Fluid Flow Measurement

Prof. Dr. M. Zahurul Haq
zahurul@me.buet.ac.bd
http://teacher.buet.ac.bd/zahurul/

Department of Mechanical Engineering
Bangladesh University of Engineering & Technology

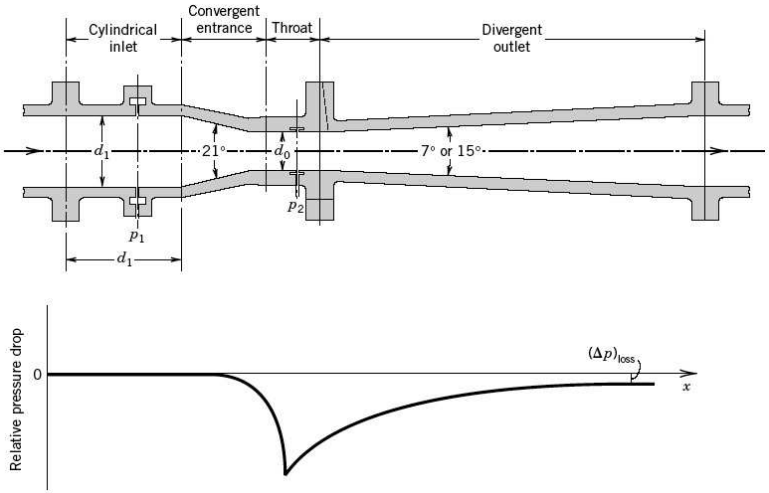
ME 361: Instrumentation & Measurement

Flow Obstruction (Differential Pressure) Meters

- The basic operating principle of differential pressure flow-meter is based on the premise that the pressure drop across the meter, ΔP is proportional to the square of the flow rate. The flow rate is obtained by measuring the ΔP and extracting the square root.
- Meters have two basic elements:
  1. *Primary element:* causes a change in K.E., which creates
  2. *Secondary element:* measures ΔP and provides the signal or read-out that is converted to the actual flow rate.
- Types: (1) Venturi, (2) Flow-nozzle (3) Orifice.
- $Q = \frac{C_D A_2}{\sqrt{1-\beta^4}} \sqrt{\frac{2}{\rho} \Delta P}$ $\qquad C_D \equiv \frac{Q_{actual}}{Q_{ideal}}$

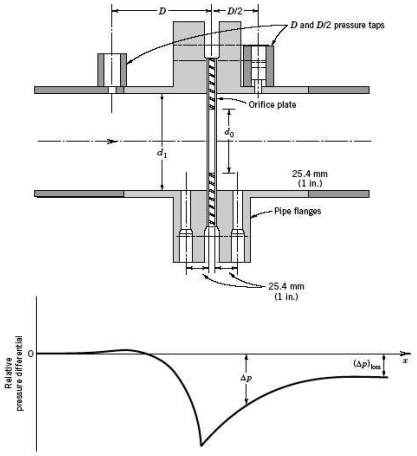
Venturi	$0.95 < C_D < 0.98$
Nozzle	$0.99622 + 0.00059D - (6.36 + 0.13D - 0.24\beta^2)/Re_D$
Orifice	$0.60 < C_D < 0.65$

Venturi

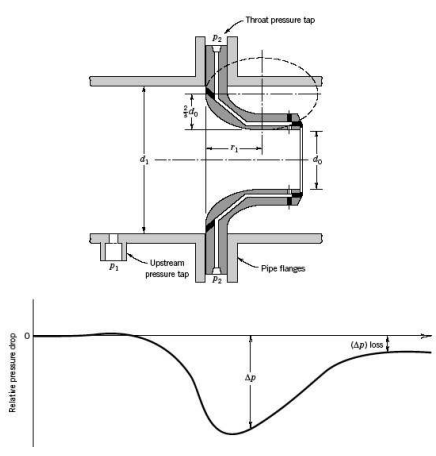


e624.eps

Orifice & Flow-nozzle



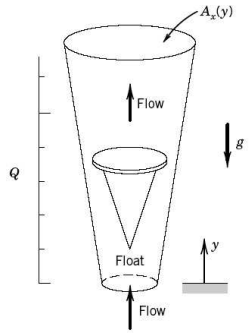
e623.eps

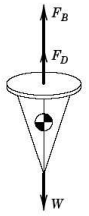


e625.eps

- Venturi can be installed in large diameter pipes using flanged, welded or threaded-ended fittings. It can be used with most liquids, including those having a high solids content. High accuracy, good pressure recovery, and resistance to abrasion are the primary advantages of the venturi. These are offset, however, by considerably greater cost and space requirements than with the orifice and nozzle.
- Orifice is inexpensive, and may often be installed between existing pipe flanges. However, its pressure recovery is poor, and it is specially susceptible to inaccuracies resulting from wear and abrasion. It may also be damaged by the pressure transients because of its lower physical strength.
- The flow-nozzle possesses the advantages of the venturi, except that it has lower pressure recovery, plus the physical advantage of shorter physical length. It is expensive as compared to orifice and is relatively difficult to install properly.

Variable Area Meter (Rotameter)





ρ_b = density of float
ρ = density of fluid
V_b = volume of float
C_D = drag coeff. of float
$\overline{U}$ = av. vel. past the float
A_x = X-section of float

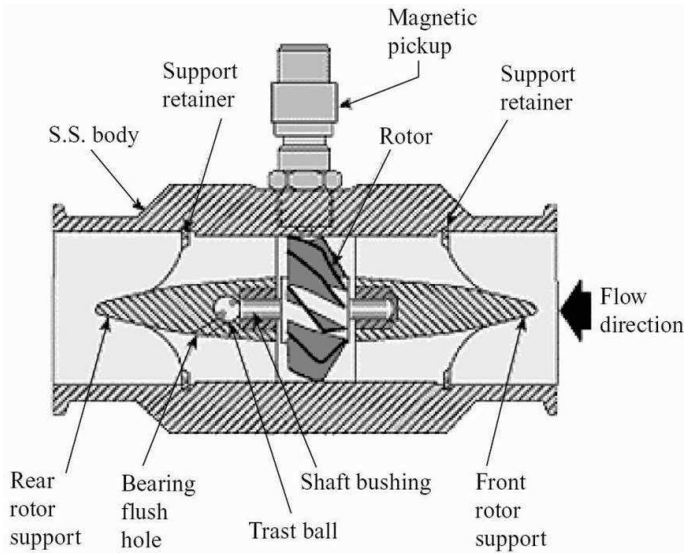
e626.eps

$$F_y = 0 = -F_D + W - F_B = -[0.5 C_D \rho \overline{U}^2 A_x] + [\rho_b V_b] - [\rho V_b]$$

In operation, the float will rise to some position within the tube at which such a force balance exists.

- **Advantages:**
  - Flow rates can be read directly without any secondary reading devices,
  - Uniform scale over the range of the instrument,
  - Fixed pressure loss at all flow rates,
  - Many corrosive fluids may be handled without complication,
  - Capacity may be changed with relative ease by changing the float and/or tube.
- **Disadvantages:**
  - Meter must be installed vertically,
  - Float may not be visible when opaque fluids are used,
  - It cannot be used with liquids carrying large percentages of solids in suspension,
  - For high pressures and temperatures, it is expensive.

Turbine Flow-meter



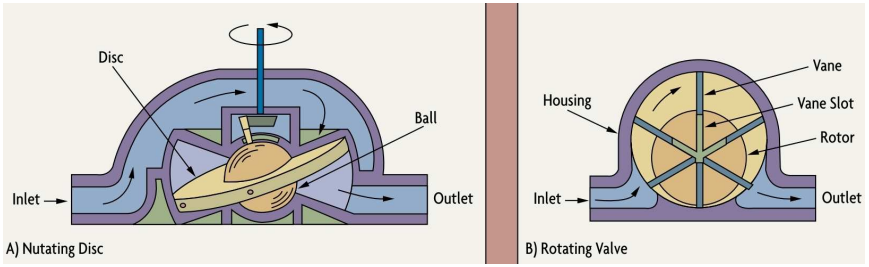
e479.eps

- Turbine flow-meter consists of a multiple-bladed rotor mounted within a non-magnetic stainless steel pipe, perpendicular to the fluid flow. The rotor spins as the fluid passes through the blades.
- The rotor speed is a direct function of the flow rate. Rotor speed can be measured simply and accurately by counting the rate at which turbine blades pass a given point, using a magnetic proximate detector to produce voltage pulses.
- By feeding these voltage pulses to an electronic pulse-rate meter, one can measure flow rate; by accumulating the total number of pulses during a time interval, the total flow is obtained.

Advantages/Disadvantages:

- Very good accuracy, particularly with low-viscosity fluids.
- Operation over wide range of pressure, temperature and fluids.
- Flexibility in flow control and computer interfacing.
- Intrusive method - pressure drops.
- Bearing wear is a major concern.

Positive Displacement Flow-meter

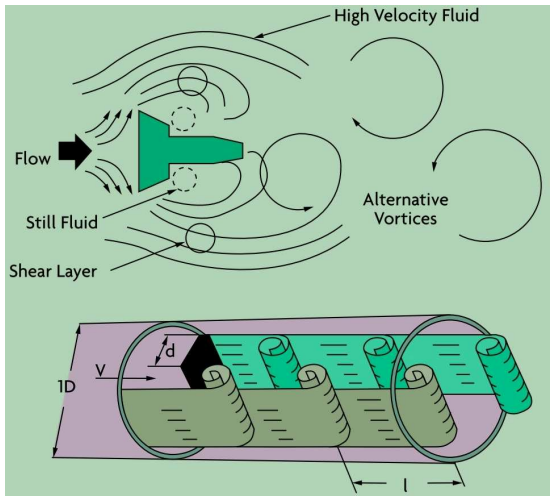


e410.eps

Positive displacements meters use the ''fill & dump" technique to measure the true flow rate. Designs vary, but the fluid is allowed to fill a chamber until a limit is reached, at which point the chamber is discharged while a second one fills.Used to measure steady-state fluid flow rate with high accuracy.

1. Nutating-disk flow-meters: operates on nutating-disk principle, where a disk nutates about the vertical axis to allow to pass a certain amount of fluid. It is most probably the most commonly encountered flow-meter found throughout the world for commercial, utility and industrial applications. The meter is of particular importance in the measurement of commercial and domestic water.
2. Rotary-vane Flow-meters: The basic unit consists of an equally divided, rotating impeller (containing two or more compartments) mounted inside the meter's housing. The impeller is in continuous contact with the casing. A fixed volume of liquid is swept to the meter's outlet as the impeller rotates. A wet-meter is a special version of rotary vane flow-meter used to measure gas flow rate.

Vortex Flow Meter



e414.eps

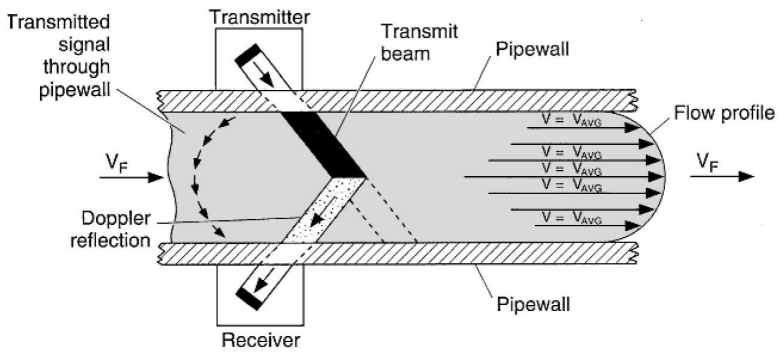
The **three** major components of the the meter are:

1. A bluff body mounted across the flow-meter bore.
2. A sensor to detect the the vortex and to generate electrical impulse. The vortices cause alternating forces on the shedder; piezoelectric and strain-gauges can be used to detect it. The interruption of ultrasonic beams by the passing vortices can be used to detect it.
3. A signal amplification and conditioning stage to give flow rate/flow tantalizing measurements.

The vortex shedding frequency, f_s, flow velocity, v, and the shedder width, d, are related using the following formula: $\boxed{f_s = St\ \frac{v}{d}}$

where, $St \equiv$ Strouhal number $= 0.88 \pm 1\%$ for $10^4 < Re < 10^6$

Ultrasonic Flow-meter



e415.eps

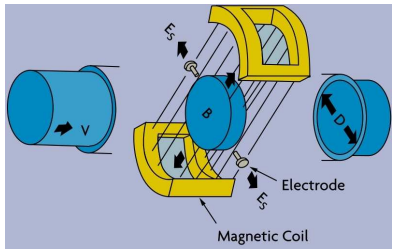
Doppler Effect of an ultrasonic signal reflected by suspended particles or bubbles present in the fluid is employed. Ultrasonic sound of known frequency is transmitted into the pipe & the reflected wave with slightly different frequency is received by the receiver. The frequency difference is directly proportional to the flow of liquid.

- Most devices require that the fluid contain at least 25 ppm of particles or bubbles having diameters of 30 micron or more.
- Ultrasonic measurement of gas flow is not common.
- Meters available as in-line pipe sections with installed transducers or as clamp-on devices. Suitable electronics are used to display fluid flow rates or total flow quantities.

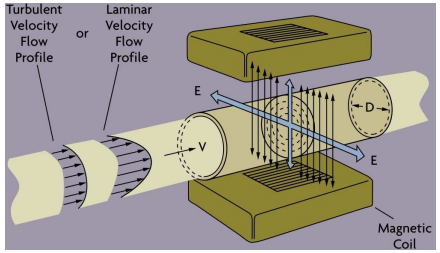
Advantages: ⊙ Non-intrusive, ⊙ No pressure drop, ⊙ Good accuracy can be maintained without frequent field calibration, ⊙ Can be used to measure the flow of liquids & slurries which ordinarily cause damage to conventional sensors

Disadvantages: ⊙ Very expensive, ⊙ Measures particle velocity which may be different from that of the fluid, ⊙ Doppler shift is proportional to the sound velocity in fluid which depends on pressure & fluid composition.

Magnetic Flow-meter



e632.eps

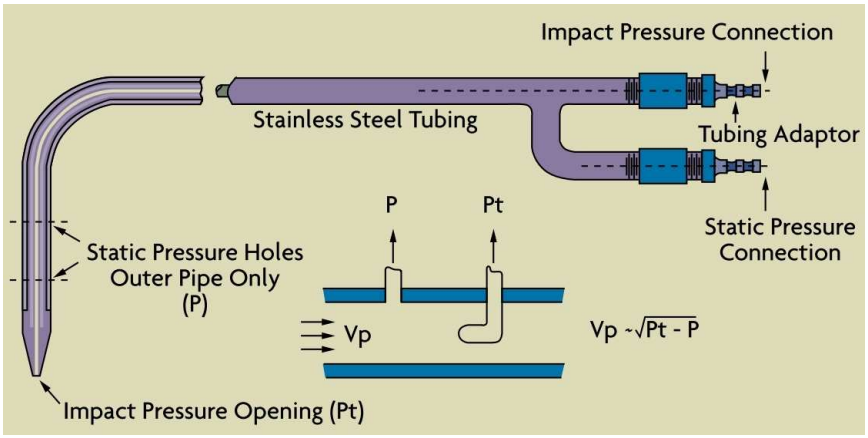


e633.eps

Magnetic flow detector's principle of operation is based on Faraday's Law of Electromagnetic Induction, which states that a voltage will be induced into a conduction when it moves through a magnetic field. The fluid serves as a moving conductor. Hence,

$$E = V \times B \cdot D = VBD$$

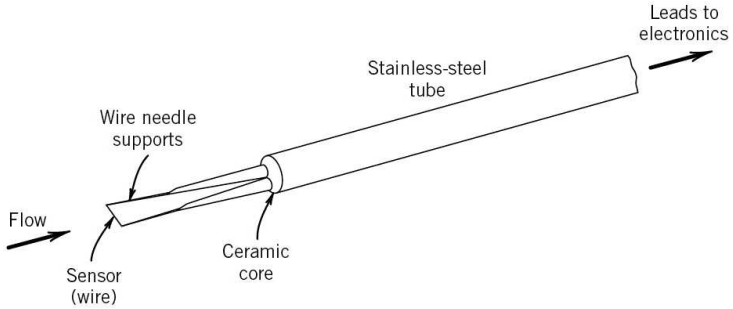
Pitot-Static Pressure Probe



e407.eps

$$V_P = \sqrt{\frac{2(P_t - P)}{\rho}}$$

Hot-wire Anemometer

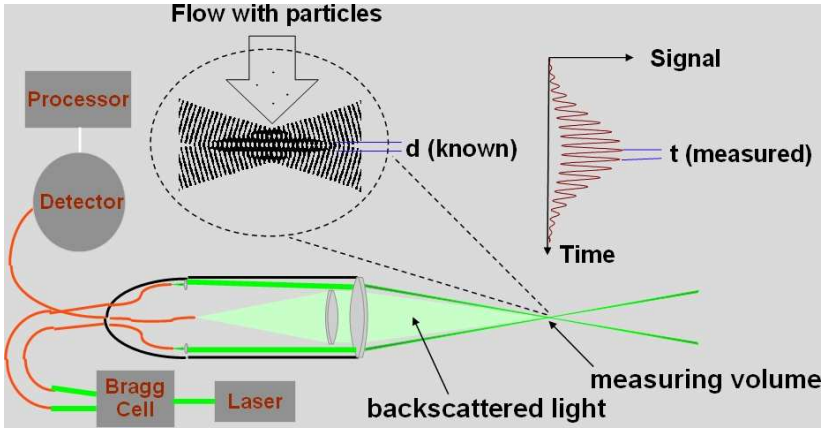


e634.eps

$$q = i^2 R = i^2 R_o[1 + \alpha(T_w - T_o)] = (a + b\sqrt{V})(T_w - T_\infty)$$

T_w = *wire temperature,* T_∞ = *free stream temperature of fluid,* V = *fluid velocity*

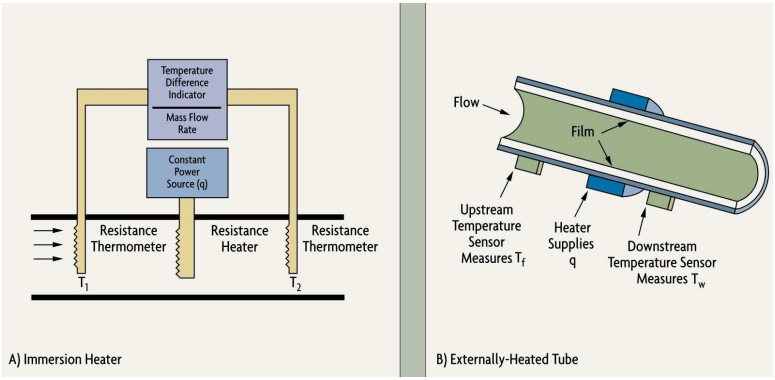
Laser Doppler Anemometer (LDA)



e635.eps

LDA measures the velocity of the scattering particles.

Thermal Mass-flow-meter

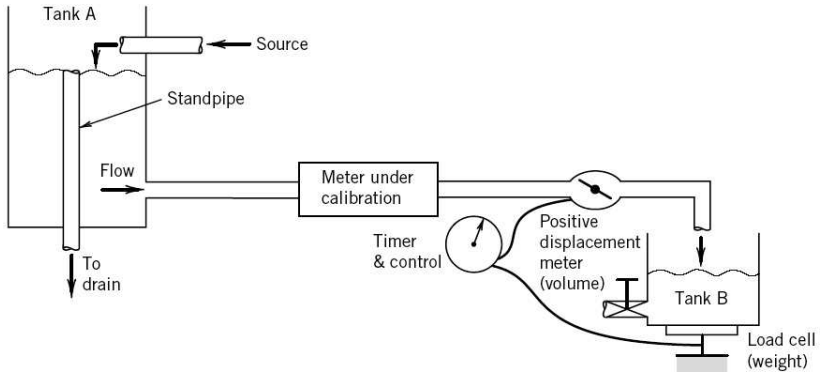


e417.eps

The rate at which energy, E, must be input to a flowing fluid to raise the temperature of the fluid to some desired amount between two control surfaces is directly related to the mass flow rate by

$$E = \dot{m} c_p \Delta T$$

Flow Meter Calibration



e636.eps