Basic Instrumentation Course

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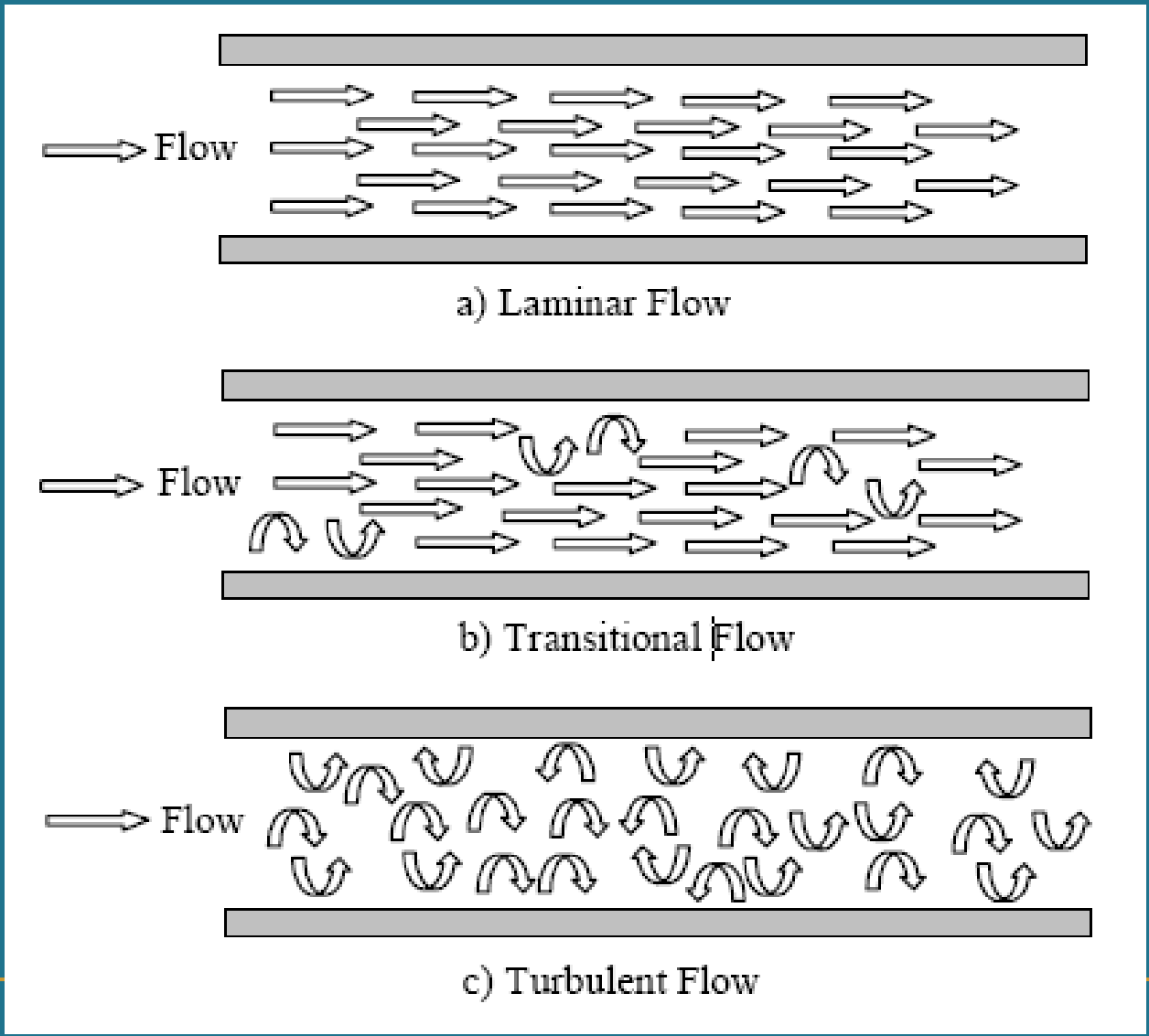
2. Flow Measurements

2- Flow Measurement

- We will consider only a so-called ideal fluid, that is, a liquid that is incompressible and has no internal friction or viscosity.
- The techniques used to measure flow fall into four general classes:
  - Differential pressure technique
  - Velocity technique
  - Volumetric technique
  - Mass technique

Flow Profile Types



Differential-Pressure Flowmeters

- We use the relationship between the pressure drop and the rate of flow

$$Q = K \sqrt{\Delta P}$$

where

Q = the volumetric flow rate

K = a constant for the pipe and liquid type

ΔP = the differential pressure drop across the restriction

to measure the flow.

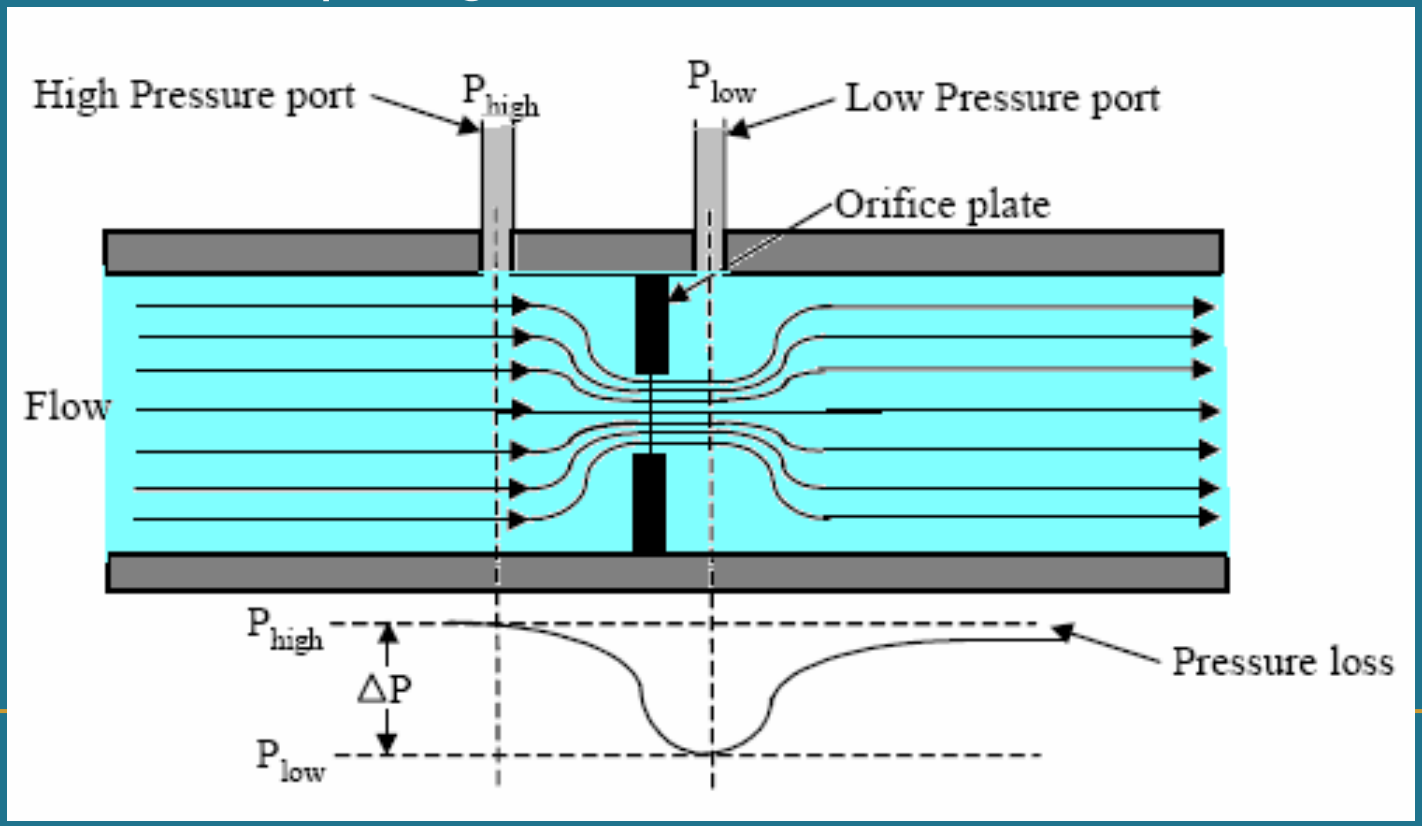
- The constant depends on numerous factors, including the type of liquid, the size of the process pipe, and the temperature of the liquid, among others.

Flow Detectors

- To measure the rate of flow by the differential pressure method, some form of restriction is placed in the pipeline to create a pressure drop.
- Since flow in the pipe must pass through a reduced area, the pressure before the restriction is higher than after or downstream.
- So by measuring the differential pressure across a restriction, one can measure the rate of flow.
- Using DP transmitter in a square mode of operation can detect the flow.

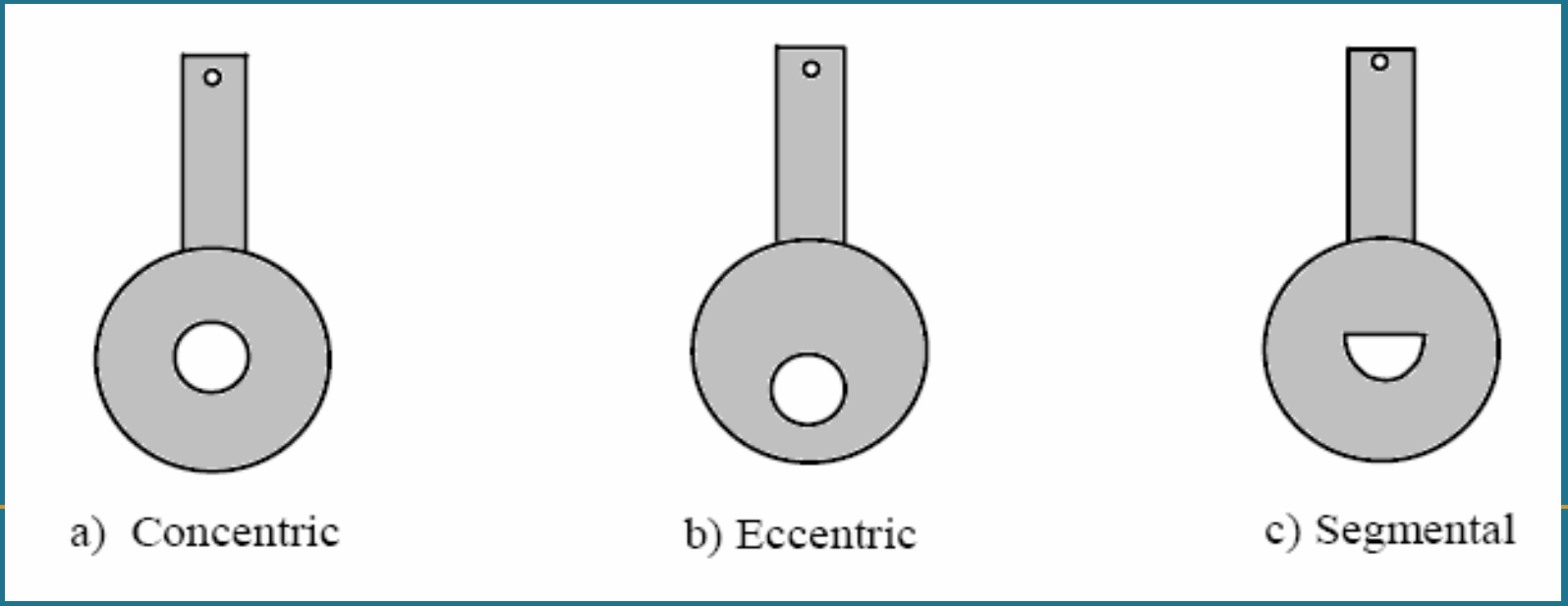
Orifice Plate

- An orifice plate is basically a thin metal plate with a hole bored in the center.
- Usually clamped between a pair of flanges.
- suitable for liquid, gas, and steam



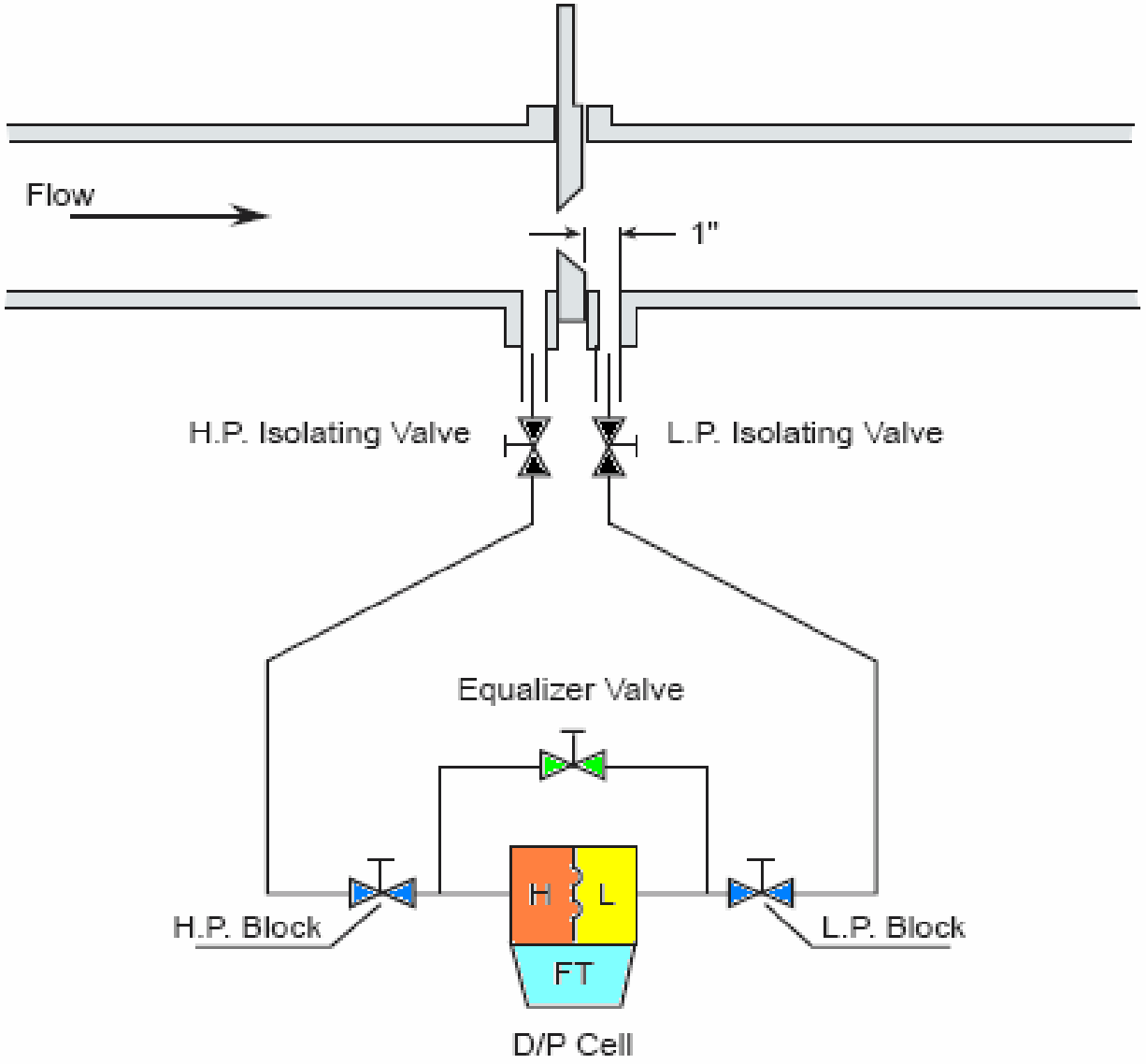
Orifice Plate

- The concentric orifice plate is the most widely used type.
- Eccentric and segmental orifices are preferable to concentric orifices for measuring dirty liquids as well as gas or vapor where liquids may be present, especially large slugs of liquid.
- Where the stream contains particulate matter, the segmental orifice may be preferable because it provides an open path at the bottom of the pipe.



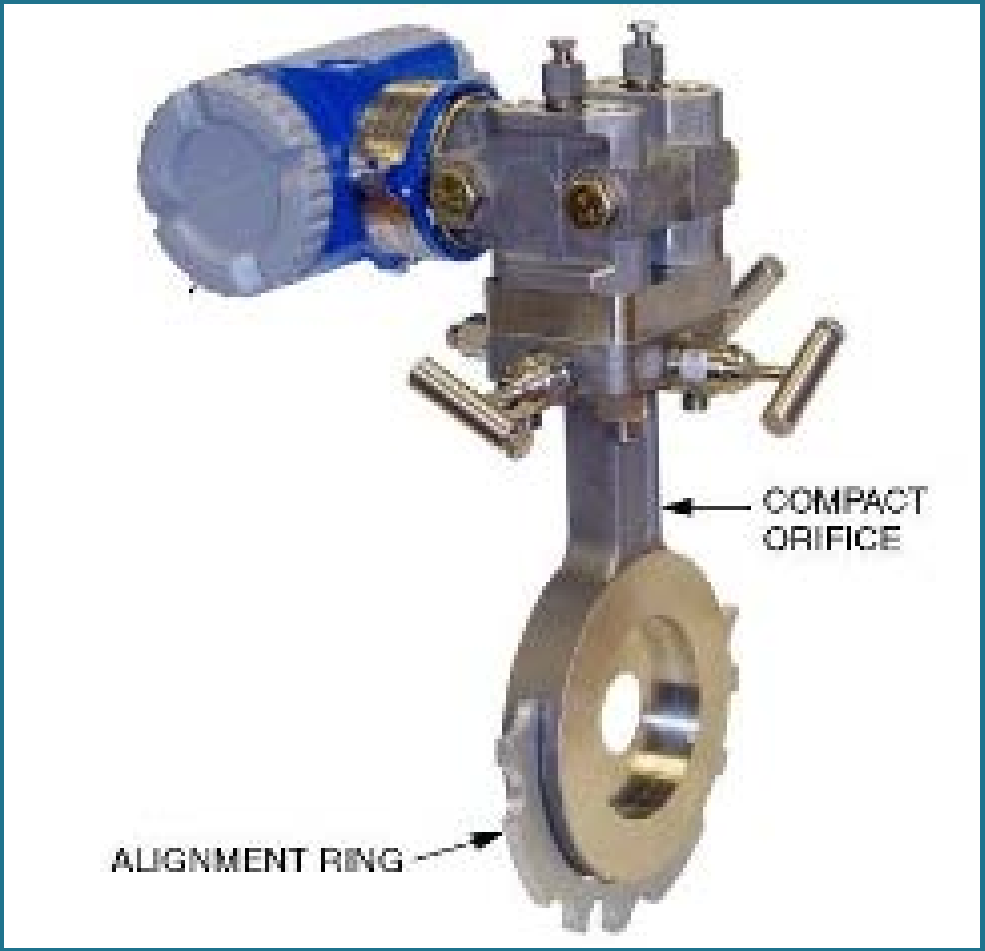
Orifice Plate

DP Flow Transmitter Installation

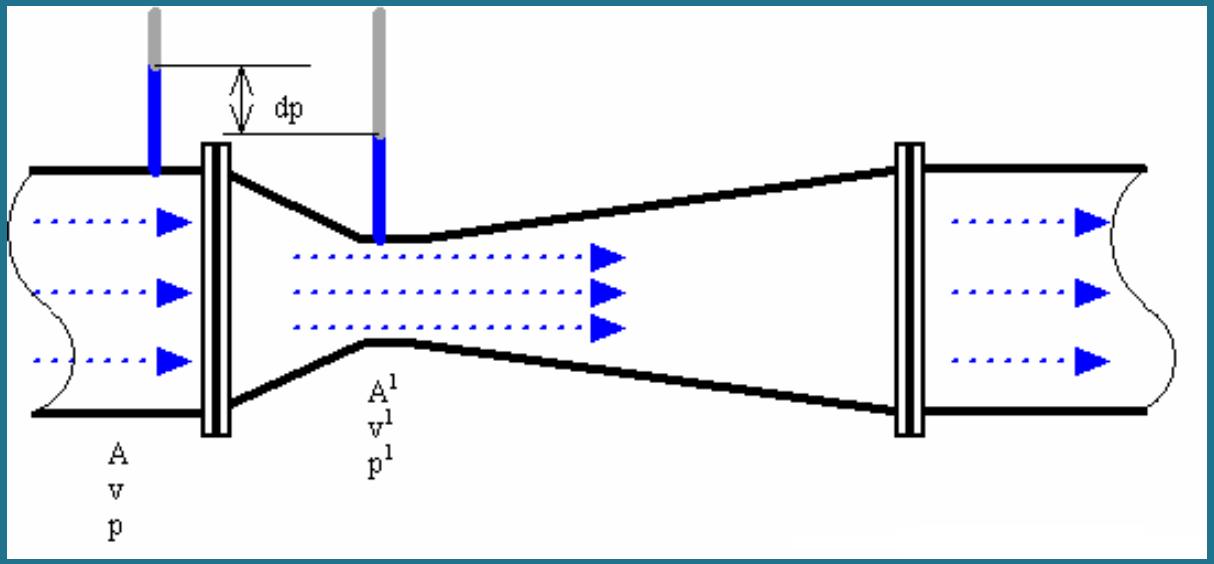


Flow Transmitter Installation

Flow Transmitter Installation



Venturi Tubes

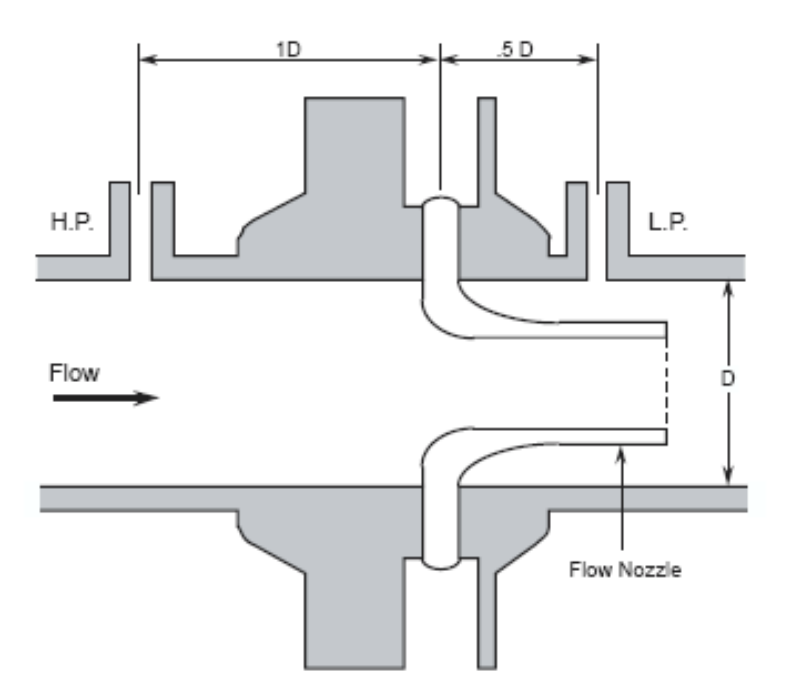


- Used for applications where high permanent pressure loss is not tolerable (no permanent pressure drop occurs).
- Used to measure dirty fluids.
- It is more bulky and more expensive than Orifice.

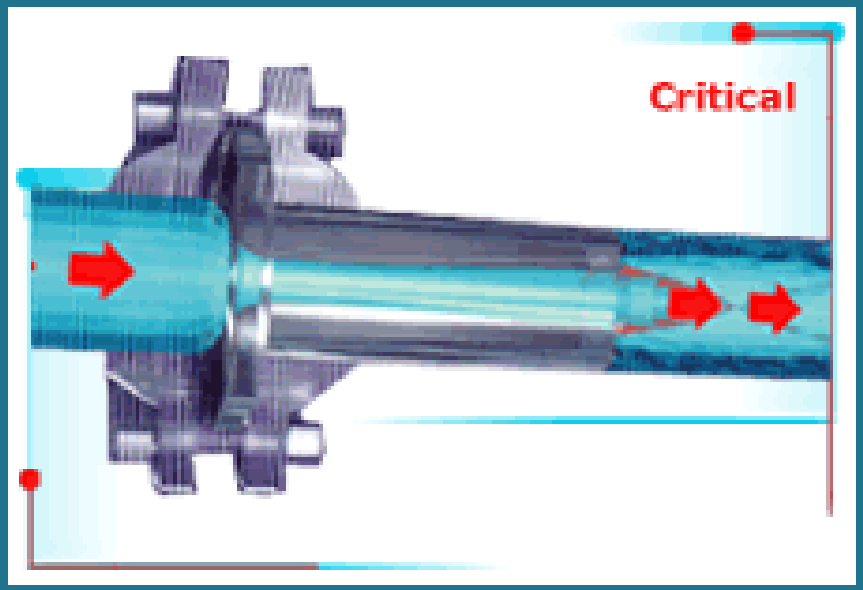
Venturi Tubes

Flow Nozzle

- Flow nozzle has properties between an orifice plate and a venturi tube (lower permanent pressure loss than an orifice plate & less expensive than the venturi tubes)
- Widely used for flow measurements at high velocities.
- More rugged and more resistant to erosion than the sharp-edged orifice plate

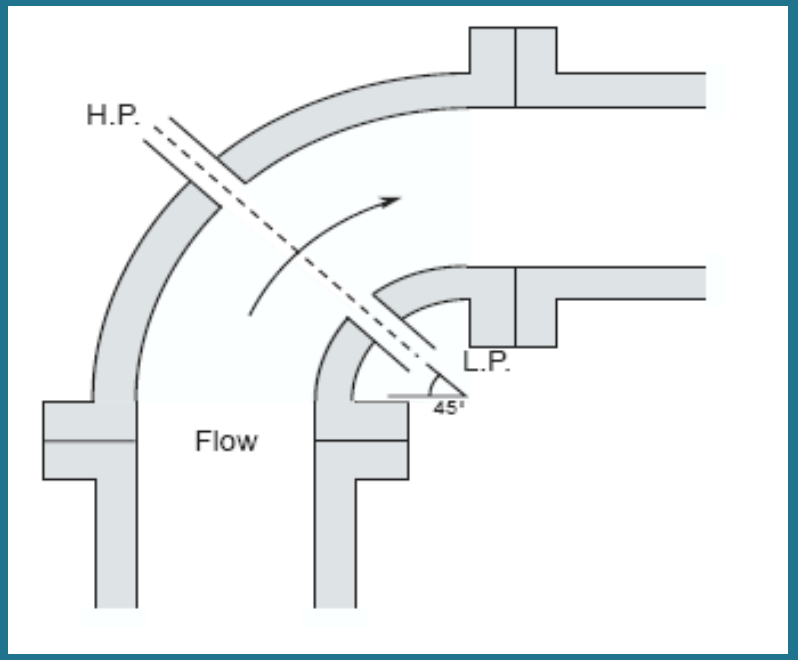


Flow Nozzle



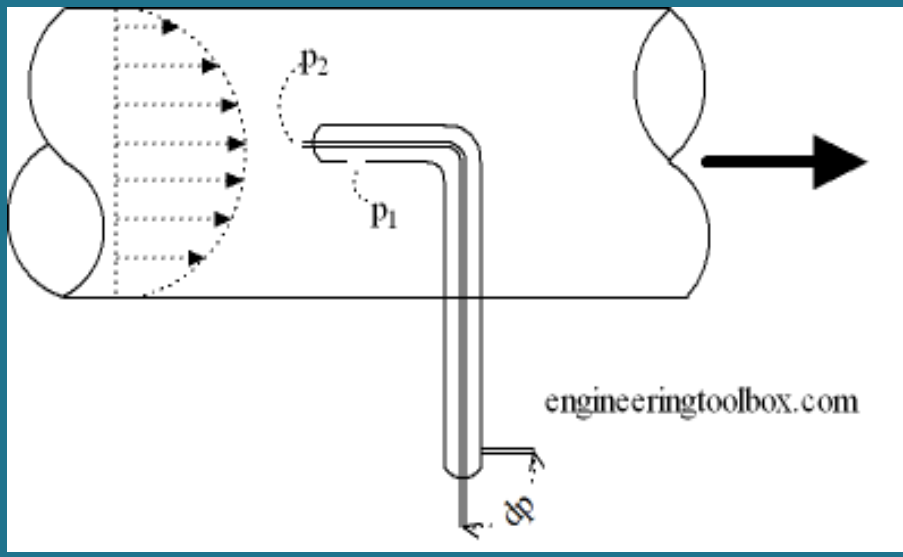
Elbow Taps

- Centrifugal force generated by a fluid flowing through an elbow can be used to measure fluid flow.
- As fluid goes around an elbow, a high-pressure area appears on the outer face of the elbow.
- One use of elbow taps is the measurement of steam flow from the boilers, where the large volume of saturated steam at high pressure and temperature could cause an erosion problem for other primary devices.
- The elbows are often already in the regular piping configuration so no additional pressure loss is introduced.

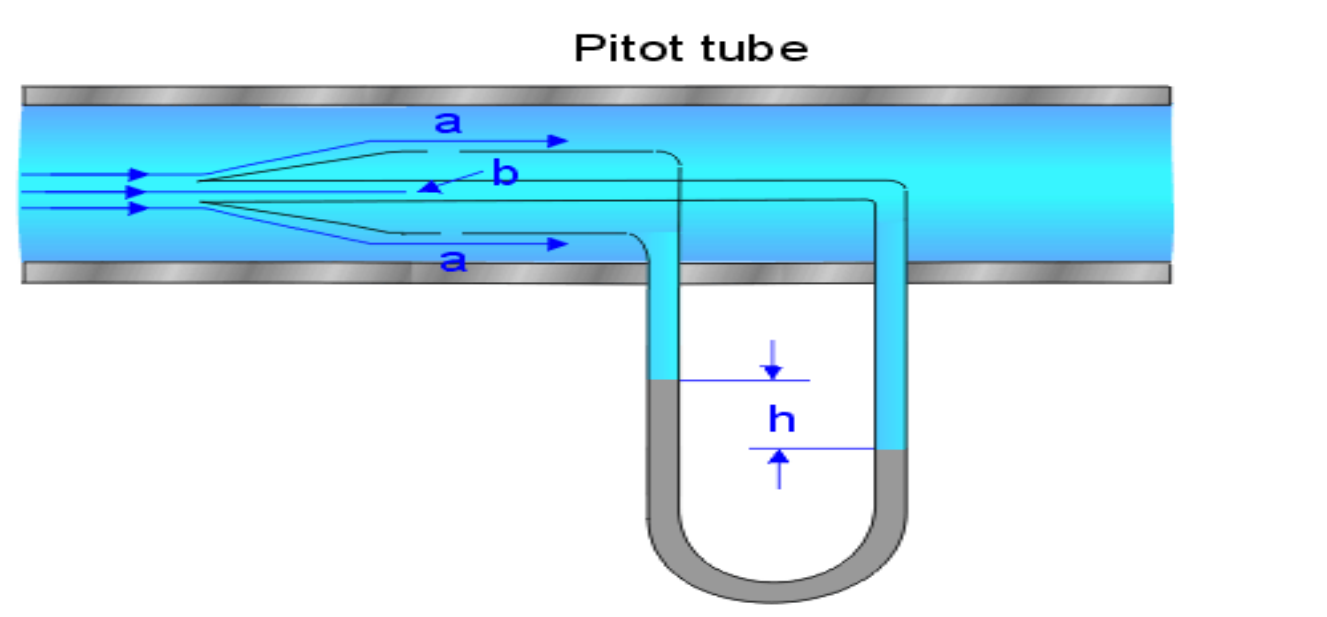


Pitot Tubes

- Pitot tubes actually consist of two tubes. One, the low pressure tube measures the static pressure in the pipe, the second is the high pressure tube is inserted in the pipe in such a way that the flowing fluid is stopped in the tube.
- The pressure in the high-pressure tube will be the static pressure in the system plus a pressure dependant on the force required stopping the flow.
- Pitot tubes have two problems
  - The pressure differential is usually small and hard to measure.
  - The differing flow velocities across the pipe make the accuracy dependent on the flow profile of the fluid and the position of the pitot in the pipe.

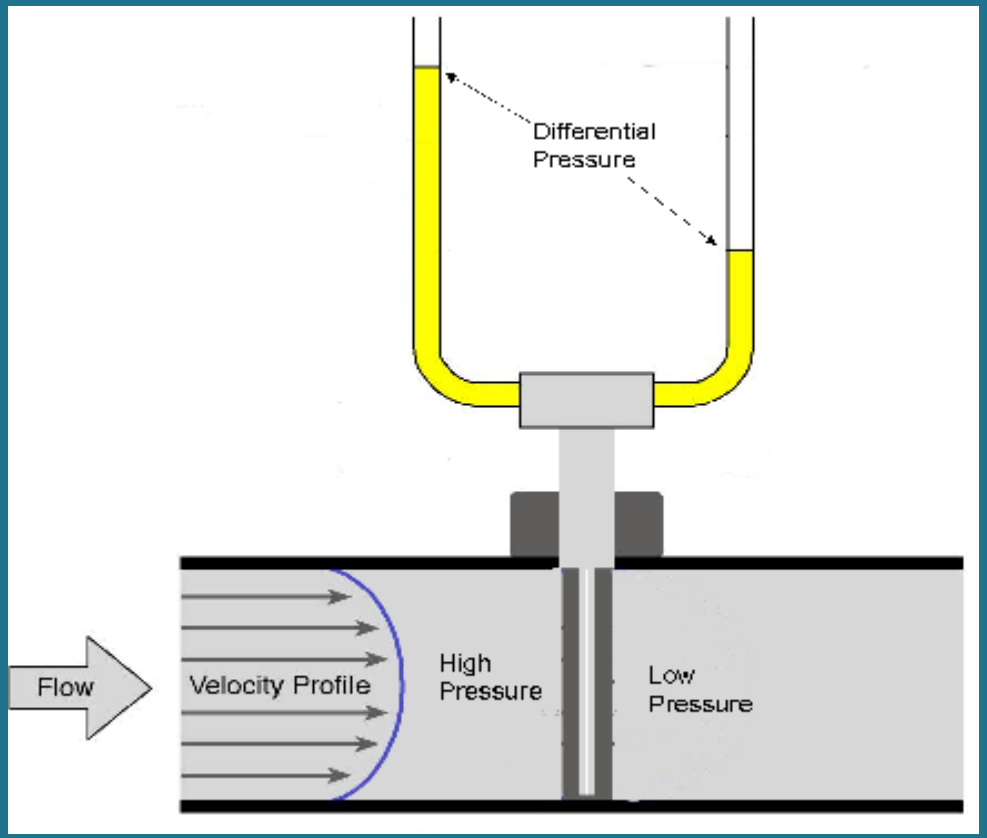


Pitot Tubes



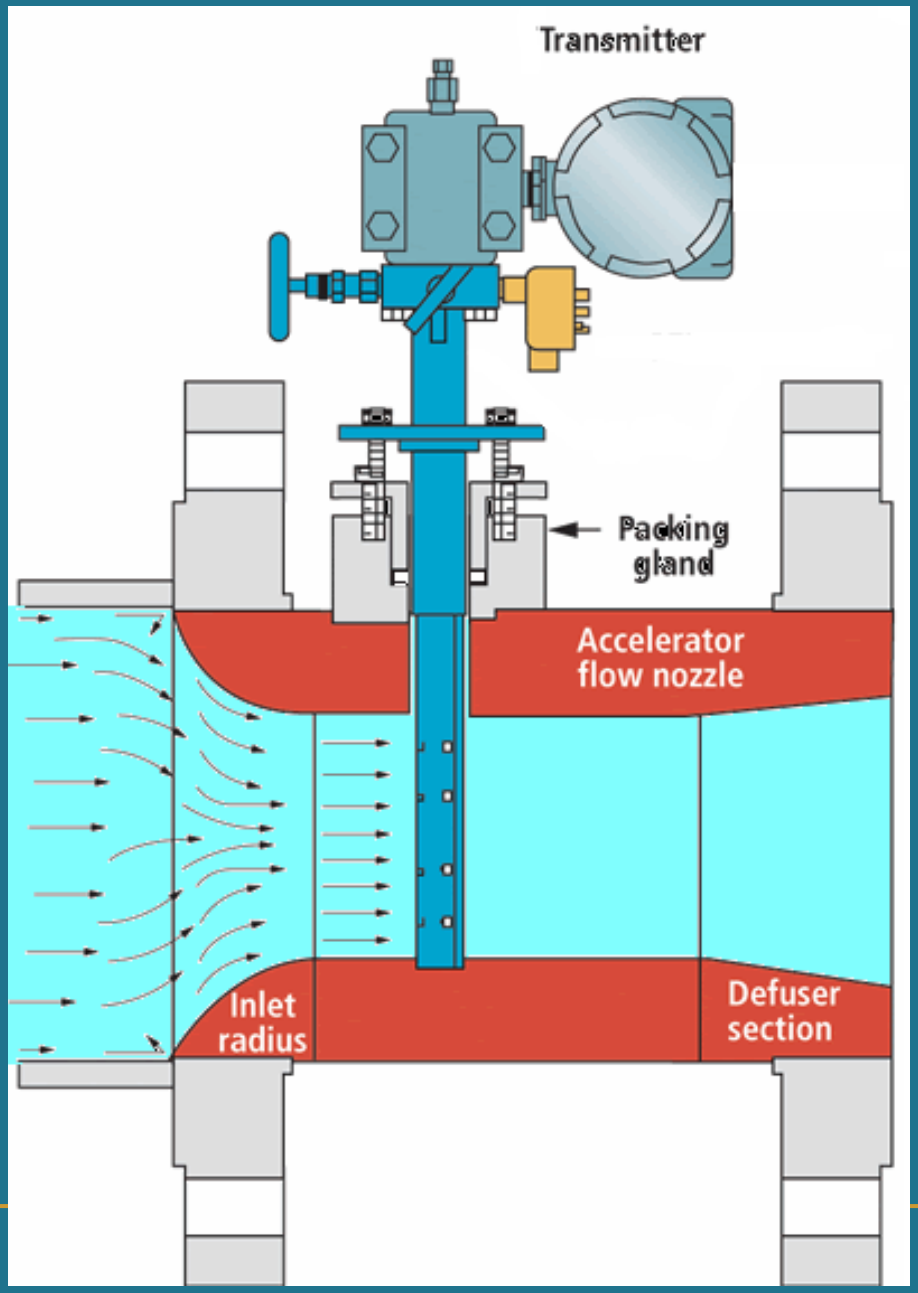
Annubars

- An annubar is very similar to a pitot tube, the difference is that there is more than one hole into the pressure measuring chambers.
- The pressure in the high-pressure chamber represents an average of the velocity across the pipe.



Annubars

Annubars


Transmitter
Packing gland
Accelerator flow nozzle
Inlet radius
Defuser section

Velocity-Type Flowmeters

- Volumetric flow is defined as the volume of fluid that passes a given point in a pipe per unit of time.

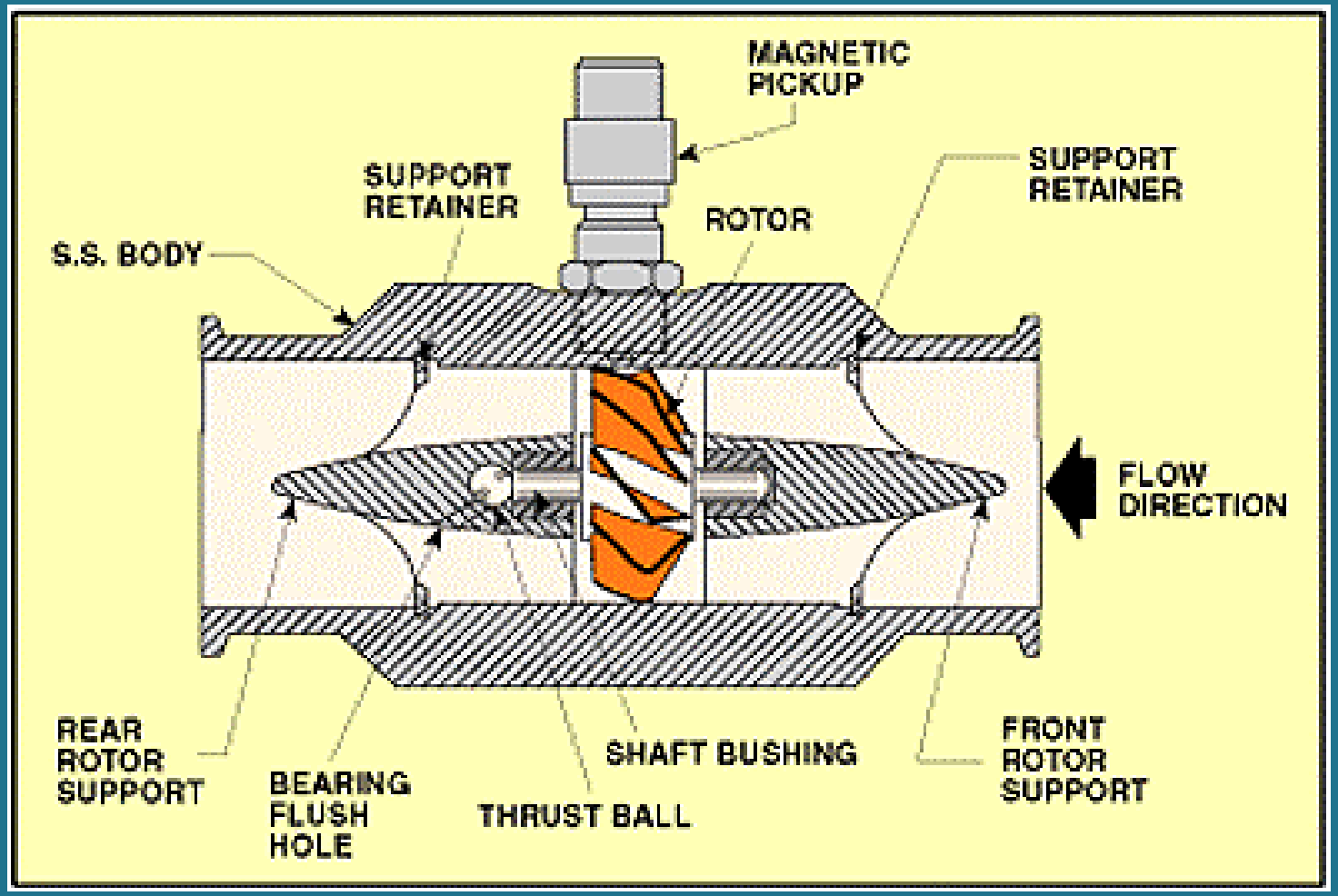
$$Q = AV$$

  where
  - Q = the volumetric flow
  - A = the cross-sectional area of the flow carrier (e.g., pipe)
  - v = the fluid's velocity
- By measuring the fluid velocity and knowing the pipe cross-sectional area, we can determine the flow.

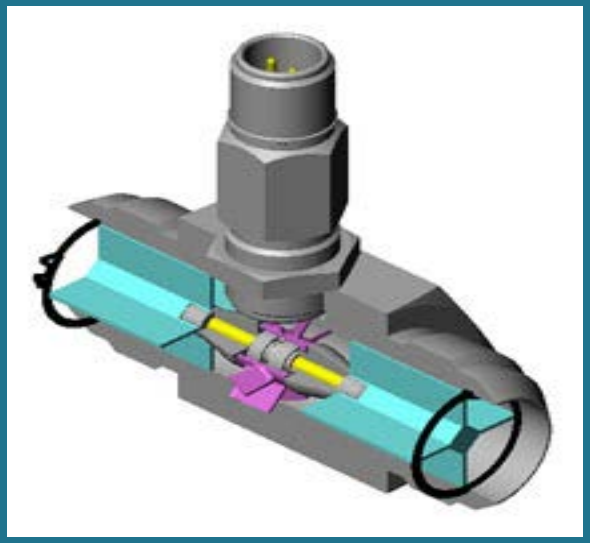
The Turbine Flowmeter

- The fluid passing the rotor causes it to turn with an angular velocity that is proportional to the fluid linear velocity.
- The pickup probe converts the rotor velocity into an equivalent frequency signal.
- The output signal from a turbine flowmeter is a frequency that is proportional to volumetric flow rate.
- Each pulse generated by the turbine flowmeter is therefore equivalent to a measured volume of liquid.
- The flow rate can be indicated digitally or in analog form.
- Flow rates are converted into flow totals by totalizer-type instruments.

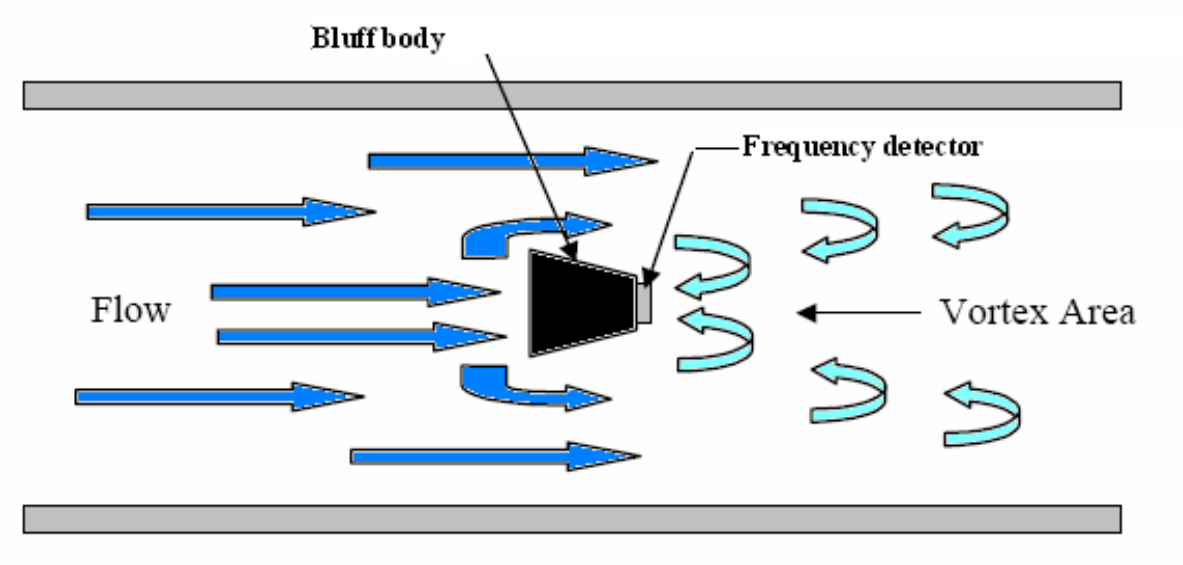
The Turbine Flowmeter



The Turbine Flowmeter

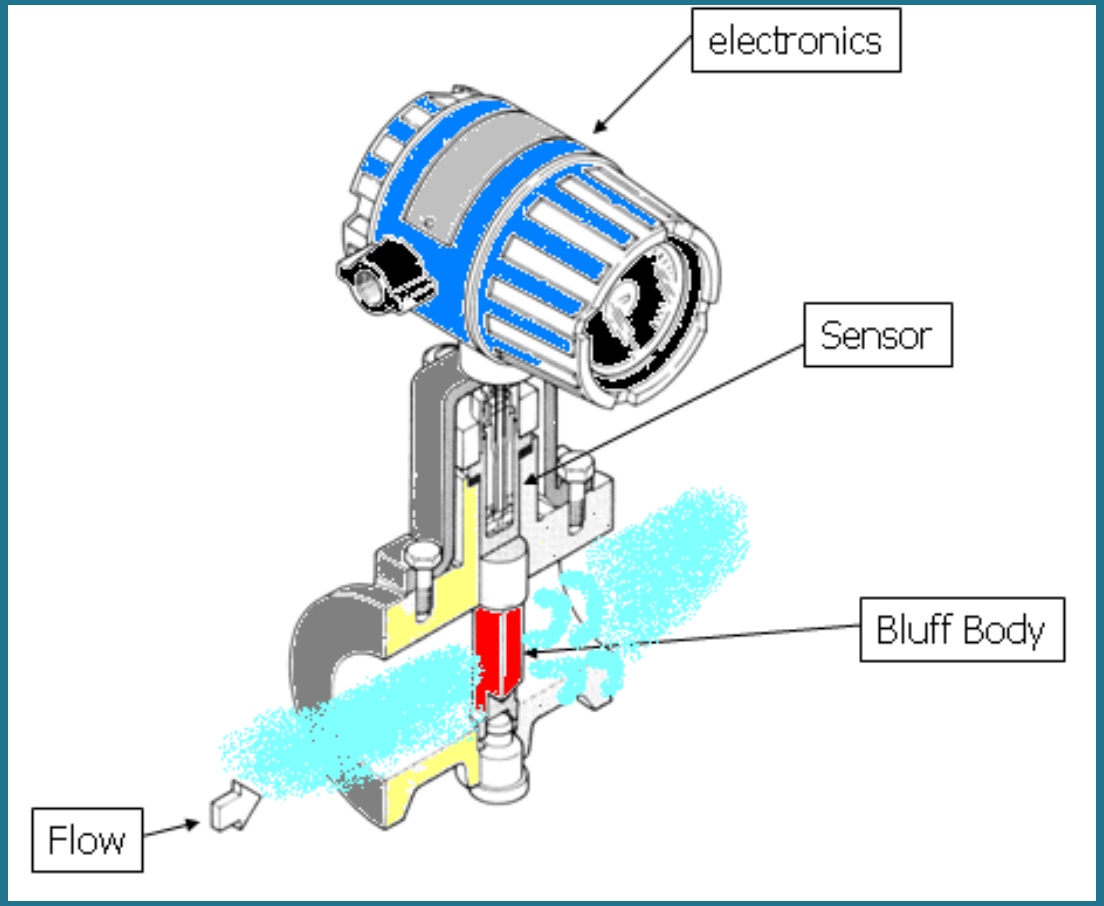


Vortex Shedding Device



- As fluid flows past a bluff body, the fluid separates from each side of the shedder and swirls to form vortices downstream of the shedder.
- Flow sensors that detect the frequency of vortices shed by a bluff body placed in a flow stream.
- The frequency of the vortices is proportional to the flow velocity.

Vortex Shedding Device

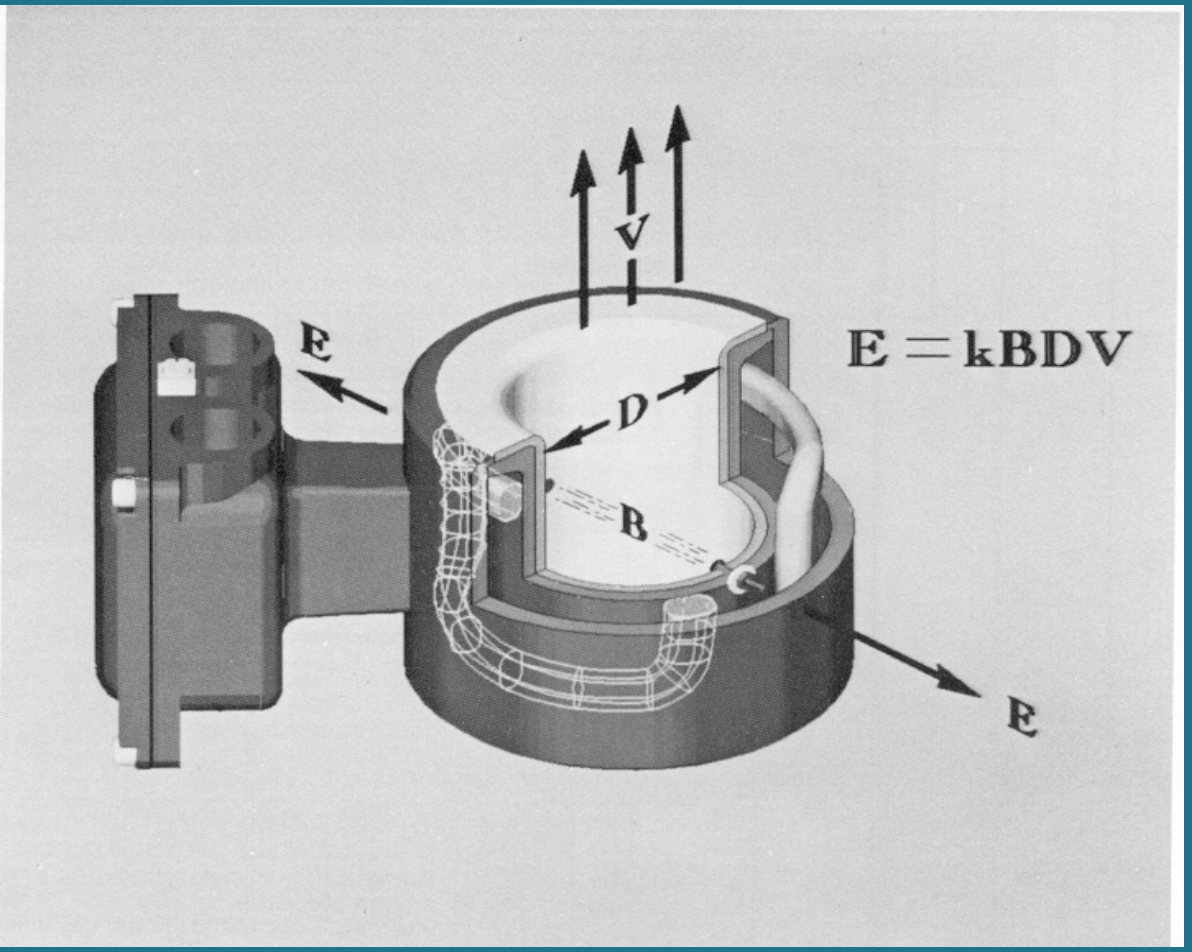


Vortex Shedding Device

Magnetic Flowmeters

- Magnetic flowmeters use Faraday's law of induction to measure flow.
- Relative motion at right angles between a conductor and a magnetic field will develop a voltage in the conductor, and the induced voltage is proportional to the relative velocity of the conductor and the magnetic field.
- The fluid has some minimum conductivity and acts as a series of fluid conductors that cut the magnetic field, generate an induced voltage can be detected by the meter electrodes.

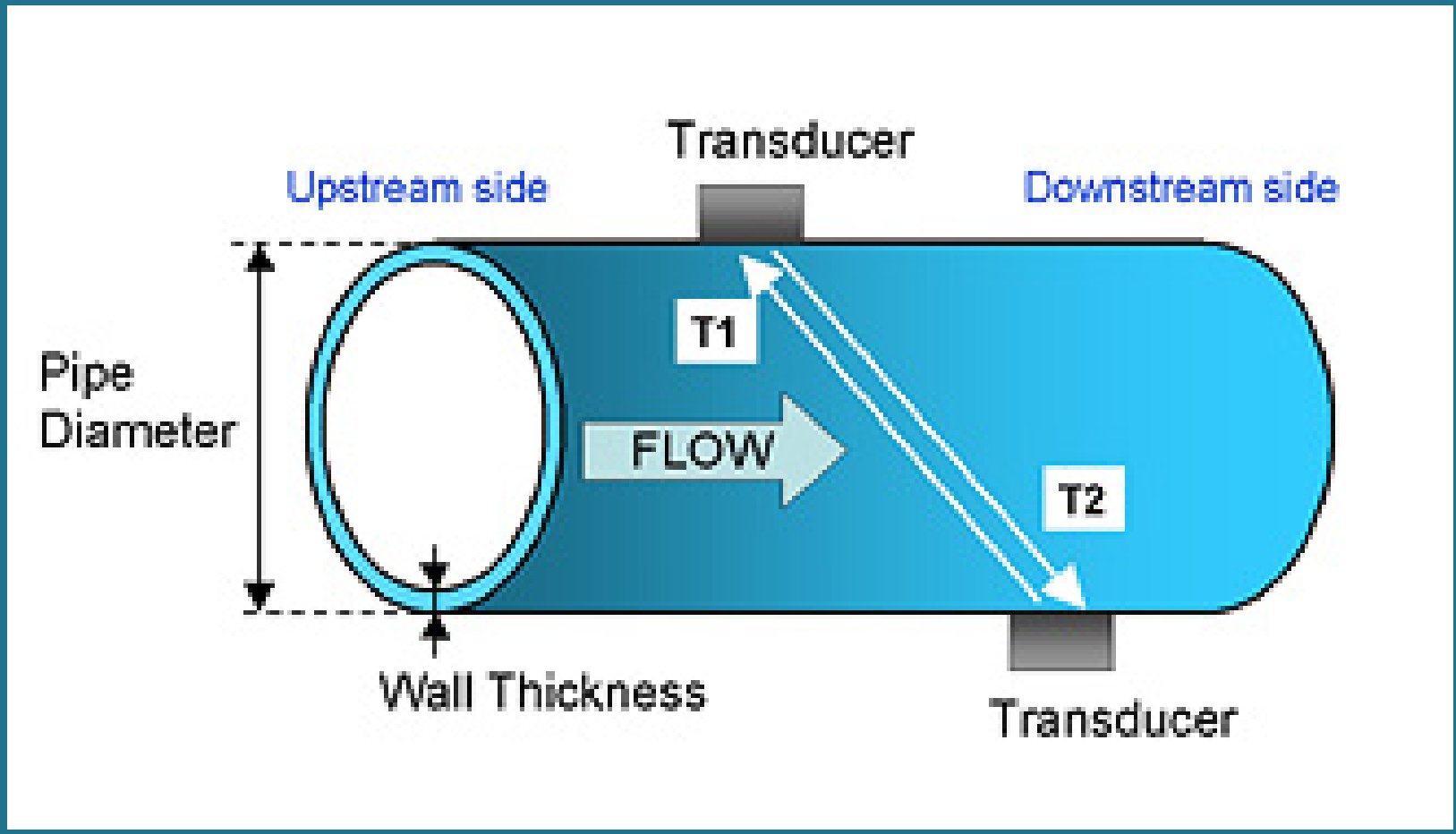
Magnetic Flowmeters



Ultrasonic Flowmeters

- Ultrasonic flowmeters are ideal for wastewater applications or any dirty liquid which is conductive or water based.
- There are two main types of ultrasonic flowmeters: Transit time and Doppler.
- **Transit Time Ultrasonic Meters** have both a sender and a receiver.
- They send two ultrasonic signals across a pipe: one traveling with the flow and one traveling against the flow.
- The ultrasonic signal traveling with the flow travels faster than a signal traveling against the flow.
- The ultrasonic flowmeter measures the transit time of both signals. The difference between these two times is proportional to flow rate.
- Transit time ultrasonic flowmeters usually monitor clean liquids.

Transit Time Ultrasonic Flowmeters

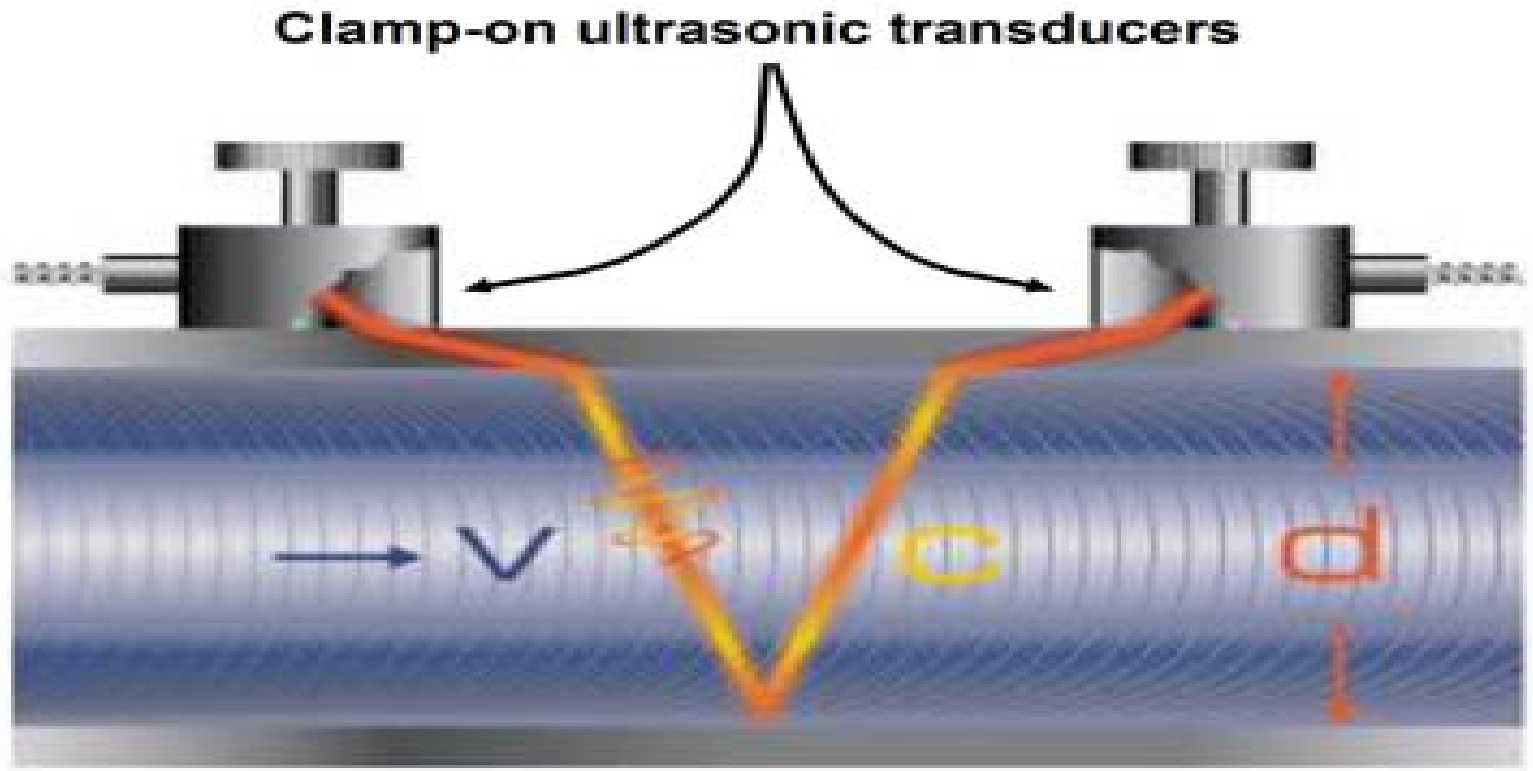


Transit Time Ultrasonic Flowmeters

Doppler Ultrasonic Flowmeters

- This metering technique utilizes the physical phenomenon of a sound wave that changes frequency when it is reflected by moving discontinuities in a flowing liquid.
- They compute flow rate based on a frequency shift that occurs when their ultrasonic signals reflect off particles in the flow stream.
- Using the frequency change between transmitted and received sound waves to calculate the velocity of a flow.

Doppler Ultrasonic Flowmeters



Doppler Ultrasonic Flowmeters

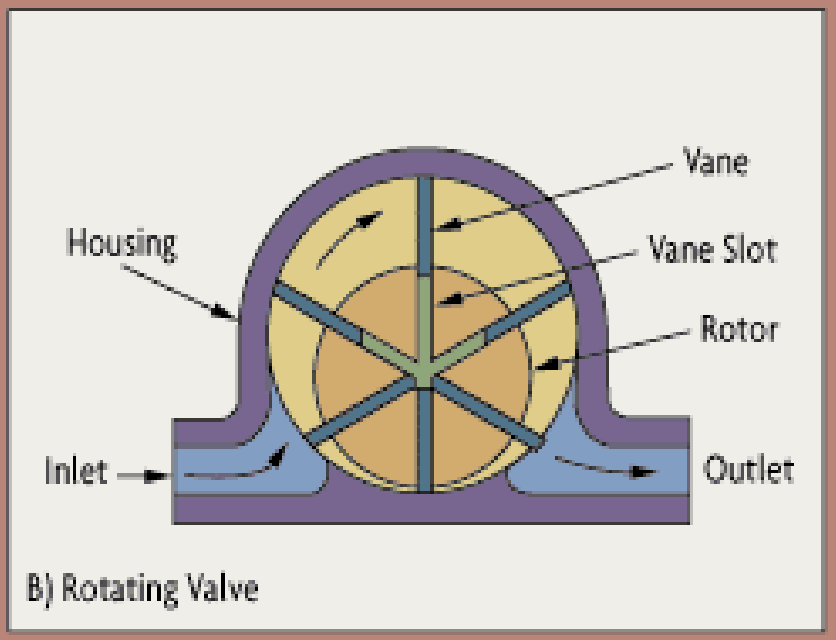
Positive-Displacement Flowmeters

- A type of Volumetric type flowmeter
- Positive-Displacement (PD) operates by isolating and counting known volumes of a fluid (gas or liquid) while feeding it through the meter.
- By counting the number of passed isolated volumes, a flow measurement is obtained.

Rotating Vane Meters

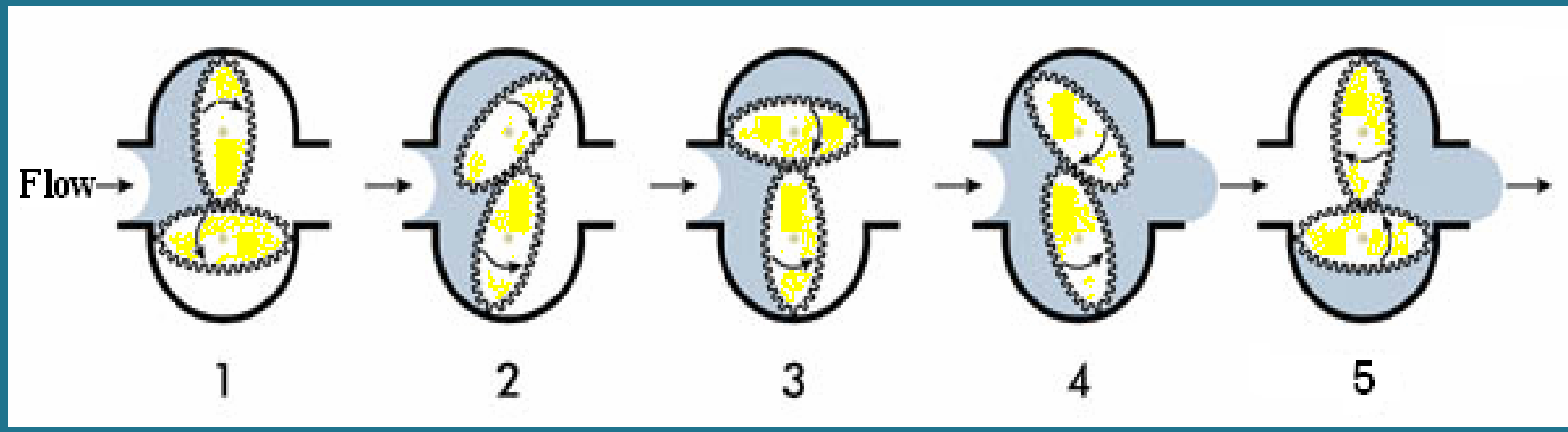
- **Rotating vane meters** have spring-loaded vanes that entrap increments of liquid between the eccentrically mounted rotor and the casing.
- The rotation of the vanes moves the flow increment from inlet to outlet and discharge.
- used in the petroleum industry and are capable of metering solids-laden crude oils.

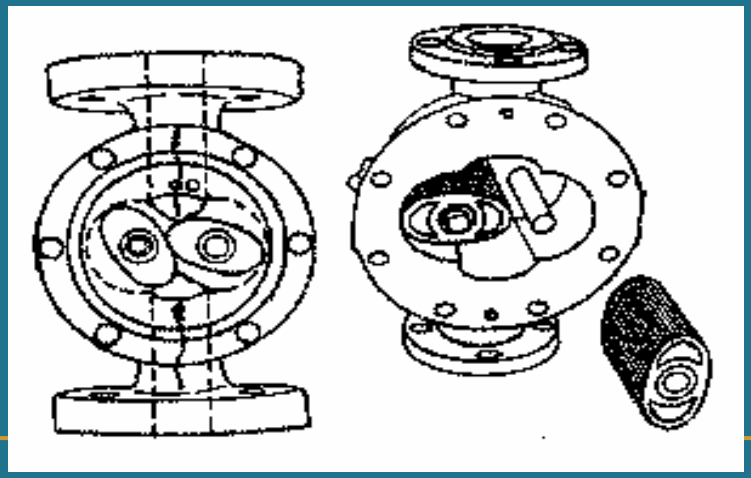
Rotating Vane Meters



Oval-Gear PD Flowmeters

- Oval-gear PD flowmeters are generally used on very viscous liquid, which is difficult to measure using other flowmeters.

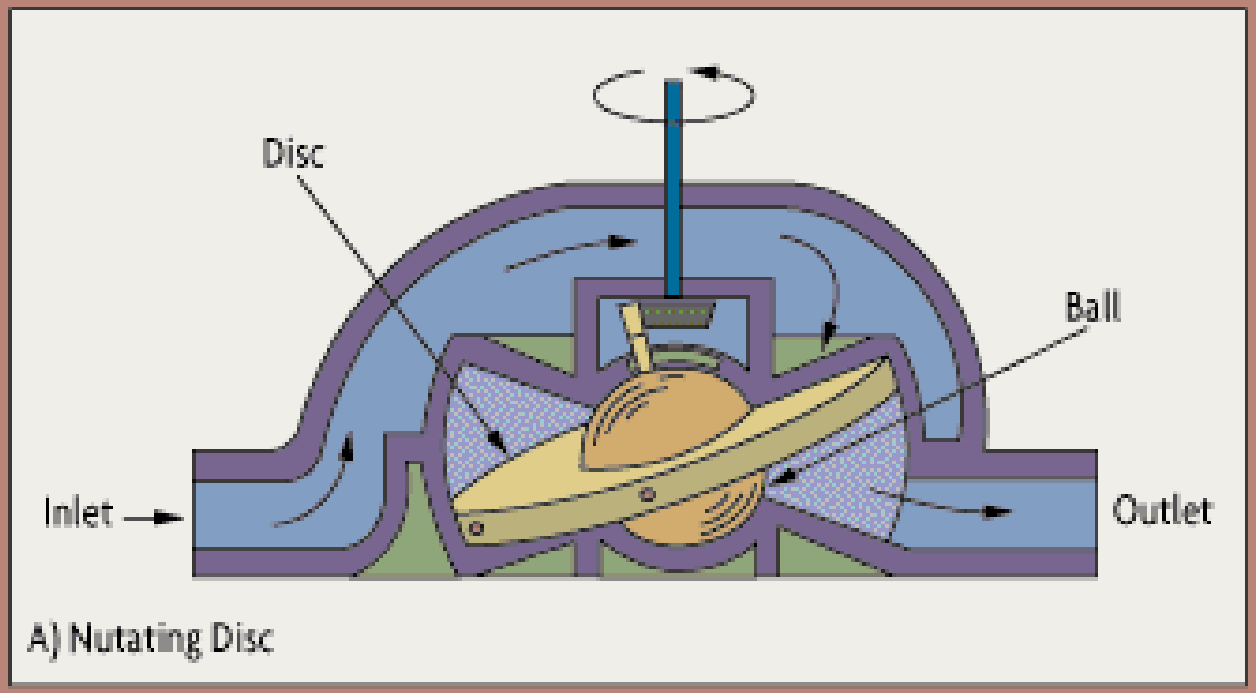




Nutating-Disk PD Flowmeters

- As liquid flows through the metering chamber, it causes a disc to nutate, turning a spindle, which rotates a magnet.
- This magnet is coupled to a mechanical register or a pulse transmitter.
- The rate of flow is proportional to the rotational velocity of the spindle.
- Designed for water service and the materials of which they are made must be checked for compatibility with other fluids.

Nutating-Disk PD Flowmeters

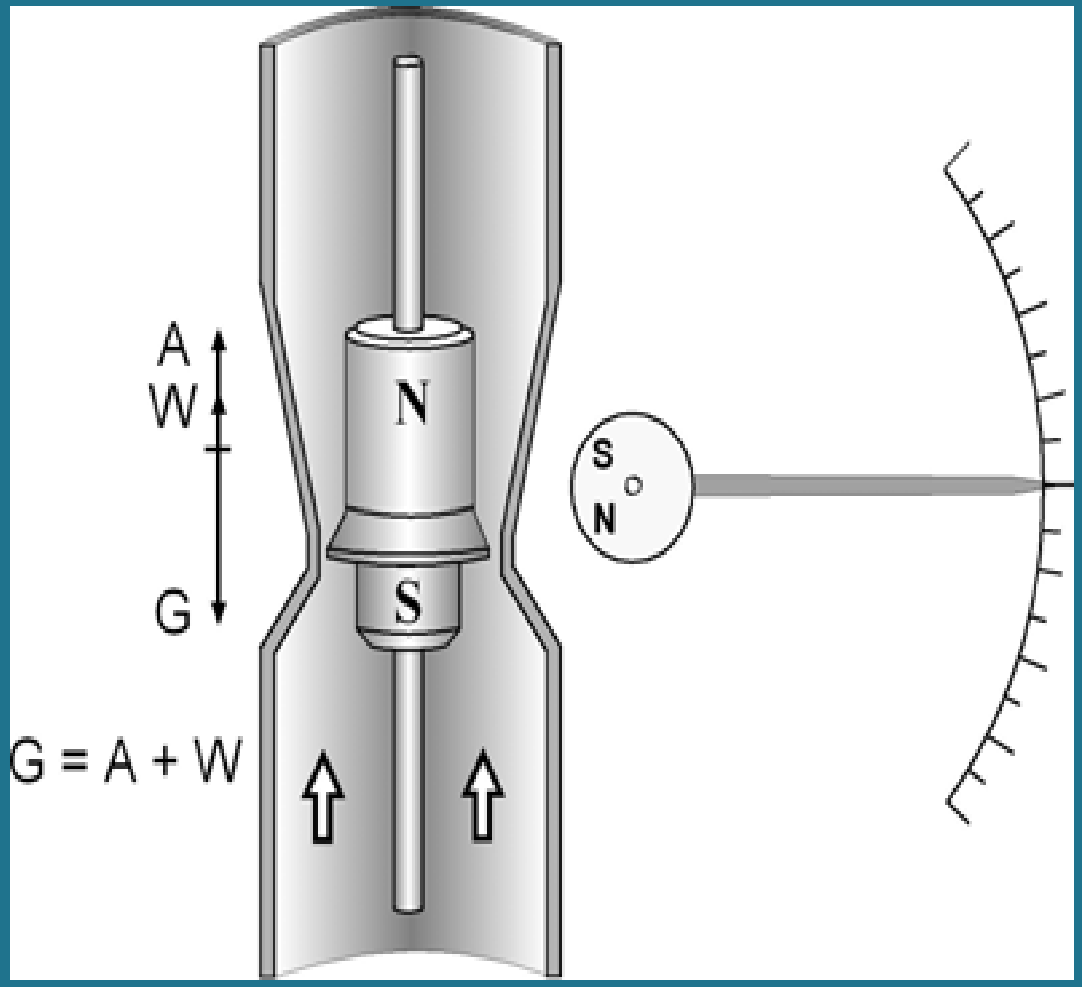


Variable Area Flowmeters

- The flowmeter operates in accordance with the float measuring principle.
- A metal cone or a ring orifice is installed in the measuring unit in which a suitably shaped float can move freely up and down.
- The flowmeter is inserted into a vertical pipeline and the medium flows through it from bottom to top.
- The guided float adjusts itself so that the buoyancy force (A) acting on it, the form drag (W) and weight (G) are in equilibrium

  (G = A + W).
- An annular gap which depends on the flow rate results.
- The height of the float in the measuring unit, which depends on the flow, is transmitted by a magnetic coupling and displayed on a scale.
- Strong deflecting magnetic fields can lead to deviations in the measured value.

Variable Area Flowmeters

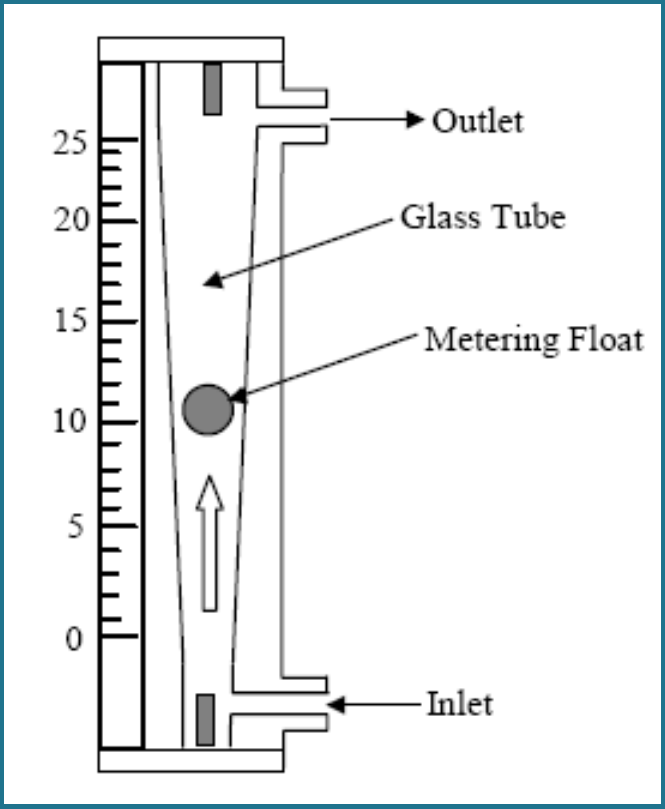


Rotameter

- The rotameter is a type of variable-area flowmeter
- Consists of a tapered metering tube and a float, which is free to move up and down within the tube.
- In order to pass through the tapered tube, the fluid flow raises the float, the greater the flow, the higher the float is lifted.
- In liquid service, the float rises due to a combination of the buoyancy of the liquid and the velocity head of the fluid.
- With gases, buoyancy is negligible, and the float responds mostly to the velocity head.
- The metering tube is mounted vertically, with the small end at the bottom.
- The fluid to be measured enters at the bottom of the tube, passes upward around the float, and exits the top.

Rotameter

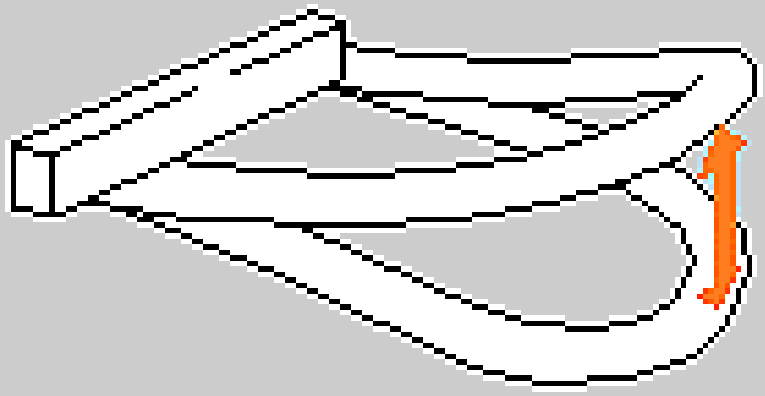
- When no flow exists, the float rests at the bottom. When fluid enters, the metering float begins to rise.



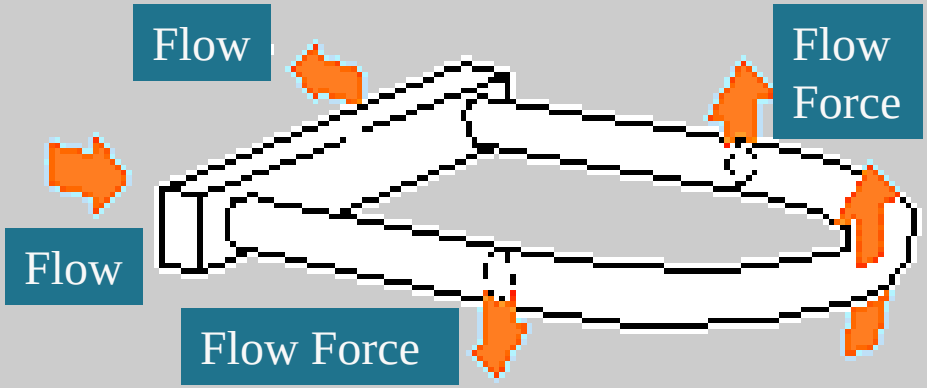
Coriolis Mass Flowmeters

- Coriolis mass flowmeters measure the force resulting from the acceleration caused by fluid moving toward (or away from) a loop of flexible hose that is "swung" back and forth in front of the body with both hands, & opposite forces are generated and cause the hose to twist.
- In a Coriolis mass flowmeter, the "swinging" is generated by vibrating the tube(s) in which the fluid flows.
- The amount of twist is proportional to the mass flow rate of fluid passing through the tube(s).
- General applications are found in the water, wastewater, petroleum, chemical, and petrochemical industries.

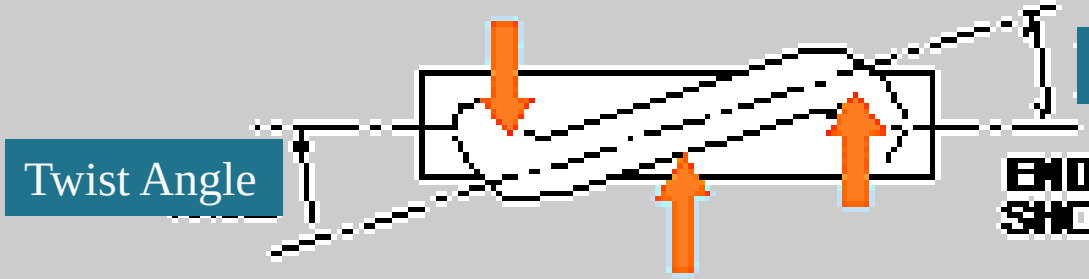
Coriolis Mass Flowmeters



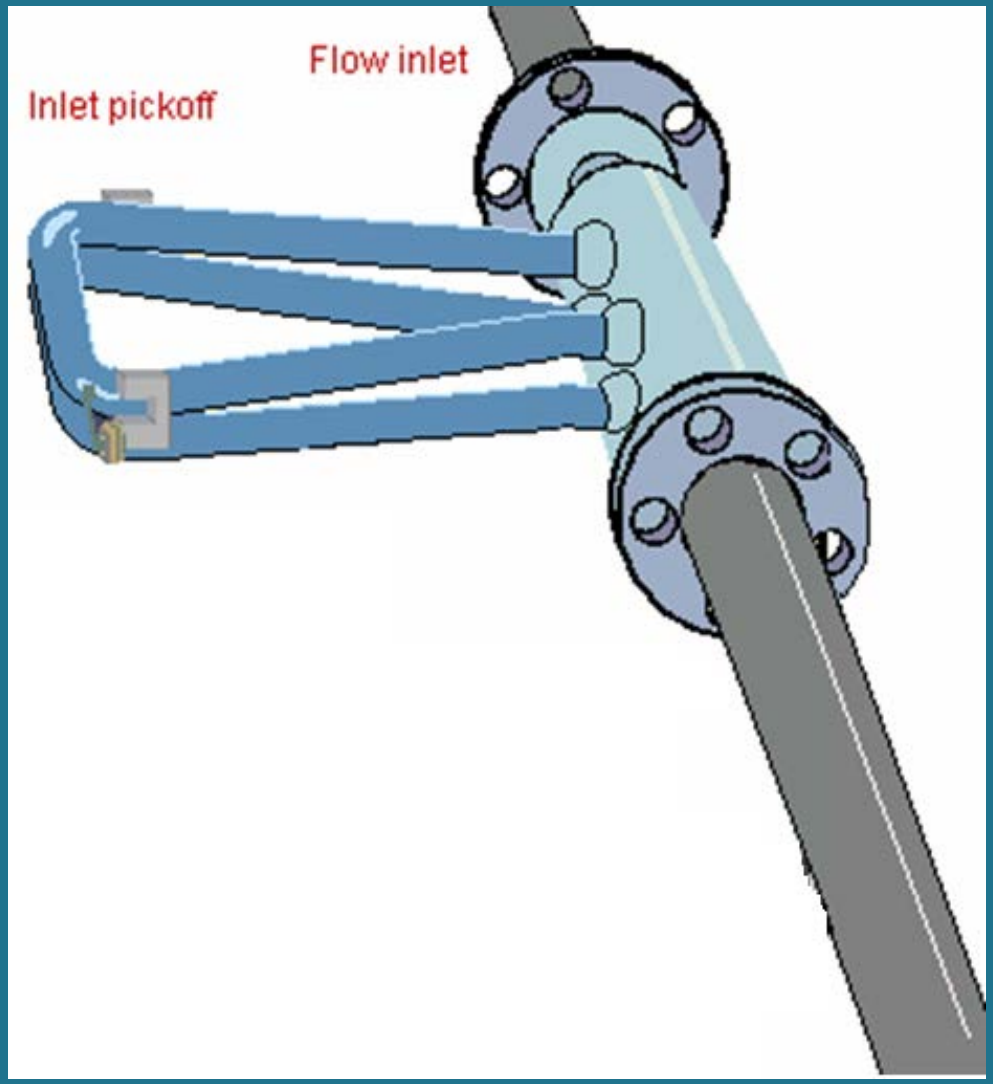
Vibrating Flow Tube



Fluid Force is Reacting to Vibration of Flow Tube



Coriolis Mass Flowmeters

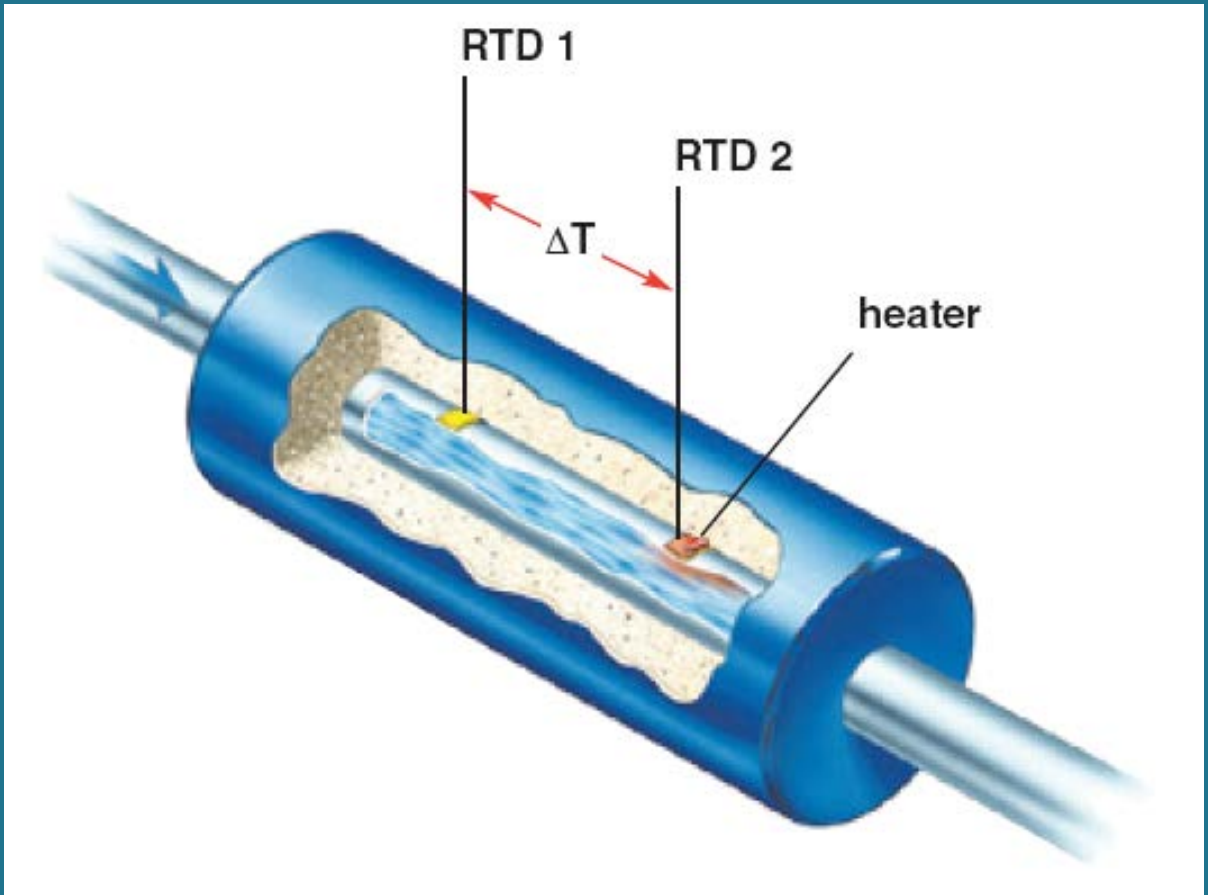


Coriolis Mass Flowmeters

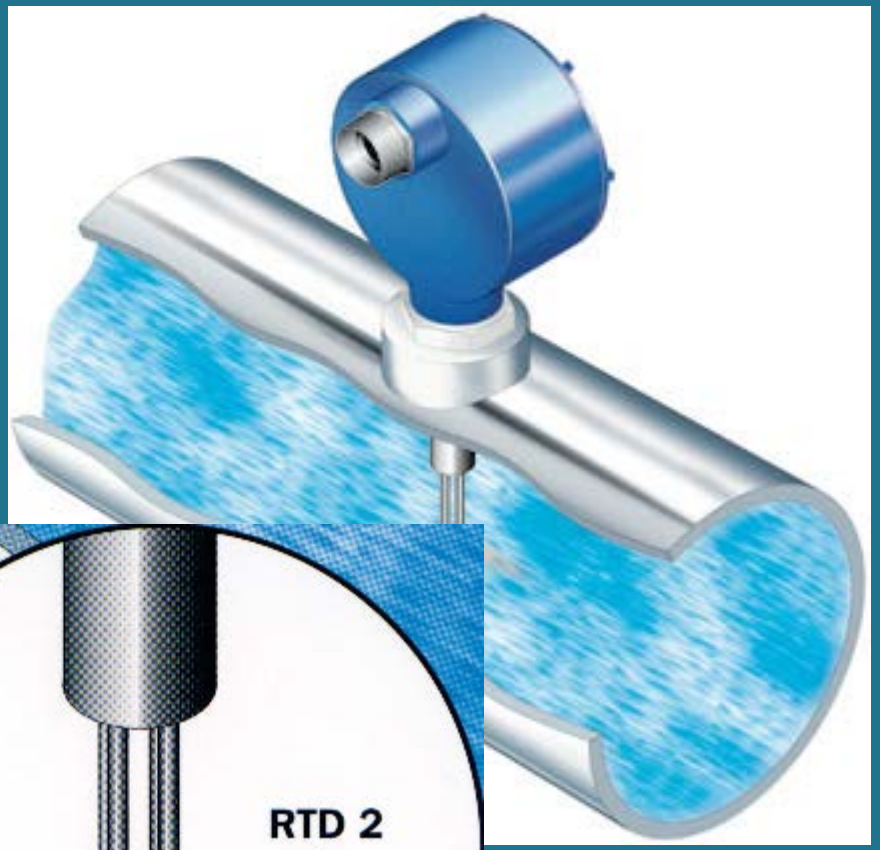
Thermal Mass Flowmeter

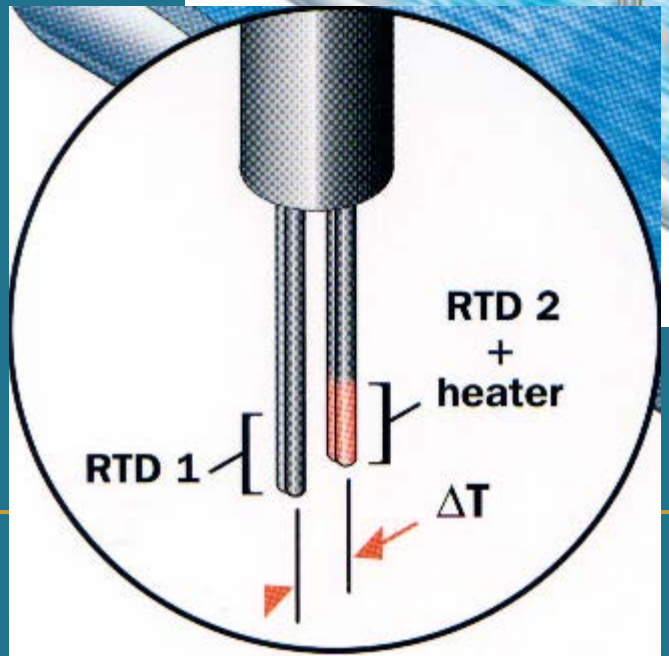
- Thermal measurement method employs two Resistance Temperature Detectors (RTDs) to measure flow. One RTD measures the fluid temperature, and the other RTD measures the temperature of a constant low-power heater which is cooled by the flowing fluid.
- The temperature differential between the heated and unheated RTDs provides the primary flow signal.
- At higher flow rates, the cooling effect on the heated RTD is greater, so the temperature differential decreases.
- This differential signal is a logarithmic function of the flow rate.

THERMAL FLOW MEASUREMENT



THERMAL FLOW MEASUREMENT





Flow Measurement Errors

- **Over ranging Damage to the D/P Cell**
- **Faulty Sensing Lines**
- **Loss of Loop Electrical Power**
- **Erosion** Particulate, suspended solids or debris in the piping will erode the sensing device.
- The orifice, by its design with a thin, sharp edge is most affected.
- **Vapour Formation in the Throat** A small amount of gas pockets or vapour at the HP side in liquid flow measuring, makes the flow sensor indicate a lower flow rate than there actually is.

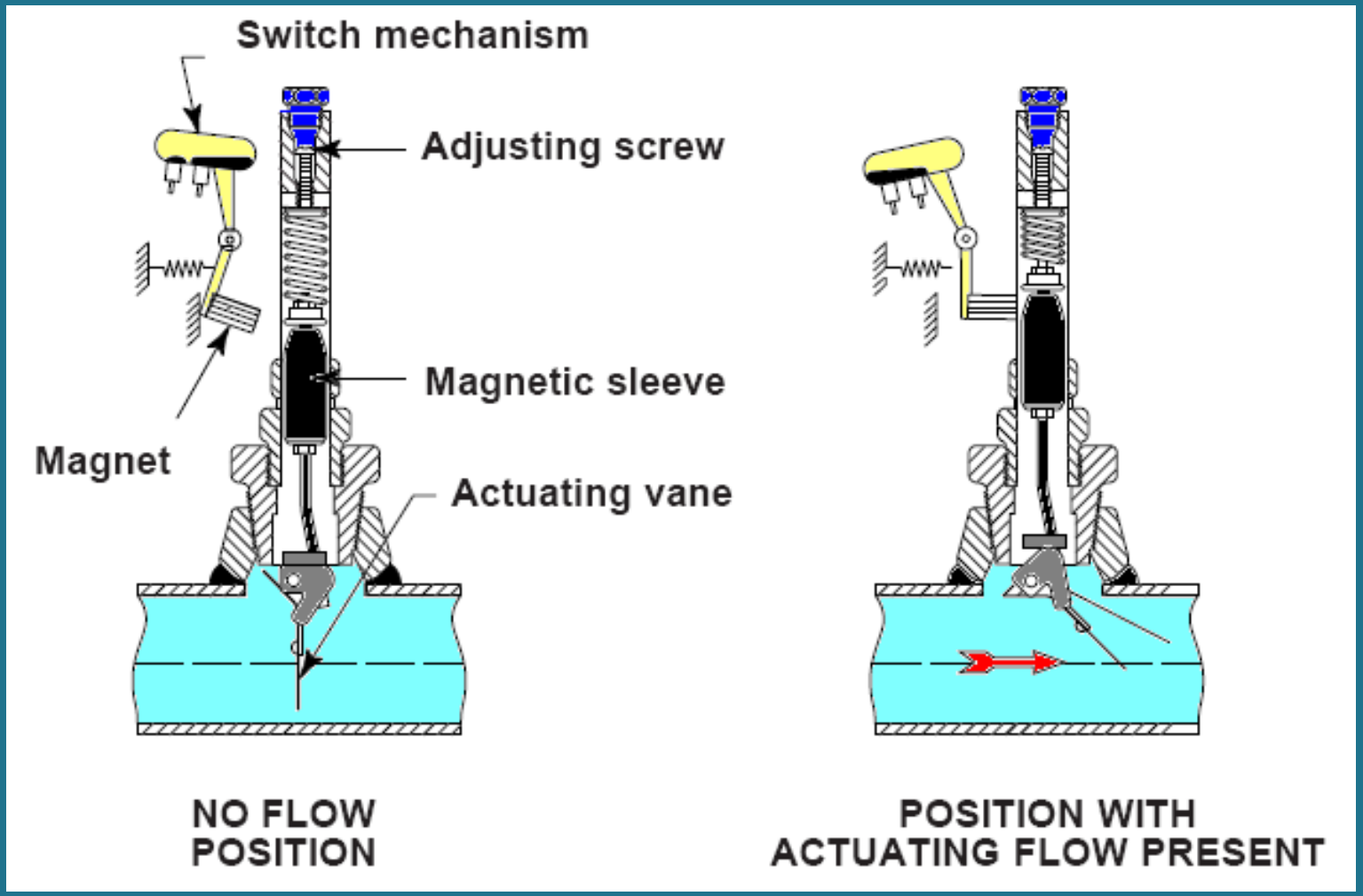
Flow Switch

- A Flow switch is normally a simple device that monitors flow and sends a trip signal to another device such as a pump to protect it.
- Some flow switch applications are
  - Pump Protection.
  - Cooling circuit protection.
  - High and low flow rate alarm and general flow monitoring.
- Flow switch types are used on air, steam and liquid.
- Flow switch types are
  - PADDLE flow switches
  - VANE actuated flow switches
  - PISTON flow switches
  - ULTRASONIC flow switches
  - THERMAL flow switches

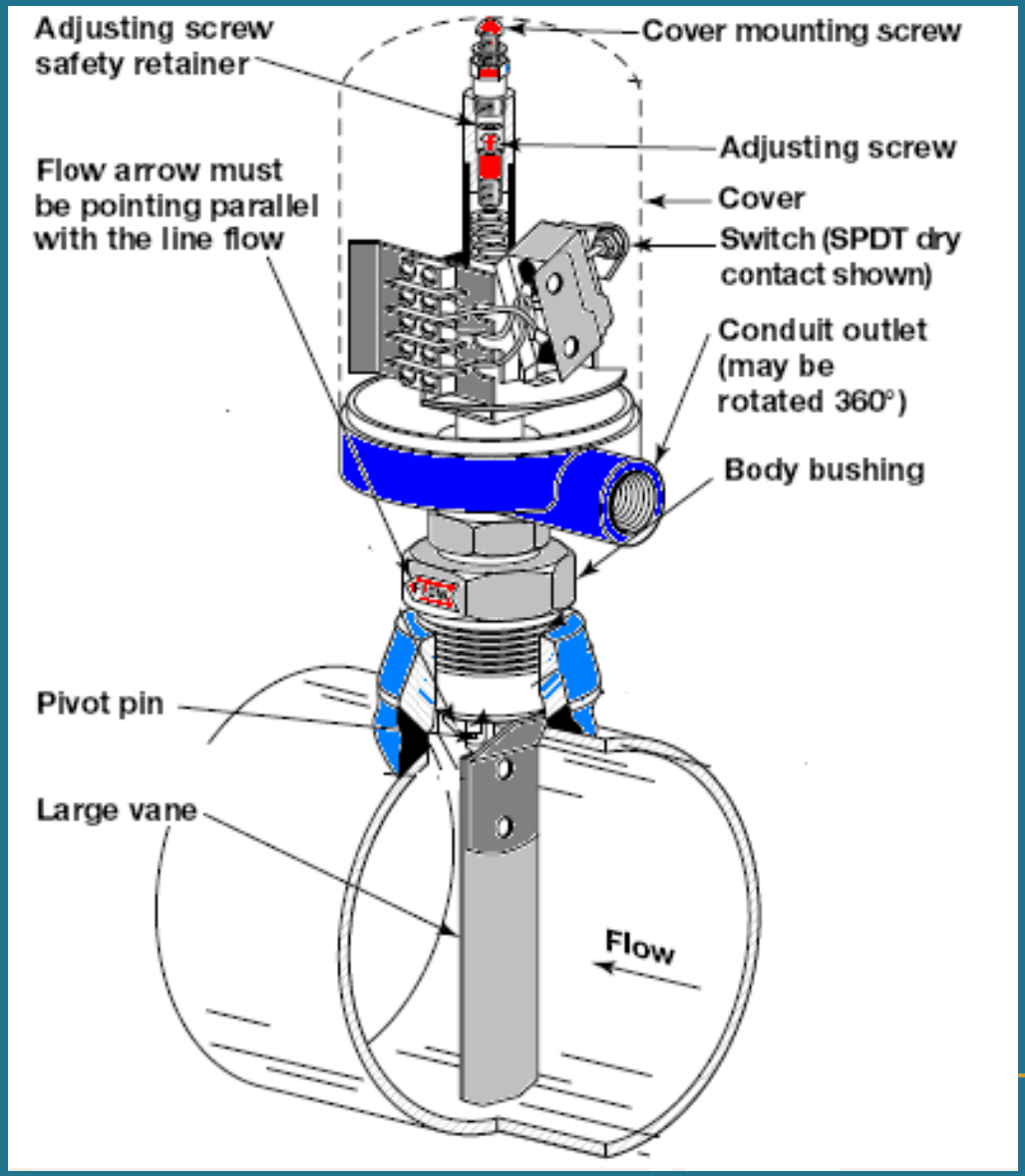
Paddle Type Flow Switch

- The flow of liquid through the valve body applies a force to a flow disc (paddle).
- This in turn raises the magnetic sleeve, within its sealed non-magnetic enclosing tube into the field of the switch magnet, located outside the enclosing tube, actuating the attached switch mechanism.
- The status of the switch may then be used to electrically control the fluid flow.
- The movable switch allows the contacts to be set either normally open (N/O) or normally closed (N/C).

Paddle Type Flow Switch



Paddle Type Flow Switch

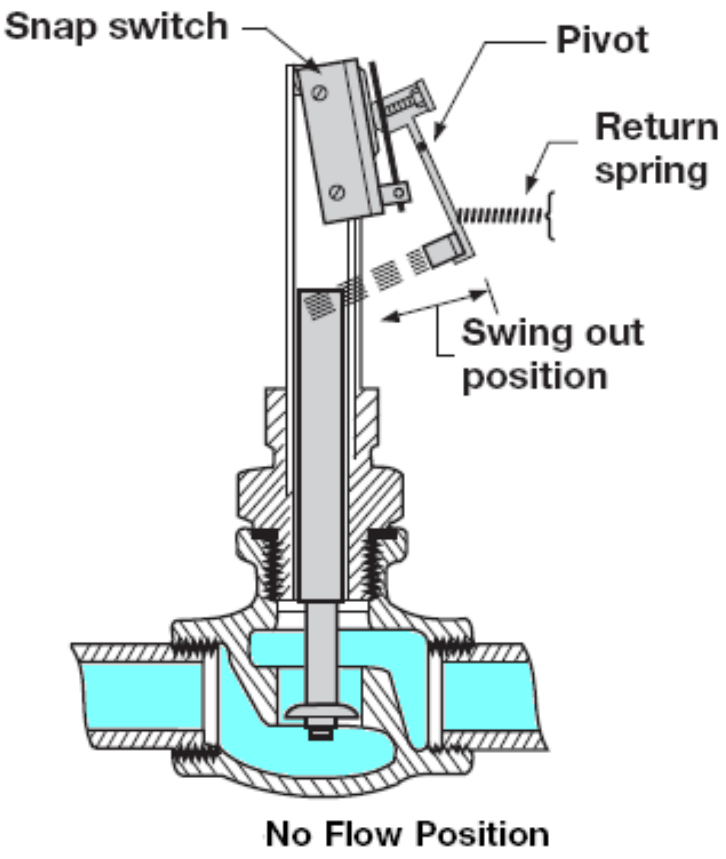


Vane Actuated Flow Switch

- The actuating vane is magnetically linked to a pivoted electric switch, which is isolated from the process by a non-magnetic barrier tube.
- As the actuating vane moves with an increase in flow, it drives a magnetic sleeve into the field of a permanent magnet located

  outside the barrier tube which trips the switch.
- As flow decreases, the actuating vane returns to a vertical position, allowing the magnet and switch assembly to return to the “No Flow” position.

Vane Actuated Flow Switch



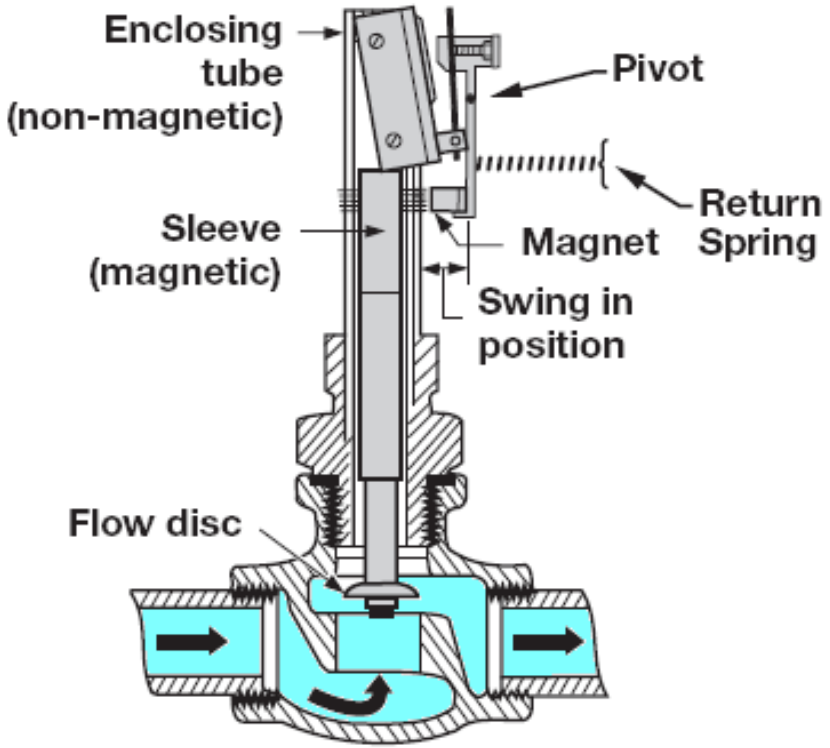


Figure 4—Position w/Actuating Flow Present

Vane Actuated Flow Switch