Advanced Measurement Systems & Sensors

(0640732)

Lecture (10)

# Flow and Temperature Sensors

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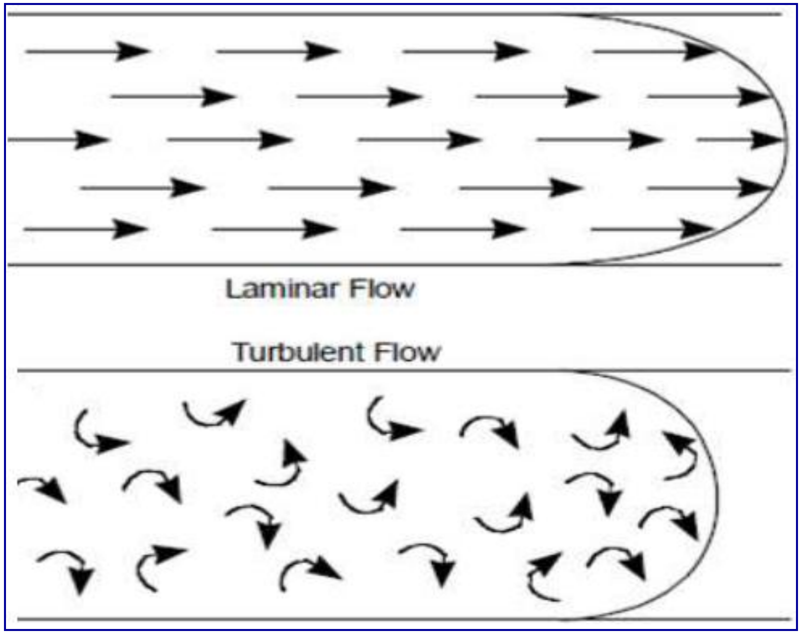
# Flow Sensing:

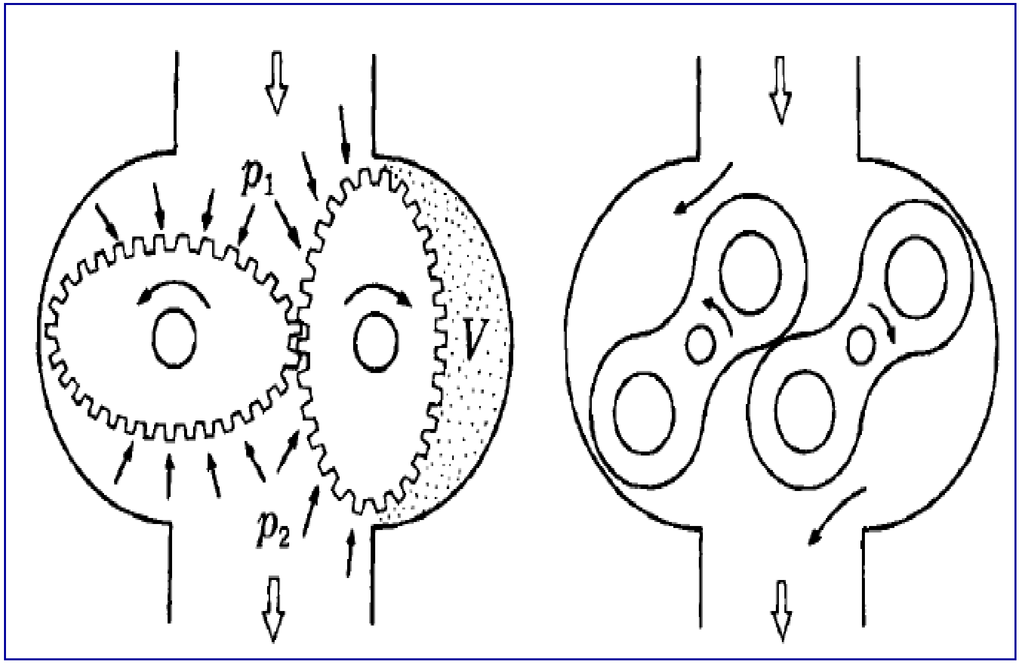
A flowmeter is a device that measures the rate of flow or quantity of a moving fluid in an open or closed conduit.

- The fluid medium can be liquid, gas, or a mixture of the two.
- The flow could be laminar or turbulent and can be a time-varying phenomenon.
- Flow sensors may be classified roughly as;
  1. POSITIVE DISPLACEMENT TYPES
  2. INFERENTIAL TYPES
  3. VARIABLE AREA TYPES
  4. DIFFERENTIAL PRESSURE TYPES



# 1. POSITIVE DISPLACEMENT TYPES:

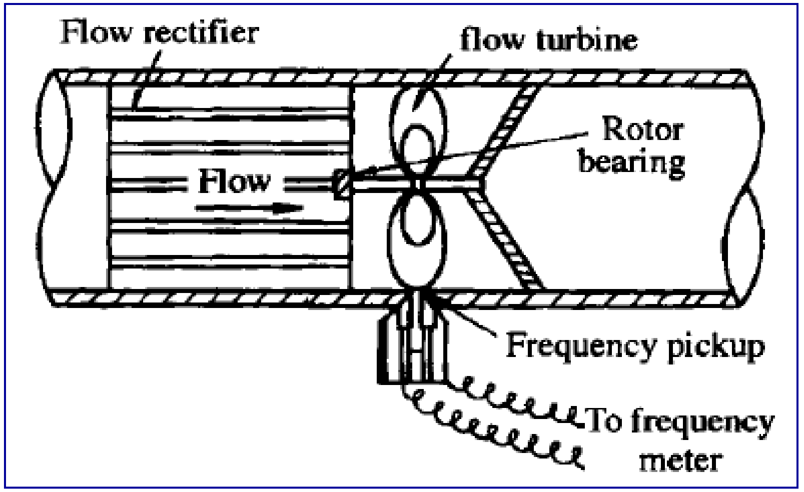
- These types have a mechanical element that makes the shaft of the meter rotate once for an exact known quantity of fluid.
- The quantity of fluid depends on the number of revolutions of the meter shaft and the flow rate depends upon the speed of rotation. Both the revolutions and speed may be measured with mechanical or electronic devices such as;
  - ✓ Rotary piston type.
  - ✓ Vane type.



## 2. INFERENTIAL TYPE:

A rotor which is made to spin, then the speed of the rotor is sensed mechanically or electronically, such as **Turbine rotor** type or **Rotating vane** type.

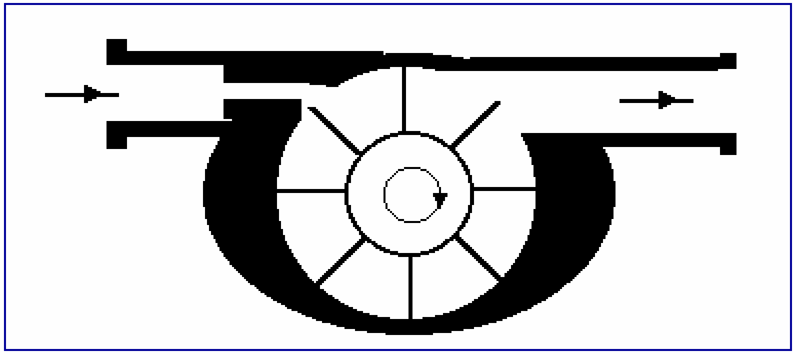
### Turbine Rotor:




- It has an axial rotor which is made to spin by the fluid and the speed represents the flow rate.
- This may be sensed electrically by coupling the shaft to a small electric tachometer.

### Rotating Vane:

- The jet of fluid spins around the rotating vane and the speed of the rotor is measured mechanically or electronically.



## Advantages and Disadvantages of the turbine meters

**Advantages**

- The turbine meter is easy to install and maintain.
- Bi-directional
- Have fast response
- Compact and light weights

**Disadvantages**

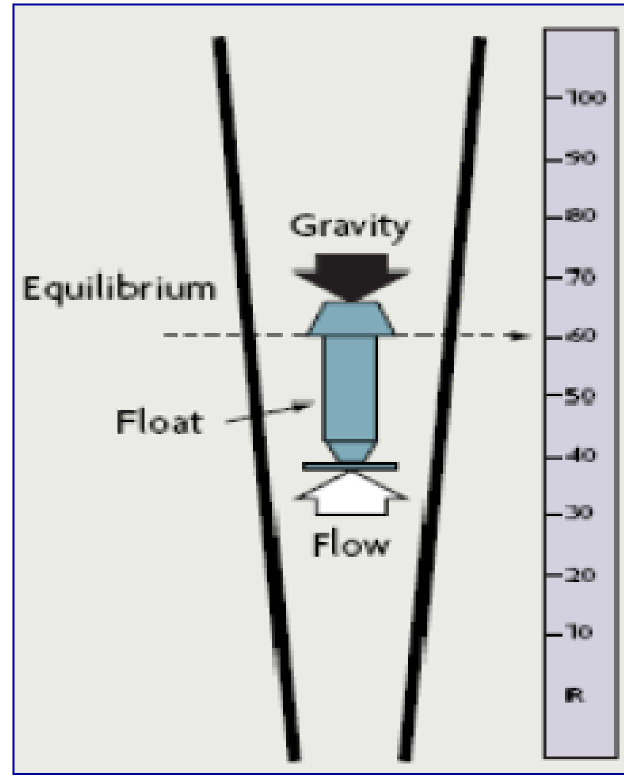
- They generally are not available for steam measurement (since condensate does not lubricate well.
- They are sensitive to dirt and cannot be used for highly viscous fluids.
- Flashing or slugs of vapour or gas in the liquid produce blade wear and excessive bearing friction that can result in poor performance and possible turbine damage.
- They are sensitive to the velocity profile to the presence of swirls at the inlet; they require a uniform velocity profile (i.e. pipe straightness may have to be used).
- Turbine meters have moving parts that are sensitive to wear and can be damaged by over speeding. To prevent sudden hydraulic impact, the flow should increase gradually into the line.
- When installed, bypass piping may be required for maintenance.
- The transmission cable must be protected to avoid the effect of electrical noise.

## 3. VARIABLE AREA TYPES:

Variable area flowmeters are simple and versatile devices that operate at a relatively constant pressure drop and measure the flow of liquids, gases, and steam. There are two main types of this meter; the float type, and the tapered plug type.

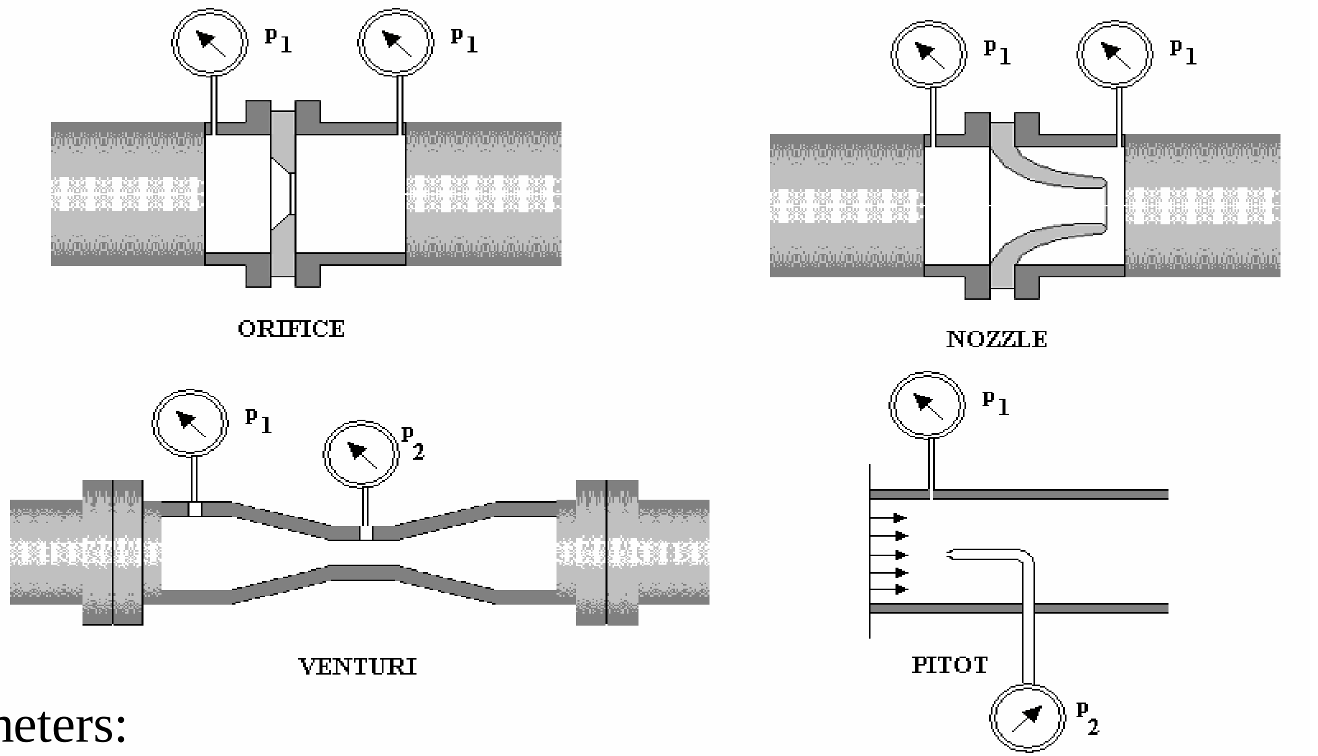
**Float type (Rotameter):**

- The float is inside a tapered tube. The fluid flows through the annular gap around the edge of the float.
- The restriction causes a pressure drop over the float and the pressure forces the float upwards. Because the tube is tapered, the restriction is decreased as the float moves up.
- The level of the float indicates the flow rate. If the flow changes the float moves up or down to find a new balance position.



# 4. DIFFERENTIAL PRESSURE FLOW SENSING:

These are several meters that convert flow rate into a differential pressure, such as;




For all these meters:

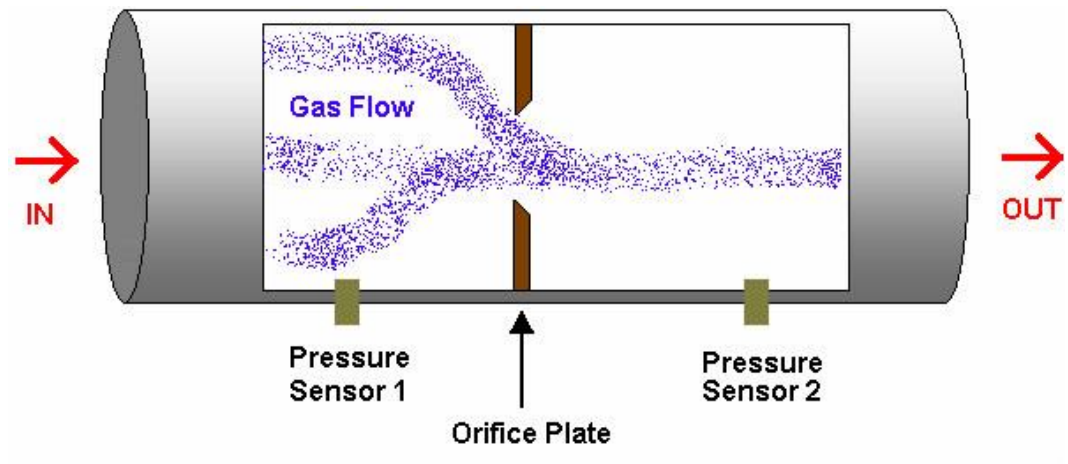
- The working principle is that something makes the velocity of the fluid change and this produces a change in the pressure so that a difference ($\Delta p = p_2 - p_1$) is created.
- It can be shown that the volume flow rate Q is related to Δp by; $Q = K\sqrt{\Delta p}$ where K is the meter constant.

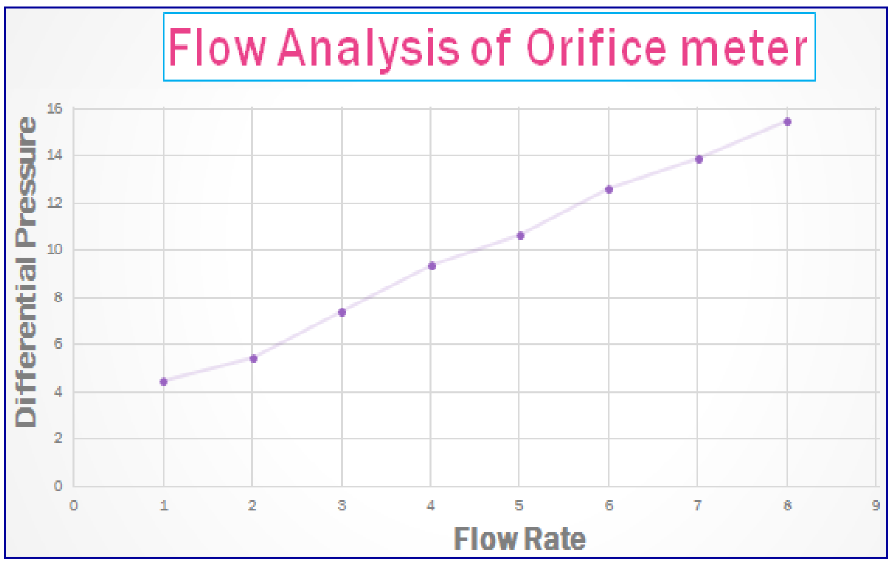
# Orifice Meter:

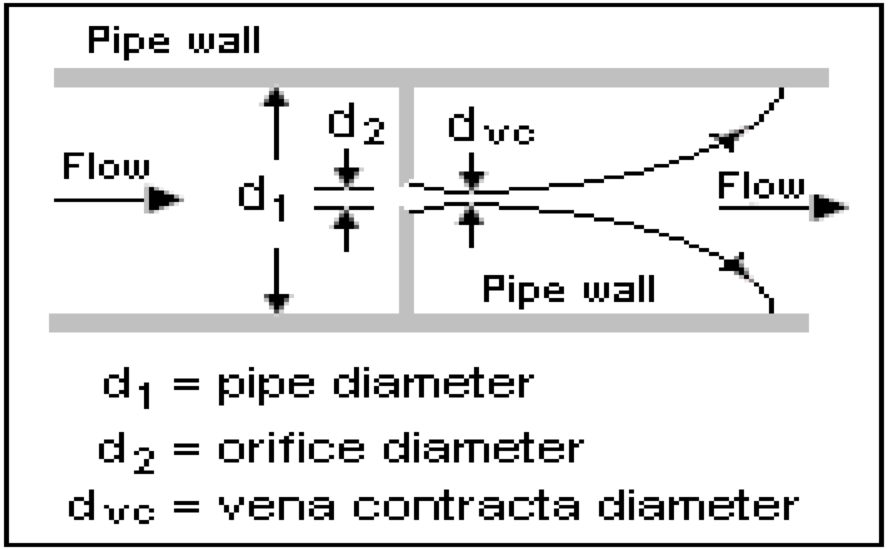
Bernoulli's equation is given by:

$$Q = CA_2\sqrt{\frac{2(P_1 - P_2)}{\rho}}$$

where; C = Orifice flow coefficient



## Advantages and Disadvantages of Orifice flowmeters

**Advantages:**

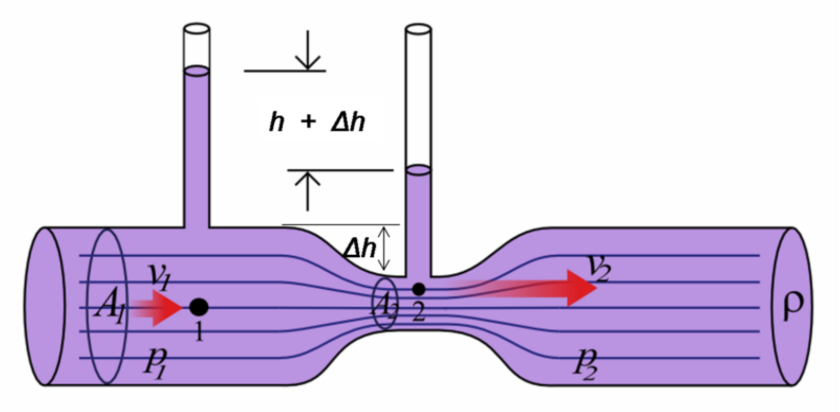
- They are easy to install.
- One differential pressure transmitter applies for any pipe size.
- Many DP sensing materials are available to meet process requirements.
- Orifice plates have no moving parts and have been researched extensively; therefore, application data well documented (compared to other primary differential pressure elements).

**Disadvantages:**

- The process fluid is in the impulse lines to the differential transmitter may freeze or block.
- Their accuracy is affected by changes in density, viscosity, and temperature.
- They require frequent calibration

## **Venturi Meter:**

- Venturi tube consists of a section of pipe with a conical entrance, a short straight throat, and a conical outlet.
- The velocity increases and the pressure drops at the throat.
- The differential pressure is measured between the inlet (upstream of the conical
- entrance) and the throat.
- Bernoulli's equation is;




$$Q = A_1 \sqrt{\frac{2(P_1 - P_2)}{\rho\left\{\left(\frac{A_1}{A_2}\right)^2 - 1\right\}}} = A_2 \sqrt{\frac{2(P_1 - P_2)}{\rho\left\{1 - \left(\frac{A_2}{A_1}\right)^2\right\}}}$$

**Advantages and Disadvantages of VENTURI TUBES**

**Advantage**

- It can handle low-pressure applications
- It can measure 25 to 50% more flow than a comparable orifice plate
- It is less susceptible to wear and corrosion compared to orifice plates
- It is suitable for measurement in very large water pipes and very large air/Gas ducts.
- Provides better performance than the orifice plate when there are solids in Suspension.

**Disadvantage**

- It is the most expensive among the differential pressure meters
- It is big and heavy for large sizes
- Its has considerable length

**ELECTRONIC FLOWMETERS:**

Electronic flowmeters represent a logical grouping of flow measurement technologies. All have no moving parts, are relatively non-intrusive, and are made possible by today's sophisticated electronics technology.

There are three types of electronic flowmeters:

1. Magnetic flowmeters,
2. Vortex flowmeters,
3. Ultrasonic flowmeters

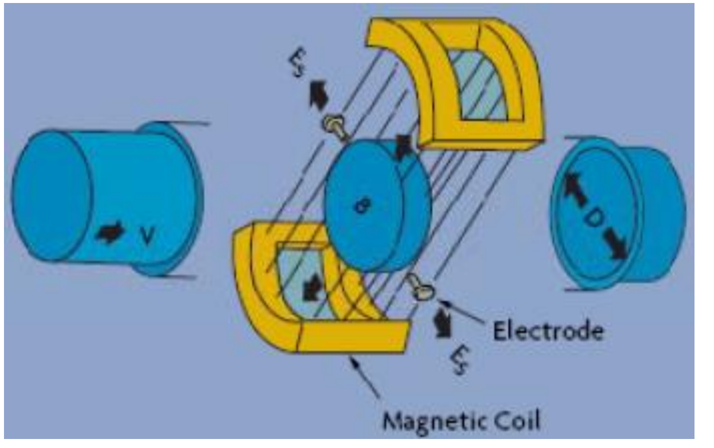
## MAGNETIC FLOWMETERS:

The magnetic flow meter design is based on Faraday's law of magnetic induction, which states that: **"The voltage induced across a conductor as it moves at right angles through a magnetic field proportional to the velocity of that conductor".** If a conductor is moving perpendicular to its length through a magnetic field, it will generate an electrical potential (E) between its two ends;

$$\mathbf{E = B \times L \times v}$$

where:

B = the strength of the magnetic field (induction)
L = the length of the conductor (distance of electrodes)
v = velocity of the conductor (average flow velocity)




## Magmeter Flow Equation:

If a conductive fluid flows through a pipe of diameter (D) through a magnetic field density (B) generated by the coils, the amount of voltage (E) developed across the electrodes will be proportional to the velocity (V) of the liquid. Because the magnetic field density and the pipe diameter are fixed values, they can be combined into a calibration factor (K) and the equation reduces to: $\mathbf{E = K \times V}$

## Advantages and Disadvantages of Magmeter

**Advantages:**

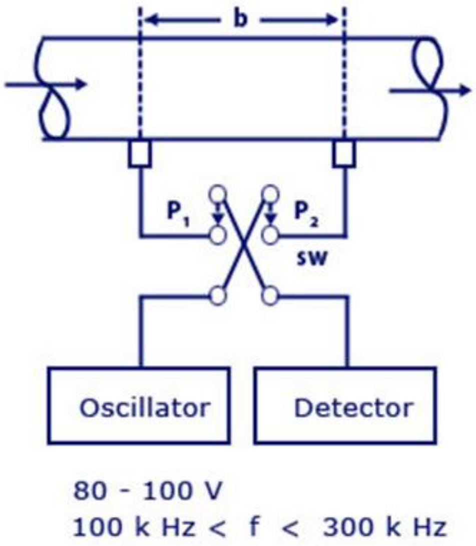
- Are bi-directional, have no flow obstruction, easy to re-span
- Are available with DC or AC power
- It can measure pulsating and corrosive flow.
- It can measure multiphase; however, all components should be moving at the same speed; the meter can measure the speed of the most conductive component.
- It can install vertically or horizontally (the line must be full, however) and can be used with fluids with conductivity greater than 200 umhos/cm.
- Changes in conductivity value do not, affect the instrument performance.

**Disadvantages**

- It's above average cost
- It's large size
- Its need for a minimum electrical conductivity of 5 to 20 μmhos / cm
- Its accuracy is affected by slurries containing magnetic solids.
- Electrical coating may cause calibration shifts
- The line must be full and have no air bubbles (air and gas bubbles entrained in the liquid will be metered as liquid, causing a measurement error).
- In some applications, appropriate mechanical protection for the electrodes must be provided.

**Ultrasonic Flowmeter:**

When pressure waves are released into the flowing fluid, their velocity and amplitude are affected by the fluid velocity. Ultrasonic flowmeters help in measuring these pressure wave changes.



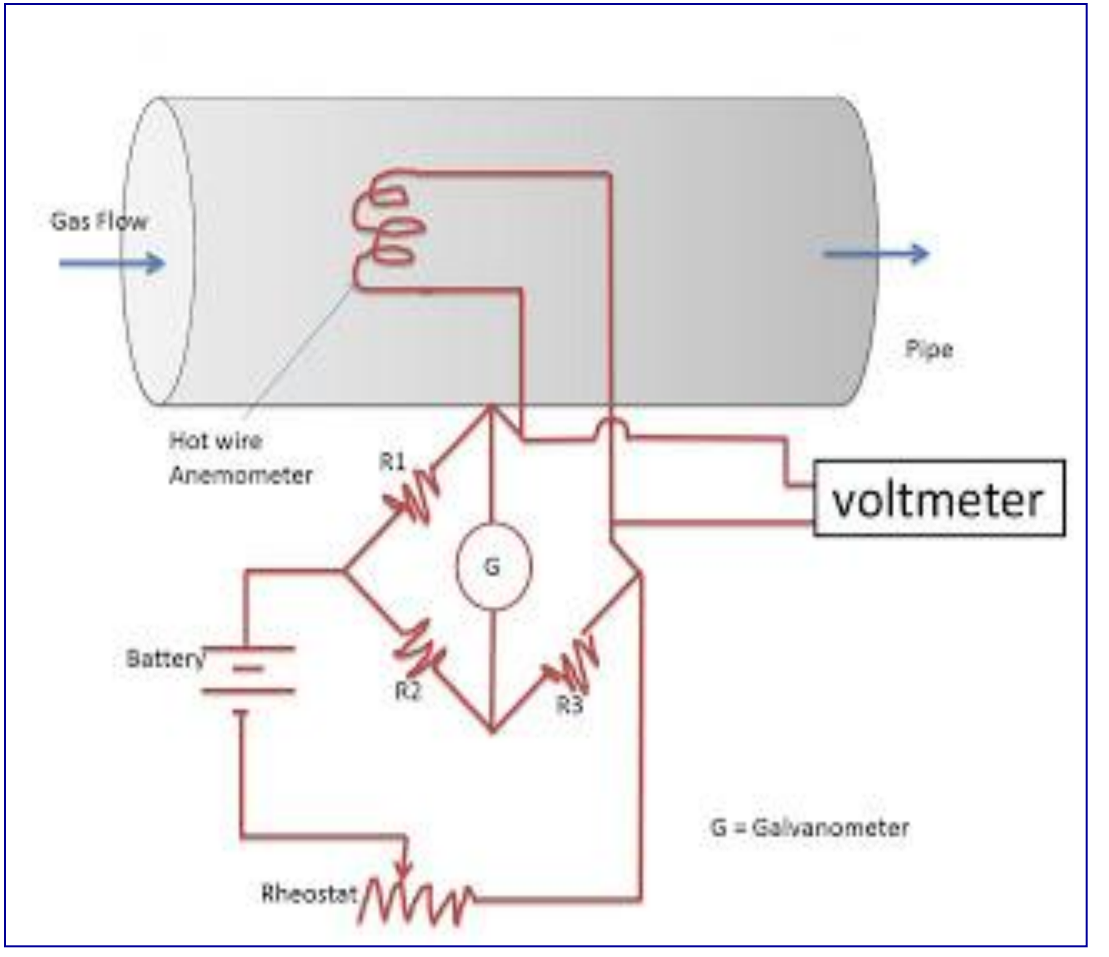

- Its working depends on measuring the phase difference.
- The two peizo-crystals (p1 and p2) working both as transmitter and receiver of signals alternatively, so that the ultrasonic signals are transmitted between them as well as through the liquid.
- Switch 'sw' is utilized to supply p1 and p2 alternately from an oscillator simultaneously connecting the detector to p2 and p1 respectively.
- The detector is designed to measure the transit time from upstream to downstream and vice versa via phase shift measurement.

**Anemometer:**

When an electrically heated wire is placed in a flowing gas stream, heat is transferred from the wire to the gas and hence the temperature of the wire reduces, and due to this, the resistance of the wire also changes.

This change in resistance of the wire becomes a measure of flow rate.

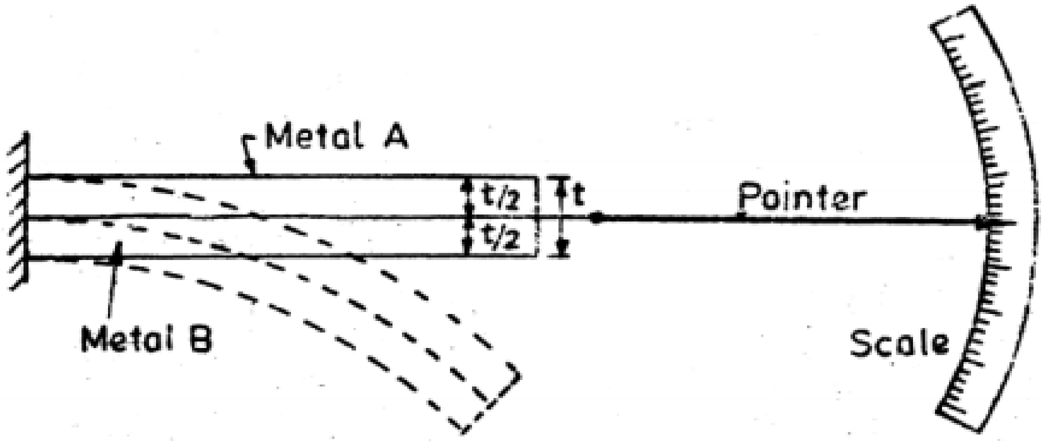
Due to this, the galvanometer which was initially at zero position deflects and this deflection of the galvanometer becomes a measure of flow rate of the gas when calibrated.



# Temperature Sensing:

## Bimetallic Thermometer:

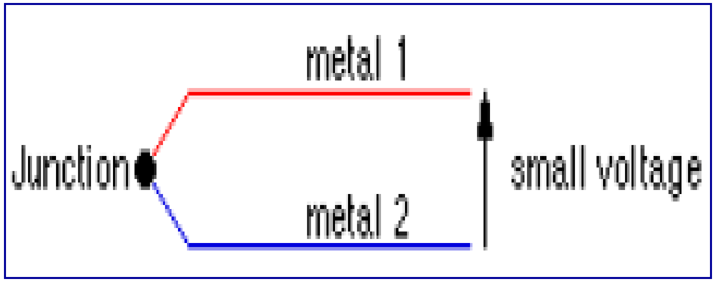
- They are used for local temperature measurements.
- It is constructed by bonding two different metals such that they cannot move relative to each other. All metals try to change their physical dimensions at different rates when subjected to same change in temperature.
- The differential change in expansion of two metals results in bending or flattening the structure, which in turn moves the pointer via the intermediate element.



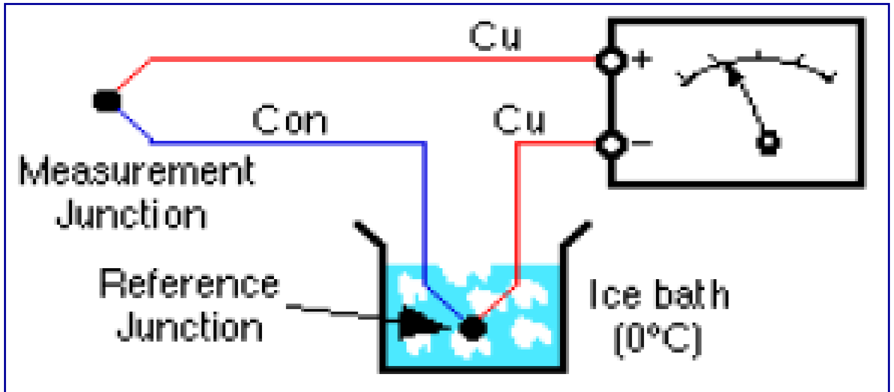

Strip Type

## 1. Thermocouple:

It consists of two wires of dissimilar metals joined near the measurement point. The output is a small voltage measured between the two wires.




- The output voltage is related to the temperature difference between the measurement and the reference junctions (held at 0°C by an ice bath). This is phenomena is known as the Seebeck effect.

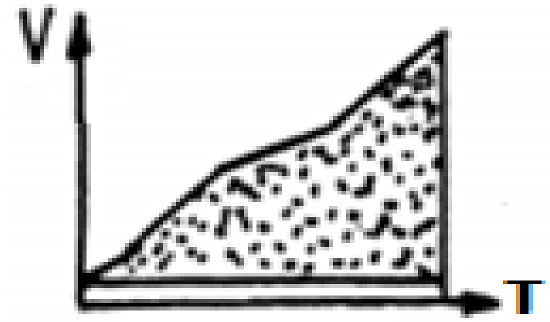



Traditional Thermocouple Measurement

- In practice the Seebeck voltage is made up of two components:
  1. Peltier voltage generated at the junctions, and
  2. Thomson voltage generated in the wires by the temperature gradient.
- The Peltier voltage is proportional to the temperature of each junction while the Thomson voltage is proportional to the square of the temperature difference between the two junctions.

**The advantages and disadvantages of thermocouples:**

Because of their physical characteristics, thermocouples are the preferred method of temperature measurement in many applications. Thermocouples are wonderful sensors to experiment with because of their robustness, wide temperature range and unique properties.




**Advantages:**

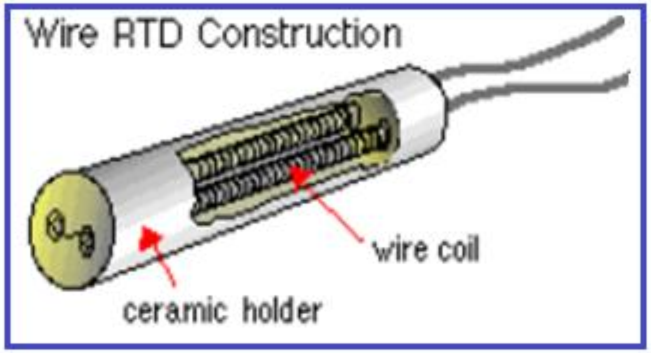
They can be very rugged, are immune to shock and vibration, are useful over a wide temperature range, are simple to manufactured, require no excitation power, there is no self heating and they can be made very small.

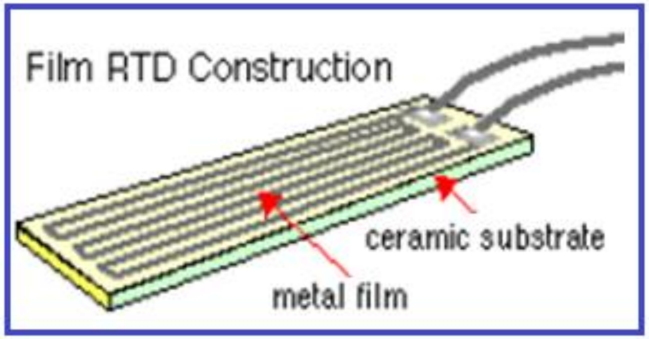
**Disadvantages:**

- ✓ Nonlinear
- ✓ Low voltage output.
- ✓ Reference required.
- ✓ Less stable.

## 2. Resistance Temperature Detector (RTD):


- RTDs rely on the predictable and repeatable phenomena of the electrical resistance of metals changing with temperature.
- The temperature coefficient for all pure metals is of the same order (0.003-0.007) Ω/Ω/°C.
- The most common metals used for temperature sensing are platinum, nickel, and copper.




**Advantages:**

Stable, Accurate, and Linear.

**Disadvantages:**

- ✓ Expensive.
- ✓ Current source required.
- ✓ Small DR.
- ✓ Self-heating

**Characteristics of RTDs:**

Metal RTDs have a response given by:

$$\mathbf{R(t) = R_0 (1 + a.t + b.t^2 + c.t^3)}$$

Where; $R_0$ is the resistance at 0°C,
t is the temperature in Celsius, and
a, b & c are constants dependent on the characteristics of the metal.

In practice this equation is a close but not perfect fit for most RTDs, so slight modifications are required.

The temperature characteristics of an RTD are specified as a single number (α), representing the average temperature coefficient over the 0 to 100°C temperature range as calculated by:

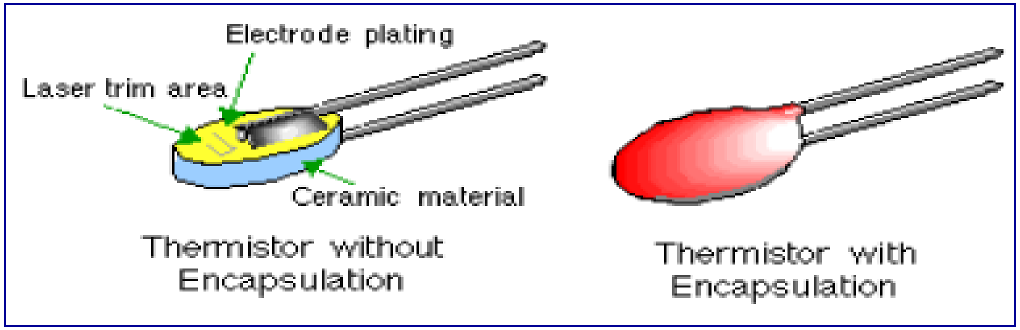
$$\alpha = (R_{100} - R_0) / 100 . R_0 \quad (\Omega / \Omega /^\circ C)$$

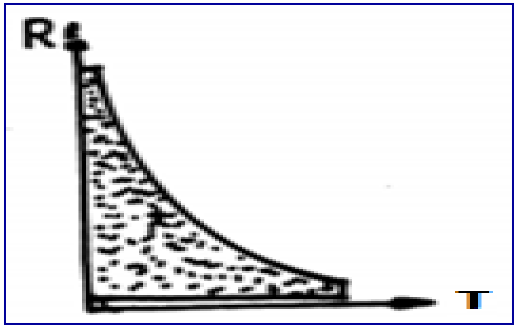
| Metal | Temperature Range | Alpha | Comments |
|---|---|---|---|
| Copper (Cu) | -200°C to 260°C | 0.00427 | Low cost |
| Molybdenum (Mo) | -200°C to 200°C | 0.00300<br>0.00385 | Lower cost alternative to platinum in the lower temperature ranges |
| Nickel (Ni) | -80°C to 260°C | 0.00672 | Low cost, limited temperature range |
| Nickel-Iron (NiFe) | -200°C to 200°C | 0.00518 | Low cost |
| Platinum (Pt) | -240°C to 660°C | 0.00385<br>0.00392 | Good precision |

## 3. Thermistor:

Thermistor temperature sensors are constructed from sintered metal oxide in a ceramic matrix that changes electrical resistance with temperature.

- They are sensitive but highly non-linear. Their sensitivity, reliability, ruggedness and ease of use, has made them popular in research application, but they are less commonly applied to industrial applications, probably due to a lack on interchangeability between manufactures.
- The most common form of the thermistor is a bead with two wires attached. The bead diameter can range from about 0.5mm to 5mm.




**Advantages:**

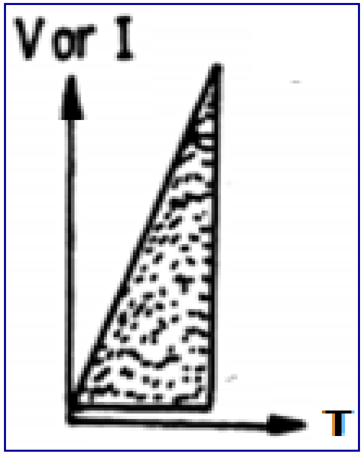
- ✓ High output.
- ✓ Fast response.

**Disadvantages:**

- Nonlinear.
- Self-heating.
- Limited temp.
- Current source required.

## 4. Semiconductor or IC Temperature Sensor:

- The semiconductor temperature sensor is an electronic device based on the fundamental temperature and current characteristics of the transistor.
- Semiconductor temperature sensors are available from a number of manufacturers.
- These sensors share a number of characteristics:
  - ✓ linear outputs,
  - ✓ relatively small size,
  - ✓ limited temperature range (-40 to +120°C),
  - ✓ low cost,
  - ✓ good accuracy if calibrated but also poor interchangeability.




**Disadvantages:**

- ✓ Limited temp. range (0 to less than 200°C).
- ✓ Power supply required.
- ✓ Slow response.
- ✓ Self heating.

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