Fluids & Flow

Types of Measurement for Fluids & Flow

- Fluid level (m)
- Fluid velocity (m/s)
- Volume flow rate (m^3/s)
- Mass flow rate (kg/s)
- Velocity distribution/profile
- Viscosity ($N \cdot s/m^2$)
- Surface tension (N/m)

Common Principles of Fluid Level Measurement

- Weight of a volume of fluid
- Hydrostatic pressure based on depth in a liquid
- Buoyancy forces that change position of a float
- Resistance or conductance between terminals
- Dielectric constant in a capacitor
- Ultrasonic reflection off a surface

Bernoulli Equation (Review)

$$p + \frac{1}{2}\rho V^2 + \rho g z = \text{Constant}$$

- Arriving at this equation assumed ALL of the following assumptions, which are essential for its validity:
  - Steady flow
  - Flow along a streamline
  - Inviscid flow
  - Incompressible flow

Pitot-Static Tubes

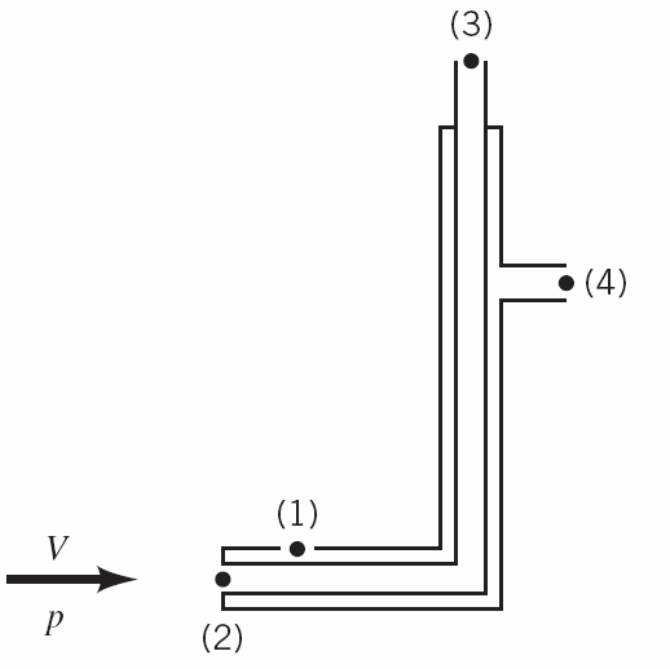
- A Pitot-static tube is a common device for quantifying fluid velocity based on stagnation pressure.
- How does it work?

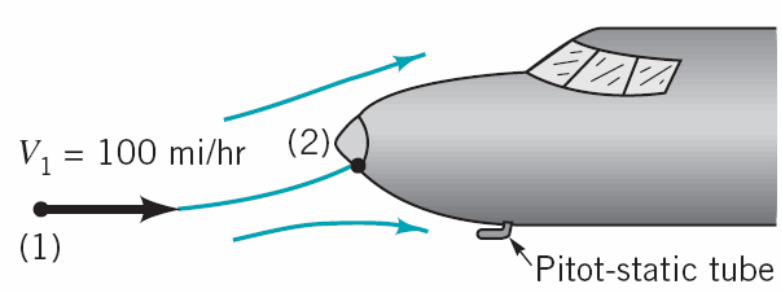
$$p + \tfrac{1}{2}\rho V^2 + \rho g z = \text{Constant}$$

$$p + \tfrac{1}{2}\rho V^2 = p_3$$

$$p + \tfrac{1}{2}\rho V^2 = p_4 + \tfrac{1}{2}\rho V^2$$

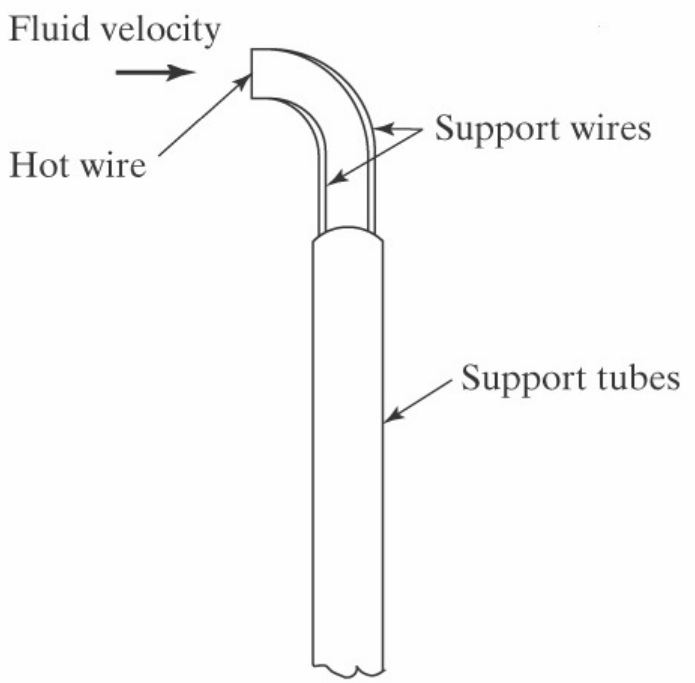
$$V = \sqrt{2(p_3 - p_4)/\rho}$$

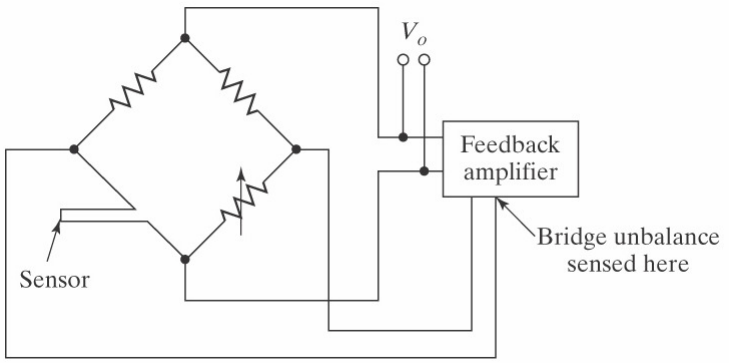




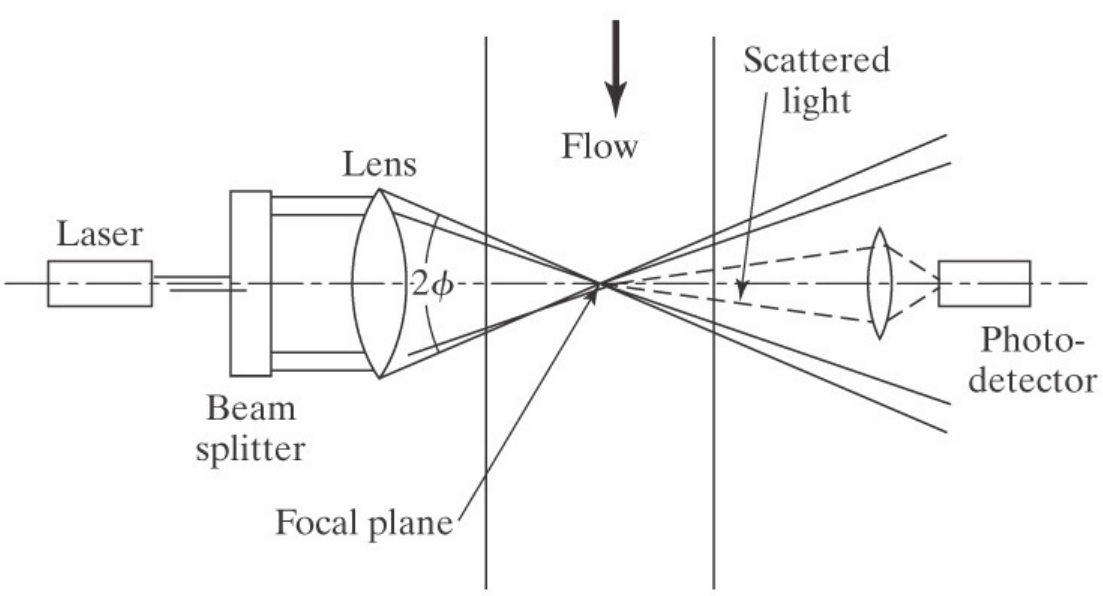
Hot-Wire Anemometer

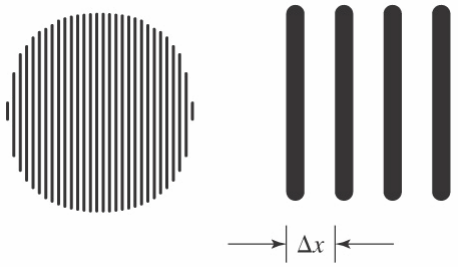
- Hot-wire anemometers measure fluid velocity based on effectiveness of heat transfer away from a heated wire.
- The output is a voltage that is needed to balance a bridge circuit.
- One major advantage is directional sensitivity and the possibility of having 3-axis probes to acquire *u/v/w* velocity components.
- A variant of the same principle that is less sensitive to contamination uses a thin film rather than a wire.





Laser-Doppler Velocimeter (LDV)



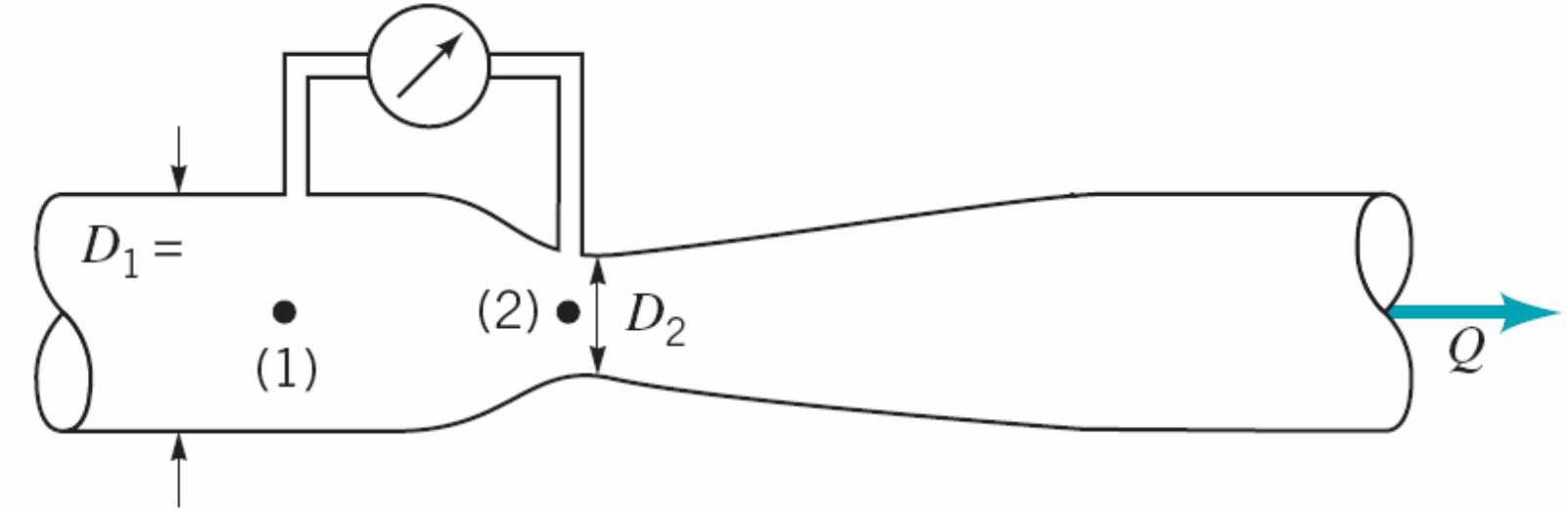


$$\Delta x = \frac{\lambda}{2\sin\phi}$$

$$f = \frac{V}{\Delta x} = \frac{2V\sin\phi}{\lambda}$$

- A laser-Doppler velocimeter (LDV) uses interference patterns between beams to establish a "grid" of light and dark fringes.
- When particles pass through the fringe pattern, they scatter light.
- A photodetector and signal processing algorithms extract the time-varying light intensity to determine the velocity of the particles.
- Sufficiently small particles are dominated by viscosity, and thus move with the same velocity as the surrounding fluid.
- It is common to "seed" the fluid with particles of preferred size and concentration.

Venturi Meters



- A Venturi meter is a common device for quantifying flow rate Q based on differences in pressure p.
- Flow nozzles and orifice meters follow similar principles and are less expensive, but suffer greater energy losses.

$$p_1 + \tfrac{1}{2}\rho V_1^2 + \rho g z_1 = p_2 + \tfrac{1}{2}\rho V_2^2 + \rho g z_2$$

$$p_1 - p_2 = \tfrac{1}{2}\rho V_2^2 - \tfrac{1}{2}\rho V_1^2$$

$$Q = A_1 V_1 = A_2 V_2$$

$$p_1 - p_2 = \tfrac{1}{2}\rho \left(\frac{1 - (A_2 / A_1)^2}{A_2^2} \right) Q^2$$

Rotameters

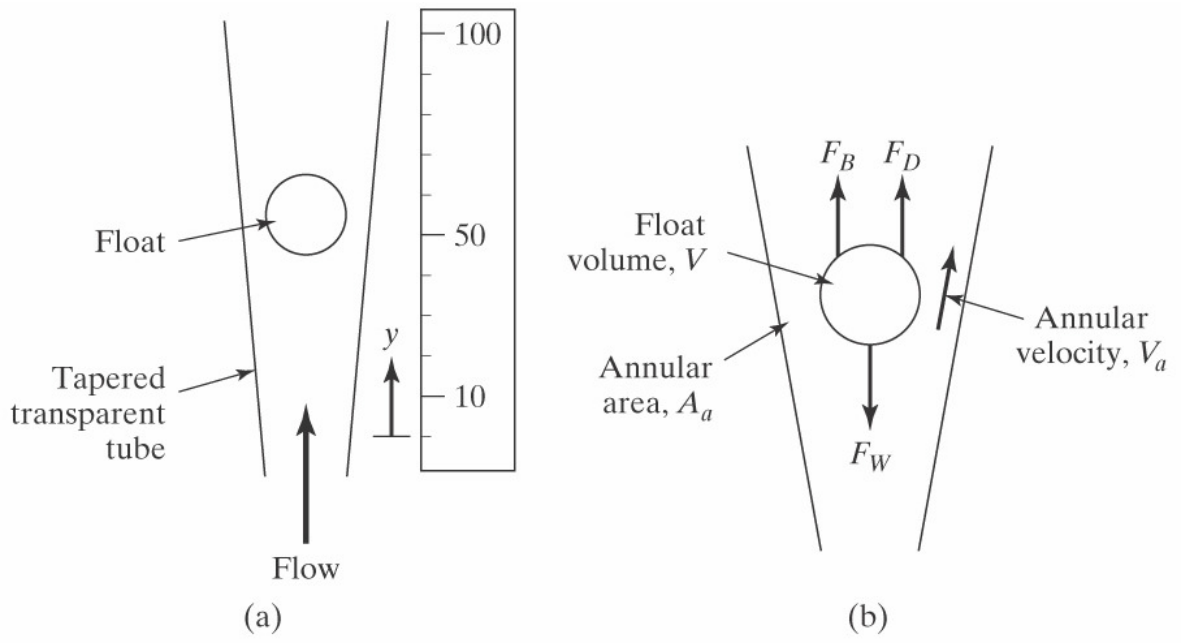
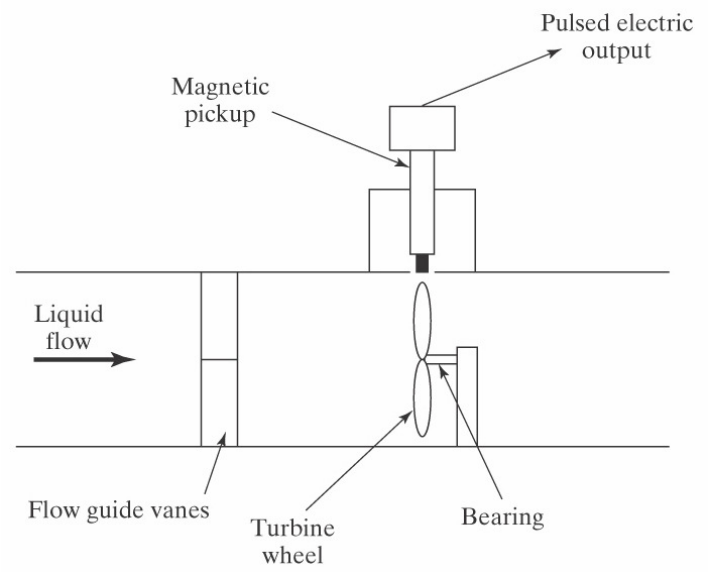
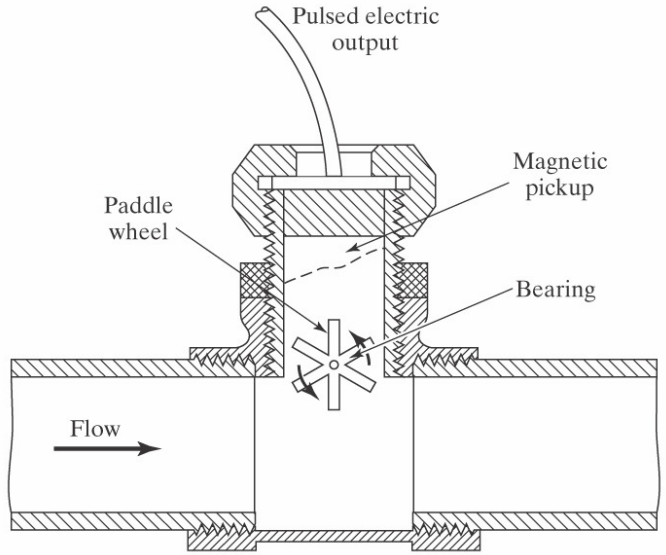


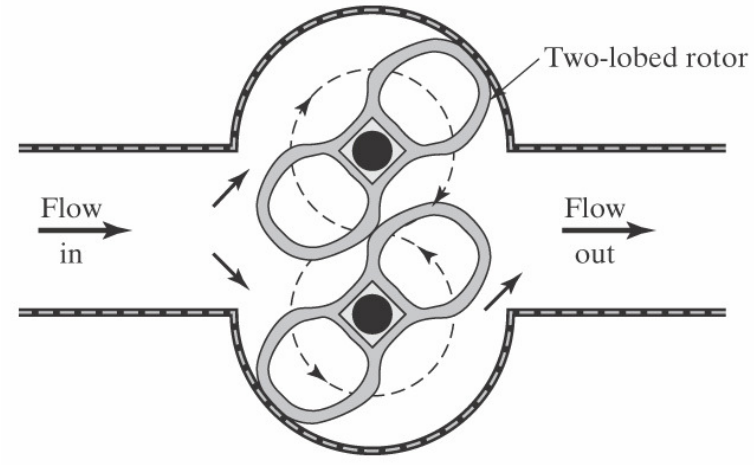
Image retrieved October 2008
from http://www.mathesontrigas.com/

- Rotameters use drag on a floating object in equilibrium with its weight and buoyancy to indicate volume flowrate by position of the float.
- Float geometry and channel profile can be customized for a wide variety of liquids and gases.
- Most rotameters are used only for measurement by visual inspection.

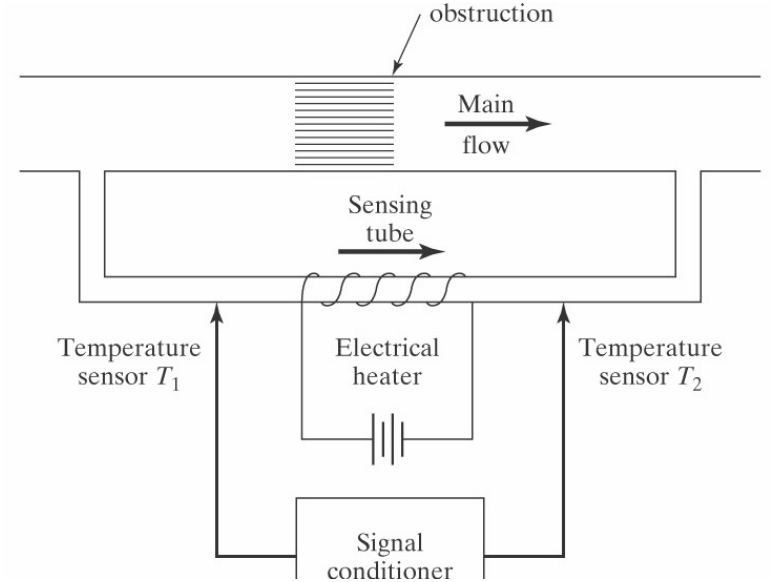
Various Mechanical Displacement Flowmeters







Thermal Mass Flowmeter



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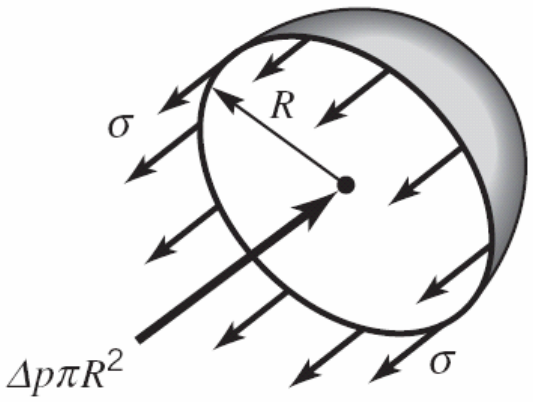
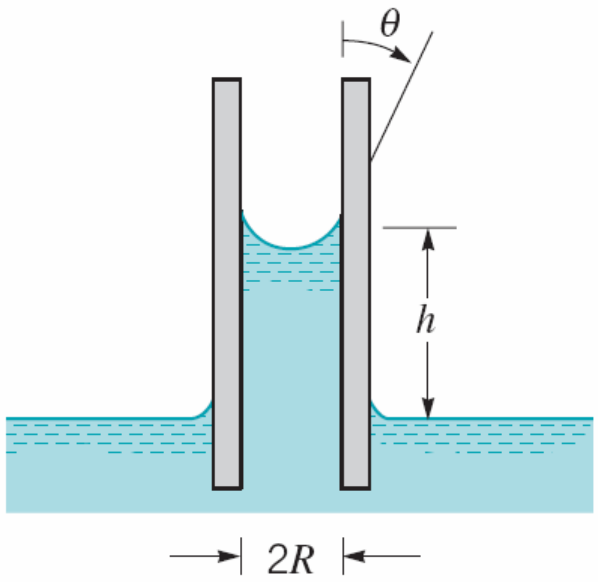
- A thermal mass flowmeter diverts a portion of the flow into a sensing tube, and uses temperature sensors to measure how effectively the fluid is heated.
- For a deliberate rate of heat transfer q and a known specific heat c_p , the mass flowrate is determined from:

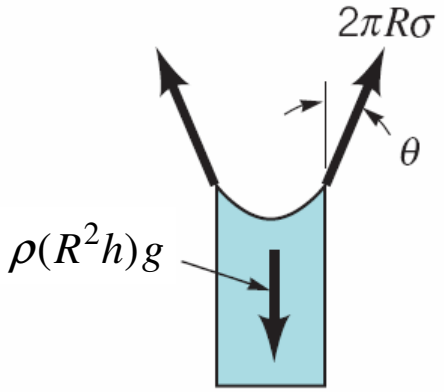
$$q = \dot{m} c_p (T_2 - T_1)$$

Surface Tension



$$\Delta p(\pi R^2) = (2\pi R)\sigma$$





$$h = \frac{2\sigma\cos\theta}{\rho g R}$$

- Surface tension is the result of an imbalance of cohesive molecular forces between interior molecules and those at the surface.
- Force equilibrium dictates that the (coefficient of) surface tension σ times the perimeter of a spherical droplet with radius R must balance the differential pressure Δp times the mid-section area.
- Force equilibrium also reveals that the force of surface tension $2\pi R\sigma$, balancing the weight of a liquid column, determines the height h of that column. A 1-micron capillary can support a water column 30 m!