1. Different Kind of Force Acting on Fluid Particle

- Pressure force
- Gravity force
- Viscous force

Remember:

☑ If all the three forces are taken into account then equation obtained is known as Naiver-Stokes equation.

2. Euler's Equation

It represents momentum equation in a 2-D, **inviscid** steady flow.

$$\frac{dp}{\rho} + gdz + VdV = 0$$

- No viscous effects are considered.

3. Bernoulli's Equation

- Assumptions in Bernoulli's equation:
  - fluid is ideal
  - flow is steady
  - flow is continuous
  - fluid is incompressible
  - flow is non-viscous
  - flow is irrotational
  - applicable along a stream line

This equation is obtained by integrating Euler's equation.

$$\frac{p}{w} + z + \frac{V^2}{2g} = C$$

Here, $\frac{p}{w} + z$ = Pressure head + gravitational head

= Piezometric head

Remember:

☑ Bernoulli's equation is applicable across the streamlines, if flow is **irrotational**.

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Fluid Dynamics

Introduction - The dynamics of fluid flow is defined as that branch of science which deals with the study of fluids in motion considering the forces which cause the flow.

→ **Different types of energies or Head of a liquid in motion**

* Total Energy = Potential Energy + Kinetic Energy + Pressure Energy
* Total Head = Potential Head + Kinetic Head + Pressure Head

$$= z + \frac{v^2}{2g} + \frac{p}{w}$$

→ **Bernoulli's Equation** -

→ It states that, "for a perfect incompressible fluid or liquid, flowing in a continuous stream, the total energy of a particle remains the same, while the particle moves from one point to another."

→ It is obtained by integrating the Euler's eq^n.

Euler's eq^n $= \frac{dp}{\rho} + g.dz + v.dv = 0$ —— (1)

Integrating eq^n (1) we get,

$$\int \frac{dp}{\rho} + \int g.dz + \int v.dv = 0$$

$$\Rightarrow \int \frac{dp}{\rho g} + \int dz + \int \frac{v}{g} dv = 0$$

$$\Rightarrow \frac{p}{\rho g} + z + \frac{v^2}{2g} = 0$$

$$\Rightarrow \frac{p}{w} + z + \frac{v^2}{2g} = 0$$

For ideal fluid, Bernoulli's eq^n is :-

$$z_1 + \frac{p_1}{w} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{w} + \frac{v_2^2}{2g}$$

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→ Assumptions of Euler's Eq^n / Bernoulli's Eq^n :-

(1) The fluid is non-viscous
(2) Fluid is homogeneous and incompressible
(3) Flow is continuous, steady and along the streamline
(4) Velocity of flow is uniform over the section.

→ Bernoulli's Equation for Real fluids -

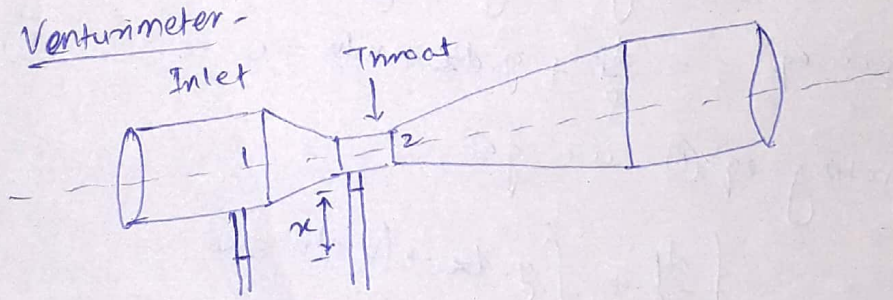
$$\frac{p_1}{w} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{w} + \frac{V_2^2}{2g} + Z_2 + h_L$$

Here, h_L = loss of energy between sections 1 and 2

→ Applications of Bernoulli's Eq^n -

Applied to → (i) Venturimeter
(ii) Orifice meter
(iii) Pitot tube
(iv) Siphon

(1) Venturimeter -



Converging part
Throat
Diverging part

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

Horizontal $Z_1 = Z_2$

$$\Rightarrow \frac{p_1 - p_2}{\rho g} = \frac{V_2^2 - V_1^2}{2g}$$

$$\Rightarrow h = \frac{V_2^2 - V_1^2}{2g}$$

Again, $A_1V_1 = A_2V_2 \Rightarrow V_1 = \frac{A_2V_2}{A_1}$

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$$\therefore \quad h = \frac{V_2^2}{2g}\left[\frac{A_1^2 - A_2^2}{A_1^2}\right]$$

$$\Rightarrow \quad V_2 = \frac{A_1}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh}$$

$$Q = A_1 V_1 = A_2 V_2$$

$$\therefore \quad \boxed{Q = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh}} = \text{Theoretical discharge}$$

$$\boxed{Q_{actual} = C_d \sqrt{2gh} \times \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}}$$

C_d = coeff. of discharge < 1

→ Expression for 'h' by differential U-tube manometer

Case-I Liq. in manometer is heavier than liquid in pipe.

$$\boxed{h = x\left[\frac{S_h}{S_o} - 1\right]}$$

S_h = Sp. gravity of heavier fluid

S_o = Sp. gr. of flowing fluid in pipe

Case-II Liq. in manometer is lighter than liq. flowing in pipe

$$h = x\left[1 - \frac{S_L}{S_o}\right]$$

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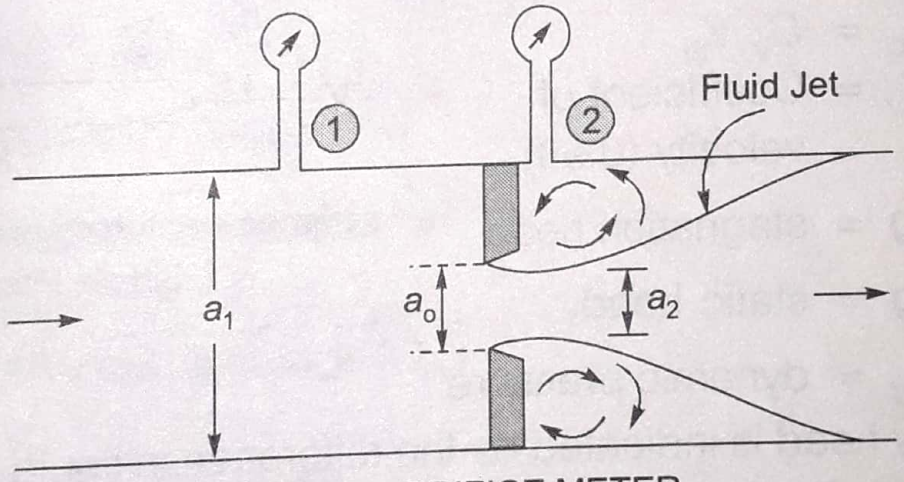
Remember:

☑ Venturimeter is used for measuring rates of flow in both incompressible and compressible fluids.

5. Orifice Meter

- It is cheaper arrangement but has more energy loss.



ORIFICE METER

$$Q = \frac{C_d\, a_1 a_o}{\sqrt{a_1^2 - a_o^2}} \sqrt{2gh}$$

$$a_1 = \frac{\pi}{4} D^2$$

$$a_o = \frac{\pi}{4} d_o^2$$

d_o = diameter of orifice

Remember:

☑ It is used to measure **discharge**

☑ $C_d = 0.63 - 0.65$

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☑ For orifice, $C_c = \frac{C_d}{C_v}$

Here, C_c = Coefficient of contraction
C_d = Coefficient of discharge
C_v = Coefficient of velocity'

☑ A **flow nozzle** is essentially an orifice meter in which jet contraction is eliminated by smooth entrance boundary and thus result in much **smaller losses** than orifice meter.

6. Pitot Tube

- It is based on principle of conversion of kinetic head into pressure head. The point at which velocity reduces zero is called **stagnation point.**

$$p_s = p_o + p_d$$

$$V_{th} = \sqrt{2gh}$$

$$= \sqrt{2g\left(\frac{p_s - p_o}{\rho g}\right)}$$

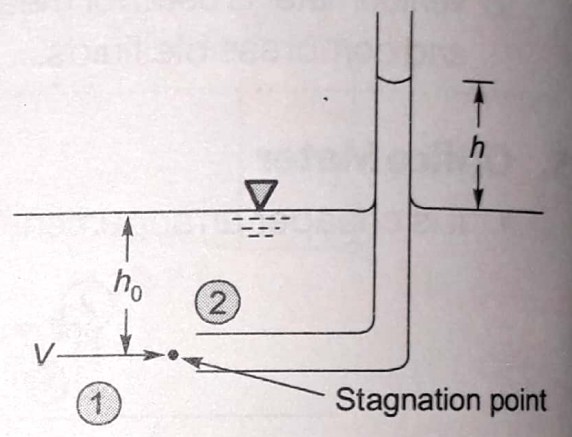
$$V_{ac} = C_v V_{th}$$

C_v = Coefficient of velocity (0.98)

$p_s/\rho g$ = stagnation head

$p_o/\rho g$ = static head.

p_d = dynamic pressure

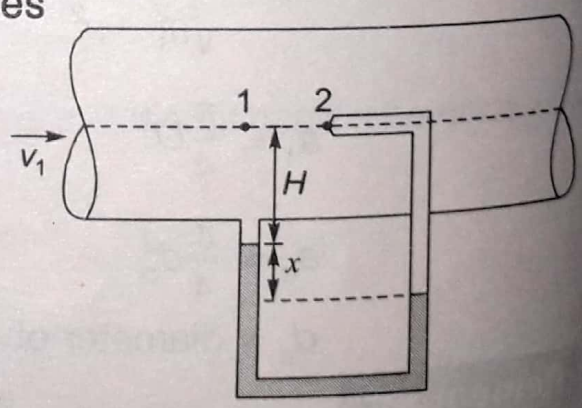


Simple Pitot Tube

- Velocity head is indicated by the difference in liquid level between the Pitot tube and the piezometer. The **Pitot tube** measures the total head and therefore known as **total head tube**.
- **Application of Pitot Tube in Pipes**

$$v_1 = \sqrt{2gh}$$

$$h = x\left(\frac{S_m}{S} - 1\right)$$



where, S_m = Relative density of manometric fluid
S = Relative density of flowing fluid

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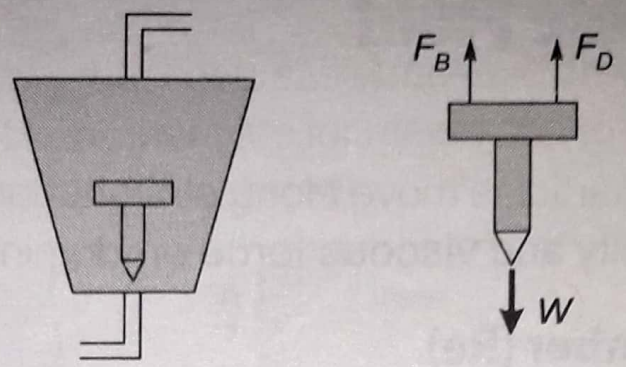
7. Rotameter



- $W = F_D + F_B$

  F_D = Drag force

  F_B = Byouant force

8. Hydraulic Coefficients

- Contraction coefficient (C_c)

$$= \frac{\text{Area of jet at vena contracta}}{\text{Area of orifice}}$$

- Coefficient of velocity (C_v)

$$= \frac{\text{Actual velocity } (V_{ac})}{\text{Theoretical velocity } (V_{th})}$$

- Coefficient of discharge (C_d)

$$= \frac{\text{Actual discharge } (Q_{ac})}{\text{Theoretical discharge } (Q_{th})}$$

9. Devices and Their Uses

Device	Measurement
Venturimeter	Rate of flow (discharge)
Flow nozzle	Rate of flow
Orifice meter	Rate of flow
Bend meter	Rate of flow
Rotameter	Rate of flow
Pitot tube	Velocity
Hot wire anemometer	Air & gas velocity
Current meter	Velocity in open channels

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