1

Flow measurement

the continuous movement of a fluid, i.e. either a liquid or a gas, from one place to another.

2

Why flow measurement

- No industrial measurement is more important than the accurate detection of the flow rates of gases, liquids, and solids.
- Most of the industrial control loops control the flow rates of incoming liquids or gases in order to achieve the control objective.
- Accurate measurement of flow rate is very important.
- From flow of blood in artery to flow of oxygen in rockets.

3

Measurement depends Upon:

- Material and its condition
- Type of flow
- Volume
- Temperature and pressure range
- Degree of accuracy required

4

Flow measurement methods:

- Inferential methods:
  - Head type
  - Variable area type
  - Magnetic meter
  - Turbine meters
  - Target meters
  - Thermal flow meters
  - Swirl meters
  - Sonic meters
- Positive displacement methods
- Mass measurement (Rarely used)

5

Units of flow:

Depends on what flow are we measuring

- Flow rate : $Q = V \times A$
- volumetric flow rate :represented by the symbol *Q*. The SI unit is m^3/s (cubic meters per second).
- US Customary Units and British Imperial Units, volumetric flow rate is often expressed as ft^3/s (cubic feet per second) or gallons per minute
- **mass flow meter measures**:
- g/min and kg/min

6

FLOW MEASURING TECHNIQUES

- Measurement of flow can be :
  - Flow rate measurement
  - Total Flow Measurement
- Flow Rate measurement is :
  - Direct fluid velocity
  - Volume flow rate
  - Mass flow rate
- Total flow measurement is :
  - Total volume
  - Total Mass

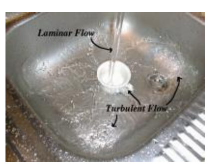
7

- So there are two types of flow meters :
- Rate meters
  - Measures the rate of the fluid (volume/mass) either directly.
- Quantity meters
  - Measures the amount of fluid flowing across a given point in a specific interval of time. Can be used for measurement of either weight or volume.
  - Measures either the weight or volume of fluid flowing.

8

Flow characteristics

- Two types of flows, namely
  - *Laminar flows*
  - *Turbulent flows.*
- Roughly speaking we can say that a laminar flow is a 'simple' flow while a turbulent flow is a 'complicated' flow



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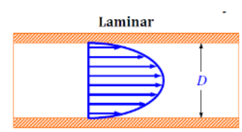
Flow characteristics

- **1.Laminar flow**
  - Flow velocity is less
  - Motion of the individual particles are along lines parallel to the wall
  - Velocity is maximum at the center.
  - The frictional forces at the stationary pipe wall exert the highest retarding force



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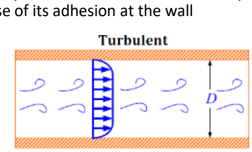
2.Turbulent flow

- High velocity of flow
- Particle motion becomes random and complex.
- Occurs after critical Velocity.
- Flow doesn't have a specific distribution.
- A boundary layer is formed in the vicinity of the wall in which the velocity must accelerate from zero to v, because of its adhesion at the wall



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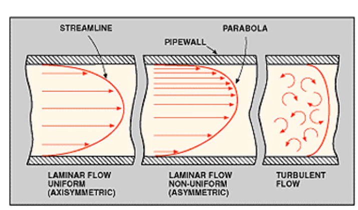
- The transition is not abrupt but gradual.



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Reynolds Number

- Critical velocity of a fluid flowing through a pipe depends on several factors.
- Those factors are put together to form Reynolds number.

$$R_e = \frac{vd\rho}{\mu}$$

- V=flow velocity
- d= diameter of the pipe
- ρ= density of fluid
- μ= viscosity of fluid

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Range of Reynolds number

- 0-2000 : Laminar flow
- 2000-4000 : Turbulent flow
- 4000- Infinity : Turbulent flow

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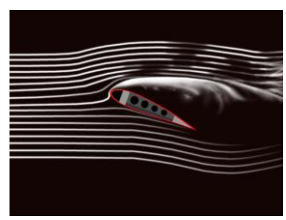

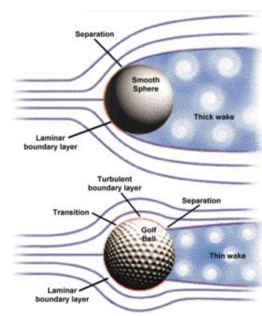

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Variable head type flow meters

- Most common type of flow meters used
- **Principle: Produce a pressure differential or Head across any suitable restriction to the flow of liquid**.
- Thus also called as obstruction meters
- Contains a primary and secondary element.
  - Primary for producing pressure differential and secondary for pressure measurement

18

Works based on two fundamental theories:

- **a.) Continuity equation:**

  mass in = mass out
- **b.) Bernoulli's Eqn.**
  - **Total energy is conserved**

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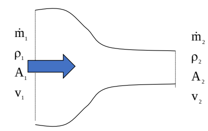
Continuity equation

- In fluid dynamics, the **continuity equation** states that, in any steady state process, the rate at which mass enters a system is equal to the rate at which mass leaves the system. ρ is fluid density, t is time, u is the flow velocity vector field.

20

Flow through a Obstruction meter

$$\dot{m}_1 = \dot{m}_2$$
$$\dot{m} = \rho A v$$
$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$
incompressible
$$\rho_1 = \rho_2$$
$$A_1 v_1 = A_2 v_2$$



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Bernoulli's Principle

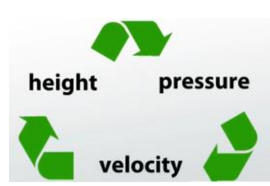
- In fluid dynamics, **Bernoulli's principle** states that for an flow of a non- conducting fluid, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.
- Derived from the principle of conservation of energy.
- In a steady flow, the sum of all forms of energy in a fluid along a streamline is the same at all points on that streamline.

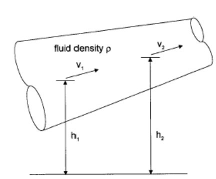
23

24

Bernoulli's equation

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + h_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + h_2$$





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Derivation of flow equation through a differential pressure flow meter.

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28

$$v_2 = \frac{1}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}}\sqrt{\frac{2\,\Delta P}{\rho}}$$

Flow Rate

$$Q = A_2 v_2 = A_2 \frac{1}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}}\sqrt{\frac{2\,\Delta P}{\rho}} \qquad \textit{Ideal}$$

For Real Flow

$$Q = C_d A_2 \frac{1}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}}\sqrt{\frac{2\,\Delta P}{\rho}}$$

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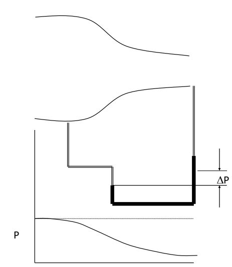
Cd= Discharge Coefficient

= f(Re) and

nature of specific flow meter



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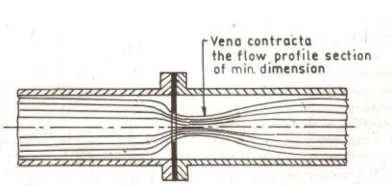
Flow through a constriction : Vena Contracta



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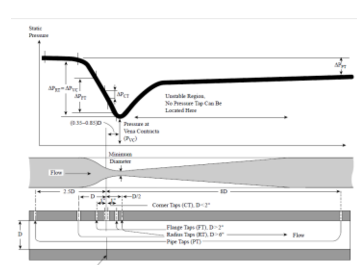

Pressure profile of fluid flow through obstruction

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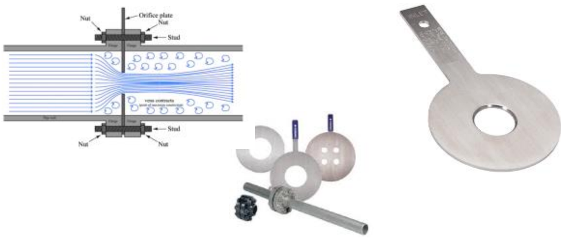
ORIFICE PLATES



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How do orifice plates work ?

- An orifice plate installed in a line creates a pressure differential as the fluid flows through it.
- This differential pressure is measured by a differential pressure transmitter which converts it into an analogue or digital signal
- This signal can be processed to provide a display of the instantaneous rate of flow.

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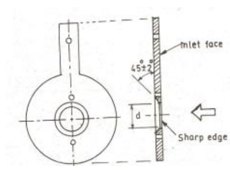
Types:

- Concentric
- Eccentric
- Segmental
- Quadrant

35

Concentric Orifice plate

- Sharp edge concentric circular hole.
- Steel of thickness 3mm to 12.5 mm depending on the flow size.
- Nickel or monel is also used.



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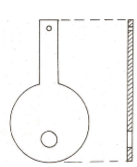
Eccentric orifice plates

- Boring is made tangential to a circle concentric with the pipe and diameter 0.98 of that of the pipe.
- Used when measuring fluid contains suspended particles, which may build up the pressure in the back of the concentric plate.
- So used for measuring flow rate of fluids containing solids



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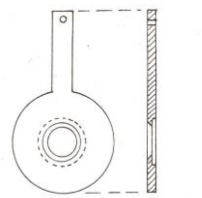
Segmental Orifice plates

- Used in applications similar to those of eccentric orifice plates.
- Opening is a segment of circle which is 0.98 of the pipe diameter
- Segment is placed at the bottom of the pipe.

38

Quadrant edge orifice plates

- So constructed that the edge is rounded so as to form a quarter circle.
- Plate has a round concentric opening with a round edge on the upstream as this arrangement gives a constant discharge coefficient.
- Used for measuring flow of crudes, Syrups. slurries etc…



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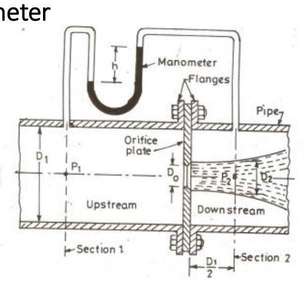
Orifice meter



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- **Advantages:**
  - Low Initial Cost.
  - Easy to Install
  - Simple and less expensive maintenance compared to venturi.
- **Disadvantages:**
  - They have Cd of about 0.6 as compared to venture having Cd of about 1.
  - Loss in head is much high about 60-70%
  - Flat orifices cannot be used for the flow measurements of slurries as they tend to clog.

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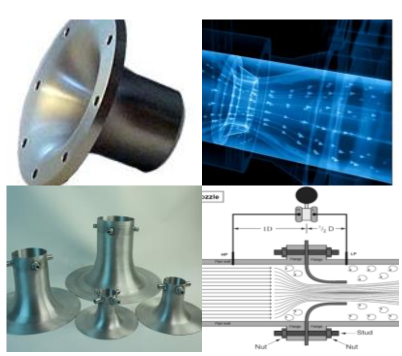
FLOW NOZZLES:



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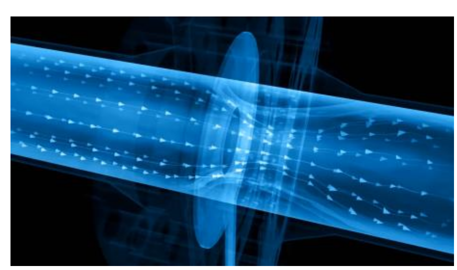

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- Venturi meter without a diverging cone.
- It differs from an orifice meter that the the jet contraction is not so large as in orifice.
- Fluid flow equation is the same as that of a Venturi and flow meter

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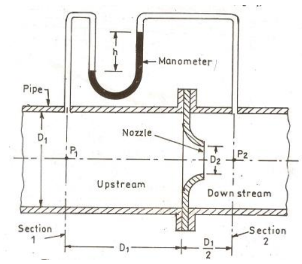

46

- **Advantages:**
  - Cheaper and easier to install as compared to venturi
  - Used for flow measurement of fluids with solids that tend to settle.
  - For flow measurement of high fluid velocities as they are more rugged to corrosion.
- **Disadvantages:**
  - Poor pressure recovery
  - More expensive than orifice meter
  - High maintenance as it is required to remove a section of pipe to inspect and install that.

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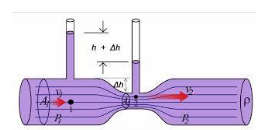
VENTURIMETER



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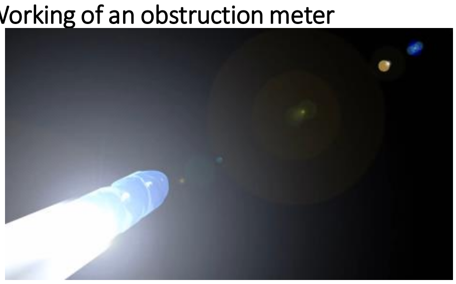
Working of an obstruction meter



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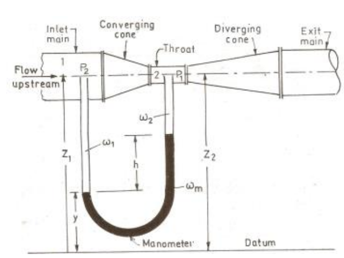
Venturimeter



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- Used to measure the discharge of fluid through a pipe.
- Works on the principle of differential pressure.
- Flow velocity is increased in reduced section : Pressure decreases causing a difference in pressure.
- Differential pressure then accounts the flow rate.

51

- Consists of five sections:
  - Inlet main
  - Convergent Cone
  - Cylindrical throat
  - Diverging cone
  - Exit Main
- Pressure head is due to the difference in pressure between main inlet and the throat.
- Size is expressed in terms of inlet and throat diameter

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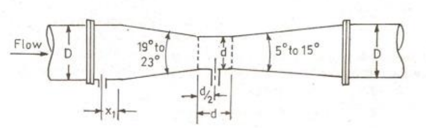
Typical dimensions of a venture meter



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- Square root relationship between flow rate and differential pressure.
- Not the case with just venturimetre but with all variable head type flow meters
- Has both advantages and disadvantage

54

- **Advantages:**
  - Extensively used over a long period. So characteristics well known
  - Low head loss (10 %)
  - High coefficient of discharge
- **Disadvantages:**
  - Relatively large size
  - Cost is high due to large size

55

WELCOME ALL TO OFFLINE CLASS..

ENJOY THE DAYS!!!

56

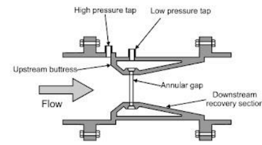
The Lecture

Uninterrupted, rambling exposition of apparently irrelevant trivial information delivered in a sleep-inducing monotone for one hour

57

DALL TUBE

- The Dall tube is a shortened version of a Venturi meter, with a lower pressure drop than an orifice plate.



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(1) A horizontal venturimeter with inlet dia 200mm and throat dia 100mm is employed to measure the flow of water. The reading of the differential manometer connected to the inlet is 180 mm of mercury. If coefficient of discharge is 0.98, determine the rate of flow.

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PITOT TUBE

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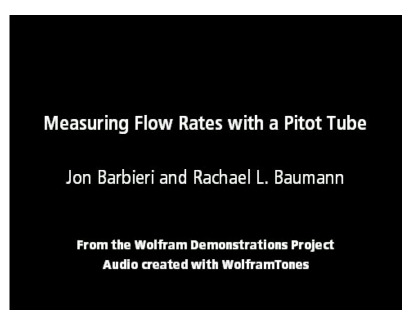

63

- **Advantages:**
  - Produce a negligible loss of head.
  - Cost is much smaller than those of venture and orifice plates.
- **Disadvantages:**
  - Small openings may get clogged if fluids flowing has solid particles.
  - They require high flow velocity of the of about 15m/s for producing measurable heads.

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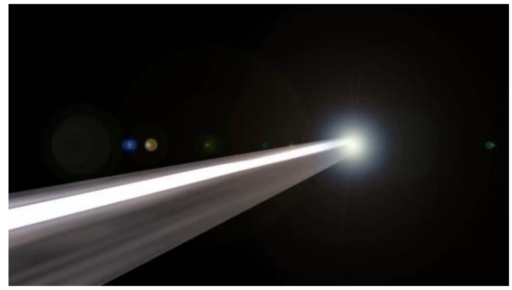

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Measurement Of Mass Flow Rate

The mass flow rate is the mass of the fluid traveling past a fixed point per unit time.

The mathematical relationship between volumetric flow (Q) and mass flow (W) is one of proportionality with mass density (ρ):

$W = \rho Q$

66

- Volumetric flow rate is the mass flow rate divided by the fluid density.
- If the density is constant, then the relationship is simple. If the fluid has varying density, then the relationship is not simple.
- The density of the fluid may change with temperature, pressure, or composition, for example.
- The fluid may also be a combination of phases such as a fluid with entrained bubbles.
- Actual density can be determined due to dependency of sound velocity on the controlled liquid concentration.

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RADIATION TYPE MASS FLOWMETER

❖Two sensors are installed.
❖One to measure the volumetric flow and the other to detect the density of the flowing stream
❖And then to use the two transmitter signals as inputs into a mass flow computing module.
❖This approach was feasible, but it required coordination between the products of different suppliers and corrections for such process variables

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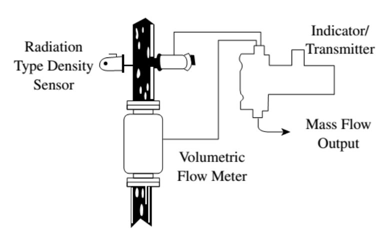

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- The multiple-input transmitter which, in addition to a radiation-type density input, accepts a flow measurement signal from any volumetric flowmeter.
- Based on these two inputs, the microprocessor-based transmitter generates an output signal that relates to mass flow.

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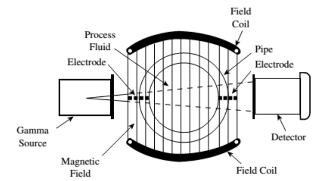

FIG. 2.12b
Mass flowmeter combining a magnetic flowmeter and a radiation-type densitometer in a single unit.

71

- Further improvement occurred in the design of this density or mass flow system.
- In that design density and volumetric flow sensors were combined into a single package.
- These units are composed of a either a Doppler ultrasonic flowmeter or a magnetic flowmeter and a gamma-radiation-based densitometer, all in a single unit including a microcomputer.
- Its disadvantage is its bulkier and expensive.

72

Angular Momentum Type Mass Flow Meter

- Principle of angular momentum can be described by referring to Newton's 2nd law of angular motion and definition of angular momentum using following notations:
- H – Angular momentum
- I - Moment of inertia
- w - Angular velocity
- Y - Torque
- r - Radius of gyration
- m - Mass
- t – Time

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- Newton's 2nd law of angular motion states that

  Y=I*α ---------- 1
- And defines that

  H=I*w----------- 2
- But since by definition,

  I=mr^2-------- 3
- Eq 1 becomes Y=mr^2*α ---------- 4
- Eq 2 becomes H=mr^2*w ---------- 5

Since α=w/t -------- 6

74

- Therefore Eq 4 becomes Y=mr^2*(w/t) ------ 7
- Solving for mass flow rate m/t (lbm/sec) we get :

  m/t=Y/(r^2*w) -------------8
- Also dividing both sides of Eq 5 by t.

  H/t=(m/t)r^2*w -----------9

❖Since r^2 is constant, mass flow of the fluid can be determined if an angular momentum is introduced into the fluids stream and measurements are made of the torque produced by this angular momentum and of the fluid's angular velocity.

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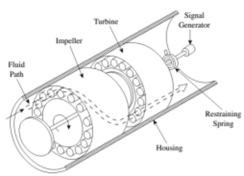
•Impeller-Turbine Flowmeter



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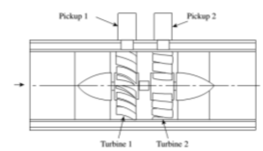
Twin-Turbine Flowmeter

❖In this instrument, two turbines are mounted on a common shaft .They are connected with a calibrated torsion member.

❖A reluctance-type pickup coil is mounted over each turbine, and a strong magnet is located in each turbine within the twin-turbine assembly.



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Gyroscopic mass flow meters

- A motor introduces an oscillating vibration at a constant angular velocity ω about the A axis.
- When the fluid passes through the loop, a precession type moment is produced about the B axis and is measured by the deflection of a sensing element.
- This deflection can be shown to be directly proportional to mass flow.

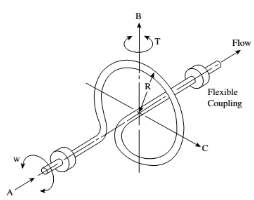

FIG. 2.12f
Gyroscopic mass flowmeter.

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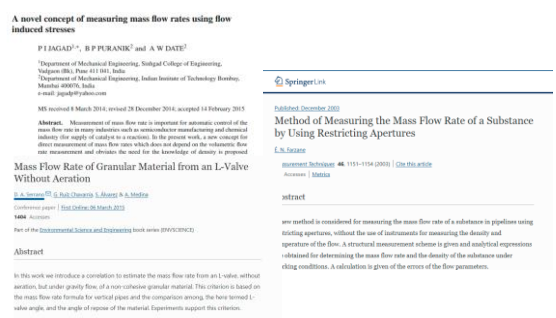

A novel concept of measuring mass flow rates using flow induced stresses

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MS received 8 March 2014; revised 28 December 2014; accepted 14 February 2015

Abstract. Measurement of mass flow rate is important for automatic control of the mass flow rate in many industries such as semiconductor manufacturing and chemical industry (for supply of catalyst to a reaction). In the present work, a new concept for direct measurement of mass flow rates which does not depend on the volumetric flow rate measurement and obviates the need for the knowledge of density is proposed

Mass Flow Rate of Granular Material from an L-Valve Without Aeration

D. A. Serrano, G. Ruiz Chavarria, S. Álvarez & A. Medina

Conference paper | First Online: 06 March 2015

1404 Accesses

Part of the Environmental Science and Engineering book series (ENVSCIENCE)

Abstract

In this work we introduce a correlation to estimate the mass flow rate from an L-valve, without aeration, but under gravity flow, of a non-cohesive granular material. This criterion is based on the mass flow rate formula for vertical pipes and the comparison among the here termed L-valve angle, and the angle of repose of the material. Experiments support this criterion.

SpringerLink

Published: December 2003

Method of Measuring the Mass Flow Rate of a Substance by Using Restricting Apertures

É. N. Farzane

asurement Techniques 46, 1151–1154 (2003) | Cite this article

Accesses | Metrics

bstract

ew method is considered for measuring the mass flow rate of a substance in pipelines using tricting apertures, without the use of instruments for measuring the density and nperature of the flow. A structural measurement scheme is given and analytical expressions obtained for determining the mass flow rate and the density of the substance under king conditions. A calculation is given of the errors of the flow parameters.

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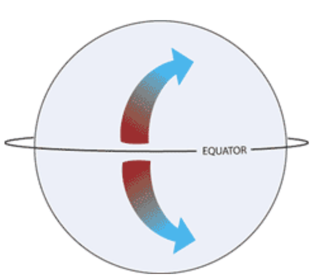


2 Qns

The circulating air is deflected toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere.

&

Planes traveling long distances around the Earth appear to move at a curve as opposed to a straight line.

WHY???

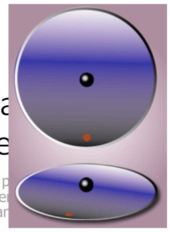
82

- https://www.nationalgeographic.org/encyclopedia/coriolis-effect/#what-is-the-coriolis-effect

83

Coriolis ma
flowmete

Coriolis effect – a notable (and strange) p
mass moving in a rotating system exper
perpendicular to the direction of motion ar



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MEASURING PRINCIPLE AND THEORY

- ❖The measuring principle of CMF is Coriolis force, which appears in rotating and oscillating(vibrating) systems.
- ❖Such a vibrating system is shown in for a straight tube.
- ❖The tube is excited by an external force . The excitation frequency is kept at the natural frequency of the tube, which minimizes the energy needed for vibration.
- ❖The general expression for the Coriolis force is **F=2mvw** , where **q=mv** is mass flow and w is the rotation vector.
- ❖When fluid is not flowing within a vibrating tube, the Coriolis force is zero . When fluid begins to flow, the Coriolis force is no longer zero

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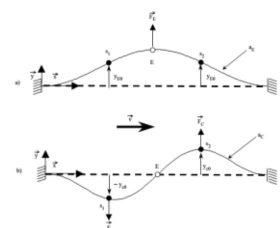
- *Panel a) describes the movement of a straight tube conveying a fluid, which is oscillating at the excitation frequency. The oscillation is maintained with the excitation force FE at location E. The measuring signal is detected with the two sensors S1 and S2. When the fluid begins to flow, the Coriolis force FC induces an oscillation as shown in panel b). The final lateral displacement is the superposition of both oscillation*



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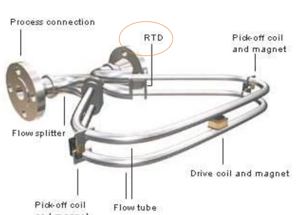
Theory of Operation -Temperature



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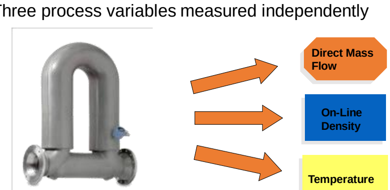
Coriolis Multi-Variable Capability

Three process variables measured independently



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ADVANTAGES

- Coriolis flow meter is capable of measuring wide range of fluids.
- Coriolis flow meter provides a direct mass flow measurement.
- Coriolis flow meter is having outstanding accuracy.
- Coriolis flow meter is capable of measuring the mass flow rate, volume flow rate, fluid density and temperature.
- The operation of Coriolis flow meter is independent of flow characteristic such as turbulence flow

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APPLICATIONS

- Food & beverages: beer, pet food.
- Chemical & petrochemicals: Alcohol, nitric acid.
- Petroleum products: tar and jet fuel.
- Pharmaceuticals: alcohol, soap.
- Pulp and paper: paper pulp, red liquor.
- Other: Ink, wax.

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Hot Wire Anemometers

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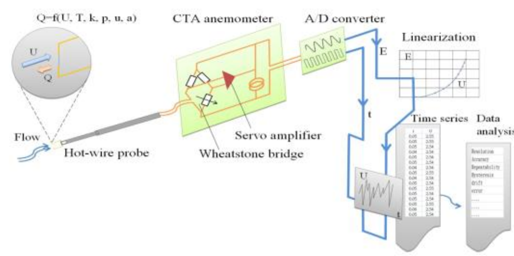

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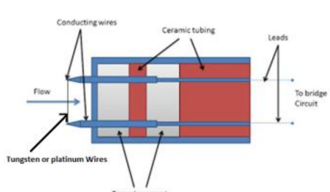
Hot Wire Anemometer



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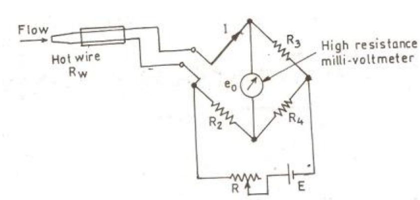

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Hot-film Anemometers

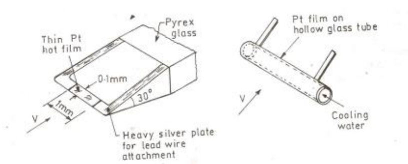

Fig. 13.32. Hot film transducers.

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Mass Flowmeters—Thermal

- Divided into the following two categories:
- 1. Hot wire anemometers: Flowmeters that measure the effect of the flowing fluid on a hot body. These instruments are sometimes called *hot-wire probes*
- 2.Flowmeters that measure the rise in temperature of the fluid after a known amount of heat has been added to it. They can be called *heat transfer flowmeters.*

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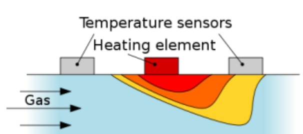

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- The operation of the heat transfer flowmeter is based on

$$Q = WC_P(T_2 - T_1)$$

Where Q = heat transferred
W= mass flow rate of fluid
Cp= specific heat of fluid
T1= temperature of fluid before heat is transferred to it (°F or °C)
T2= temperature of the fluid after heat has been transferred to it (°F or °C)

- Heat is added to the fluid stream with an electric immersion heater.

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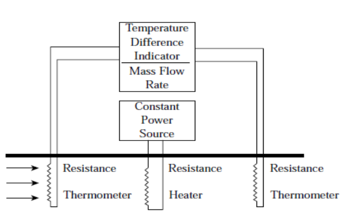
HEAT TRANSFER MASS FLOW METER



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- The power to the heater equals the heat transferred to the fluid (*Q*) and is measured using a wattmeter.
- *T1* and *T2* are thermocouples or resistance thermometers.
- Since we know the fluid, we also know the value of its specific heat.
- Thus, by measuring *Q*, *T1*, and *T2*, the flow rate (*W*) can be calculated. *T1* and *T2* do not have to be separately detected; they can be connected to each other so that the temperature difference (*T1* − *T2*) is measured directly

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Disadvantages

- The temperature sensors and the heater must protrude into the fluid stream.
- Thus, these components (particularly the heater) are easily damaged by corrosion and erosion.
- Furthermore, the integrity of the piping is sacrificed by the protrusions into the fluid stream, increasing the danger of leakage.

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- To overcome these problems, the heater and the upstream and downstream temperature sensors can be mounted outside of the piping
- In this type of construction, the heat transfer mechanism becomes more complicated, and the relationship between mass flow and temperature difference becomes nonlinear.
- To understand the operating principle of this flowmeter, we must review the effects of fluid mechanics and heat transfer.

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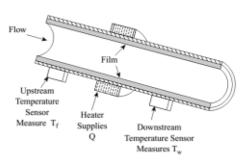
Thermal flowmeter with external elements and heater.



When a fluid flows in a pipe (turbulent or laminar), a thin layer (film) exists between the main body of the fluid and the pipe wall. When heat is passing through the pipe wall to the fluid, this layer resists the flow of heat. If the heater is sufficiently insulated, and if the piping material is a good heat conductor, the heat transfers from the heater to the fluid

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Electromagnetic Flow Meters

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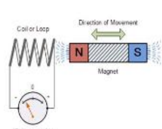
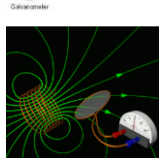
Electromagnetic Induction:

- Production of an electromotive force across an electrical conductor in a changing magnetic field.
- Michael Faraday is generally credited with the discovery of induction in 1831, and James Clerk Maxwell mathematically described it as Faraday's law of induction.





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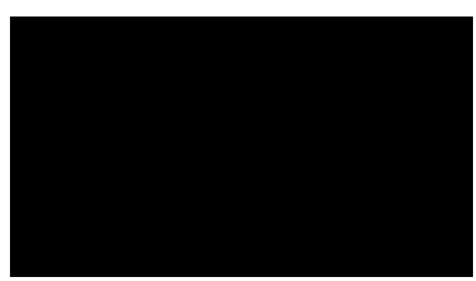

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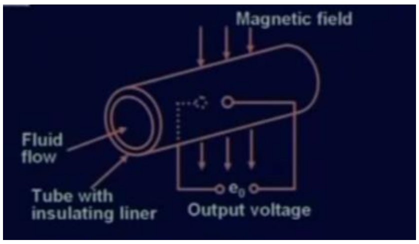
Schematic Diagram



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Constructional details

- Cylindrical tube made of stainless steel with an insulating liner
- Lining materials are: Neoprene, Polyurethane etc...
- Magnetic field is produced by energizing field coils.
- Electrodes are placed perpendicular to coils.
- Voltage induced in fluid is measured by the two electrodes inserted.
- Electrodes can be flushed or clamp mounted.

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Working principle:

- According to faradays law of EM Induction,
- Voltage is induced across the length of a moving conductor in a magnetic field.
- Voltage induced is:
  - **E=BLv**
- B=Magnetic flux density
- L is the length of the conductor
- V=Velocity of the conductor.
- Condition for using EM Flowmeter: Fluid must be conductive.
- Conductivity greater than 10µmho/cm

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In Electro Magnetic Flow meter,

- **L is the diameter of the pipe.**
- B&L are constant so that we get a direct relationship between velocity and Induced emf.

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Advantages:

- No Obstruction is there to the flow. Thus no pressure loss is associated with the measurement.
- Suitable for installation in areas where less pressure drop is there.(Where differential pressure meters become insensitive)
- Absences of internal equipment's helps to avoid the corrosion
- Operating principle is independent on the fluid density and the viscosity of the fluid.

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Disadvantages

- Not suitable for Non-conducting fluids.
- Hydrocarbons have very low conductivity. So it cannot be used for measurement in petroleum industries.
- Require a minimum length of straight pipe upstream from the meter for accurate measurement.
- Trapped gas bubbles causes errors.
- In the case of flush mounted electrodes fouling of the electrodes occurs sometime which causes reduction of the output signal.

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- Calibration needed separately for different fluids.
- B=μH
- μ= Absolute permeability
- H=Magnetic field intensity.

- μ changes with fluids .So B also changes with the fluids.

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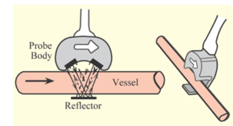
Ultrasonic & Doppler Flow meters

measures the velocity of a fluid with ultrasound to calculate volume flow.



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Ultra sonic flowmeters:

- Short burst of sine waves with frequency above 20KHz
- Typical frequency of signal is 10 MHz
- Two types of Ultrasonic Flowmeters:
  - Doppler's Shift Flow meters.
  - Transit time flowmeters.

- Both work on the principle of transmitting and receiving of acoustic energy.
- Piezoelectric crystals are used for both transmission and reception of signals.

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Basic working principle:

- Electrical energy in the form of short burst of high frequency voltage is applied to a piezo crystal which vibrates.
- This vibration is allowed to contact the fluid and thus vibration is communicated to the receiving end through the fluid.
- The vibration at the receiving end hits the piezo in the receiver which in turn is converter into an electric signal

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Ultrasonic Flow meter

- The operating principle of this type of instrument is based on the apparent change in the velocity of propagation of small magnitude pulses which travel through a fluid at a definite velocity, normally at the velocity of sound relative to fluid.

- Since the flow rate is related to velocity, this effect may be used in several ways as the effect may be used in several ways as the operating principle of Ultrasonic Flow Meter

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Ultrasonic Flow meter

- Piezoelectric crystals are generally used as transmitters and receivers.
- The transmitter emits an electronic pulse which is received at the receiver a time Δt later. The time in the direction of flow is

$$\Delta t_1 = \frac{d}{c+v}$$

where,
d= distance between transmitter and receiver
c= velocity of sound propagation in medium
v= linear velocity of flow

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Ultrasonic Flow meters

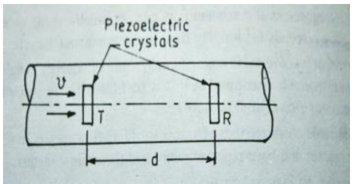

Fig. 13.38. Ultrasonic method for measurement of flow.

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Ultrasonic Flow meter

- When signal is travelling in the opposite direction against the flow

$$\Delta t_2 = \frac{d}{c-v}$$

The difference in transit time is

$$\Delta t = \Delta t_2 - \Delta t_1$$
$$= \frac{2dv}{c^2 - v^2}$$

- The time measured by a phase sensitive detector driven synchronously with the commutator. Usually c>>v

$$\Delta t = \frac{2dv}{c^2}$$

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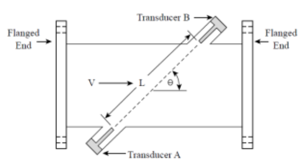

$$t_{AB} = L/(C + V \cdot \cos\theta)$$

The time (t_{BA}) to go from B to A is given by

$$t_{BA} = L/(C - V \cdot \cos\theta)$$

$$\Delta t = t_{BA} - t_{AB} = 2 \cdot L \cdot V \cdot \cos\theta / C$$

Ultrasonic Flow meter: system based upon frequency

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Ultrasonic Doppler Flow meter:
Based on Doppler effect

Change of wavelength caused by motion of the source.

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Doppler Flow Meter

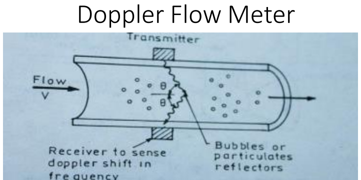

Fig. 13.40. Ultrasonic Doppler flowmeter.

$$\Delta f = f_t - f_r = \frac{2 f_t Cos\theta}{c}(v)$$

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Doppler Flow Meter

- <u>Advantages:-</u>
- Offers no Obstruction to flow
- Output insensitive to variations in viscosity, density and temperature
- No moving parts
- Linear relationship between input and output
- Excellent dynamic response

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Doppler Flow Meter

- Disadvantages:-
- Very complex
- Relatively high cost due to complexity in the design and manufacture of mechanical, acoustical and electronics parts.
- Limited use in industrial applications

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