Flow Measurement

- In all the production processes, measurement of rate of flow of solids, liquids and gases assume great importance.
- Equally important is the knowledge of the total quantity that has gone past a section during a certain interval of time.
- Flow measurement is an everyday event. Whether you are filling up a car with petrol (gasoline) or wanting to know how much water the garden sprinkler is consuming, a flowmeter is required.
- Commonly used Flowmeters:-

1. Differential pressure flowmeters
   - Orifice plate
   - Venturi tube
   - Nozzle
   - Pilot tube
2. Variable Area flowmeters ⊢ Rotameter.
3. Turbine flowmeter.
4. Electromagnetic flowmeter.
5. Ultrasonic flowmeter.
6. Positive-displacement meters. (eg Petrol Pump)
   ↳ Tell us about total quantity of fluid flowing.
7. Vortex-Flow meters.

Important Principles of fluid flow in Pipes

These principles are 1) Difference between Laminar and turbulent flow
2) Meaning of Reynolds number.
3) Importance of flow's velocity profile.

- Fluid motion in a pipe characterised by: two types mainly: laminar, turbulent.

In Laminar flow, the fluid travels as parallel layers that do not mix as they move in the direction of flow.

If the flow is turbulent, the fluid does not travel in parallel layers, but moves in a haphazard manner

Flow characteristics or velocity distribution can be predicted by a no. known as 'Reynold's number'.

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

D - Pipe diameter, ρ - density of fluid.
v - mean velocity of fluid,
μ - Dynamic viscosity of fluid.

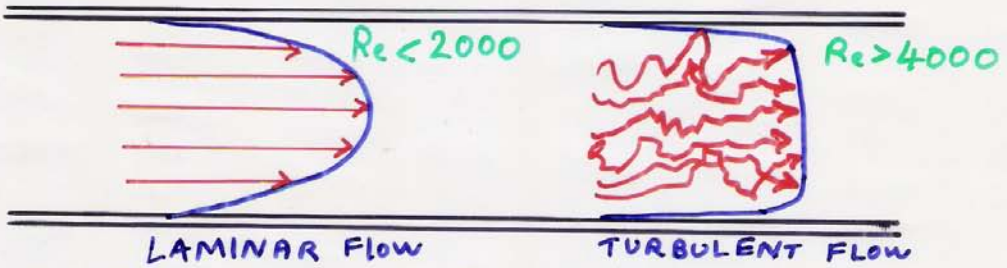


fig. Velocity profiles in Laminar and turbulent flow.

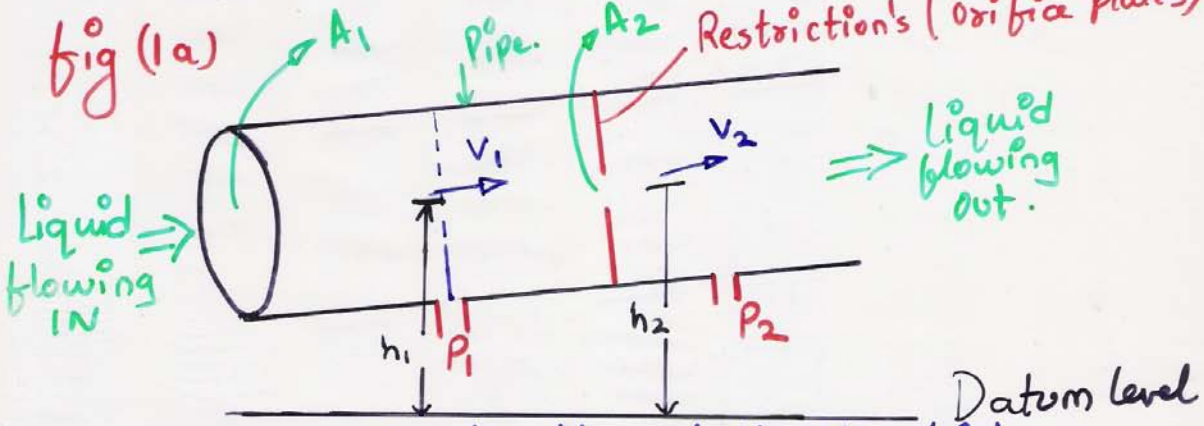
- The fluid velocity across a pipe cross-section is not constant & depends on type of flow present.
- In laminar flow, velocity profile is 'Parabolic', whereas in turbulent flow it is 'flatter'.

- Differential Pressure flowmeter :-

Over 40% of all liquid, gas, and steam measurements made in industry are still done using Differential Pressure flowmeter ie Orifice plate, Venturi tube, and nozzle.

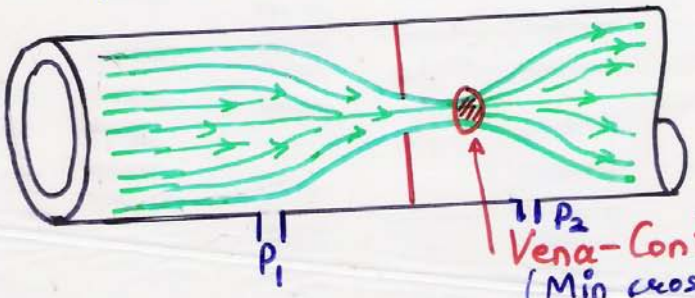
→ The operation of these flowmeters is based on the observations made by Bernoulli. ie they are based on Bernoulli's principle.

fig (1a)



We are obstructing the flow of liquid, which creates the pressure difference (ΔP)

fig(1b)



($A_2 < A_1$, ie $v_1 < v_2$, & $P_2 < P_1$)

Bernoulli's equation :-

$$\frac{P_1}{S_1} + \frac{v_1^2}{2} + h_1 g = \frac{P_2}{S_2} + \frac{v_2^2}{2} + h_2 g$$

where, P_1 → Upstream Pressure , A → Area of cross-section.
P_2 → Downstream Pressure. , S → Fluid density

Differential Pressure flow meters:-

- Principle of operation of these flowmeters is based on Bernoulli's Observations that

1. If an restriction (eg Orifice plates) is placed in a pipeline, then the velocity of fluid through the restriction is increased.
2. The ↑se in velocity at restriction causes the static pressure to ↓se at this section ie (P_2) and a pressure difference ($\Delta P = P_1 - P_2$) is created.
3. The difference between the pressure upstream (P_1) and pressure downstream (P_2) of this obstruction is related to rate of fluid flowing through the restriction and ∴ through pipe.
4. Thus, differential Pressure O/P is calibrated in terms of Volume Flow Rate.
5. A differential Pressure flowmeter consists of two basic elements: an obstruction/restriction to cause a pressure drop in the flow and a method of measuring the pressure drop across restriction (a differential Pressure transducer)

The theoretical value of Volume flow Rate in a differential pressure flow meter (Venturi tube, Orifice plate) is

$$Q_{theo} = \left(\frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \right) \sqrt{\frac{2(P_1 - P_2)}{S}} \quad -(1)$$

Flow - Obstruction Elements:-

1) Orifice Plate:-

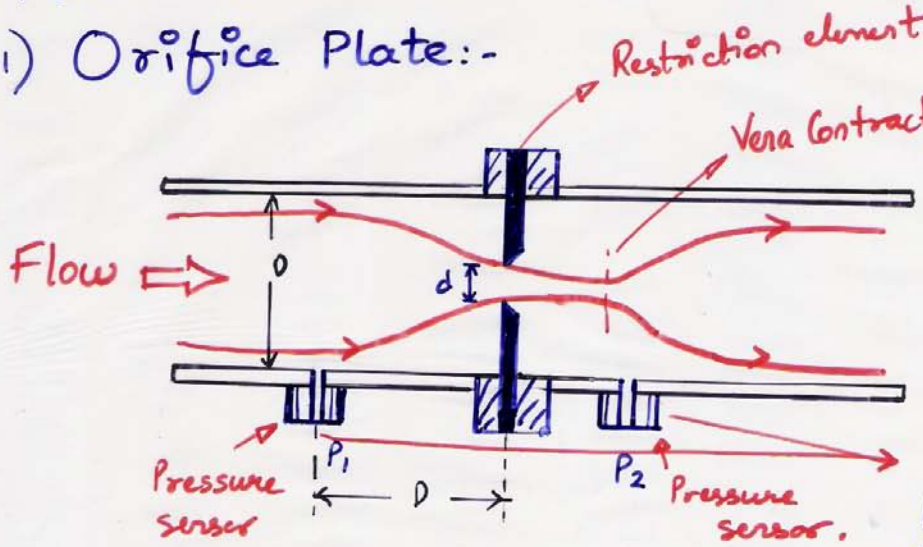


fig (a)

Two Pressure Tapping (Pressure drop across flowmeter measured at these points)

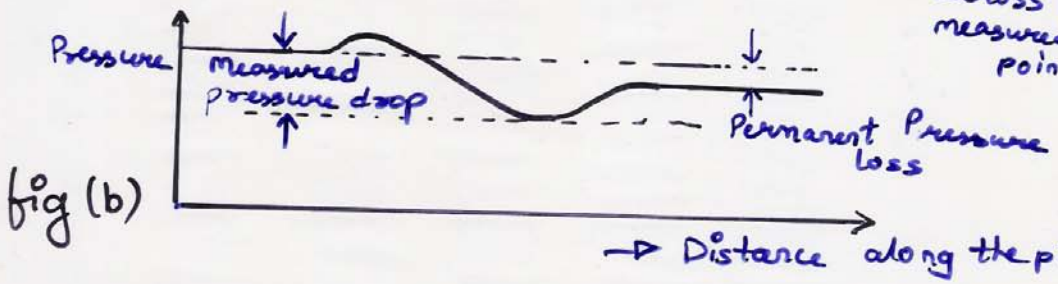


fig (b)

- Orifice plate is most widely used (80%) flow-measuring element mainly becoz of its simplicity and low cost.
- It is metal plate with a hole of specified size & position cut in it.
- When inserted in a pipeline, it causes ↑se in velocity of fluid as it passes through hole in plate & consequent ↓se in downstream pressure (P_2).
- After passing through this restriction, the fluid flow jet continues to contract until a minimum diameter known as 'Vena Contracta' is reached ie at this point (Fluid velocity is max, fluid pressure is 'minimum'.

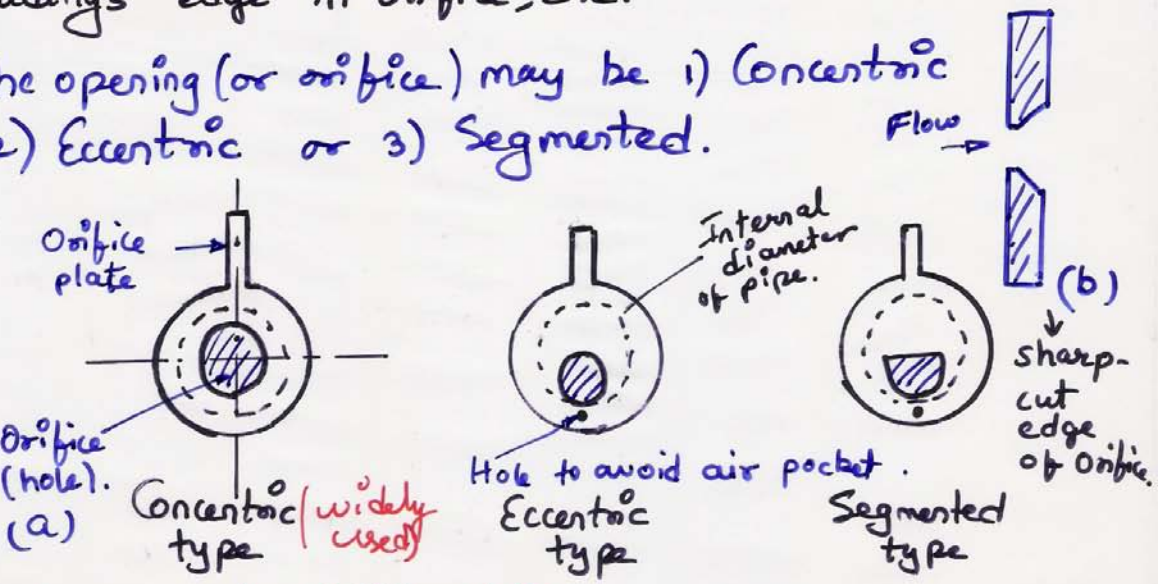
- If eqn (1) is used to calculate Volumetric flow rate, then error would result.
  This is because A_2 should strictly be area of vena contracta, which of course is unknown.

$$Q_{Practical} = \frac{C}{\sqrt{1-\beta^4}} \epsilon \frac{\pi}{4} d^2 \sqrt{\frac{2(P_1 - P_2)}{\rho}}$$

where, ρ - density of fluid upstream of orifice plate
d - Diameter of hole in orifice plate.
β = Diameter ratio d/D.
C = Discharge co-eff or Correction factor.

Discharge co-eff (C) is affected by changes in β, Reynold no (Re), pipe roughness, sharpness of leadings edge in orifice, etc.

- The opening (or orifice) may be 1) Concentric 2) Eccentric or 3) Segmented.



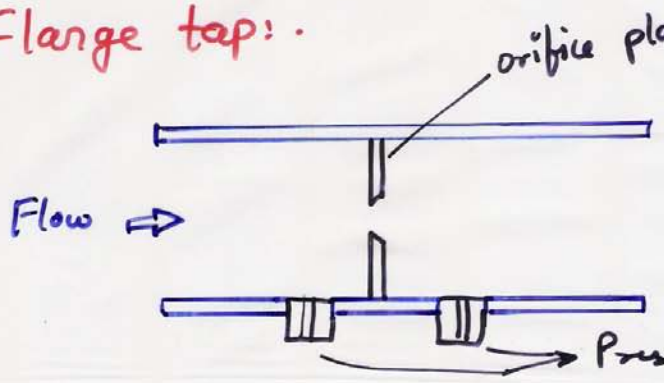
Disadvantages of Orifice plate.

1. There is permanent pressure loss in downstream. (Pressure recovery by pumping (cost ↑ses))
2. Wear of sharp edge on account of long use.
3. Flow rate is non-linear w.r.t pressure drop.

Eccentric orifice plate suited for dirty fluids.

Orifice Pressure Taps:-

1) Flange tap:-



Advantage:- Entire orifice assembly easily replaceable & pressure taps are accurately located.

2) D and D/2 taps.

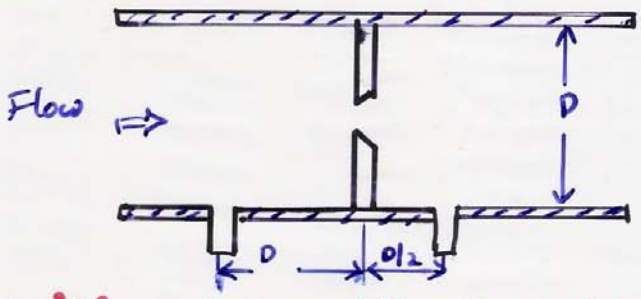


fig Orifice plate with D and D/2 tappings.

3) Vena-Contracta taps:-

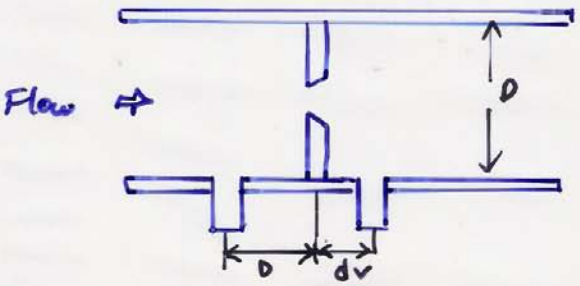
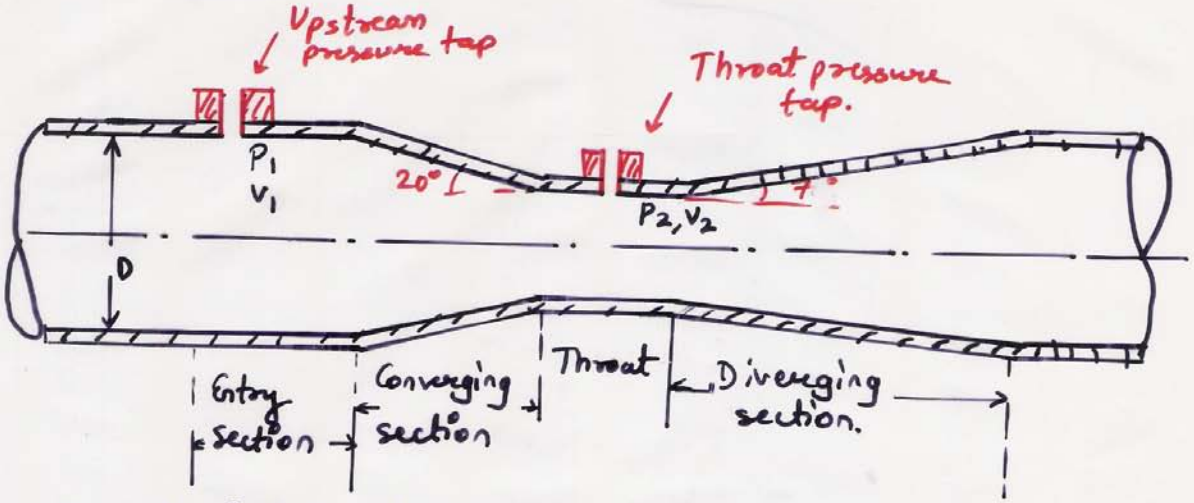


fig orifice plate with vena-contracta taps.

In vena-contracta tap, the differential pressure (ΔP) is maximum for a given flow rate.

Venturi tubes:-



- A venturi tube is used where Permanent pressure loss is of prime importance & where max accuracy is desired.
- It has following improvements over orifice:-
  1) Permanent pressure loss is less.
  2) Tube can be used for very high flow rate.
  3) Tube is suitable for high viscous fluids / having suspended particle.
  4) long working life and almost no maintenance.
- Here, Pressure taps are made of Piezometer rings as to average the measurement around periphery.
- Large Venturi tubes usually made of concrete.
- It is widely used in high flow situation such as Municipal water systems.
- Smooth internal shape of Venturi tube means it is unaffected by solid particles / slurries in flowing fluid.
- Only disadv is Cost, and we need D/P transmitter for electrical o/p if desired.

The Nozzle flowmeter:-

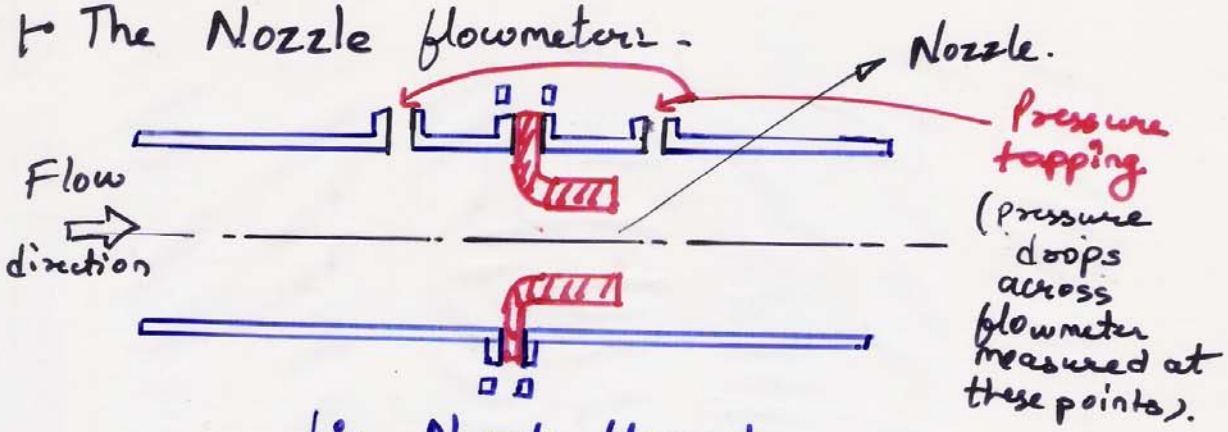


fig Nozzle flowmeter

- The nozzle combines some of features of orifice plate & Venturi tube.
- Same operating principle as orifice (ie Measure Pressure difference in term of flow rate).
- The smooth inlet of nozzle means it is more expensive than orifice but cheaper than Venturi tube.
- Permanent pressure loss in flow nozzle is same as orifice.
- The device has no sharp edges hence more suited for use with dirty and abrasive fluids.
- The nozzle is also commonly used for high-velocity (fluid flow velocity), high-temperature applications such as steam-metering.

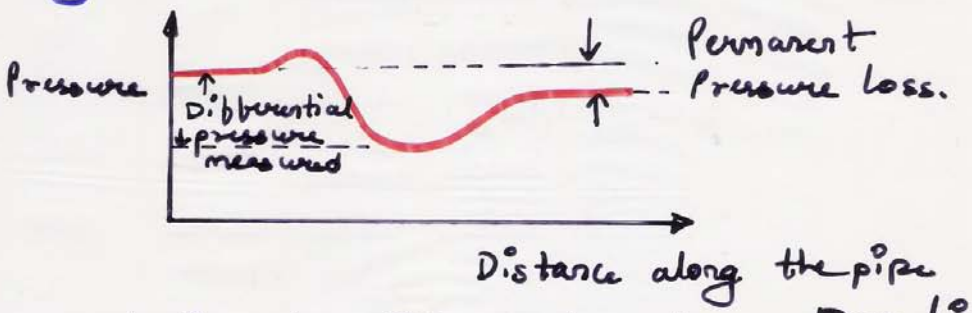
Other Differential Pressure Flaometers:-

1) V-cone 2) Elbow 3) Dall tube.

Each one for specific application & unique features.

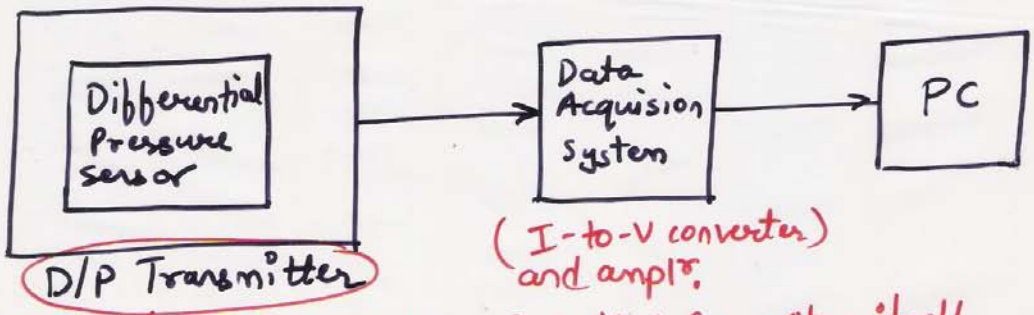
• Features of Differential Pressure flowmeters: (Orifice, Venturi, Nozzle)

1. It has No moving parts, robust, reliable & easy to maintain and widely established.
2. There is always a Permanent Pressure loss and thus extra Pumping energy is necessary to overcome it.



3. Both Venturi and orifice meter have Non-linear nature ie $Q \propto \sqrt{\Delta P}$ which limits useful range of meter.
4. Discharge co-efficient (C) changes with
   1) Type of flow meter (orifice or Venturi)
   2) Reynolds no (Re) 3) Diameter ratio (β) & etc.
5. These can be used for Turbulent flow if $Re > 10^4$.

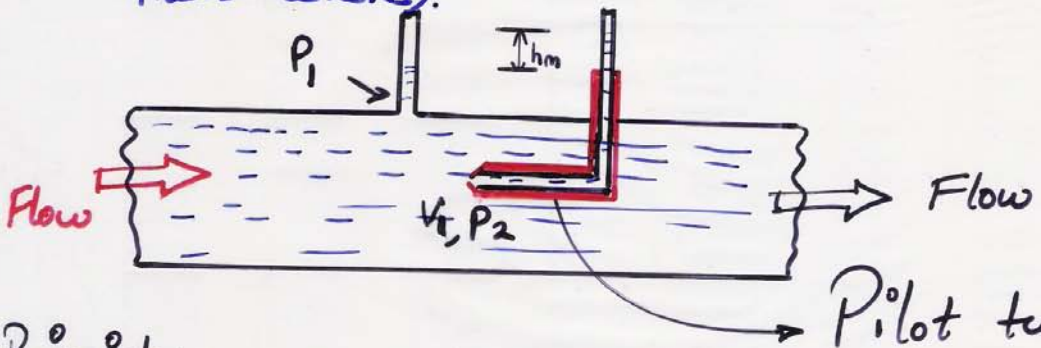
↳ Typical Flow meter system:-



↳ This should be installed in pipe itself.

Pilot tube (Used for Velocity-of-flow measurement)

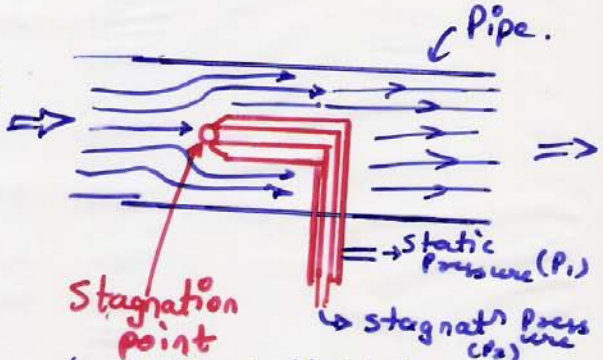
- Follows Differential Pressure Technique.
- Used in flow measurements, velocity measurement.
- Special appln :- Used for measuring speed of high speed vehicles (aircraft speed measurements)
- Sometimes some estimation is necessary ie how much is the flow in a pipeline (Pilot tube can be inserted & take the measurements).



Principle -

- If a solid body is held stationary in a pipe in which fluid is flowing in a pipeline, the velocity of fluid starts decelerating until a point directly in front of body, it reaches zero. This point is called 'Stagnation point'.

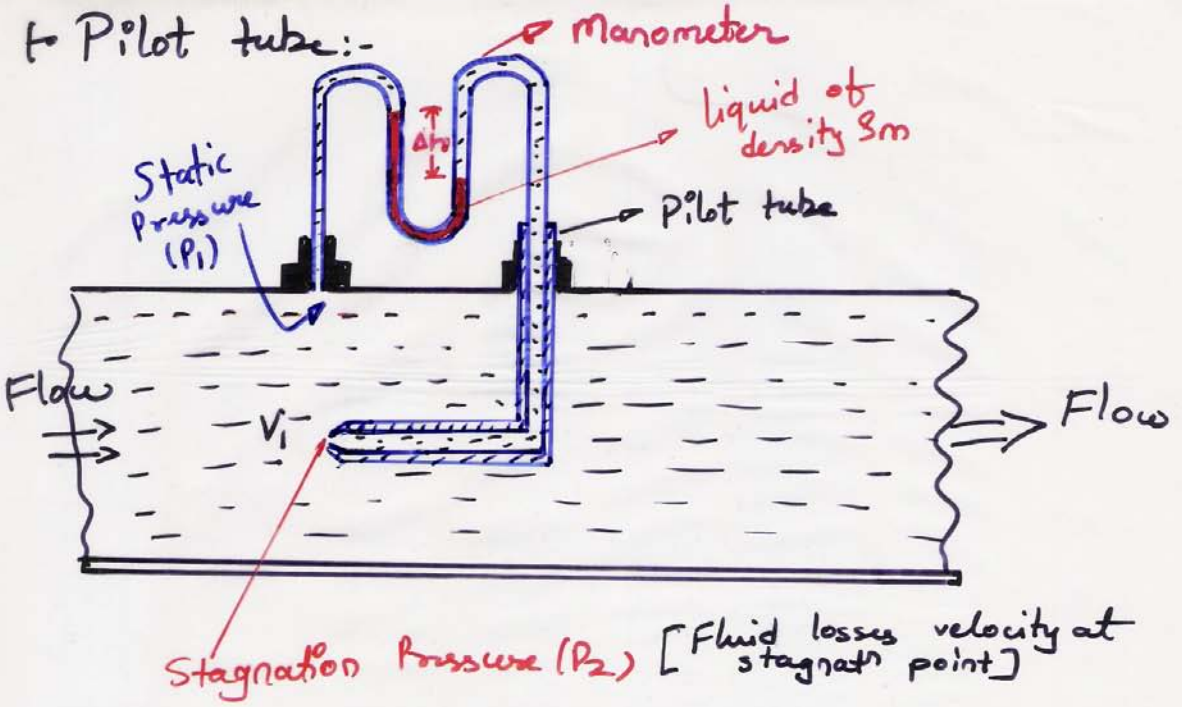
This is principle of Pilot tube.



(Velocity of fluid is zero here, Pressure at this point is highest).

fig. Principle of Pilot Tube

Pilot tube:-



- A Pilot tube having a small opening facing the direction of fluid flow is kept in pipe to measure velocity of stream at mouth of tube.
- Fluid striking open end of tube will be brought to rest and K.E is converted into P.E (Pressure energy).
- Hence, pressure built up in tube, known as 'stagnation pressure' will be higher than free-steam pressure or static pressure (in absence of tube case).
- This excess pressure head is measured as Δh, & this ↑sed in pressure is 'impact pressure'.

$$\boxed{\Delta P = h_m \rho_m g}$$

h_m - difference in height of manometer level (two legs)

$$\boxed{V_1 = \sqrt{\frac{2 h_m \rho_m g}{\rho}}} \rightarrow \text{Velocity of fluid at mouth of Pilot tube.}$$