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PHARMACEUTICAL ENGINEERING

UNIT 1

TOPIC :

- **Flow of fluids :** Types of manometers, Reynolds number and its significance, Bernoulli's theorem and its applications, Energy losses, Orifice meter, Venturimeter, Pitot tube and Rotometer.

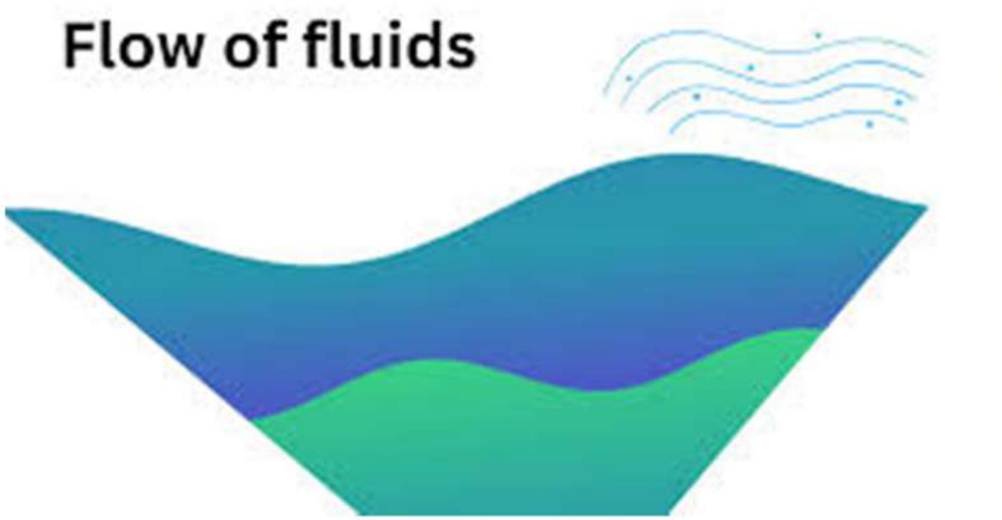
Flow of Fluids

Fluid

- Any substance that possesses the property of *flow* and can continuously change its shape under the influence of an external force is called a fluid.
- Fluids mainly include liquids and gases.

Branches of Fluid Flow

1. **Fluid Statics** – Study of fluids at rest and the pressure exerted by them.
2. **Fluid Dynamics** – Study of fluids in motion and the forces causing the motion.



Applications of Fluid Flow in Pharmacy

- Used in manufacturing dosage forms (syrups, emulsions, suspensions, injections, etc.).
- In mixing of solids with liquids to form suspensions.
- In handling and packaging of pharmaceutical products.
- To measure the rate of flow of fluids during industrial processes.

Fluid Pressure

- Consider a vertical cylinder filled with liquid up to a height h.
- Pressure at the bottom of the cylinder is due to the weight of the liquid column.

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

Where:

- $F = mg$ = weight of liquid
- $m = \rho \times V$
- $V = A \times h$

So,

$$P = \frac{\rho \times A \times h \times g}{A}$$

$$P = \rho g h$$

Final Expression

$$P = \rho g h$$

Where:

- P = Pressure at depth h
- ρ = Density of liquid
- g = Acceleration due to gravity
- h = Height (depth) of liquid column

Manometer

- A manometer is a device used to measure the pressure of a fluid (liquid or gas) at a single point or the pressure difference between two fluids.

Types of Manometers

1. **Simple Manometer** – Measures the pressure at a single point in a fluid system.
2. **Differential Manometer** – Measures the pressure difference between two points in the same or different fluids.

1. Simple Manometer

Simple manometers are used to measure the pressure at a point in a fluid contained in a pipe or vessel.

They are further classified into:

- **Piezometer**
- **U-Tube Manometer**
- **Single Column Manometer**

(a) Piezometer

- Simplest type of manometer.
- Used to measure low to moderate pressures.
- Consists of a vertical glass tube connected to the fluid container or pipe.
- The fluid rises in the tube until equilibrium is reached.

- Equation:

$$P_A = \rho g h$$

Where:

- P_A = Pressure at point A
- ρ = Density of the liquid
- g = Acceleration due to gravity
- h = Height of liquid column

Limitation: Cannot measure negative pressure (vacuum) or very high pressures.

(b) U-Tube Manometer

- Consists of a U-shaped glass tube partly filled with a manometric fluid (usually mercury).
- Manometric fluid must have higher density than the fluid whose pressure is to be measured.
- One limb is connected to the pipe/vessel containing the fluid, while the other limb is open to the atmosphere.
- Used to measure moderate to high pressures.

Equation:

$$P_A = \rho_m g h_2 - \rho_f g h_1$$

Where:

- P_A = Pressure at point A
- ρ_m = Density of manometric (heavy) fluid
- ρ_f = Density of lighter fluid
- h_2 = Height of manometric fluid above reference line
- h_1 = Height of lighter fluid above reference line

(C) Single Column Manometer

- A modified form of the U-tube manometer.
- One limb is connected to a reservoir having a very large cross-sectional area compared to the other limb.
- Due to the large area, the liquid level change in the reservoir is negligible.
- More sensitive than the U-tube manometer.

Types:

1. **Vertical Single Column Manometer**
2. **Inclined Single Column Manometer** (more sensitive because a small vertical pressure difference causes a larger movement along the inclined tube).

Equation:

$$P_A = \rho g h$$

Where:

- P_A = Pressure at point A
- ρ = Density of manometric fluid
- h = Height difference of liquid column

2. Differential Manometer

- A Differential Manometer is a device used to measure the pressure difference between two points in a fluid system or between two different fluids.
- It works by balancing the pressure difference with the height of a column of a manometric fluid (generally mercury, oil, or other heavy liquids).

Types of Differential Manometers

1. **U-Tube Differential Manometer**
2. **Inverted U-Tube Differential Manometer**

1. U-Tube Differential Manometer

- **Construction**:
  - Similar to a simple U-tube manometer.
  - Both ends are connected to two different vessels (say vessel A and vessel B) containing fluids of different pressures.
  - The U-tube contains a manometric fluid of higher density than both fluids.
- **Working**:
  - The difference in pressure between vessels A and B is balanced by the height difference of the manometric fluid.

- Equation:

$$P_A - P_B = \rho_m g h_m + \rho_B g h_B - \rho_A g h_A$$

Where:

- $P_A - P_B$ = Pressure difference between points A and B
- ρ_A = Density of fluid in vessel A
- ρ_B = Density of fluid in vessel B
- ρ_m = Density of manometric fluid
- h_A, h_B, h_m = Heights of liquid columns above the reference line

Use: Measures **moderate to high pressure differences** between two fluids.

2. Inverted U-Tube Differential Manometer

- **Construction**:
  - Consists of an **inverted U-shaped glass tube**.
  - Both ends are connected to vessels A and B containing two fluids.
  - The tube is filled with a manometric fluid of **lower density** than both fluids (commonly oil or lighter liquid).
- **Working**:

- Pressure difference is indicated by the displacement of the lighter manometric fluid.

- **Equation:**

$$P_A - P_B = \rho_A g h_1 - \rho_m g h_m - \rho_B g h_2$$

Where:

- $P_A - P_B$ = Pressure difference between fluids A and B
- ρ_A = Density of fluid in vessel A
- ρ_B = Density of fluid in vessel B
- ρ_m = Density of lighter manometric fluid
- h_1, h_2, h_m = Heights of liquid columns

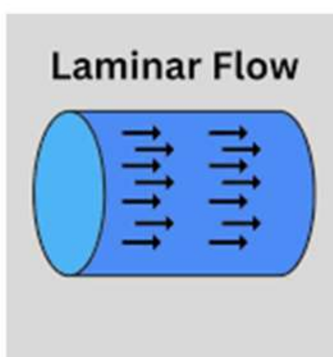
Use: Suitable for measuring **small to moderate pressure differences**, because the lighter manometric fluid provides greater sensitivity.

Types of Fluid Flow

When fluids flow in pipes, their motion depends on velocity, viscosity, and other factors. Generally, three types of flow are observed:

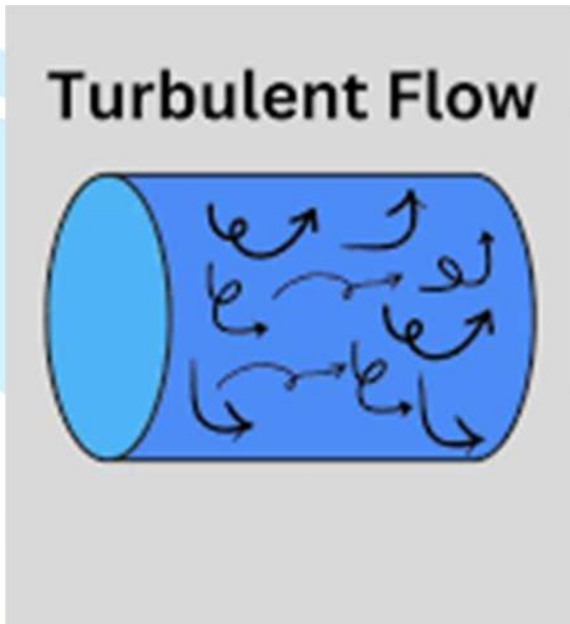
1. Laminar Flow

- Fluid particles move in parallel layers (laminae) without mixing.
- Each layer slides smoothly over the adjacent layer.
- Also called Streamline Flow or Viscous Flow.
- The path of a fluid particle is smooth and regular.
- Condition: Occurs at low velocities and in fluids with high viscosity.
- Example: Flow of glycerin, oil, or blood in narrow vessels at slow speed.



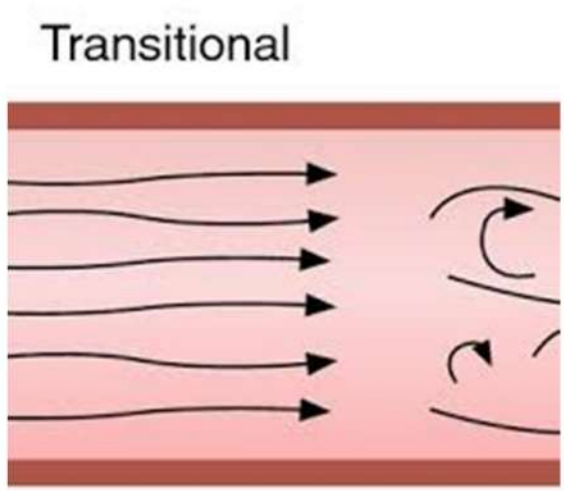
2. Turbulent Flow

- Fluid particles move in a random, irregular, and chaotic manner.
- There is complete mixing of fluid layers.
- Energy loss is high due to friction and eddies.
- Condition: Occurs at high velocities and in fluids with low viscosity.
- Example: Flow of water in rivers, air around moving vehicles.



3. Transition Flow

- Intermediate state between laminar and turbulent flow.
- Contains characteristics of both laminar and turbulent flow.
- Flow pattern is unstable; small disturbances may lead to turbulence.
- Condition: Occurs at medium velocities.



Reynolds Number

- Reynolds Number (ReReRe) is a dimensionless number that indicates the nature of fluid flow in a pipe.
- It is the summarized form of Reynolds' Experiment (1883), where flow was classified into laminar, turbulent, or transition types.
- It is obtained by combining four important factors affecting flow:
    1. Diameter of the pipe (D)
    2. Average velocity of flow (v)
    3. Density of fluid (ρ\rhoρ)
    4. Viscosity of fluid (μ\muμ)

Expression

$$Re = \frac{\rho v D}{\mu}$$

Where:

- ρ = Density of fluid
- v = Mean velocity of fluid
- D = Diameter of pipe
- μ = Viscosity of fluid

Physical Meaning

- Reynolds number is the **ratio of inertial forces to viscous forces**:

$$Re = \frac{\text{Inertial Forces}}{\text{Viscous Forces}}$$

Flow Conditions Based on Re

- If **Re < 2000** → Flow is **Laminar** (smooth, orderly).
- If **2000 < Re < 4000** → Flow is **Transition** (unstable, partly turbulent).
- If **Re > 4000** → Flow is **Turbulent** (chaotic, mixed).

Significance of Reynolds Number

1. **Prediction of Flow Nature**
    - Helps determine whether the fluid flow in a system will be laminar, turbulent, or transition.
2. **Pipe Flow Studies**
    - Useful in studying the flow of incompressible fluids through closed pipes, important in fluid transport in industries.
3. **Sedimentation Studies**
    - Stokes' Law equation (used in sedimentation) is modified using Reynolds Number to determine sedimentation rate in suspensions.
4. **Heat Transfer**
    - Heat transfer in liquids depends strongly on whether the flow is laminar or turbulent.
    - Turbulent flow enhances mixing, thus increasing heat transfer efficiency.
5. **Pharmaceutical Applications**
    - Used in design of mixing, filtration, and suspension systems.
    - Helps in understanding **blood flow** in pharmacology and physiology studies.

Energy Losses in Pipe Flow

When a fluid flows through a pipe, it encounters resistance due to friction, fittings, sudden changes in cross-section, etc. This causes loss of energy (head loss) in the fluid.

The major types of energy losses are:

1. Friction Losses
2. Losses in Fittings
3. Loss due to Sudden Enlargement
4. Loss due to Sudden Contraction

1. Friction Losses

- Loss of energy due to frictional resistance offered by the walls of the pipe and fittings.
- It results in decreased pressure and velocity of fluid.
- Darcy–Weisbach Equation (for head loss due to friction):

$$h_f = \frac{4fLv^2}{2gD}$$

Where:

- h_f = Head loss due to friction
- f = Friction factor (dimensionless)
- L = Length of pipe (m)
- D = Diameter of pipe (m)
- v = Velocity of fluid (m/s)
- g = Acceleration due to gravity (9.81 m/s^2)

Note: Longer pipe length, smaller diameter, or higher velocity increases friction losses.

2. Losses in Fittings

- Energy losses caused due to bends, elbows, tees, valves, and other fittings that disturb smooth flow.
- These losses occur due to change in direction or obstruction of fluid.

- Equation:

$$h_f = \frac{kv^2}{2g}$$

Where:

- h_f = Head loss due to fittings
- k = Resistance coefficient (depends on type of fitting)
- v = Velocity of fluid
- g = Acceleration due to gravity

Examples of fittings causing losses:

- **Elbow fittings** (change direction)
- **T-fittings** (dividing flow)
- **Valves** (control flow)

3. Loss due to Sudden Enlargement

- When a pipe suddenly increases in diameter, velocity of the fluid decreases and part of energy is lost as eddies.

- **Equation:**

$$h_e = \frac{(v_1 - v_2)^2}{2g}$$

Where:

- h_e = Head loss due to enlargement
- v_1 = Velocity in smaller diameter section
- v_2 = Velocity in larger diameter section

Note: Greater the difference between v1 and v2, greater is the loss.

4. Loss due to Sudden Contraction

- When a pipe suddenly decreases in diameter, fluid contracts and eddies are formed, leading to energy loss.

- Equation:

$$h_c = \frac{kv^2}{2g}$$

Where:

- h_c = Head loss due to contraction
- k = Coefficient of contraction (depends on geometry)
- v = Velocity at smaller section
- g = Acceleration due to gravity

Bernoulli's Theorem

- Bernoulli's theorem is based on the law of conservation of energy. It states that:
- The total energy of a fluid in motion (i.e., the sum of pressure energy, kinetic energy, and potential energy) per unit volume remains constant at any cross-section of a streamline, provided there is no loss of energy.

Mathematical Expression

At point **A** in a pipe:

- Pressure Energy per unit volume = Pa
- Potential Energy per unit volume = **ρgh.**
- Kinetic Energy per unit volume = ½**ρv.**^{2}

So,

$$P_a + \rho g h_a + \frac{1}{2}\rho v_a^2 = Constant$$

At point **B** in the same pipe:

$$P_b + \rho g h_b + \frac{1}{2}\rho v_b^2 = Constant$$

Thus,

$$P_a + \rho g h_a + \frac{1}{2}\rho v_a^2 = P_b + \rho g h_b + \frac{1}{2}\rho v_b^2$$

Bernoulli's Equation in Terms of Head

Dividing the above by **ρg**,

$$\frac{P}{\rho g} + h + \frac{v^2}{2g} = Constant$$

Where:

- $\frac{P}{\rho g}$ = Pressure Head
- h = Potential Head
- $\frac{v^2}{2g}$ = Kinetic Head

Practical Form of Bernoulli's Equation

In real situations, energy is added by pump work (W) and energy is lost due to friction (F). So the equation becomes:

$$\frac{P_a}{\rho g} + h_a + \frac{v_a^2}{2g} + W - F = \frac{P_b}{\rho g} + h_b + \frac{v_b^2}{2g}$$

Limitations of Bernoulli's Theorem

The theorem is valid only when:

1. Fluid is incompressible.
2. Fluid is non-viscous (no internal resistance).
3. Flow is steady and streamline.
4. Frictional losses are negligible.

Applications of Bernoulli's Theorem

1. Working of Venturimeter (measuring fluid flow).
2. Working of Orifice meter.
3. Working of Pitot tube (measures velocity of fluid).
4. Working of centrifugal pumps.
5. Explains flight of an aeroplane (lift force due to pressure difference).
6. Blowing off roofs during strong winds (pressure drop above the roof).

Flow of Fluids – Flow Meters

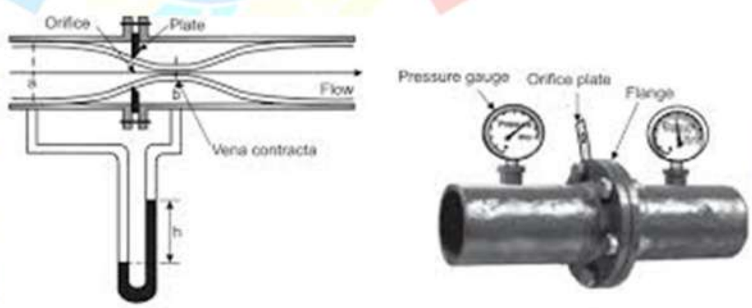
Flow meters are devices used to measure the flow rate of a fluid (liquid or gas) or the total quantity of fluid moving through a pipeline.

The **four most common types** of flow meters are:

1. **Orifice Meter**
2. **Venturi Meter**
3. **Pitot Tube**
4. **Rotameter**

1. Orifice Meter

An Orifice Meter is a device used to measure the flow rate of fluid through a pipe. It works by creating a pressure difference across an orifice plate inserted in the pipeline.



(i) (ii)

Principle

It works on Bernoulli's theorem**:**

- When fluid flows through a reduced cross-sectional area (orifice), velocity increases.
- As velocity increases, pressure decreases.
- The pressure difference between two points is used to calculate the flow rate.

Construction

- A thin flat orifice plate with a small hole at the center.
- Inserted into the pipeline.

- Pressure at upstream (A) and downstream (B) is measured using a **U-tube manometer.**

Working

- Fluid passes through the orifice → velocity at point B increases, pressure decreases.
- Pressure difference (ΔH) is recorded on manometer.
- Flow rate is given by:

$$Q = C_0 \cdot A_0 \cdot \sqrt{\frac{2g\Delta H}{1-(d_0/d)^4}}$$

Where:

- C_0 = Coefficient of discharge
- A_0 = Area of orifice
- d_0 = Diameter of orifice
- d = Diameter of pipe

Uses

- Measurement of flow in power plants, industrial boilers, and refineries.
- Used for steam, crude oil, and petroleum products.

Advantages

- Simple design and low cost.
- Requires less space for installation.
- Low maintenance.

Disadvantages

- Clogging occurs with viscous/dirty fluids.
- Accuracy depends on proper installation.

2. Venturi Meter

A Venturi Meter is a flow measuring device that creates a pressure difference across a constricted throat section of the meter.

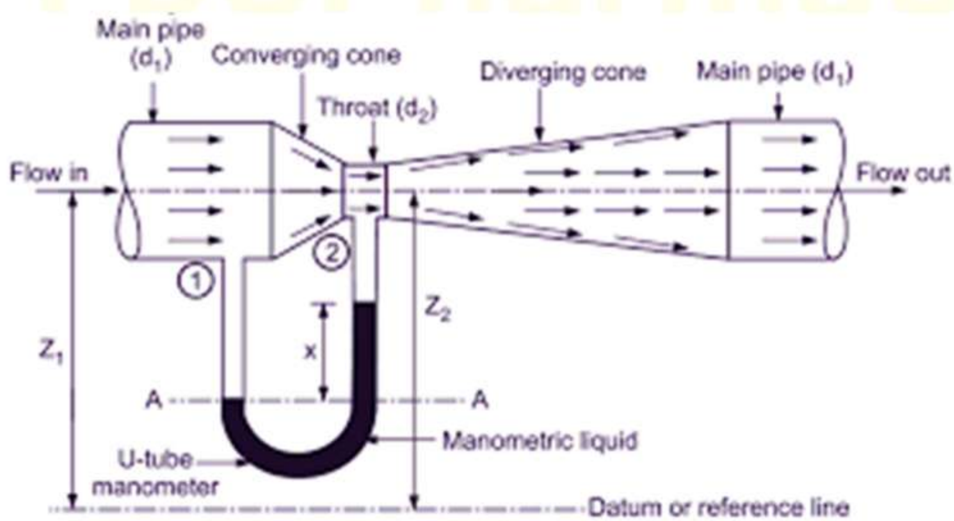
Principle

It works on **Bernoulli's theorem**.

- When the cross-sectional area decreases, velocity increases and pressure decreases.
- This pressure difference is used to calculate flow rate.

Construction

- Composed of three parts:
  1. Convergent cone (upstream section)
  2. Throat (smallest section)
  3. Divergent cone (downstream section)
- A manometer is connected between upstream (A) and throat (B).



Working

- Fluid enters convergent cone → velocity increases at throat → pressure decreases.
- Pressure difference (ΔH) measured using manometer.
- Flow rate is:

$$Q = C_v \cdot A_t \cdot \sqrt{2g\Delta H}$$

Where:

- C_v = Coefficient of Venturi meter
- A_t = Area of throat

Uses

- Measurement of crude oils, natural gas, and water.
- Standard reference device for calibrating other flow meters.

Advantages

- Very accurate and reliable.
- Can be used for large pipe sizes.
- Low energy loss.

Disadvantages

- High cost.
- Requires large installation space.

3. Pitot Tube

Named after French engineer Henri Pitot, it is used to measure the velocity of fluid flow at a point.

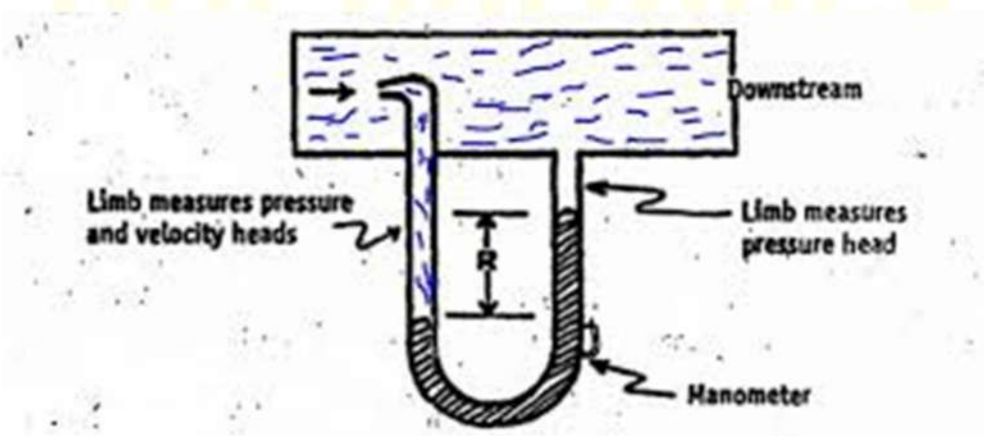
Principle

Based on **Bernoulli's theorem**:

- When fluid velocity at a point reduces to zero, kinetic energy converts to pressure energy.
- This rise in pressure (stagnation pressure) is measured to calculate velocity.

Construction

- Consists of a hollow tube bent at a right angle.
- One opening faces the fluid flow (measures stagnation pressure).
- A second tube measures static pressure.
- Difference is measured by a manometer.



Working

- The Pitot tube inserted in fluid stream measures stagnation pressure.
- Manometer gives difference between stagnation and static pressure.
- Velocity is:

$$V = C_p \cdot \sqrt{2g\Delta H}$$

Where:

- C_p = Coefficient of Pitot tube

Uses

- Commonly used in aircrafts to measure airspeed.
- Used for measuring flow velocity in liquids and gases.

Advantages

- Simple, economical, and easy to install.
- Provides direct velocity measurement.

Disadvantages

- Not suitable for dirty or viscous fluids.
- Requires frequent calibration.

4. Rotameter

A Rotameter is a variable area flow meter used to measure volumetric flow rate of fluids in a vertical tapered tube.

Principle

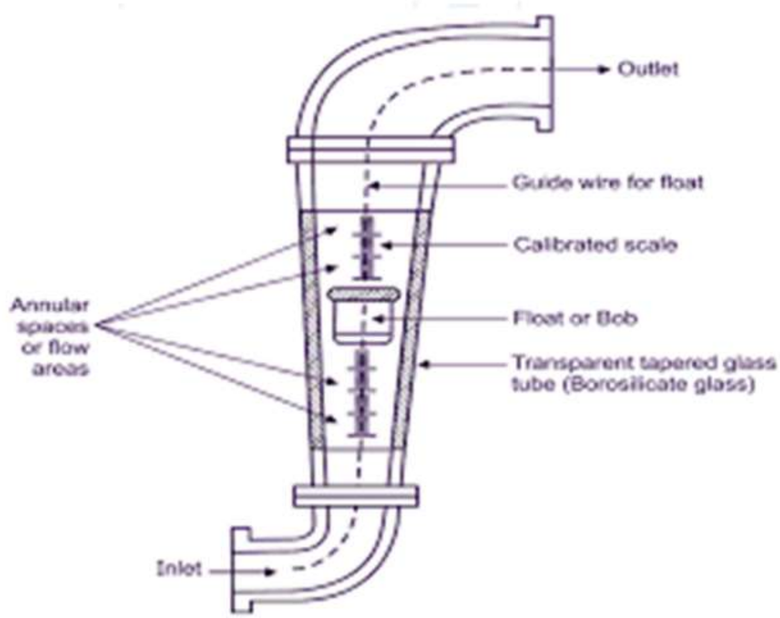
Based on the balance of:

- Gravitational force (weight of float)
- Upthrust (buoyancy force)
- Drag force (fluid force on float)

The float reaches equilibrium at a height proportional to the flow rate.

Construction

- A vertical tapered glass tube, wider at the top and narrow at the bottom.
- A float (plummet) made of glass, metal, or plastic placed inside.
- Scale attached to tube for reading flow.



Working

- Fluid flows upward → float rises until forces balance.

- Height of float corresponds to flow rate, which is read directly from the scale.

Uses

- Used in **chemical industries** and **oil industries**.
- Medical uses (e.g., oxygen flow meters in anesthesia).
- Control of gases in fermentation processes.

Advantages

- Simple and economical.
- Requires no external power.
- Suitable for small flow rates.

Disadvantages

- Can only be installed in vertical position.
- Glass tube fragile and difficult to handle.