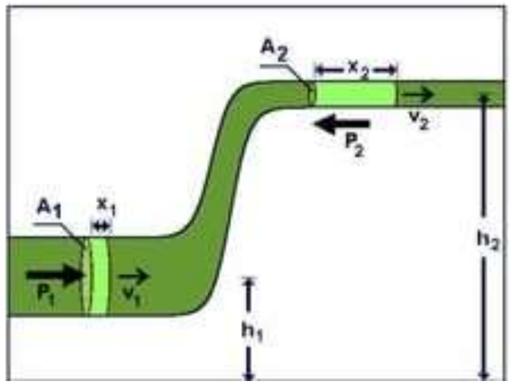
$$W_1 = P_1\, A_1 V_1\, t$$

$$W_2 = -F_2\, \Delta x_2$$

$$W_2 = -P_2\, A_2\, \Delta x_2$$

$$W_2 = -P_2\, A_2 V_2\, t$$

- The water at $P_2$ will do negative work on our system since it pushes in the opposite direction as the motion of the fluid.

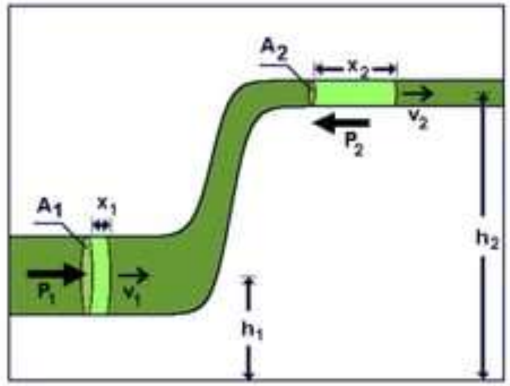


# Derivation

## Net Work done on the fluid:

$$W_{net} = W_1 + W_2$$

$$W_{net} = P_1 A_1 V_1 t - P_2 A_2 V_2 t$$




- The Volume of both sections are equal

$$A_1 V_1 t = A_2 V_2 t = V$$

So

$$W = P_1 V - P_2 V$$

$$W = (P_1 - P_2) V$$

$$W = (P_1 - P_2) V$$

$$W = (P_1 - P_2) \frac{m}{\rho}$$

As we know
(Density)

$$\rho = \frac{m}{V}$$

$$V = \frac{m}{\rho}$$

# Derivation

**Work Energy Principle:**

Work done = change in energy

$W = \Delta\,(K.E) + \Delta\,(P.E)$ —— (1)

**Changing in Δ (K.E) :**

$$\Delta\,(K.E) = \frac{1}{2}mv^2$$

$$\Delta\,(K.E) = \frac{1}{2}mv_2^{\,2} - \frac{1}{2}mv_1^{\,2}$$

**Changing in Δ (P.E) :**

$$\Delta\,(P.E) = mgh$$

$$\Delta\,(P.E) = mgh_2 - mgh_1$$

Put the values in equ (1)

$$(P_1 - P_2)\frac{m}{\rho} = \frac{1}{2}mv_2^{\,2} - \frac{1}{2}mv_1^{\,2} + mgh_2 - mgh_1$$

$$(P_1 - P_2)\frac{m}{\rho} = m\,(\frac{1}{2}v_2^{\,2} - \frac{1}{2}v_1^{\,2} + gh_2 - gh_1)$$

$$(P_1 - P_2) = \frac{1}{2}\rho v_2^{\,2} - \frac{1}{2}\rho v_1^{\,2} + \rho gh_2 - \rho gh_1)$$

$$P_1 + \frac{1}{2}\rho V_1^{\,2} + \rho gh_1 = P_2 + \frac{1}{2}\rho V_2^{\,2} + \rho gh_2$$

This is Bernoulli's equation!

**Generalize:**

$$P + \frac{1}{2}mv^2 + mgh = \text{constant}$$

This constant will be different for different fluid systems, but the value of $P + \frac{1}{2}mv^2 + mgh$ will be the same at any point along the flowing fluid.

## ENERGY FORM:

$$\frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2 = \frac{P_1}{\rho} + \frac{V_1^2}{2} + gz_1$$

Pressure energy + Kinetic energy + potential energy = constant

## HEAD FORM:

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

Pressure head + kinetic head + potential head = constant

## PRESSURE FORM:

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

Static pressure + dynamic pressure + hydrostatic pressure = constant

# APPLICATIONS:

- Sizing of Pumps
- Flow sensors
- Ejectors
- Carburetor
- Siphon
- Pitot tube

# APPLICATION IN PUMPS:

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

The conversion of kinetic energy into pressure is according  to the Bernoulli equation.

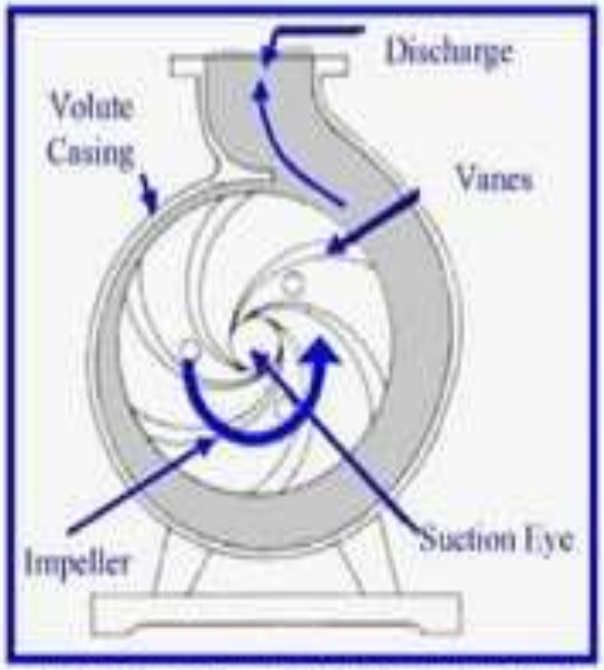



Figure A.01: Liquid flow path inside a centrifugal pump

# PITOT TUBE

Pitot tube is a pressure measurement instrument Used to measure fluid flow velocity.

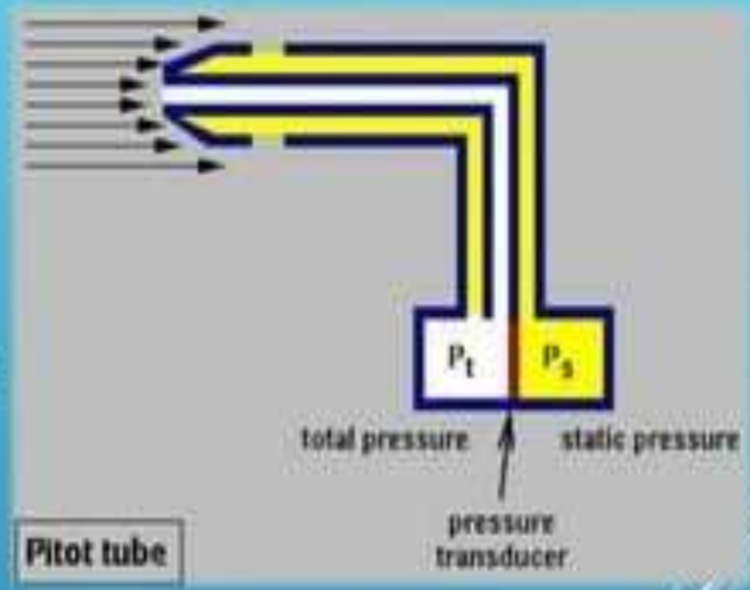
Pitot tubes can be used to indicate fluid flow velocity by measuring the difference between the static and dynamic pressures in fluids.

The principle is based on the Bernoulli Equation.

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

$$P_2 = P_1 + \frac{\rho V_1^2}{2}$$

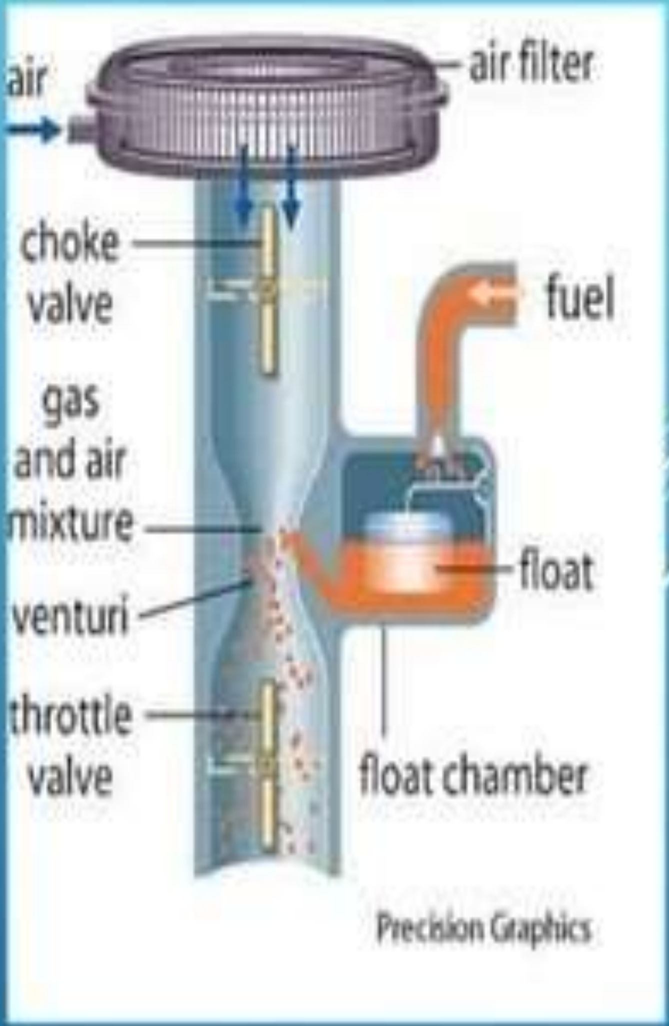
$$V_1 = \sqrt{\frac{2(P_t - P_s)}{\rho}}$$




# CARBURETOR:

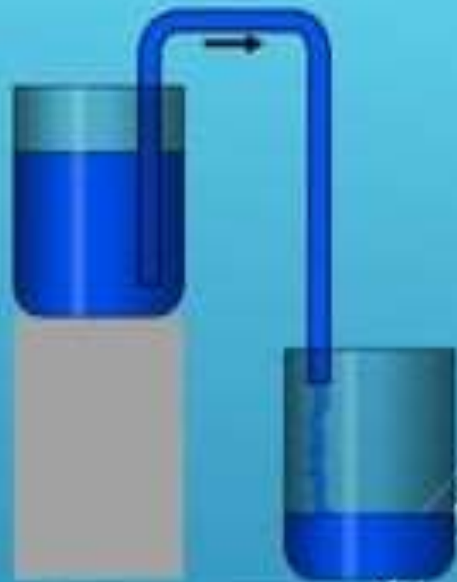
The carburetor works on Bernoulli principle: the faster air moves, the lower its static pressure, and the higher its dynamic pressure.

The throttle (accelerator) linkage does not directly control the flow of liquid fuel. Instead, it actuates carburetor mechanisms which meter the flow of air being pulled into the engine. The speed of this flow, and therefore its pressure, determines the amount of fuel drawn into the airstream.



# SIPHON

Siphon, a bent tube used to move a liquid over an obstruction to a lower level without pumping. A siphon is most commonly used to remove a liquid from its container. The siphon tube is bent over the edge of the container, one end in the liquid and the other outside end at a lower level than the surface of the liquid in the container.



**Static pressure + dynamic pressure + hydrostatic pressure=constant**

$$\frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2 = \frac{P_1}{\rho} + \frac{V_1^2}{2} + gz_1$$

$$0 + \frac{V_2^2}{2} + 0 = 0 + 0 + gH$$

$$V_2 = \sqrt{2gH}$$

# Week -7

**Lecture**

**on**

**Reynolds Number**

**Osborne Reynolds**

- Distinguish between laminar flow and turbulent flow

**Dimensional analysis**

- Characteristic
- Length L
- Velocity v
- Density $\rho$
- Viscosity μ

**Reynolds number**

$$R_e = \frac{\rho v l}{\mu}$$

## Reynolds' observations of the nature of the flow in his experiment:

From these experiments came the dimensionless Reynolds number which is the ratio of inertial forces to viscous forces.

$$Re = \frac{\text{Inertial Forces}}{\text{Viscous Forces}} = \frac{\rho v L}{\mu}$$

Inertial forces : resistance of an object to change in its state of motion
( Promotes Turbulent Flow )

Viscous forces : resistance of a liquid to change of form
( promotes laminar flow )

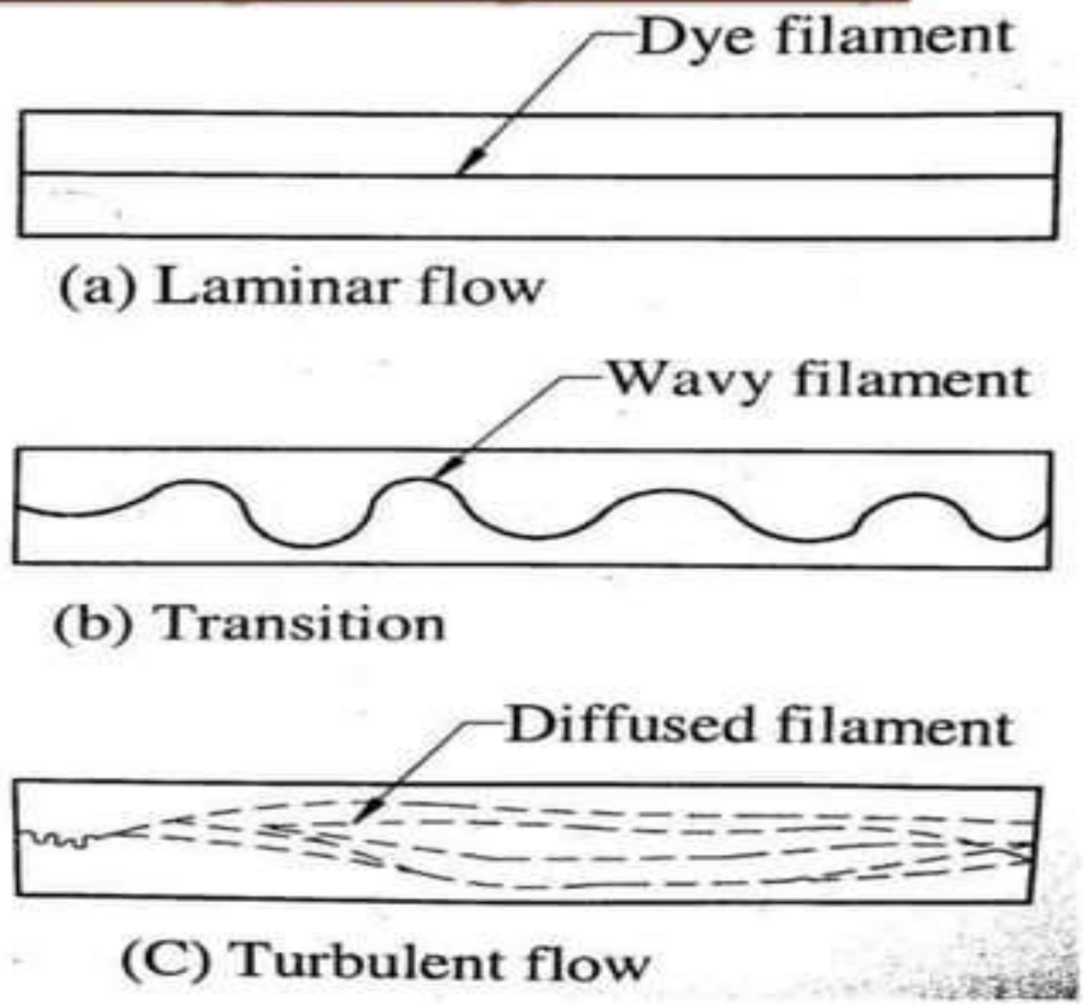
characteristic Length L (SI units : m )
Velocity v ( m/s)
(Kg/m^3)ρ Density
Viscosity μ (Pa. S or N .S/ or Kg/m .s )

# Observation by Reynolds

1. At low velocity, the dye will move in a line parallel to the tube and also it does not get dispersed.

2. At velocity little more than before the dye moves in a wave form.

3. At more velocity the dye will no longer move in a straight-



# Types Of Flows Based On Reynold Number:-

- If Reynold number, $R_N < 2000$ the flow is **laminar flow**.

- If Reynold number, $R_N > 4000$ the flow is **turbulent flow.**

- If Reynold number i.e. 2000 < $R_N$ < 4000,we observe a flow in which we can see both laminar and turbulent flow to gather. This flow is called **Transition flow.**

- $R_N = 2300$ is usually accepted as the value at transition , $R_N$ that exists anywhere in the transition region is called the **critical Reynolds number.**

## The Reynolds Number can be expressed in terms of Discharge (Q)

$$\text{Flow}(Q) = V \times A \text{ (continuity equation)}$$

$$\text{For a pipe } (Q) = V \times [\pi \left( {}^{1}/_{2}\, d \right)^{2}$$

$$\rho = \frac{\gamma}{g}$$

$$V = \frac{Q}{\pi ( {}^{1}/_{2} d^{2} )} \rightarrow Re = \frac{\rho . v . L}{\mu} \rightarrow Re \sim \frac{\rho \; Q}{d \; \mu}$$

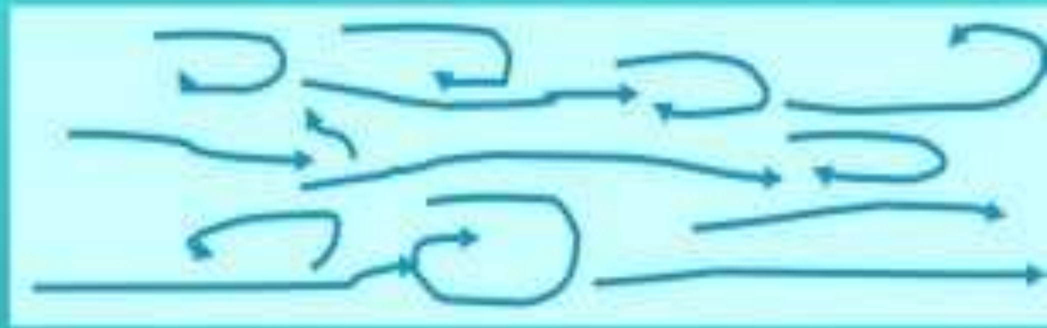
## For Low Reynolds numbers the flow is Laminar

3 conditions
fluid moves slowly
viscosity is relatively high
flow channel is relatively small

***Blood flow through capillaries is laminar flow, as it satisfies the 3 conditions***

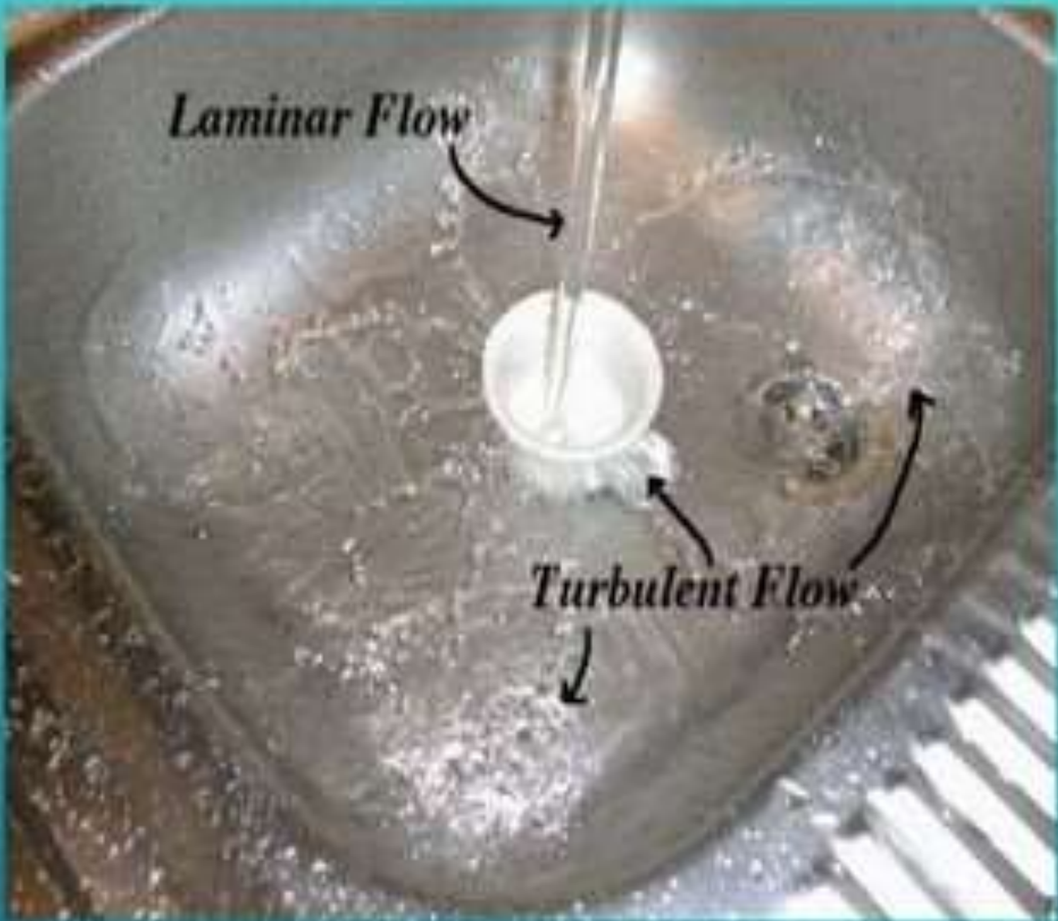
A laminar flow is characterized by smooth, orderly and slow motions. Streamlines are parallel and adjacent layers (laminae) of fluid slide past each other with little mixing and transfer (only at molecular scale) of properties across the layers. A small perturbation does not increase with time. The flow is regular and predictable.

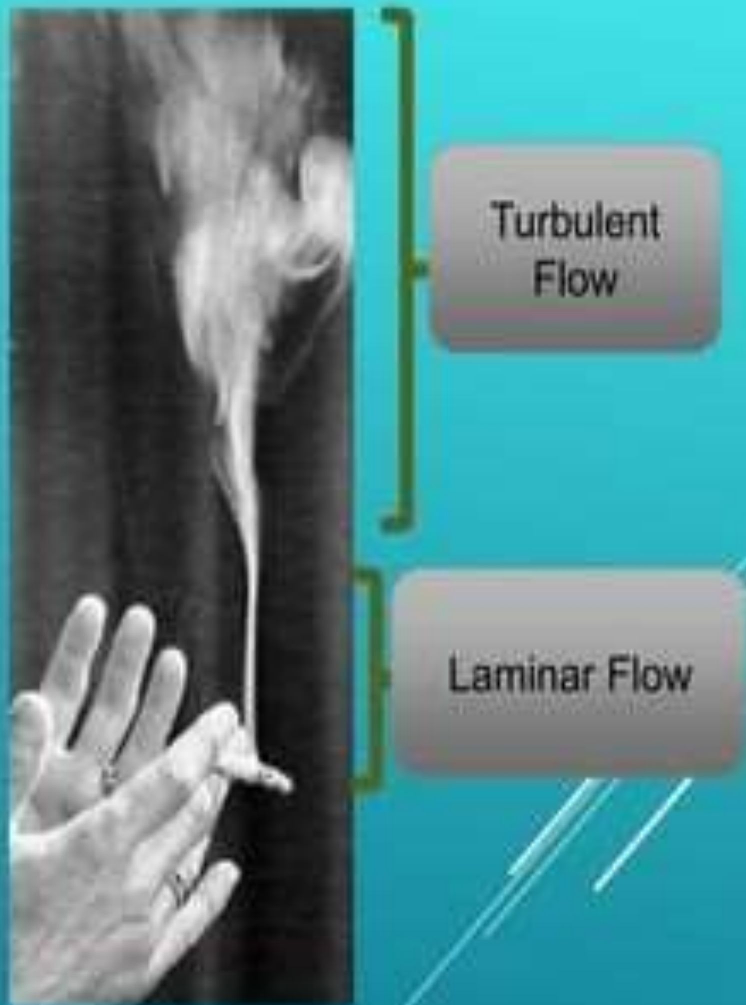
## For high Reynolds numbers the flow is turbulent



**Examples of turbulence :**
- Oceanic and atmospheric layers and ocean currents
- External flow of air/water over vehicles such as cars/ships/submarines
- In racing cars, e.g. leading car causes understeer at fast corners
- Turbulence during air-plane's flight

Turbulent flows are highly irregular, three-dimensional, rotational, and very diffusive and dissipative. A small perturbation increases with time. They cannot be predicted exactly as function of time and space. Only statistical averaged variables can be predicted.


Laminar Flow
Turbulent Flow


Turbulent Flow
Laminar Flow

➢ **Example 1** :- An oil of viscosity 0.5 stoke is flowing through a pipe of 30 cm in diameter at a rate of 320 liters per second. Find the head loss due to friction for the pipe length of 60 cm.

**Solution:-**

Q=320 liters/second

**=0.32 m³/s**

d=30 cm=0.30 m

$A = \frac{\pi}{4}$ **x 0.30²**

**=0.070m²**

L=**60 m**

$\nu$=0.5 stoke

**= 0.5 x 10⁻⁴ m²/s**

V= Q/A=0.32/0.0707

**=4.52 m/s**

- **Reynolds number($R_N$):-**

$$= \frac{900 \times 1.91 \times 0.20}{(0.006}$$

$= 57{,}300\ (> 4000) \ldots$ Flow is Turbulent

$V = Q/A$

$= 1.91$ m/s

$f = (0.079)/RN\ 1/4$

$= 0.0051$

- **Head loss due to Friction**:-

$$hf = \frac{4.f.l.V^2}{2.g.d}$$

$$= \frac{4 \times 0.0051 \times 30 \times (1.91)^2}{2 \times 9.81 \times 0.20}$$

$$= 9.48 \text{ m of water}$$

- **Power required**:-

$$P = \frac{P \times g \times Q \times hf}{\mu}$$

$$= \frac{900 \times 9.81 \times 0.06 \times 9.48}{1000}$$

$$P = 5.02 \text{ kW}$$

- **Example 3:-** oil of Sp. Gr 0.095 is flowing through a pipe of 20 cm in diameter. if a rate of flow 50 liters/second and viscosity of oil is 1 poise , decide the type of flow.

**Solution:-**

Q = 50 liters/second

= **$0.05 m^3/s$**

D =20 cm = 0.20 m

μ = 1.0poise

**= 0.1 $Ns/m^3$**

$A = \frac{\pi}{4}$ **x $0.20^2$ =0.314 $m^2$**

ρ=0.95 x 1000 **=950** kg/**$m^3$**

V= Q/A=0.05/0.0314

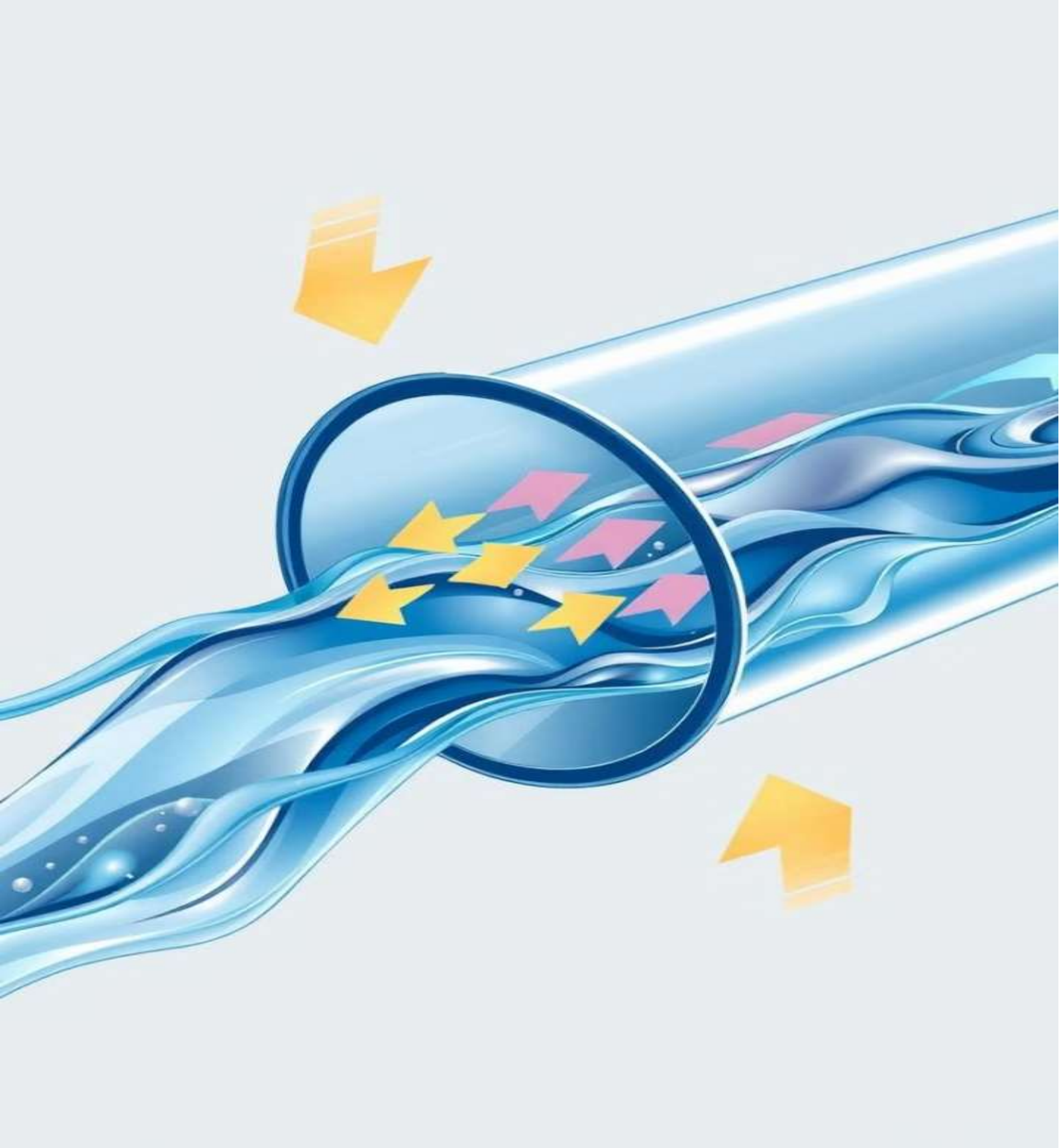
**=1.59m/s**

- **Reynolds number($R_N$):-**

$$R_N = \frac{\rho \text{ x } V \text{ x } D}{\mu}$$

$$= \frac{950 \text{ x } 1.59 \text{ x } 0.20}{0.1}$$

$$= 3021 \ (2000 < Rn < 4000) \text{..Flow is Transition}$$



# Week -8

**Lecture**

**on**

**Flow Through Pipes**

# INTRODUCTION

**Pipe is a passage with a closed perimeter through which the fluid flows under pressure.**

**The fluid flowing in the pipe is always subjected to resistance due to shear forces b/w fluid particles & surface of pipe.**

**It is also known as Frictional resistance.**

# HEAD LOSSES THROUGH PIPE

**It depends upon the type of flow. It may be either laminar or turbulent.**

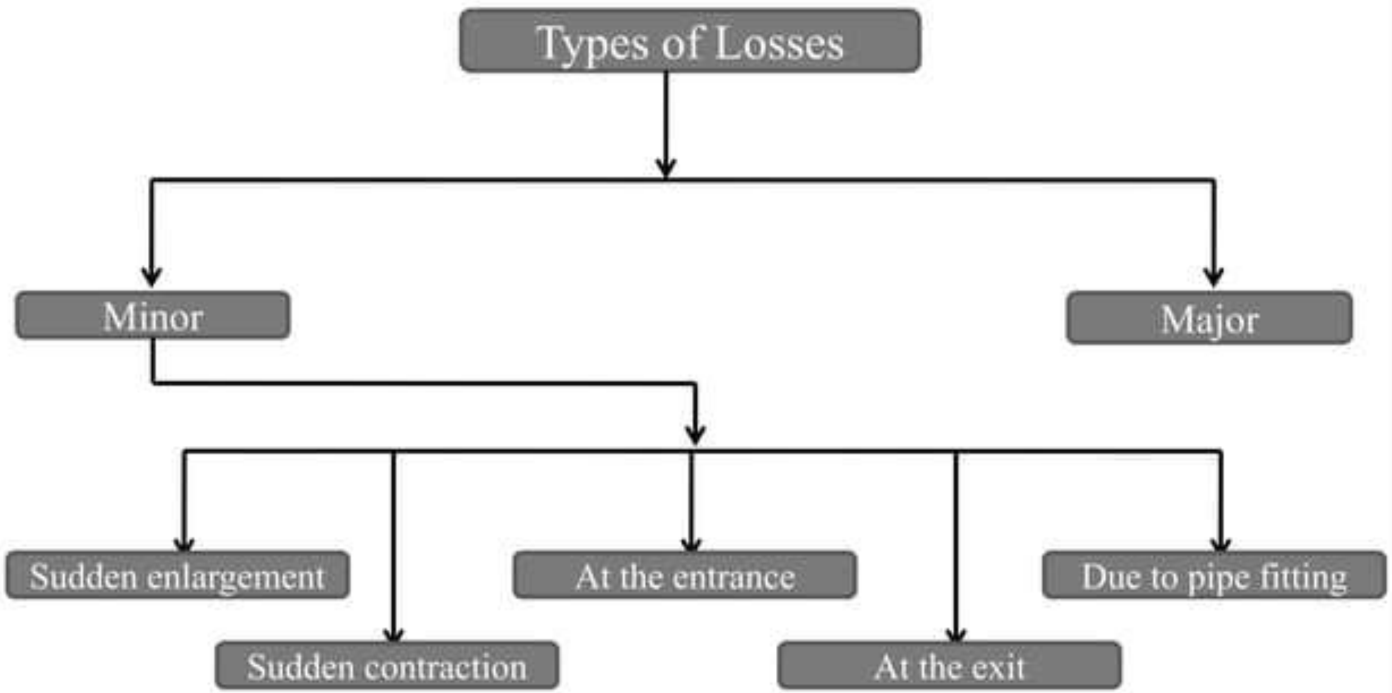
Laminar flow:

It is the type of flow of fluid in which fluid travels smoothly or in regular paths.

Turbulent flow:

It is the type of flow of fluid in which fluid undergoes irregular fluctuations and mixings.

# TYPES OF LOSSES



# Friction Loss

Frictional head losses are losses due to shear stress on the pipe walls. The general equation for head loss due to friction is the Darcy-Weisbach equation, which is

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

where f = Darcy-Weisbach friction factor, L = length of pipe, D = pipe diameter, and V = cross sectional average flow velocity.

This equation is valid for pipes of any diameter and for both laminar and turbulent flows.

# Friction Loss

For Laminar Flow

$$f_{lam} = \frac{64}{Re}$$

For Turbulent Flow

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{k_s/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

- Losses caused by fittings, bends, valves, etc…

# Minor Losses Are Due to

$$h_{Lm} = K \frac{V^2}{2g}$$

where ,

$H_{Lm}$ = minor loss

K = minor loss coefficient

V = mean flow velocity

| Type | K |
|---|---|
| Exit (pipe to tank) | 1.0 |
| Entrance (tank to pipe) | 0.5 |
| 90° elbow | 0.9 |
| 45° elbow | 0.4 |
| T-junction | 1.8 |
| Gate valve | 0.25 - 25 |

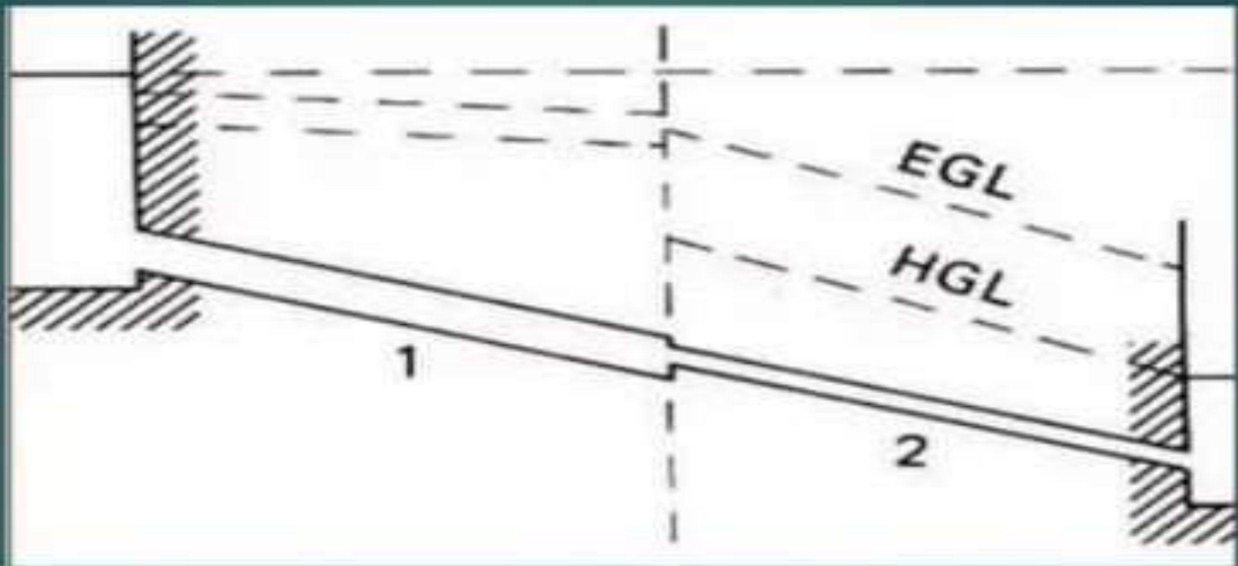
Typical K values

# Flow through pipe in series and parallel

# Flow through pipe in series

- When pipes of different diameters are connected end to end to form a pipe line, they are said to be in series. The total loss of energy (or head) will be the sum of the losses in each pipe plus local losses at connections.

- An arrangement of such pipe line between two reservoir is shown in fig.



# Flow through pipe in parallel

- Many times the flow from one reservoir to another reservoir is increased by connecting number of pipes in parallel as shown in fig.

- Assume Q1 and Q2 are the discharges through the pipes 1 and 2

$$Q = Q_1 + Q_2$$

# Flow through pipe in parallel

► Example :Two pipes connect two reservoirs (A and B) which have a height difference of 10m. Pipe 1 has diameter 50mm and length 100m. Pipe 2 has diameter 100mm and length 100m. Both have entry loss $k^L = 0.5$ and exit loss $k^L=1.0$ and Darcy *f of 0.008.*

Calculate:

a) rate of flow for each pipe

b) the diameter D of a pipe 100m long that could replace the two pipes and provide the same flow

- Apply Bernoulli to each pipe separately. For pipe 1:

$$\frac{p_a}{\rho g}+\frac{u_a^2}{2g}+z_a=\frac{p_b}{\rho g}+\frac{u_b^2}{2g}+z_b+0.5\frac{u_1^2}{2g}+\frac{4flu_1^2}{2gd_1}+1.0\frac{u_1^2}{2g}$$

$$z_1-z_2=\left(0.5+\frac{4fl}{d_1}+1.0\right)\frac{v_1^2}{2g}$$

$$10=\left(1.0+\frac{4*0.008*100}{0.05}\right)\frac{u_1^2}{2*9.81}$$

$$u_1=1.731m/s$$

$$10 = \left(1.0 + \frac{4*0.008*100}{0.05}\right)\frac{u_1^{\ 2}}{2*9.81}$$

$$u_1 = 1.731 m/s$$

$$Q_2 = u_2 \frac{\Pi d_2^{\ 2}}{4} = 0.0190 m^3/s$$

For pipe 2:

$$\frac{p_a}{\rho g} + \frac{u_a^{\ 2}}{2g} + z_a = \frac{p_b}{\rho g} + \frac{u_b^{\ 2}}{2g} + z_b + 0.5\frac{u_2^{\ 2}}{2g} + \frac{4flu_2^{\ 2}}{2gd_2} + 1.0\frac{u_2^{\ 2}}{2g}$$

Again *$p^A$ and $p^B$ are atmospheric, and as the reservoir surface move s slowly $u_A$ and $u_B$ are negligible, so*

$$Q = Au = \frac{\Pi D^2}{4} u$$

$$u = \frac{4Q}{\Pi D^2} = \frac{0.02852}{D^2}$$

$$Q_2 = u_2 \frac{\Pi d_2^{\,2}}{4} = 0.0190 m^3 / s$$

- b) Replacing the pipe,

  we need *Q = Q¹ + Q² = 0.0034 + 0.0190 = 0.0224 m³/s*

For this pipe, diameter D, velocity *u , and making the same assumptions about entry/exit losses, we have*

$$\frac{p_a}{\rho g}+\frac{u_a^{2}}{2g}+z_a=\frac{p_b}{\rho g}+\frac{u_b^{2}}{2g}+z_b+0.5\frac{u_1^{2}}{2g}+\frac{4flu_1^{2}}{2gd_1}+1.0\frac{u_1^{2}}{2g}$$

$$z_a-z_b=\left(0.5+\frac{4fl}{D}+1.0\right)\frac{u_2^{2}}{2g}$$

$$10=\left(1.0+\frac{4*0.008*100}{D}\right)\frac{u^{2}}{2*9.81}$$

$$196.2=\left(1.0+\frac{3.2}{D}\right)u^{2}$$

- The velocity can be obtained from Q

$$Q = Au = \frac{\Pi D^2}{4} u$$

$$u = \frac{4Q}{\Pi D^2} = \frac{0.02852}{D^2}$$

$$196.2 = \left(1.0 + \frac{3.2}{D}\right)\left(\frac{0.02852}{D^2}\right)^2$$

$$0 = 241212 D^5 - 1.5D - 3.2$$

which must be solved iteratively

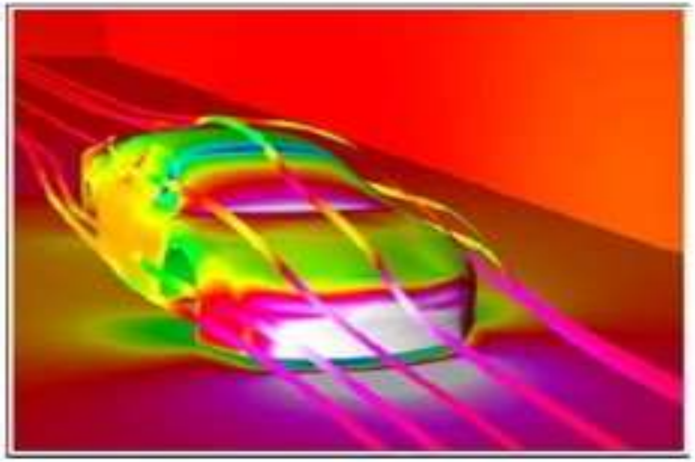
D=0.1058m

# Week -9

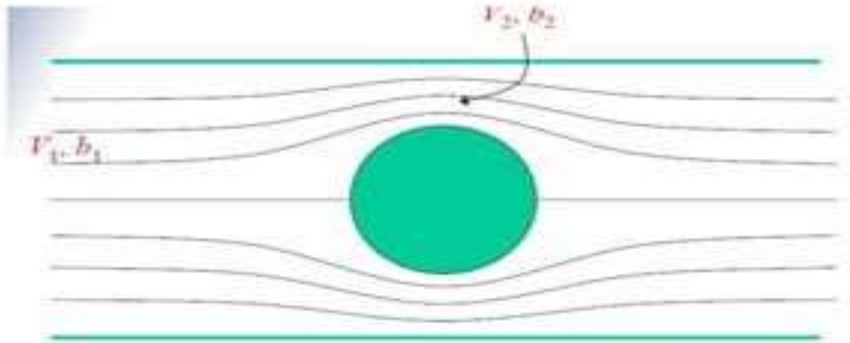
**Lecture**
**on**
**Flow Kinematics**

# Fluid Kinematics

- Branch of fluid mechanics which deals with response of fluids in motion without considering forces and energies in them.
- The study of *kinematics* is often referred to as the *geometry of motion.*



CAR surface pressure contours and streamlines



Flow around cylindrical object

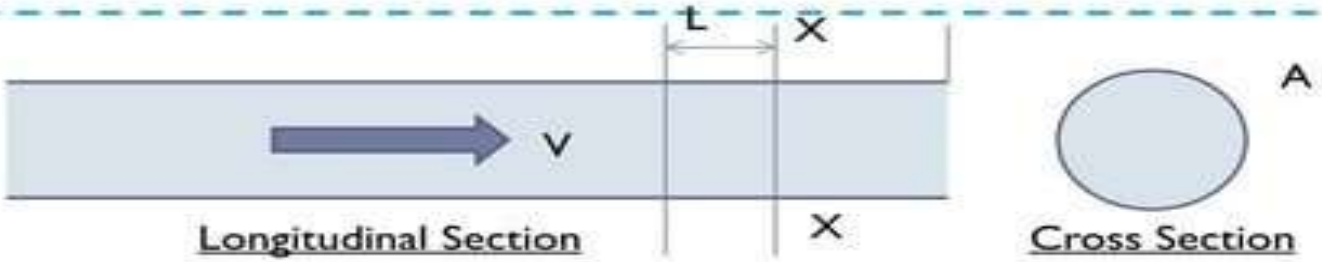
# Fluid Flow

- **Rate of flow:** Quantity of fluid passing through any section in a unit time.

$$\text{Rate of flow} = \frac{\text{Quantity of fluid}}{\text{time}}$$

- **Type:**
  - 1. Volume flow rate: $= \dfrac{\text{volume of fluid}}{\text{time}}$
  - 2. Mass flow rate $= \dfrac{\text{mass of fluid}}{\text{time}}$
  - 3. Weigh flow rate $= \dfrac{\text{weight of fluid}}{\text{time}}$

# Fluid Flow




- Let's consider a pipe in which a fluid is flowing with mean velocity, V.
- Let, in unit time, t, volume of fluid (AL) passes through section X-X,

**Units**

- 1. Volume flow rate: $$Q = \frac{\text{volume of fluid}}{\text{time}} = \frac{AL}{t}$$
- 2. Mass flow rate $$M = \frac{\text{mass of fluid}}{\text{time}} = \frac{\rho(AL)}{t}$$
- 3. Weigh flow rate $$G = \frac{\text{weight of fluid}}{\text{time}} = \frac{\rho g(AL)}{t} = \frac{\gamma(AL)}{t}$$

# Types of Flow

- **Depending upon fluid properties**
- Ideal and Real flow
- Incompressible and compressible

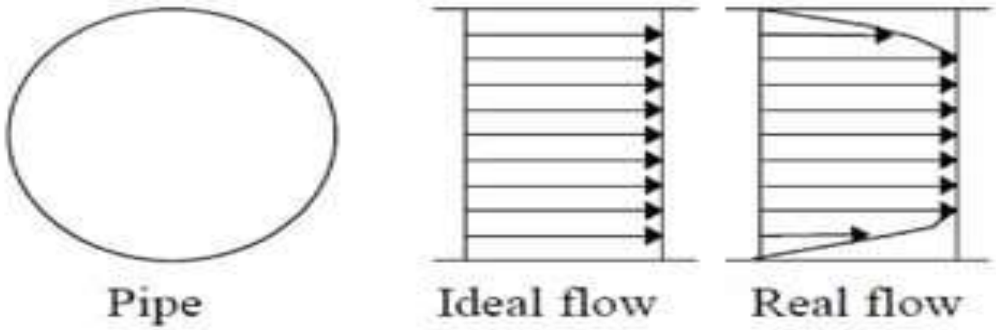
- **Depending upon properties of flow**
- Laminar and turbulent flows
- Steady and unsteady flow
- Uniform and Non-uniform flow

# Week -10

**Lecture**
**on**
**Flow Kinematics**

# Ideal and Real flow

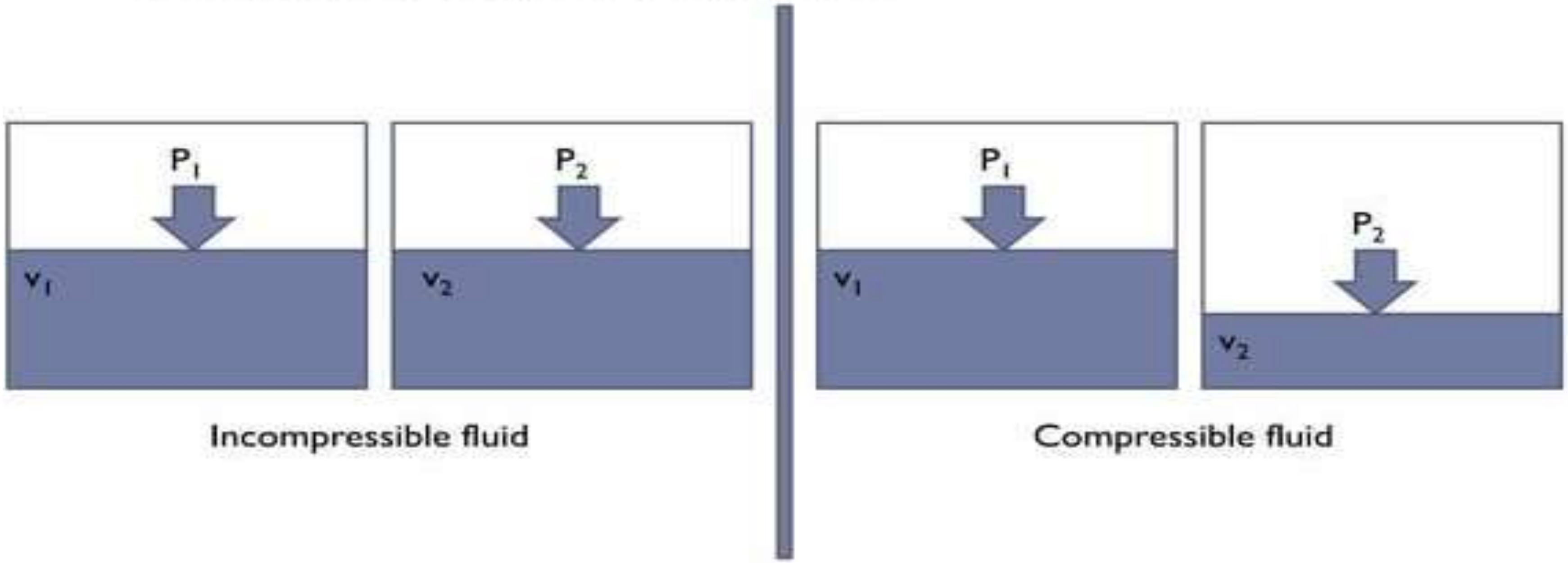
- Real fluid flows implies friction effects. Ideal fluid flow is hypothetical; it assumes no friction.




Velocity distribution of pipe flow

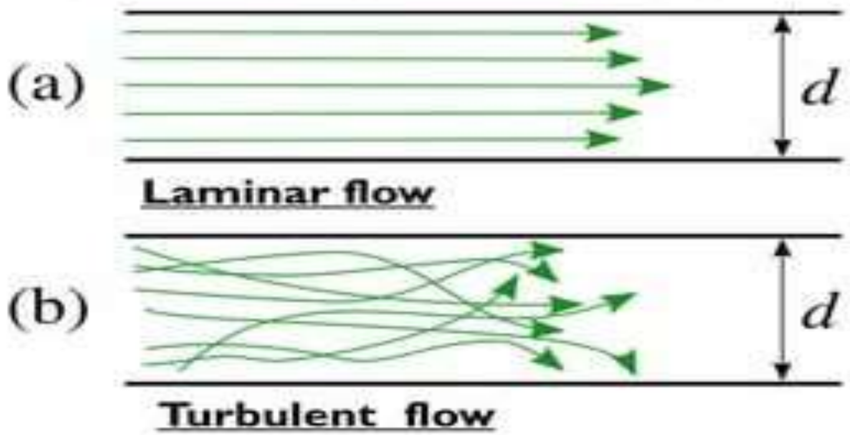
# Compressible and incompressible flows

- Incompressible fluid flows assumes the fluid have constant density while in compressible fluid flows density is variable and becomes function of temperature and pressure.



# Laminar and turbulent flow

- The flow in laminations (layers) is termed as laminar flow while the case when fluid flow layers intermix with each other is termed as turbulent flow.

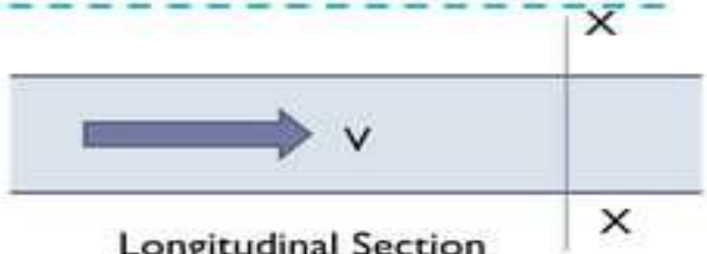



- Reynold's number is used to differentiate between laminar and turbulent flows.

Transition of flow from Laminar to turbulent

# Steady and Unsteady flows

- **Steady flow:** It is the flow in which conditions of flow remains constant w.r.t. time at a particular section but the condition may be different at different sections.
- Flow conditions: velocity, pressure, density or cross-sectional area etc.
- e.g., A constant discharge through a pipe.




Longitudinal Section

$$\frac{\partial V}{\partial t} = 0; \Rightarrow V = contt$$

- **Unsteady flow:** It is the flow in which conditions of flow changes w.r.t. time at a particular section.
- e.g.,A variable discharge through a pipe

$$\frac{\partial V}{\partial t} \neq 0; \Rightarrow V = \text{variable}$$

# Uniform and Non-uniform flow

- **Uniform flow:** It is the flow in which conditions of flow remains constant from section to section.
- e.g., Constant discharge though a constant diameter pipe


Longitudinal Section

$$\frac{\partial V}{\partial x} = 0; \Rightarrow V = contt$$

- **Non-uniform flow:** It is the flow in which conditions of flow does not remain constant from section to section.
- e.g., Constant discharge through variable diameter pipe


Longitudinal Section

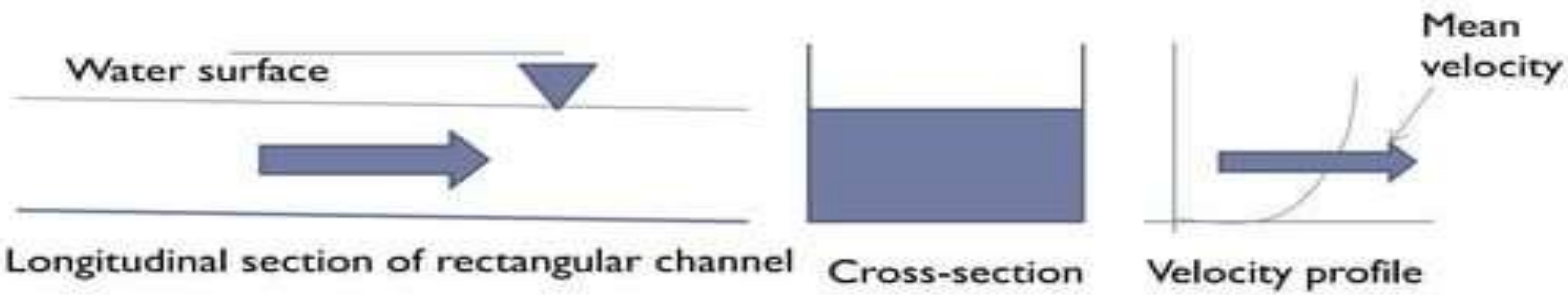
$$\frac{\partial V}{\partial x} \neq 0; \Rightarrow V = \text{variable}$$

# Week -11

## Lecture
## on
## Flow Kinematics

## One, Two and Three Dimensional Flows

- Although in general all fluids flow three-dimensionally, with pressures and velocities and other flow properties varying in all directions, in many cases the greatest changes only occur in two directions or even only in one. In these cases changes in the other direction can be effectively ignored making analysis much more simple.
- Flow is *one dimensional if the flow parameters (such as velocity, pressure, depth etc.) at a given instant in* time only vary in the direction of flow and not across the cross-section

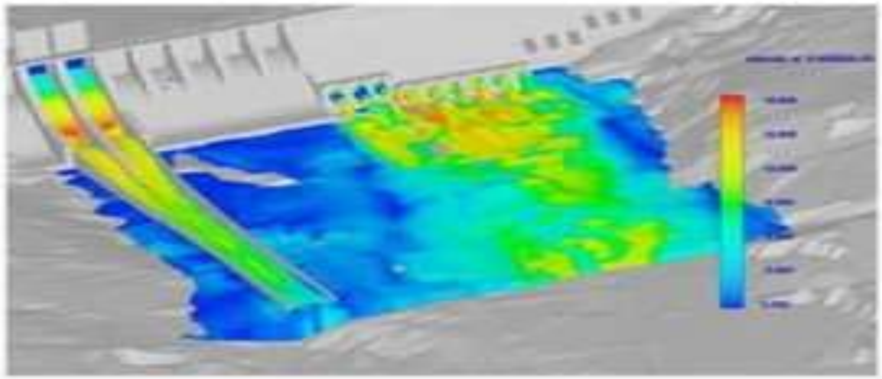


# One, Two and Three Dimensional Flows

- Flow is *two-dimensional* *if it can be assumed that the flow parameters vary in the direction of flow and in* one direction at right angles to this direction

Two-dimensional flow over a weir

- Flow is *three-dimensional* *if the flow parameters vary in all three directions of flow*



Three-dimensional flow in stilling basin

# Rotational and irrotational flow

**Rotational flow.**

A flow is said to be rotational if the fluid particles while moving in the direction of flow rotate about their mass centers. Flow near the solid boundaries is rotational.

Example. Motion of liquid in a rotating tank.

**Irrotational flow,**

A flow is said to be irrotational if the fluid particles while moving in the direction of flow do not rotate about their mass centers. Flow outside the boundary layer is generally considered irrotationa1.

Example. Flow above a drain hole of a stationary tank or a wash basin.

# Equation of Continuity

- Equation of Continuity: A relation between the speed v of an ideal fluid flowing through a tube of cross sectional area A in steady flow state
- Since fluid is incompressible, equal volume of fluid enters and leaves the tube in equal time
- Volume $\Delta V$ flowing through a tube in time $\Delta t$ is

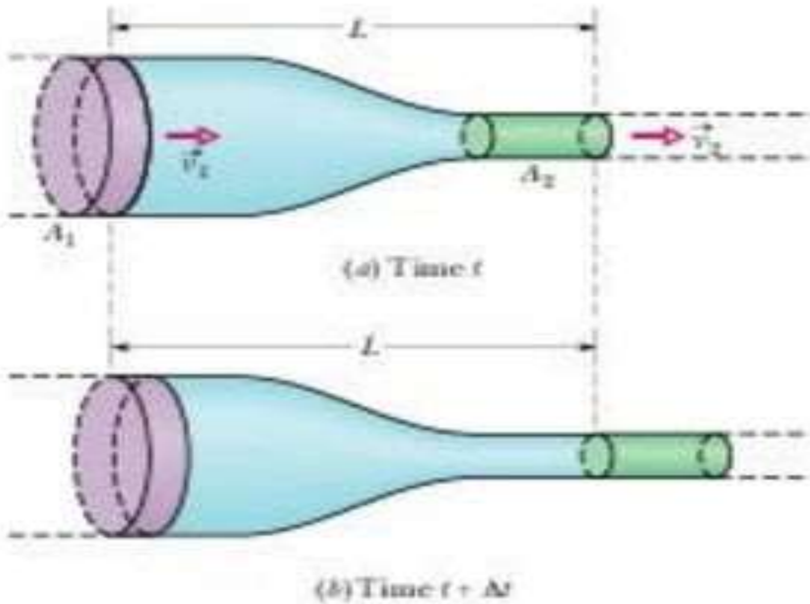
$$\Delta V = A\ \Delta x = A\ v\Delta t$$

Then $\Delta V = A_1 v_1 \Delta t = A_2 v_2 \Delta t$

$$A_1 v_1 = A_2 v_2$$

$R_V = A_1 v_1 =$ constant (Volume flow rate)

$R_m = \rho A_1 v_1 =$ constant (Mass flow rate)



# Week -12

**Lecture**

**on**

**Fluid Kinematics**

**Problem Solving**

# Example (4)

**branches into two pipes (2 and 3) of diameters 300 mm and 200 mm respectively .If the average velocity in 450 mm diameter pipe is 3 m/s find:**
**(i) Discharge through 450 mm diameter pipe;**
**(ii) Velocity in 200 mm diameter pipe if the average velocity in 300 mm pipe is 2.5**

**Solution.** Diameter $D_1 = 450$ mm $= 0.45$ m

$\therefore$ **Area** $A_1 = \frac{\pi}{4} \times 0.45^2 = 0.159$ m²

Velocity $V_1 = 3$ m/s

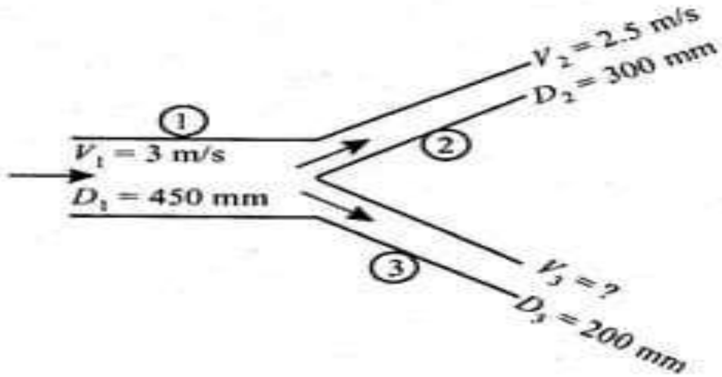
Diameter $D_2 = 300$ mm $= 0.3$ m

$\therefore$ Area $A_2 = \frac{\pi}{4} \times 0.3^2 = 0.0707$ m²

Velocity $V_2 = 2.5$ m/s

Diameter $D_3 = 200$ mm $= 0.2$ m

Area $A_3 = \frac{\pi}{4} \times 0.2^2 = 0.0314$ m²



# Example(4)

(*i*) **Discharge through pipe (1) $Q_1$:**

Using the relation,

$$Q_1 = A_1V_1 = 0.159 \times 3$$
$$= \mathbf{0{\cdot}477\ m^3/s\ (Ans.)}$$

(*ii*) **Velocity in pipe of diameter 200 mm i.e. $V_3$:**

Let $Q_1$, $Q_2$ and $Q_3$ be the discharge in pipes 1, 2 and 3 respectively.

Then, according to continuity equation

$$Q_1 = Q_2 + Q_3$$

where $\quad Q_1 = 0.447\ m^3/s$

and $\quad Q_2 = A_2V_2 = 0.0707 \times 2.5 = 0.1767\ m^3/s$

$\therefore \quad 0.477 = 0.1767 + Q_2$

or $\quad Q_3 = 0.477 - 0.1767 \simeq 0.3\ m^3/s$

But $\quad Q_3 = A_3V_3$

$\therefore \quad V_3 = \dfrac{Q_3}{A_3} = \dfrac{0.3}{0.0314} = 9.55\ m/s$

*i.e.* $\quad V_3 = \mathbf{9.55\ m/s\ (Ans.)}$

# Post test

**Q1)) (5 mark)**

**Conical pipe diverges uniformly From 100 mm to 200 m diameter over a length '1 m. Determine the local and convective acceleration at the mid-section assuming**

**(i) Rate of flow is 0.12 $m^3/s$ and it remains constant;**

**(ii) Rate of flow varies uniformly from,0.12 $m^3/s$ to 0.24 $m^3ls$ in 5 sec., at t = 2 sec**

**Q2)) (5 mark)**

**The diameter of a pipe at the section 1-1 and 2-2 are 200mm and 300mm respectively. If the velocity of water flowing through the pipe section at 1-1 4m\sec, find**

**1) discharge through the pipe**

**2)velocity of water at section 2-2**

# Key answer

## post test

### Q1))

**Solution.** *Given:* Diameter at the inlet, $D_1 = 0.1m$.

Diameter at the outlet, $D_2 = 0.2\ m$

Length $l = 1m$

Diameter at any distance $x$ metres from the inlet,

$$D_x = D_1 + \left(\frac{D_2 - D_1}{l}\right) \times x$$

$$= 0.1 + \left(\frac{0.2 - 0.1}{1}\right) \times x$$

$$= 0.1 + 0.1x = 0.1\ (1 + x)$$

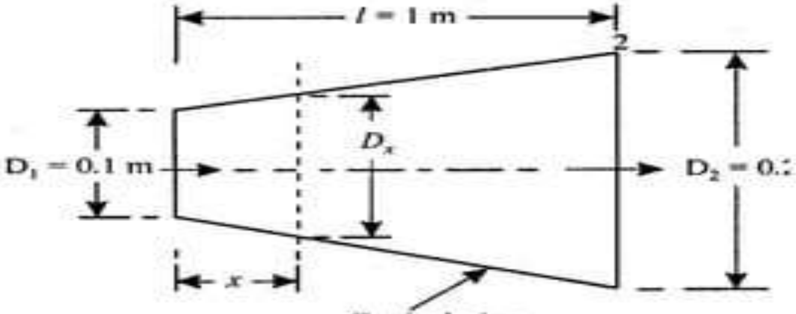


**Fig. 5.12**

∴ Cross-sectional area,

$$A_x = \frac{\pi}{4} \times D_x^2 = \frac{\pi}{4}\{0.1(1 + x)\}^2$$

$$= 0.00785\ (1 + x)^2$$

Velocity of flow, $u_x\ (= u) = \frac{Q}{A_x} = \frac{Q}{0.00785(1 + x)^2}$

Velocity gradient, $\frac{\partial u}{\partial x} = \frac{\partial}{\partial x}\left[\frac{Q}{0.00785\ (1 + x)^2}\right] = \frac{-2Q}{0.00785(1 + x)^3}$

(*i*) **Discharge Q = 0.12 $m^3/s$ = constant (at any section):**

# Key answer

**Q2))**

**Solution.** Diameter of the pipe at *section 1-1*,

$$D_1 = 200 \text{ mm} = 0.2 \text{ m}$$

∴ Area $A_1 = \frac{\pi}{4} D_1^2 = \frac{\pi}{4} \times 0.2^2 = 0.0314 \text{ m}^2$

Velocity, $V_1 = 4$ m/s

Diameter of the pipe at *section* 2-2,

$$D_2 = 300 \text{ mm}$$

∴ Area, $A_2 = \frac{\pi}{4} D_2^2 = \frac{\pi}{4} \times 0.3^2 = 0.0707 \text{ m}^2$

(*i*) **Discharge through the pipe, Q:**

Using the relation,

$Q = A_1 V_1$, we have

$Q = 0.0314 \times 4 =$ **0.1256 m³/s (Ans.)**

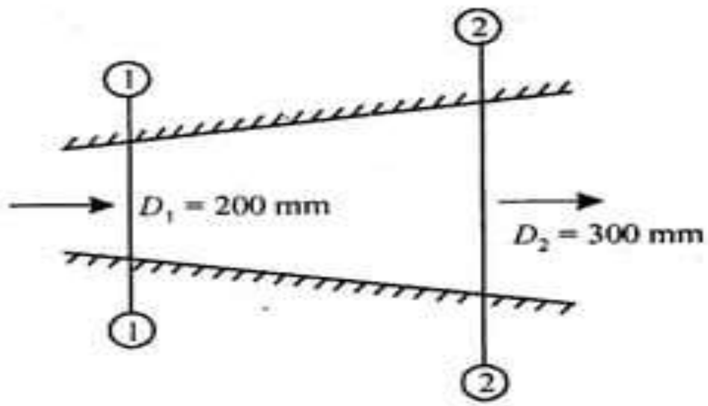
(*ii*) **Velocity of water at section 2-2, $V_2$:**

Using the relation,

$A_1 V_1 = A_2 V_2$, we have

$$V_2 = \frac{A_1 V_1}{A_2} = \frac{0.0314 \times 4}{0.0707}$$

= **1.77 m/s (Ans.)**



# Week -13

**Lecture**

**on**

**Pump**

**Classification**

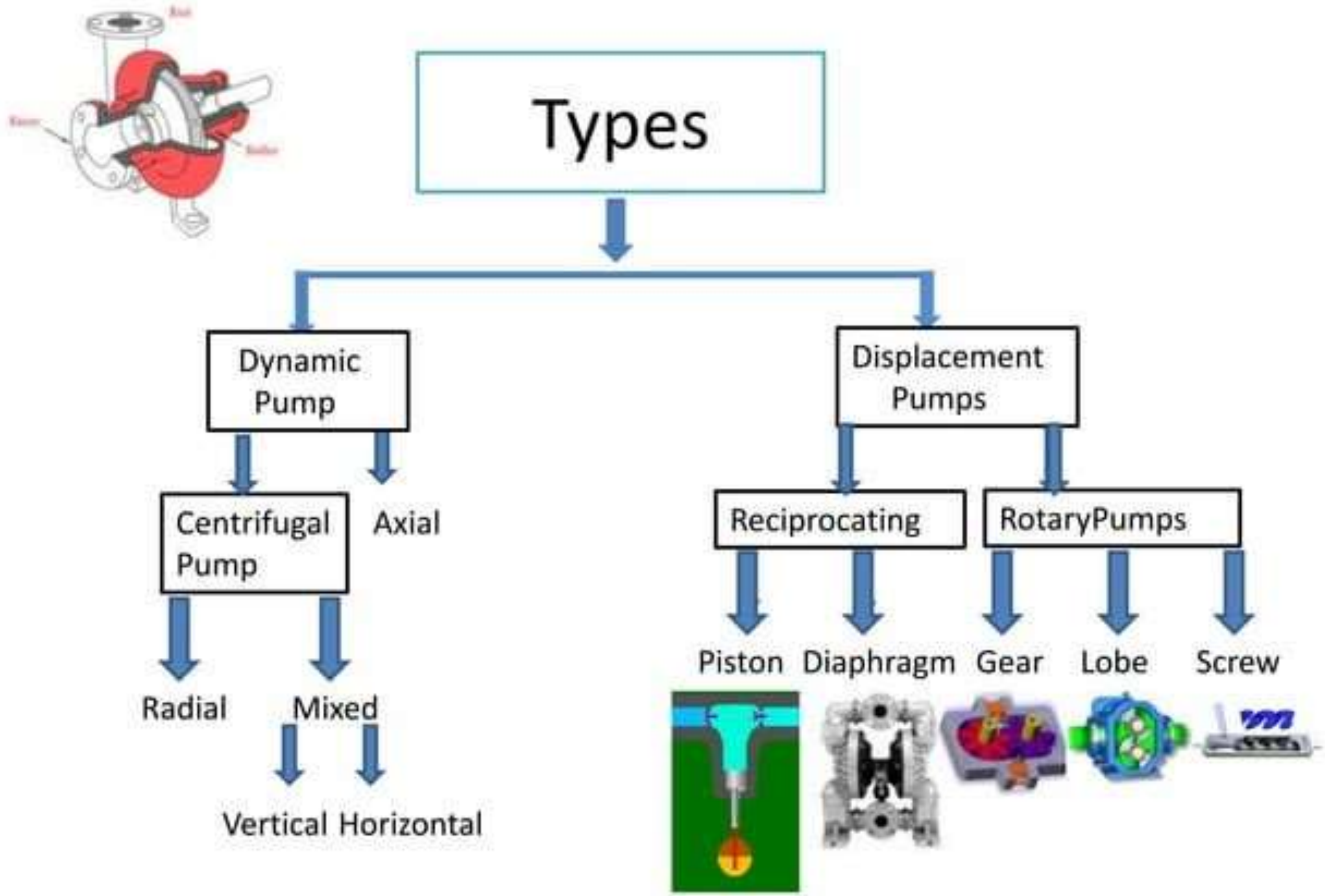
# WHAT IS PUMP?

- A pump machine is a device for converting the energy held by mechanical energy into fluid.
- **Function:-**
- Flow from a region of low pressure to one of high pressure
- Flow from a low level to a higher level

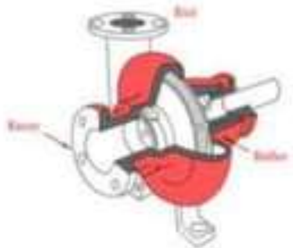
Flow at a faster rate.

**Propties:-**

- Pumps operate by some mechanism and consume energy to perform mechanical work by moving the fluid.
- Pumps operate via many energy sources.



Types
Dynamic Pump
Displacement Pumps
Centrifugal Pump
Axial
Reciprocating
RotaryPumps
Radial
Mixed
Vertical
Horizontal
Piston
Diaphragm
Gear
Lobe
Screw



# Centrifugal Pump

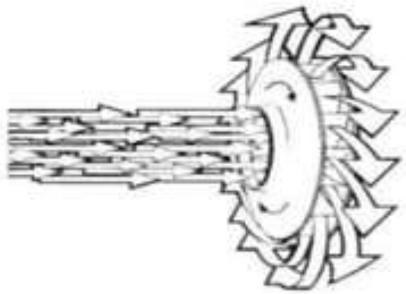
- <u>Working Principle</u>:

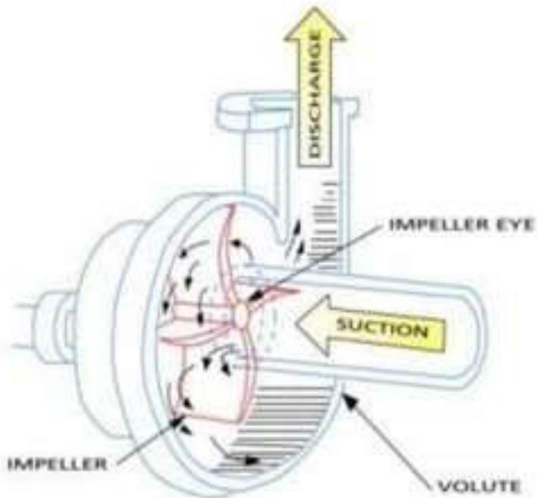
Works on the principle of centrifugal force. This is the force that pushes the liquid away from the centre(in tangential direction).

Converting Prime Mover energy into Mechanical energy through shaft .

Converting Mechanical energy into fluid energy impeller.

Converting kinetic Energy into pressure energy through the volute casing.

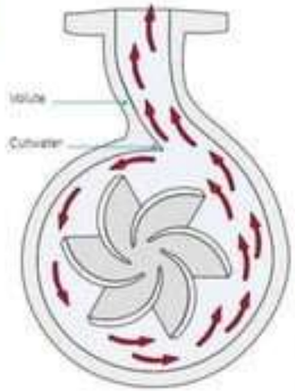




# Major Parts

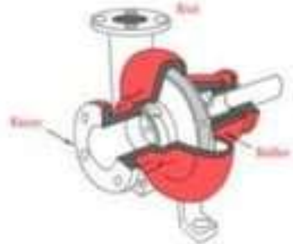
Impeller/
Blades


Volute Casing

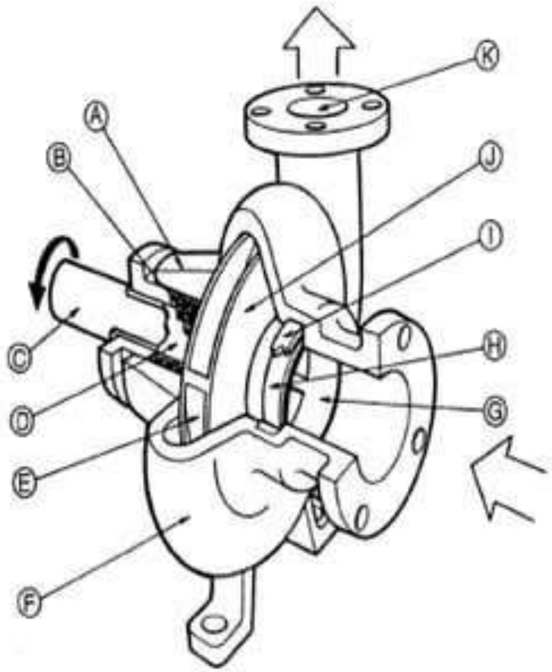




Shaft



# Major Parts




A Stuffing Box

B Packing

C Shaft

D Shaft Sleeve

E Vane

F Casing

G eye of Impeller

H Impeller

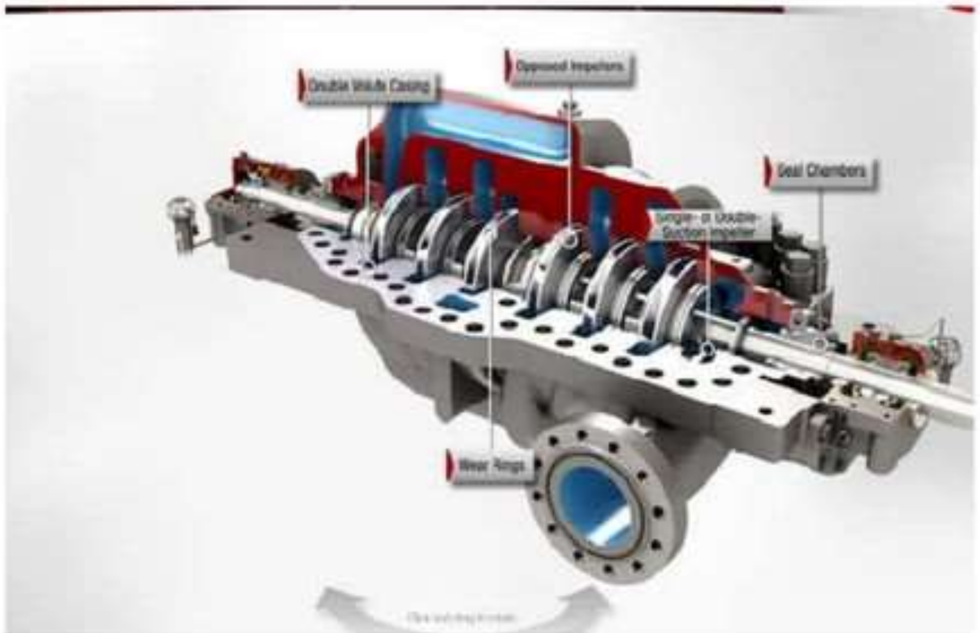
I Casing wear ring

J Impeller

K Discharge nozzle

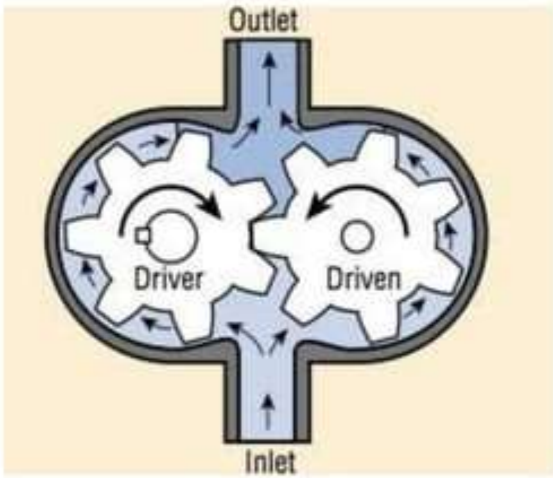
# Multistage Centrifugal Pumps.

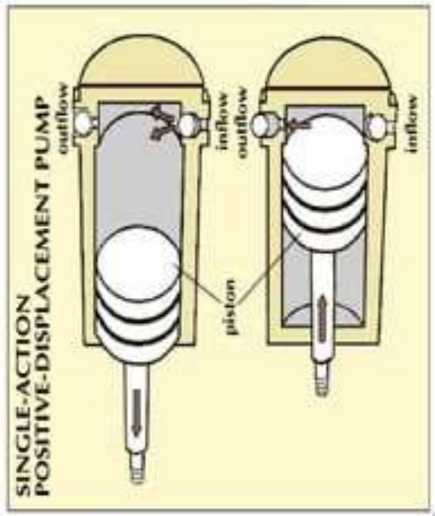
- In order to achieve a higher discharge pressure multiple impellers are used within a single pump. Depending upon the requirement.



# Positive Displacement Pumps

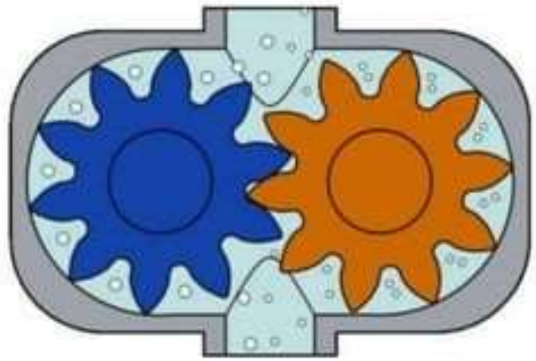
- Working Principle: *Positive Displacement Pump has an expanding cavity on the suction side of the pump and a decreasing cavity on the discharge side. Liquid is allowed to flow into the pump as the cavity on the suction side expands and the liquid is forced out of the discharge as the cavity collapses.*



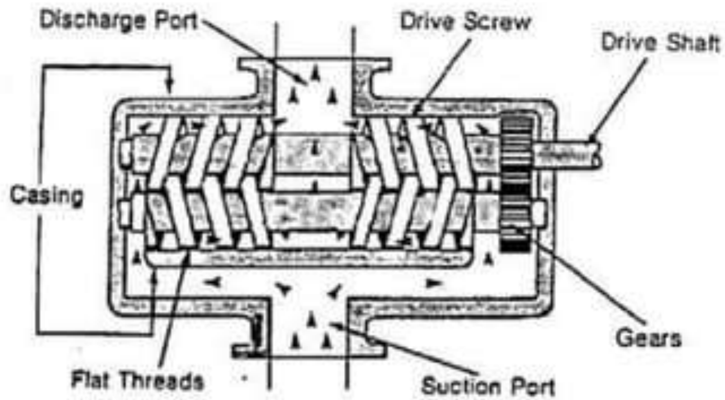
# Gear Pumps

Working Principle:

# Screw Pumps

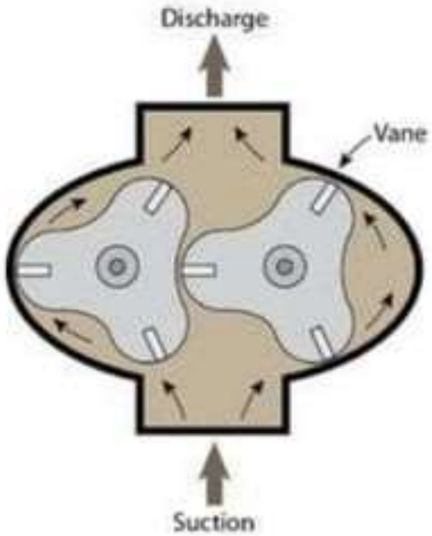
- <u>Working Principle</u>:

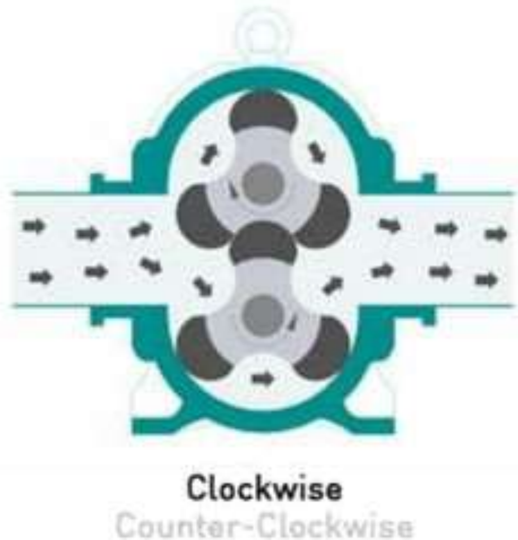



# Lobe Pump

- <u>Working Principle</u>

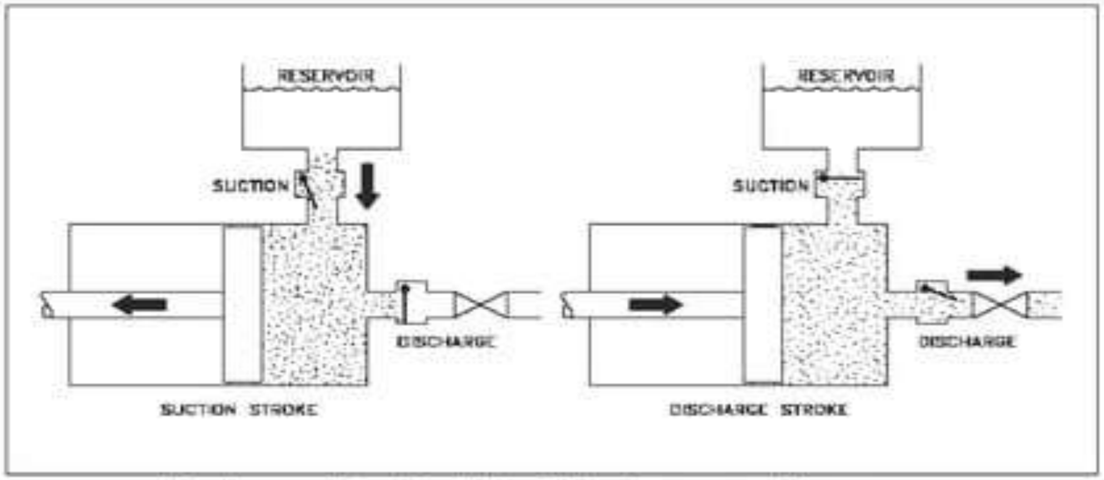
**Lobe Pump**



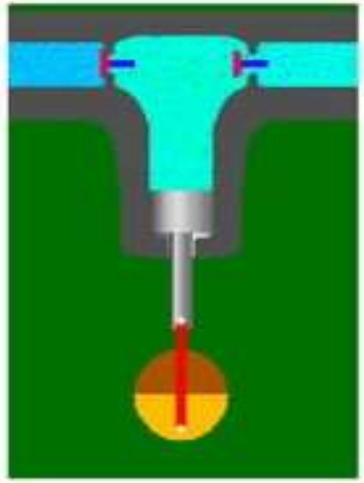



# Reciprocating Pumps:

Working Principle




Reciprocating Positive Displacement Pump

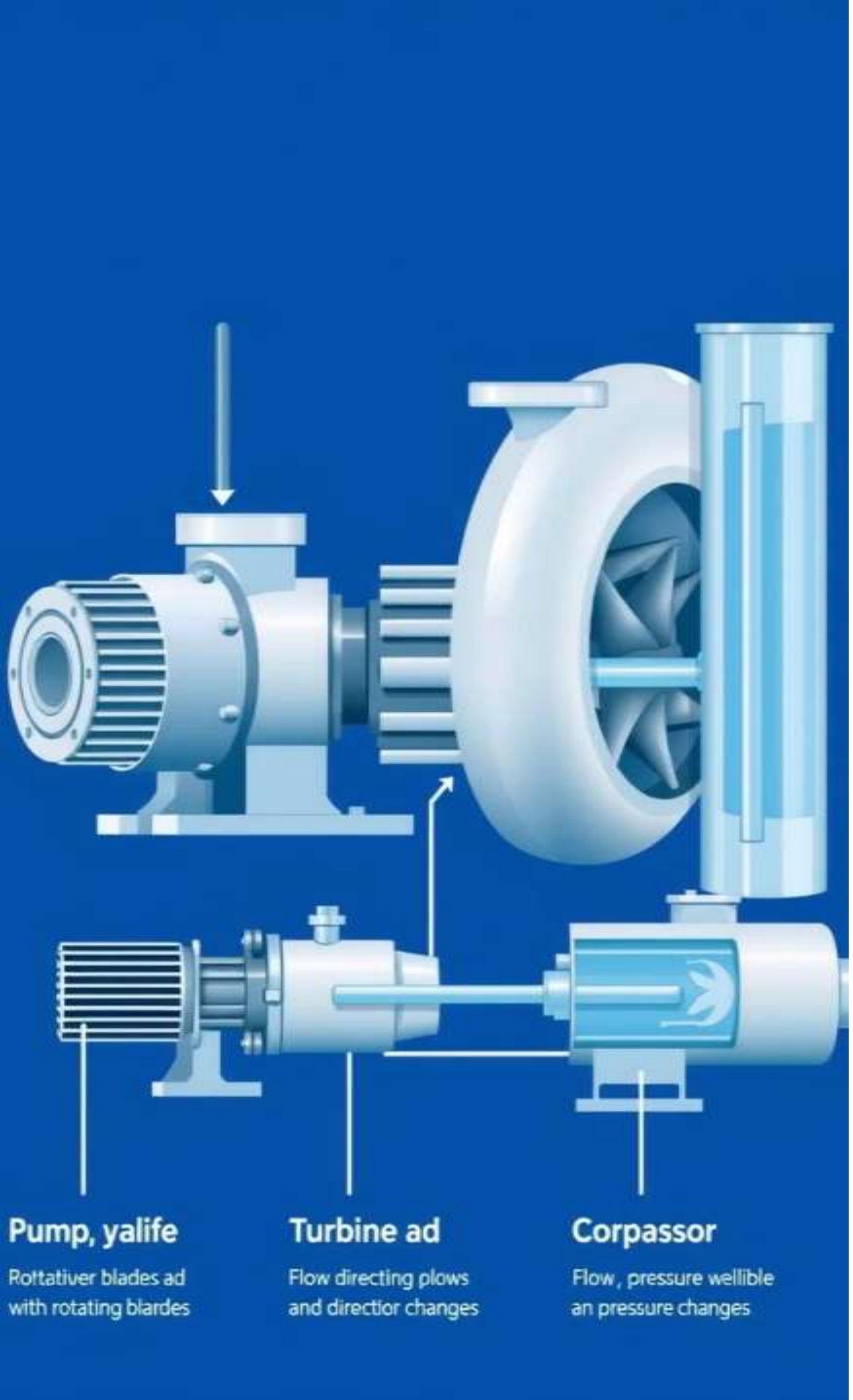


# Week -14

**Lecture**

**on**

**Centrifugal Pump**




# Fluid Machinery: Pumps, Turbines, and and Compressors

1

Pumps

Pumps are used to increase the pressure of a fluid and move it from one point to another.

2

Turbines

Turbines convert fluid energy (kinetic or potential) into mechanical energy. They are used in power generation and other applications.

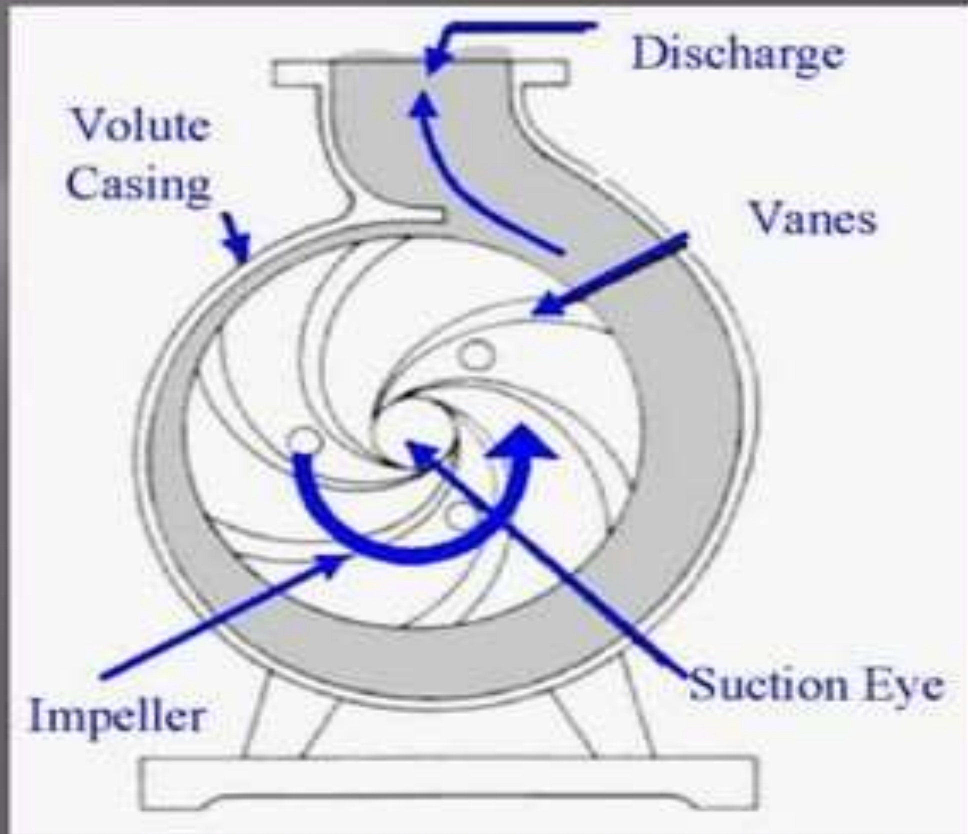
3

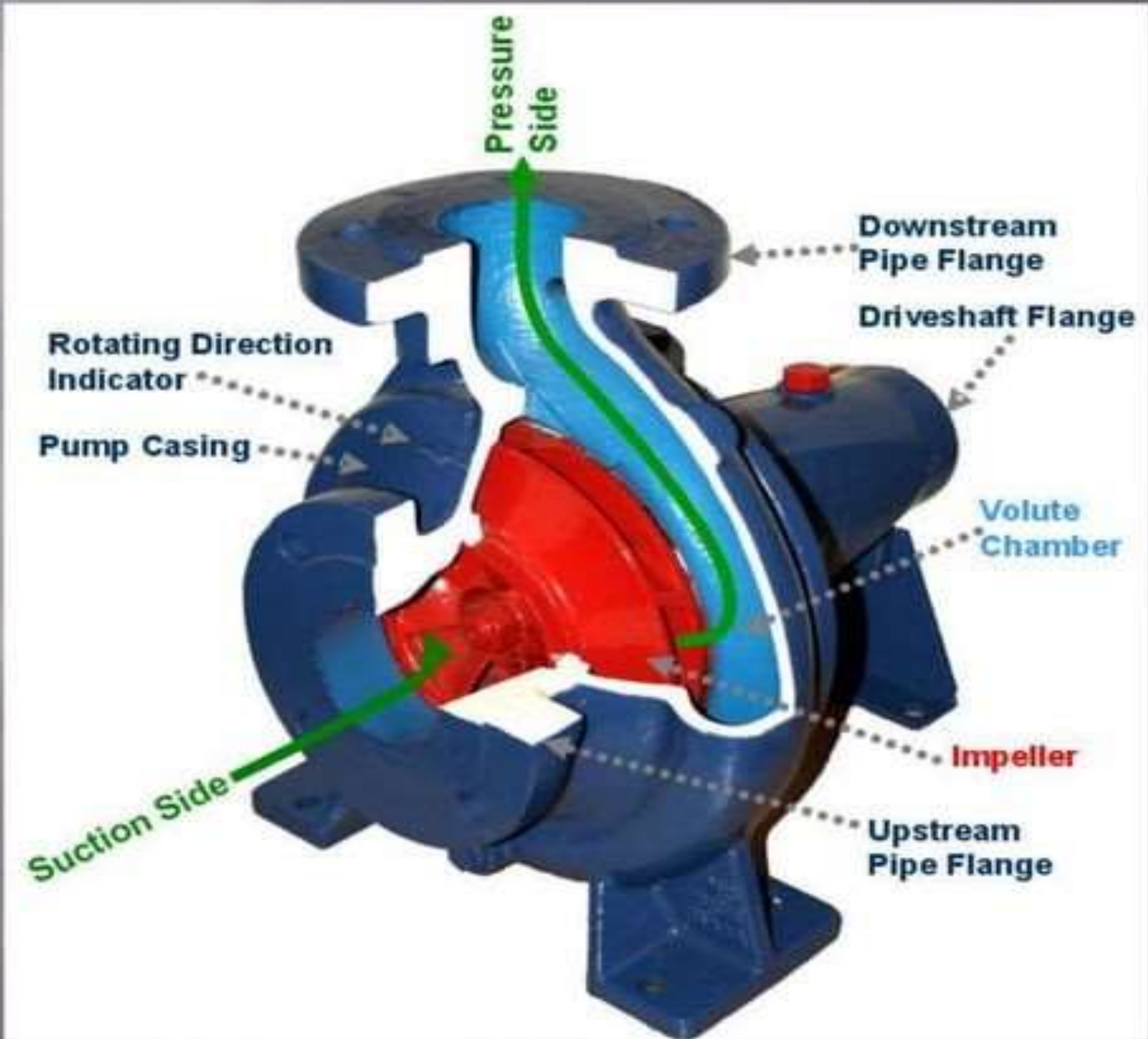
Compressors

Compressors increase the pressure and density of a gas. They are essential in refrigeration, air conditioning, and other industries.

# COMPONENTS

- Impeller
- Casing
- Suction pipe
- Foot valve and strainer
- Delivery pipe




Pressure Side
Downstream Pipe Flange
Driveshaft Flange
Rotating Direction Indicator
Pump Casing
Volute Chamber
Impeller
Upstream Pipe Flange
Suction Side

# ROTATING COMPONENTS

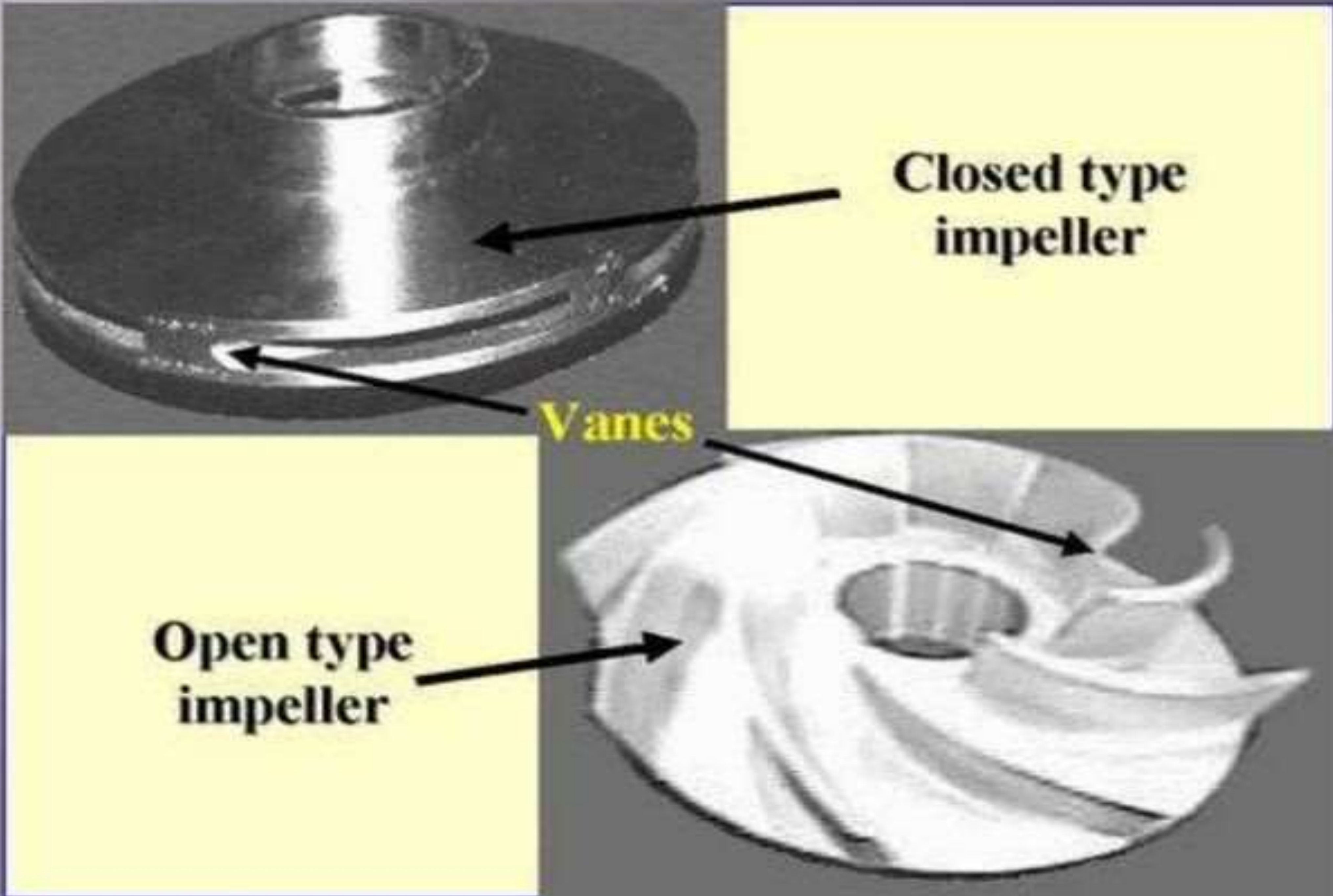
- Impeller:

  The impeller is the main rotating part that provides the centrifugal acceleration to the fluid.

- Shaft:

  Its purpose is to transmit the torques encountered when starting and during operation.

  Supports the impeller & other rotating parts.


Closed type
impeller
Vanes
Open type
impeller

# STATIONARY COMPONENTS

- Casing:

  The main purpose of casing is to convert kinetic energy into pressure energy.

Casings are generally of three types:

a) Volute : Used for higher head, eddy currents formed
b) Vortex : Eddy currents are reduced.
c) Circular : Used for lower head.

- A *volute* is a curved funnel increasing in area to the discharge port. As the area of the cross-section increases, the volute reduces the speed of the liquid and increases the pressure of the liquid.

- **Vortex Casing :A circular chamber is introduced between casing and impeller. Efficiency of pump is increased**

- **Circular casing** have stationary diffusion vanes surrounding the impeller periphery that convert velocity energy to pressure energy.
- Conventionally, the diffusers are applied to multi-stage pumps.

# PRIMING

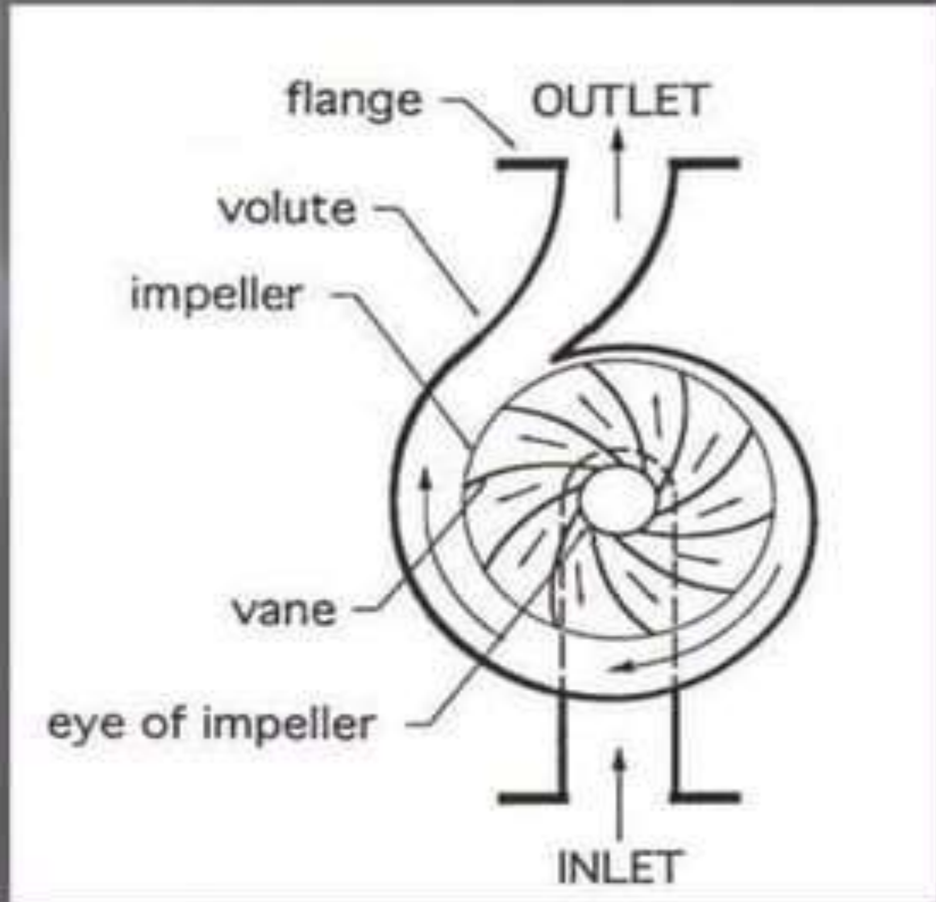
- It is the process of filling suction pipe, casing and delivery pipe upto delivery valve with water.
- Used to remove air from these parts.
- It is of 2 types:

a) Positive Priming:-The one which speeds up processing.

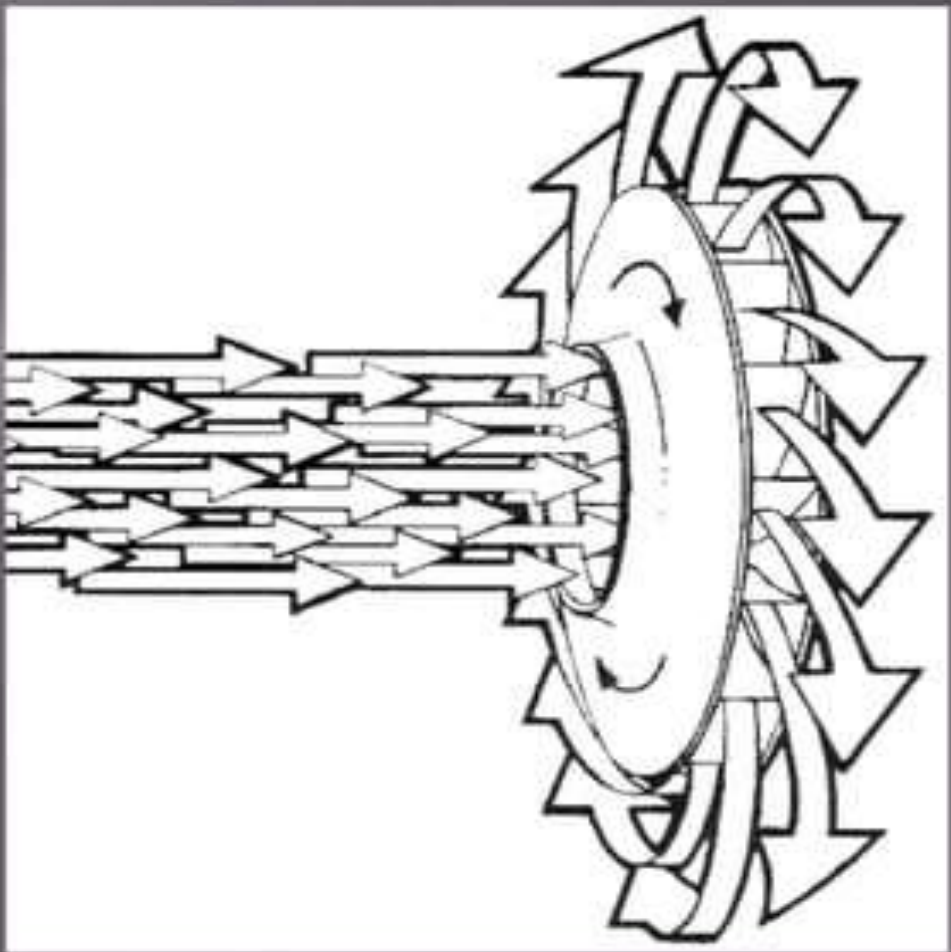
b) Negative Priming:-The one which slows down the processing.

# How do they work?

- Liquid forced into impeller
- Vanes pass kinetic energy to liquid: liquid rotates and leaves impeller
- Volute casing converts kinetic energy into pressure energy

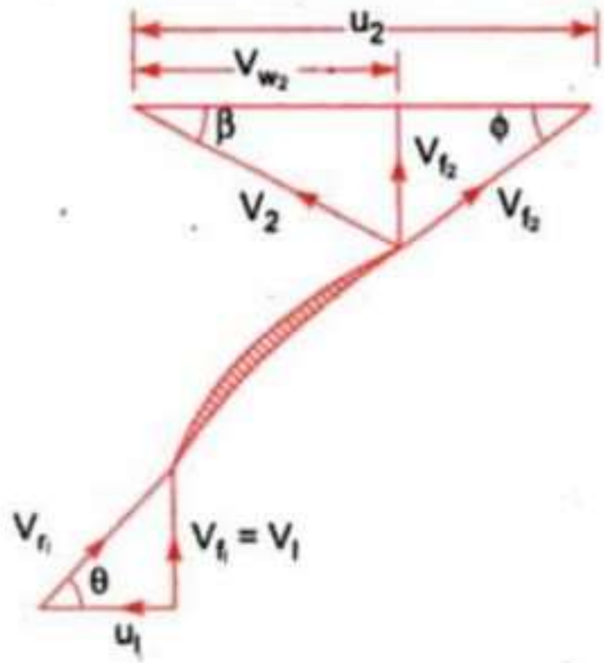


- It consists of an *IMPELLER* rotating within a casing.
- Liquid directed into the center  of the rotating impeller is picked up by the impeller's vanes and accelerated to a higher velocity by the rotation of the impeller and discharged by centrifugal force into the casing .




# Week -15

## Lecture
## on
## Centrifugal Pump




**Velocity Triangles at Inlet and Outlet**

# WORK DONE

- Work is done by the impeller on the water

$$W=[V_{w2}U_2-V_{w1}U_1]/g$$

where,

$W$=work done per unit wg. of water per sec.

$V_{w2}$=whirl component of absolute vel. of jet at outlet.

$U_2$=tangential vel. of impeller at outlet.

$V_{w1}$=whirl component of absolute vel. of jet at inlet.

$U_1$=tangential vel. of impeller at inlet.

# Minimum Starting Speed of Pump

A centrifugal pump will start delivering liquid only if the head developed by the impeller is more than the manometric head ($H_m$). If the head developed is less than $H_m$ no discharge takes place although the impeller is rotating. When the impeller is rotating, the liquid in contact with the impeller is also rotating. This is a forced vertex, in which the increase in head in the impeller is given by

$$\text{Head rise in impeller} = \frac{u_2^2}{2g} - \frac{u_1^2}{2g}$$

Discharge takes place only when

$$\frac{u_2^2}{2g} - \frac{u_1^2}{2g} \geq H_m$$

substituting for $u_1$, $u_2$ and $H_m$ in Equation (10.13), we obtain

$$N = \frac{120\eta_m V_{w_2} D_2}{\pi(D_2^2 - D_1^2)}$$

which is the minimum speed for the pump to discharge liquid.

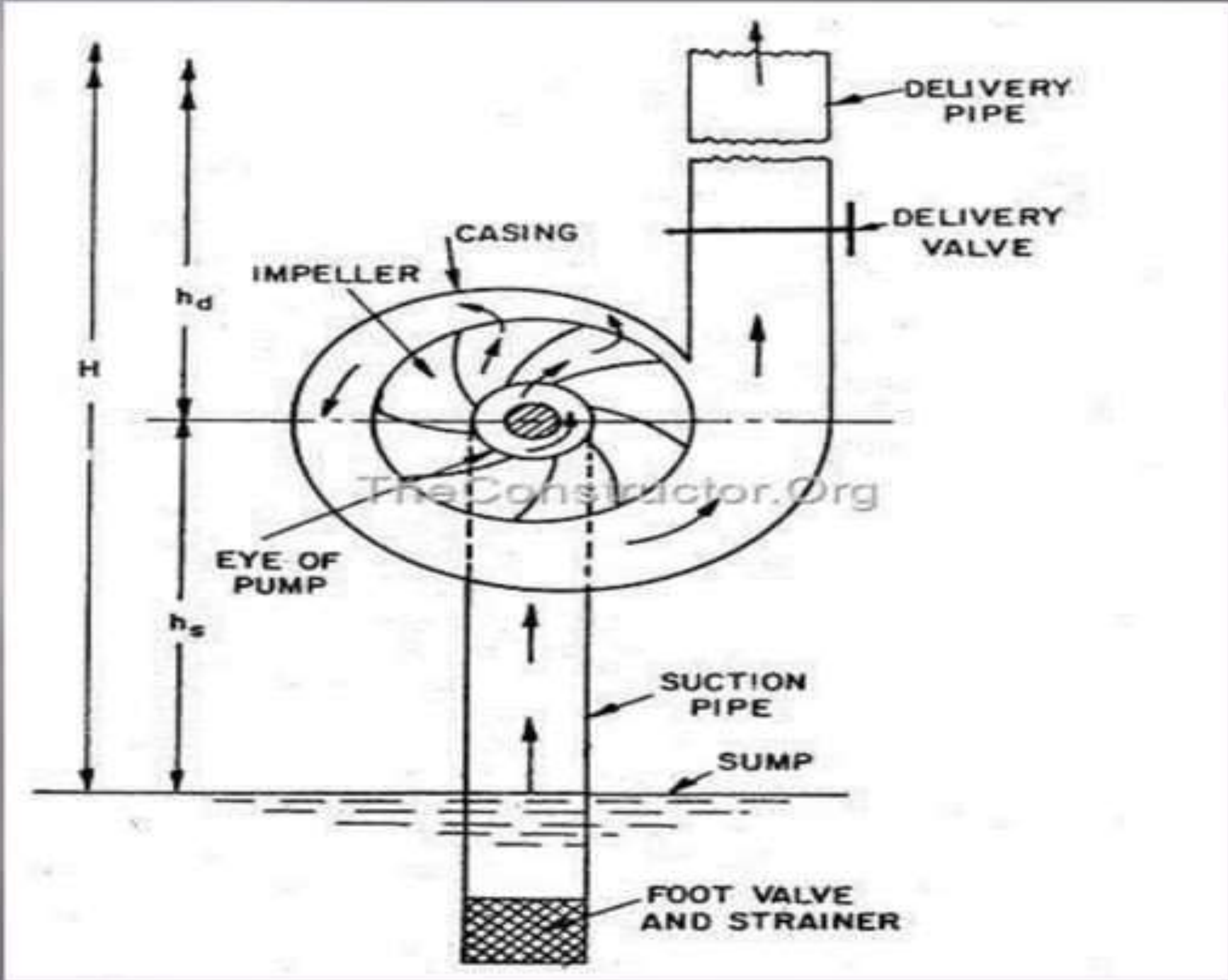
# Specific Speed of Pump

The specific speed of a centrifugal pump is defined as the speed of a geometrically similar pump which would deliver *one cubic metre* of liquid per second against a head of *one metre*. It is denoted by '$N_s$'.

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

# HEADS IN CENTRIFUGAL PUMP

- Suction Head:- Vertical height of center line of centrifugal pump above the water surface to the pump from which water to be lifted.
- Delivery Head:- Vertical distance between center line of the pump and the water surface in the tank to which water is delivered.
- Static Head:- Sum of suction head and delivery head.
- Manometric Head:- The head against which a centrifugal pump has to work.
- $H_m = h_s + h_d + h_{fs} + h_{fd} + (V_d * V_d)/2g$


DELIVERY
PIPE
DELIVERY
VALVE
CASING
IMPELLER
$h_d$
H
TheConstructor.Org
EYE OF
PUMP
$h_s$
SUCTION
PIPE
SUMP
FOOT VALVE
AND STRAINER

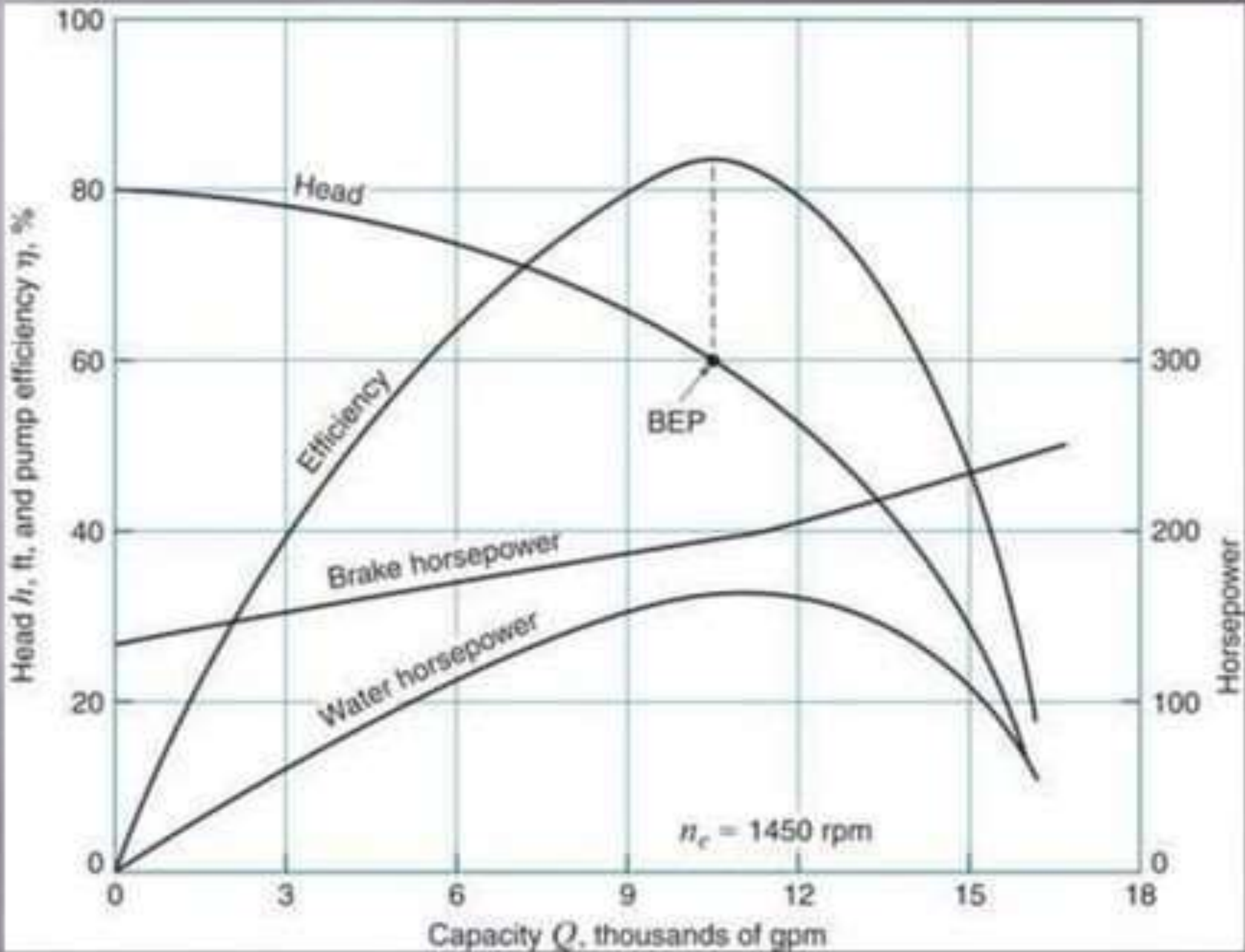
# EFFICIENCES

- Manometric efficiency:-The ratio of manometric head to the head imparted by impeller.

$$=H_m/(V_{w2}\,u_2/g)$$

- Mechanical efficiency :-The ratio of power delivered by the impeller to the liquid to the power input to the shaft.

$$=(WV_{w2}u_{2}/g)/(\text{power input to the pump shaft})$$




$NQ^{1/2}/H_m^{3/4}=C$

$P/(D^5N^3)=C$

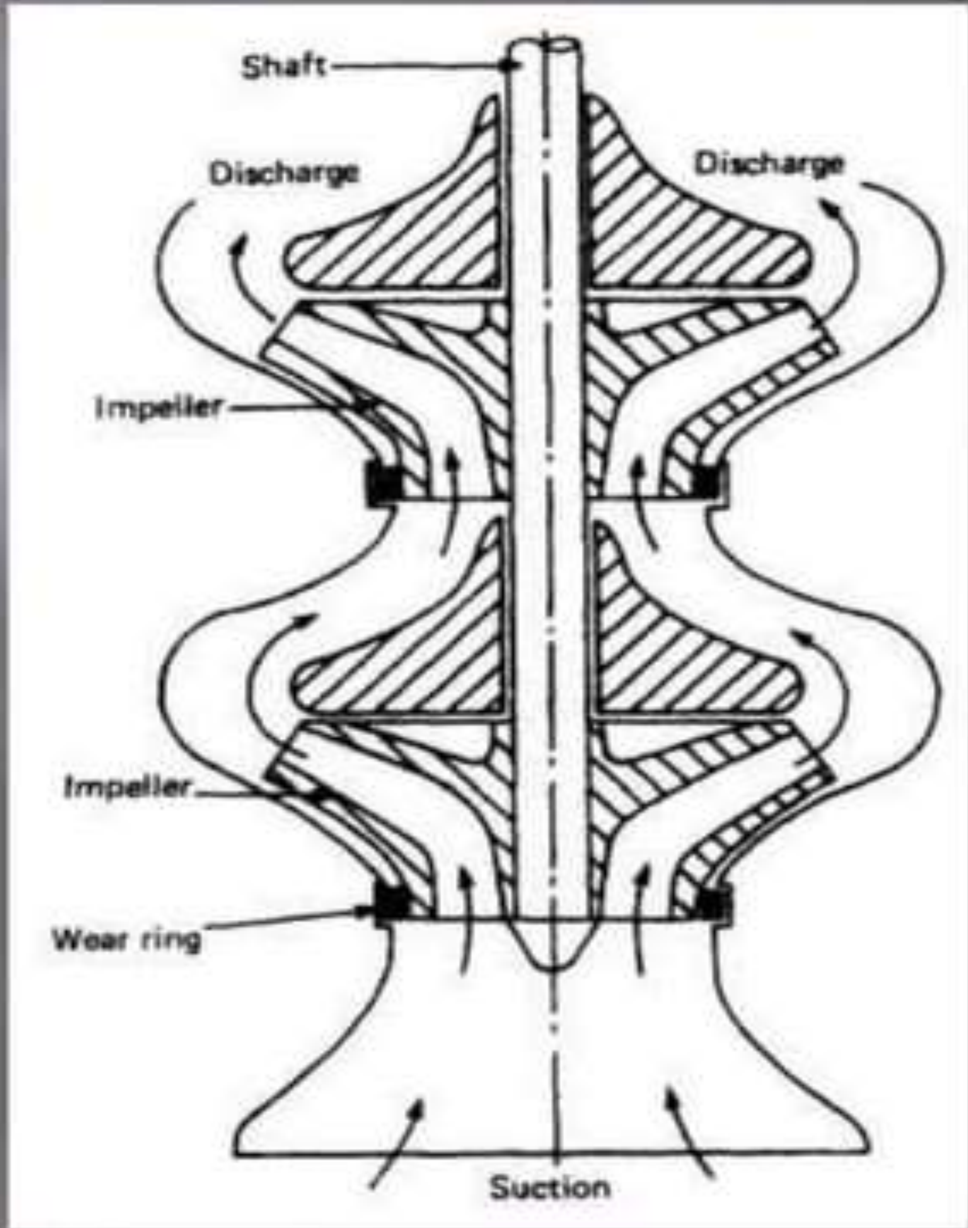
$\eta=\rho QgH/S.P.$

# Operating characteristic curve

# MULTISTAGE CENTRIFUGAL PUMP

- It consists of two or more impellers.
- There are two types as follows:
  a) SERIES :To produce high head.
  b) PARALLEL :To discharge large quantity of liquid.

# Series combination for high head



Parallel combination for high discharge

# Cavitations in Pump

**Cavitation** is the formation of bubbles or cavities in liquid, developed in areas of relatively low pressure around an impeller. The imploding or collapsing of these bubbles trigger intense shockwaves inside the pump, causing significant damage to the impeller and/or the pump housing.

If left untreated, pump cavitations can cause:

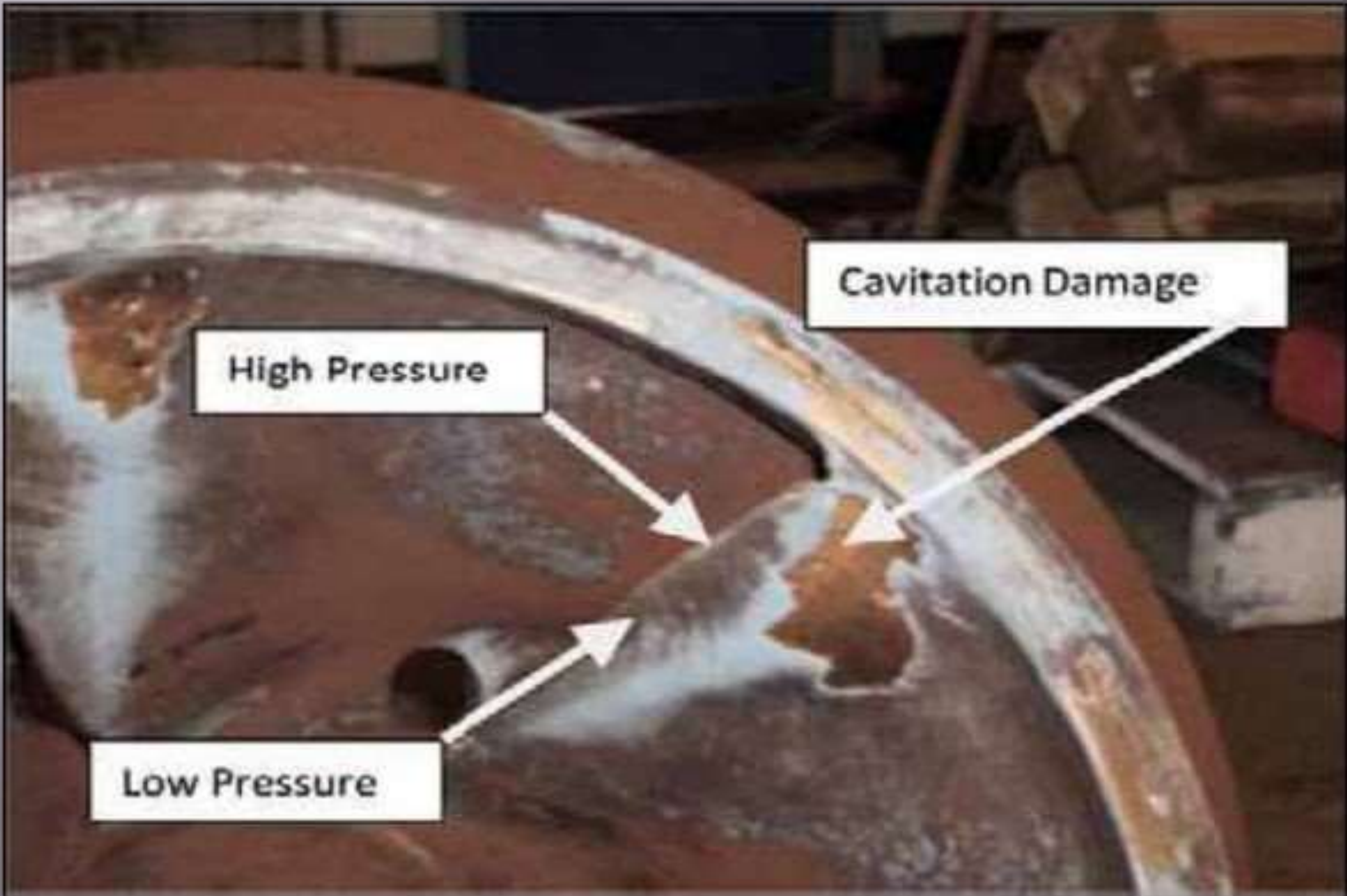
a) Failure of pump housing
b) Destruction of impeller
c) Excessive vibration leading to premature seal and bearing failure
d) Higher than necessary power consumption

**Precaution:** NPSHA > NPSHR

Where NPSHA = Net Positive Suction Head Available
NPSHR = Net Positive Suction Head Required

# CAVITATION

- It is a phenomena of formation of vapour bubble where the pressure falls below the vapour pressure of flowing liquid .
- Collapsing of vapour bubble causes high pressure results in pitting action on metallic surface.
- Erosion, noise & vibration are produced.

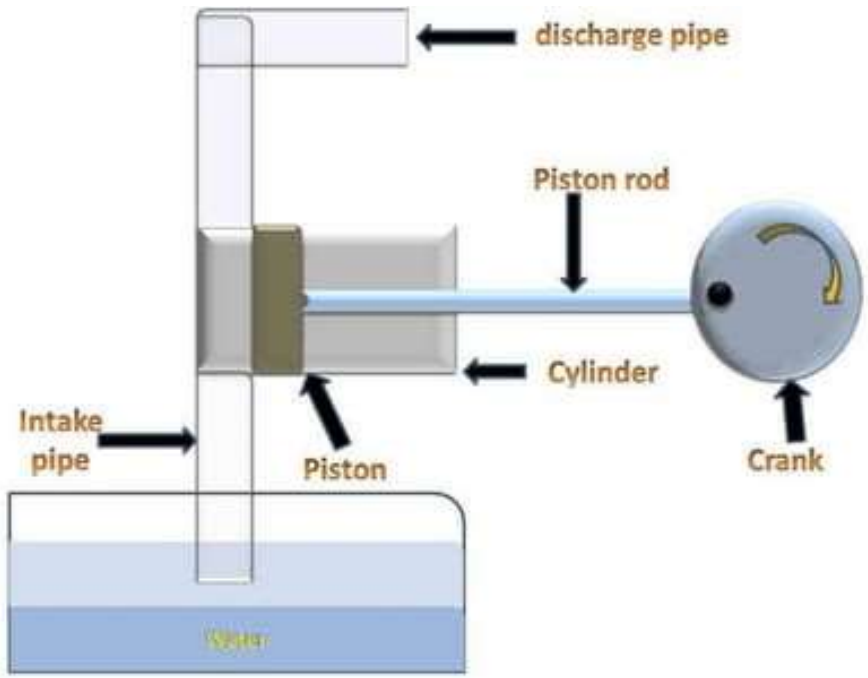

Cavitation Damage
High Pressure
Low Pressure

# EFFECT OF CAVITATION

- Metallic surface are damaged & cavities are formed.
- Efficiency of pump decreases.
- Unwanted noise and vibrations are produced.

# Week -16

**Lecture**
**on**
**Reciprocating Pump**


discharge pipe
Piston rod
Cylinder
Intake pipe
Piston
Crank

# Introduction

**Reciprocating pump** is a hydraulic machine which converts the mechanical energy into hydraulic energy.

**It works by sucking liquid into a cylinder** containing a reciprocating piston which exerts a thrust force on the liquid and increases its hydraulic energy (pressure energy of liquid).

It is also called as **positive displacement pump** which consists of piston or plunger. Piston is present in a cylinder in which it does reciprocating motion (back and forth motion).

It is used at a place where **relatively small amount of water** is to be delivered **at higher pressure/ head.**

# Classification of Reciprocating Pump

1. Piston Pumps:

Hand pump is a simplest form of piston pump used in villages for lifting water from the tube well..

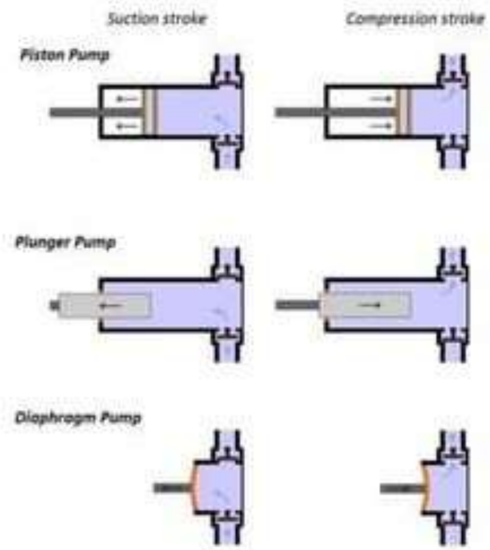
a) Single Acting
b) Double Acting

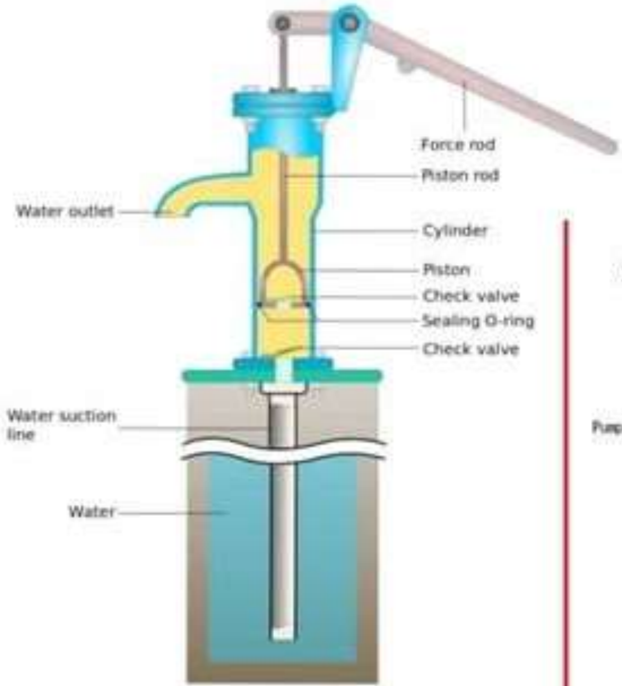
2. Plunger Pumps:

A plunger pump is a type of positive displacement pump where the high-pressure seal is stationary and a smooth cylindrical plunger slides through the seal. This makes them different from piston pumps and allows them to be used at higher pressures.

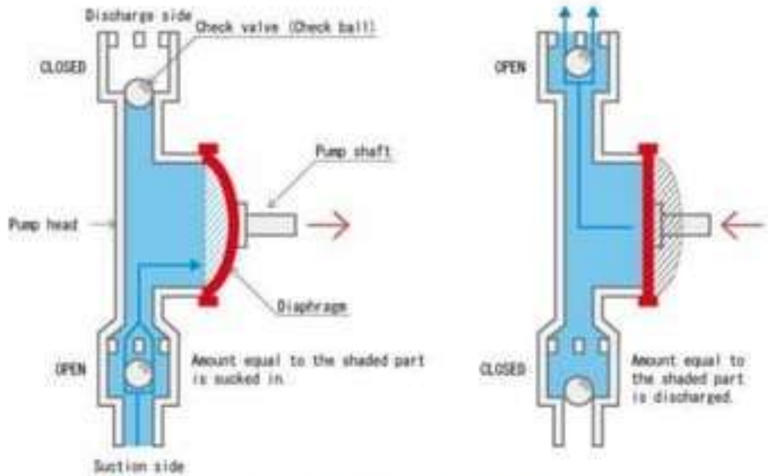
3. Diaphragm Pumps:

Diaphragm pumps employ a flexible membrane instead of a piston or plunger to displace the pumped fluid. They are truly self priming and can run dry without damage.






Piston Pump

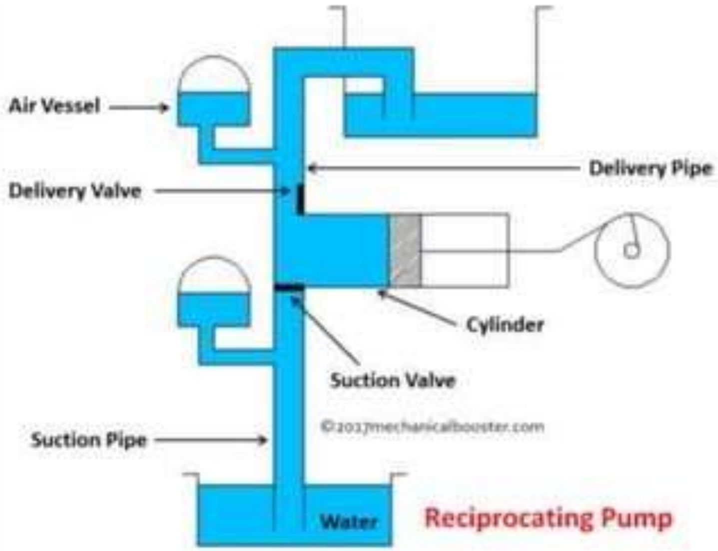



Diaphragm Pump

# Main Parts of Reciprocating Pump

**Main Parts of Reciprocating Pump:**

1. A cylinder with piston, piston rod, connecting rod and a crank
2. Suction Pipe
3. Delivery Pipe
4. **Suction Valve:** It opens during suction of water from the tank to the cylinder and remains closed during compression of the liquid.
5. **Delivery Valve:** It opens during compression of the liquid and remains closed when the water is sucked from the water tank.
6. Air Vessels



# Significance of Air Vessel

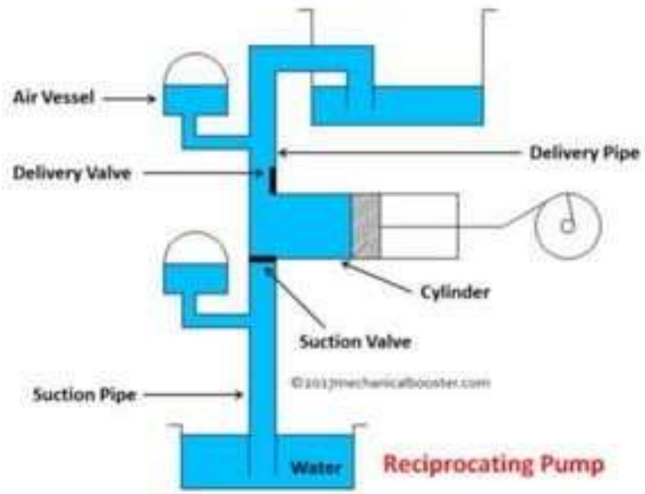
**Air vessels** are closed containers, in which the lower half is water & the upper half is compressed air.

These air vessels are installed near the suction & delivery valve to avoid separation. An air vessel is usually fitted in the discharge pipe to dampen out the pressure variations during discharge.

As the discharge pressure rises, the air in the vessel gets compressed. Similarly, air expands when the pressure falls. The peak pressure energy is thus stored in the air and returned to the system when pressure falls.

**Purposes of Air vessel:**

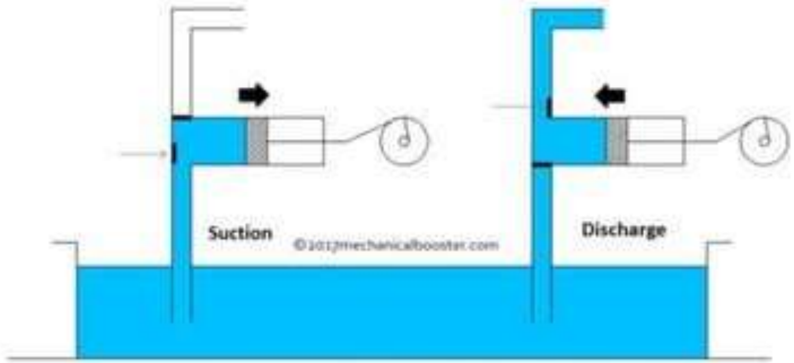
1. To obtain liquid at a uniform discharge.
2. Due to air vessels frictional head and acceleration head decreases



# Single Acting Reciprocating pump

**Working Principle:**
During suction stroke, the piston moves backward and this opens the suction valve making the water enter into the cylinder. During suction the delivery valve remains closed and no water is discharged through it.

After suction stroke, the piston moves forward, delivery valve gets open and suction valve come into close position. As the piston moves forward it exerts thrust force on the liquid and it starts escaping out of the cylinder through delivery pipe.



Single Acting Reciprocating Pump

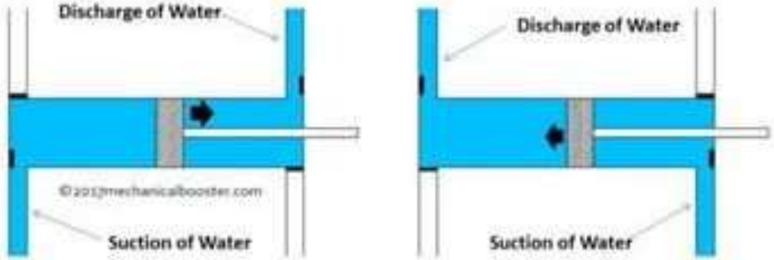
# Double Acting Reciprocating Pump

**Working Principle:**
As the piston moves to the right hand side as shown in the fig. The following process takes plac at left and right side.

**At left side:**
The suction valve opens and delivery valve ge closed. The water from the water reservoir sucked into the cylinder.

**At right side:**
The suction valve is gets closed and delivery valv gets open. the water sucked in the previous strok is discharges out of the cylinder.

In each stroke of the piston, both suction and discharge of liquid takes place at the same time. If suction is taking place at right side than discharge takes place at left and vice-versa.

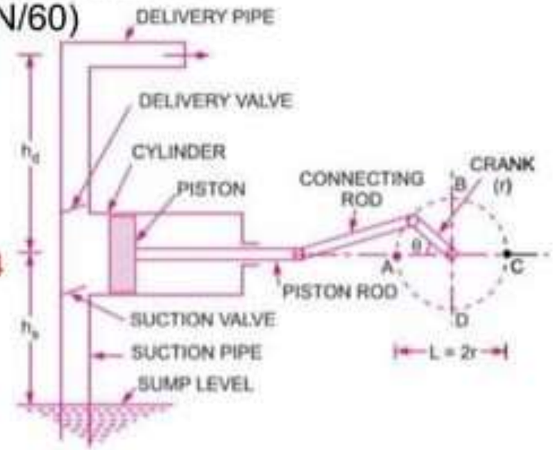



Double Acting Reciprocating Pump

# Discharge through Reciprocating Pump

Discharge through Single acting Reciprocation Pump (Q)
= Discharge in One Revolution x No. of Revolutions per Second
= Volume of Water Delivered in One Revolution x (N/60)
= (AL) (N/60)
= ALN/60

Where
D = Dia. of Cylinder
A = Cross-sectional Area of the Piston or Cylinder = $\pi D^2/4$
N = RPM of Crank
No. of Revolutions per Second = N/60
L = Length of the Stroke = 2r
r = Radius of Crank



# Work done and Power by Reciprocating Pump

A). Work done by Single Acting Reciprocating Pump per Second is given by
= Weight of Water Lifted per Second x Total Height through which water is Lifted
$= W (H_s + H_d)$
$= (\rho g Q) (H_s + H_d)$
$= [\rho g(ALN/60)] (H_s + H_d)$
$= \rho gALN (H_s + H_d)/60$ → for Single Acting Reciprocating Pump

Similarly,
B). Work done by Double Acting Reciprocating Pump per Second is given by
$= \rho g2ALN (H_s + H_d)/60$

Power required to the drive the Pump, P = (Work done per Second/1000) kW

# Slip of Reciprocating Pump

Slip in reciprocating pump is defined as the difference between the theoretical discharge and actual discharge of the reciprocating pump.

Actual discharge of a reciprocating pump will be less than the theoretical discharge of the pump due to leakage of water during operation of pump.

$$\text{Slip} = Q_{th} - Q_{act}$$

But slip is mostly expressed as percentage slip which is given by,

$$\text{Percentage slip} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100 = \left(1 - \frac{Q_{act}}{Q_{th}}\right) \times 100 \qquad \left(\because \frac{Q_{act}}{Q_{th}} = C_d\right)$$

$$= (1 - C_d) \times 100$$

where $C_d$ = Co-efficient of discharge.

# Advantages and Disadvantages of Reciprocating Pump

**Advantages:**

1. High pressure is obtained at the outlet.
2. Priming process is not needed in this pump.
3. It provides high suction lift.
4. It is also used for air.

**Disadvantages**

1. It requires high maintenance because of more wear and tear of the parts.
2. Low flow rate i.e. it discharges low amount of water.
3. They are heavy and bulky in size.
4. High initial cost.

**Applications:**

1. The reciprocating pump is used in oil drilling operations.
2. It is useful in pneumatic pressure systems.
3. Mostly used in light oil pumping.
4. It is used for feeding small boilers condensate return.

# Thank You For Your Attention