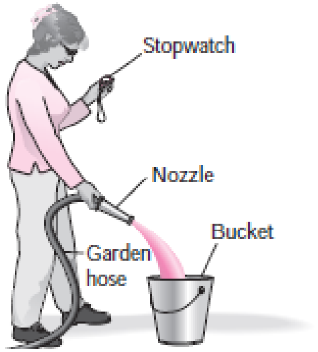
Chapter 5
Flow in Pipelines

by

Dr. Nor Azlina binti Alias
Faculty of Civil and Earth Resources Engineering
azlina@ump.edu.my

5.4 Flowrate and Velocity Measurement in Pipes

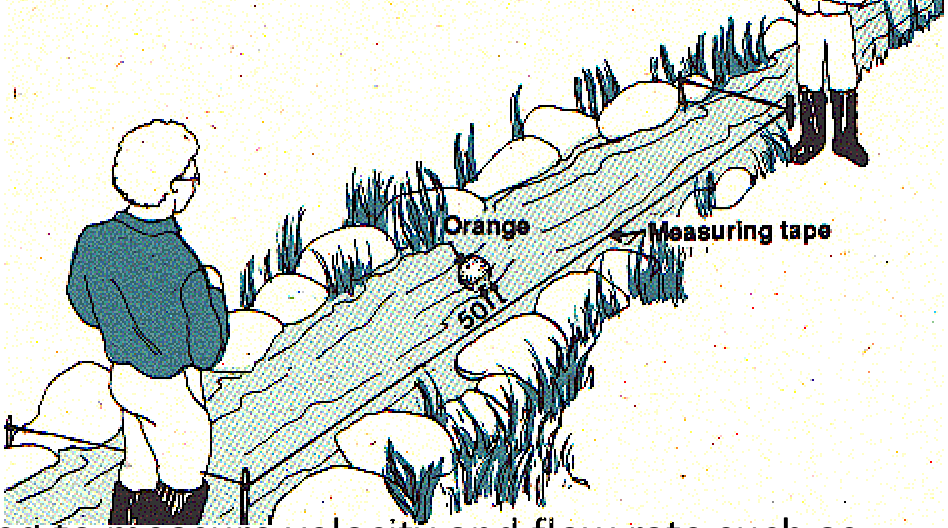
- Numerous devices have been developed over the years for the purpose of measuring flow.
- Some flowmeters measure the flow rate directly by discharging and recharging a measuring chamber of known volume, however most flowmeters measure the flow rate indirectly (in which the average velocity, v is measured directly).
- The flow rate measurement techniques range, the simplest method to measure the flowrate are :
  - The flow rate of water through a hose can be measured by collecting the water in a basin of known volume and record the time taken to fill the basin. dividing the amount collected by the collection.



$$Q = \frac{\text{volume}\,(\text{m}^3)}{\text{time}\,(\text{s})}$$

- A basic or simple way of estimating the flow velocity of a river is by dropping a float on the river and measure the drift time between two specified locations.

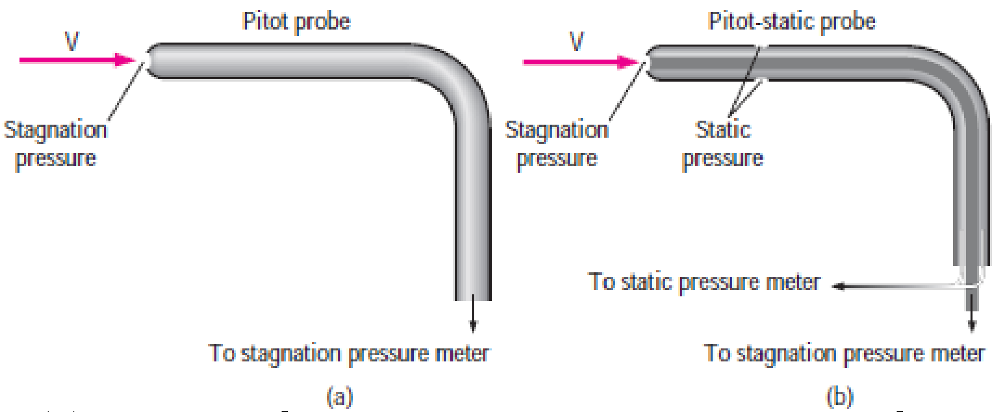
$$\text{velocity}, v = \frac{\text{distance between two locations (m)}}{\text{time taken for floating material moves from point A to B (s)}}$$



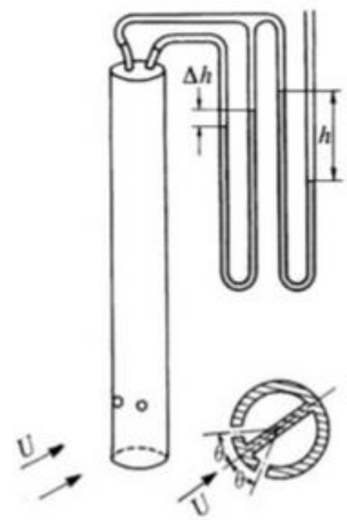
- Here, devices that are commonly used to measure velocity and flow rate such as Pitot and Orifice are presented.

5.4.1 Pitot

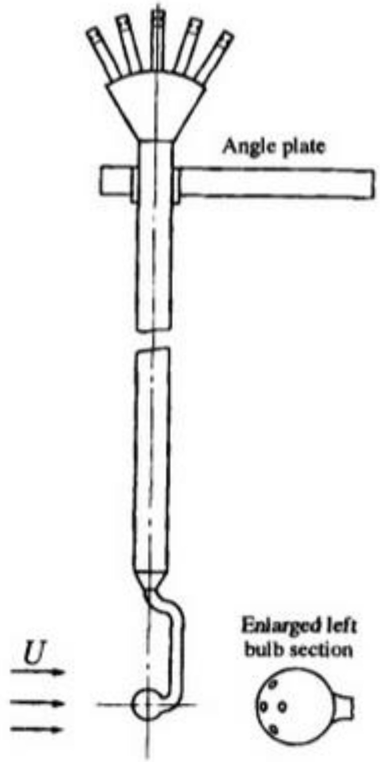
- A Pitot or impact tube makes use of the difference between th kinetic pressures at a single point.
- The Pitot-static probe measures local velocity by measuring the pre difference in conjunction with the Bernoulli equation.
- It consists of a slender double-tube aligned with the flow and conn differential pressure meter.



(*a*) A Pitot probe measures stagnation pressure at the nose of the probe, while (*b*) a Pitot-static probe measures both stagnation pressure and static pressure, from which the flow speed can be calculated.

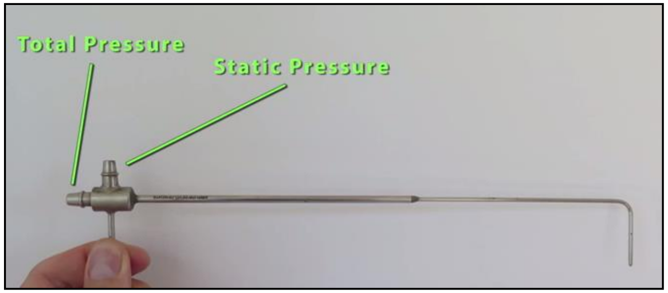


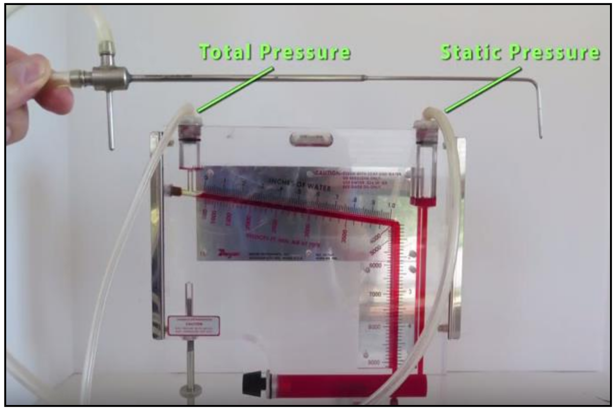
Circular type Pitot tube



Spherical Pitot tube

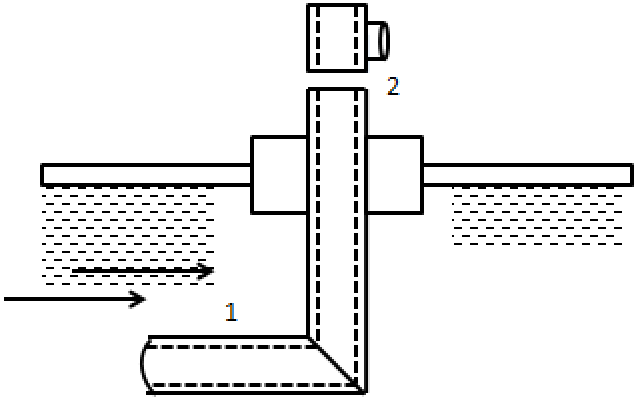
- Measuring flow velocity with a Pitot static probe. (A manometer may also be used in place of the differential pressure transducer.)





- The inner tube measures the stagnation pressure at that location (point 1). The outer tube measures the static pressure. For incompressible flow with sufficiently high velocities (so that the frictional effects between points 1 and 2 are negligible), the Bernoulli equation is applicable and can be expressed as:

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_z = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$



- Since the static pressure holes of the Pitot-static probe are arranged circumferentially around the tube, $z_1 = z_2$ and $v_1 = 0$ because of the stagnation conditions. The flow velocity $v = v_2$ becomes:

$$v = \sqrt{\frac{2(P_1 - P_2)}{\rho}}$$

This is known as the **Pitot formula.**

- The actual velocity is then given by : $v = C\sqrt{2gh}$ or $v = C\sqrt{\frac{2(P_1 - P_2)}{\rho}}$

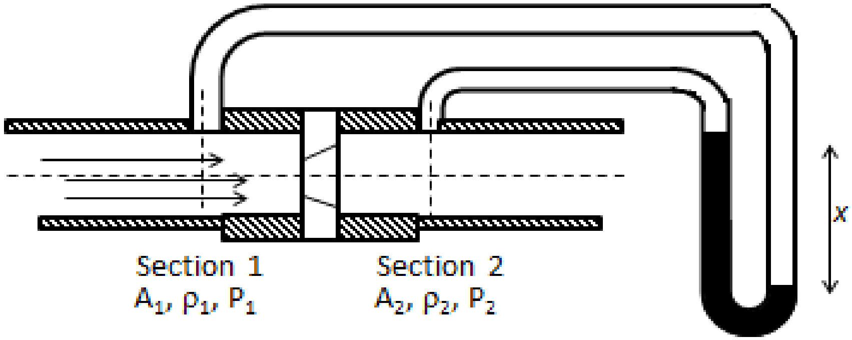
C is the coefficient of the instrument.

Example 5.8

- A pitot-static probe is mounted in a 2.5 cm diamter pipe at a location where the local velocity is approximately equal to the average velocity. The oil in the pipe has density, ρ = 788.4 kg/m^3 and viscosity, μ = 5.857 x10^{-4} kg/ms. The pressure difference is measured to be 95.8 kPa. Calculate the volume flow rate through the pipe in cubic meter per second (m^3/s).

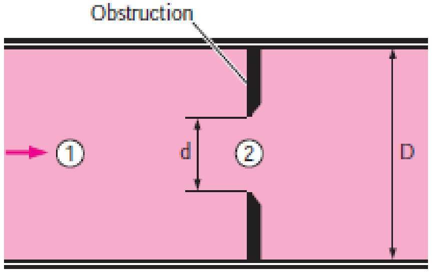
5.4.2 Orifice

- An orifice meter is a conduit and a restriction to create a pressure drop. It has a small opening on the side or bottom of a tank, through which a fluid is flowing. The opening can be of any shape or cross-section, like rectangular, triangular and circular.



- A nozzle, venturi or thin sharp edged orifice can be used as the flow restriction.
- A known volume is passing through the meter while the orifice in a pipeline with a manometer measures the drop in pressure.
- The minimum cross sectional area of the jet is known as the “vena contracta.”

- Consider incompressible steady flow of a fluid in a horizontal pipe of diameter *D* that is constricted to a flow area of diameter *d*.



- The mass balance and the Bernoulli equations between a location before the constriction (point 1) and the location where constriction occurs (point 2) where $z_1 = z_2$ can be written as $\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2$

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} \text{-------------} (1)$$

- From continuity equation: $Q = A_1 v_1 = A_2 v_2$

$$v_1 = \left(\frac{A_2}{A_1}\right) v_2 = \left(\frac{d}{D}\right)^2 v_2 \text{-------------} (2)$$

- Substitute (2) into (1) gives: $$v_2 = \sqrt{\frac{2(P_1 - P_2)}{\rho(1-\beta^4)}}$$

where β = *d*/*D* is the diameter ratio.

- The volume flowrate/discharge can be determined by :

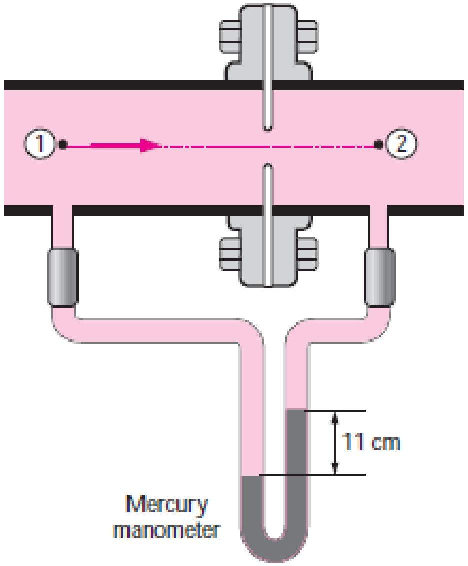
$$Q = A_2 v_2$$

- Thus : $$Q_{actual} = C_d \times A_2 v_2$$
$$Q_{actual} = C_d \times A_2 \sqrt{\frac{2(P_1 - P_2)}{\rho(1-\beta^4)}}$$

vena contracta area < flow area of the obstruction. Losses can be accounted for by incorporating a correction factor called the **discharge coefficient**

Example 5.9

- The flow rate of methanol at 20°C (ρ = 788.4 kg/m^3 and μ = 5.857 x10^{-4} kg/ms) through a 4 cm diameter pipe is to be measured with a 3 cm diameter orifice meter equipped with a mercury manometer across the orifice place as shown in figure. If the differential height of the manometer is read to be 11 cm, given the density of mercury, ρ_{Hg} = 13600 kg/m^3.
- Determine the flow rate of methanol through the pipe and the average flow velocity. The discharge coefficient, C_d = 0.61.



Summary

- There are 2 types of flow in pipeline system, i.e: **laminar & turbulent**.
- Reynold's number (Re) is given by:

$$\text{Re} = \frac{\rho v D}{\mu} = \frac{vD}{\upsilon}$$

- Types of flow:

$$\text{if Re} < 2000, \text{ the flow is laminar}$$
$$\text{if Re} > 4000, \text{ the flow is turbulent}$$

- For both laminar & turbulent flow, head loss (h_L) can be find using Darcy equation:

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

- Friction factor (f) for laminar flow:

$$f = \frac{64}{\text{Re}}$$

- Friction factor (*f*) for turbulent flow: Moody Diagram/Colebrook-White equation