Flow Measurements

FLOW MEASUREMENTS

Importance of Flow measurement in day to day life

- Refineries, chemical industries, beverages, etc
- Natural gas,
- Milk distribution system
- Petrol pumps
- Water meter, etc
- 1% error in flow measurement cause a major impact on the total system

Flow measurements

Accurate measurement of flow rate of liquids and gases is an essential requirement for maintaining the quality of industrial processes.

Industrial control loops control the flow rates of incoming liquids or gases in order to achieve the control objective. Hence, accurate measurement of flow rate is very important.

Learn

- Flow measurements can be volumetric or mass flow rate,
- medium could be gas or liquid,
- measurement could be intrusive or nonintrusive,

Types of Flowmeters

Learn

1. Obstruction type (differential pressure or variable area)
2. Inferential (turbine type),
3. Electromagnetic,
4. Positive displacement (integrating),
5. fluid dynamic (vortex shedding),
6. Anemometer,
7. ultrasonic and
8. Mass flowmeter (Coriolis).

Flow obstruction methods

Obstruction or head type flow meters are of two types:

- differential pressure type and
- variable area type

- Differential pressure type examples are Orifice meter, Venturimeter, Pitot tube.
- Variable area type example is rotameter .

In all cases, an obstruction is created in the flow passage and the pressure drop across the obstruction is related with the flow rate

DIFFERENTIAL PRESSURE FLOWMETERS

Employ the Bernoulli Equation that describes the relationship between pressure and velocity of a flow. These devices guide the flow into a section with different cross section areas (different pipe diameters) that causes variations in flow velocity and pressure. By measuring the changes in pressure, the flow velocity can then be calculated.

Types

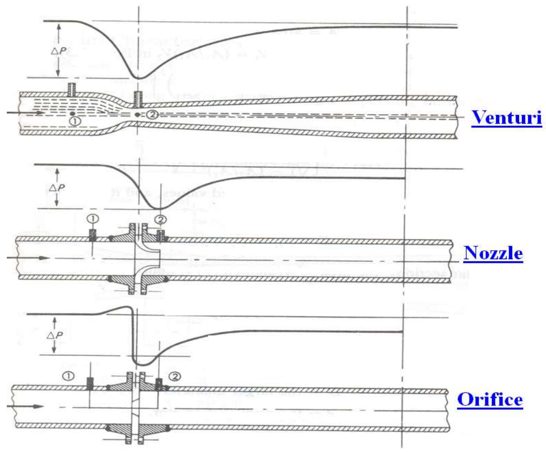
- **Venturi**
- **Nozzle**
- **Orifice**
- **Wedge**

Pipe diameter

6 ~ 300 mm (1/4 ~ 12 inch)

The discharge coefficient depends on the constriction, which could be

- Venturi tube
- Flow nozzle
- Orifice plate

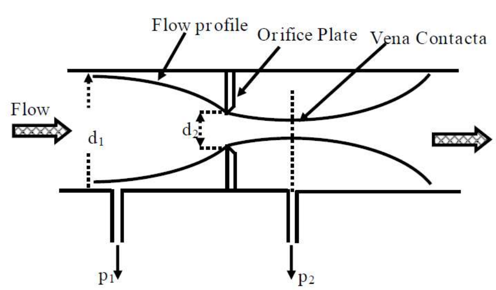


A certain pressure drop becomes irrecoverable. For orifice meter, losses of about 30%-40% occur

Based on Bernoulli's theorem

$$\frac{p_1}{\rho}+\frac{V_1^2}{2}+gZ_1=\frac{p_2}{\rho}+\frac{V_2^2}{2}+gZ_2$$

$$\frac{V_2^2-V_1^2}{2}=\frac{P_1-P_2}{\rho}$$



By continuity equation,

$$a_1V_1=a_2V_2$$

$$\frac{V_2^2}{2}\left(1-\frac{a_2^2}{a_1^2}\right)=\frac{(p_1-p_2)}{\rho}$$

$$V_2=\sqrt{\frac{2(p_1-p_2)}{\rho\left(1-\frac{a_2^2}{a_1^2}\right)}}$$

Theoretical (ideal) mass flow rate

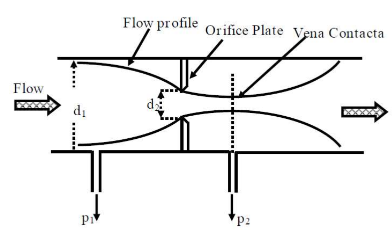
$$\dot{m}=\rho a_2 V_2=a_2\sqrt{\frac{2\rho(p_1-p_2)}{\left(1-\frac{a_2^2}{a_1^2}\right)}}$$

The channel similar to that shown in figure could be used for a flow measurement by simply measuring the pressure drop (P_1-P_2) and calculating the mass flow rate.

Since all channels has some losses during the flow, the flow rate calculated will not be equal to the actual flow rate.

The calculated and actual flow rates are related by an empirical discharge coefficient C by the relationship

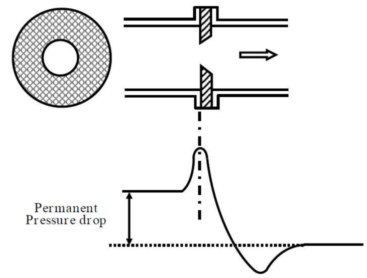
$$\frac{Q_{act}}{Q_{ideal}}=C$$



The discharge coefficient is not a constant and depend strongly on ***Re*** and the channel geometry.

For Venturimetes, 0.95 < C < 0.98

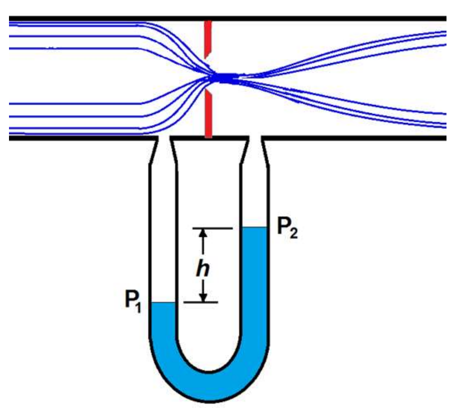
Orifice Plate



The orifice plate is a circular plate with a hole in the center. Pressure tappings are normally taken distances D and 0.5D upstream and downstream the orifice respectively (D is pipe ID)

The major disadvantage of using orifice plate is the permanent pressure drop normally experienced. The pressure drops significantly after the orifice and can be recovered only partially. The magnitude of the permanent pressure drop is around 40%, which is sometimes objectionable. It requires more pressure to pump the liquid.

Pressure tappings



Three types of pressure tapping

- Corner Tappings
- Flange Tappings
- D-D/2 Tappings

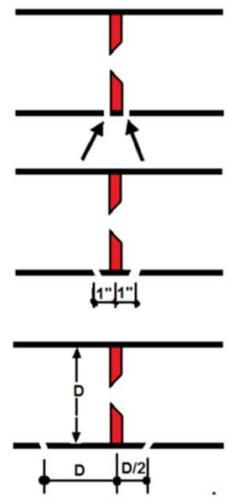
- ❑ Type and position of pressure tappings are important
- ❑ Influence Cd

Pressure Tapings

Corner tappings: Downstream faces of the orifice

Flange Tappings: Drilled through the flanges

D-D/2 tappings: Conform to geometric scaling laws



Orifice meter

The actual flow rate

$$\dot{m} = C_d \rho a_2 V_2 = C_d a_2 \sqrt{\frac{2\rho(p_1 - p_2)}{\left(1 - \frac{a_2^2}{a_1^2}\right)}}$$

If d/D = β, then the actual mass flow rate

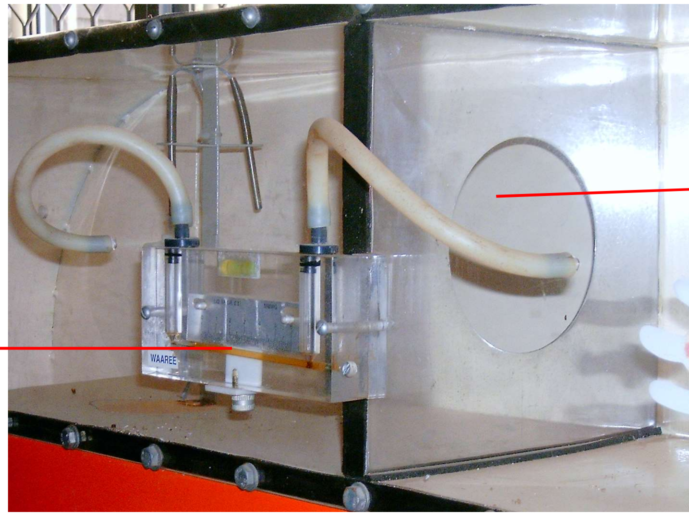
$$\dot{m} = C_d \rho a_2 V_2 = \frac{C_d a_2}{\sqrt{1-\beta^4}} \sqrt{2\rho(p_1 - p_2)}$$

Typical values of

β : 0.25 to 0.75
Cd : 0.6-0.8

Developing length of at least 25-30 dia, of pipe is required to satisfy fully developed turbulent flows

Orifice Meter used in Rectangular Ducts



Volume of flow $Q = C_d \sqrt{2 \rho \Delta P}$

Variation of Discharge Coefficient

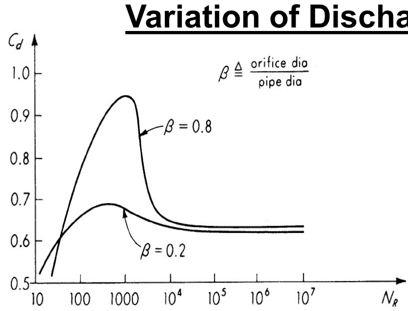


Fig. 7.29 *Variation in discharge coefficient.*

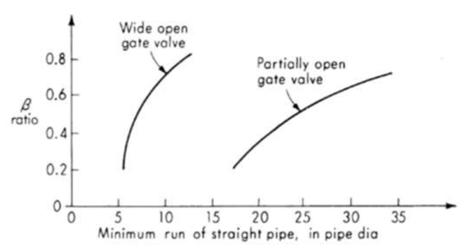
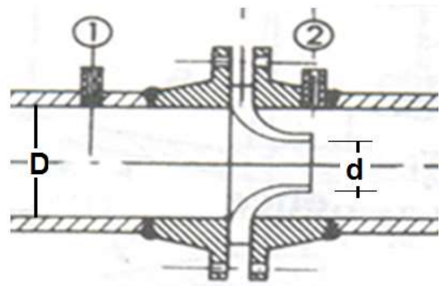


Fig. 7.30 *Effect of upstream disturbances.*

Source: Doebelin, Measurement systems

Flow nozzle

The approach curve must be proportioned to prevent separation between the flow and the wall, and the parallel section is used to ensure that the flow fills the throat.



The usual range of discharge coefficients can be obtained by empirical equation

$$C = 0.99622 + 0.0059D - \frac{\left(6.36 + 0.13D - 0.24\beta^2\right)}{\mathrm{Re}}$$

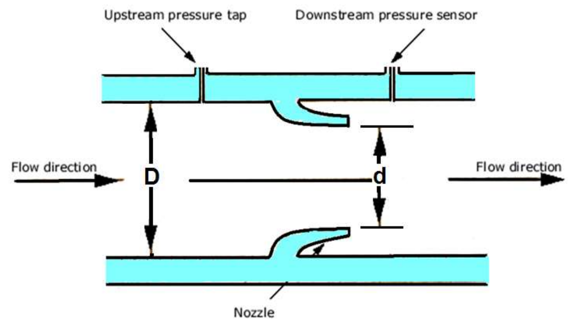
where, $\beta = d/D$

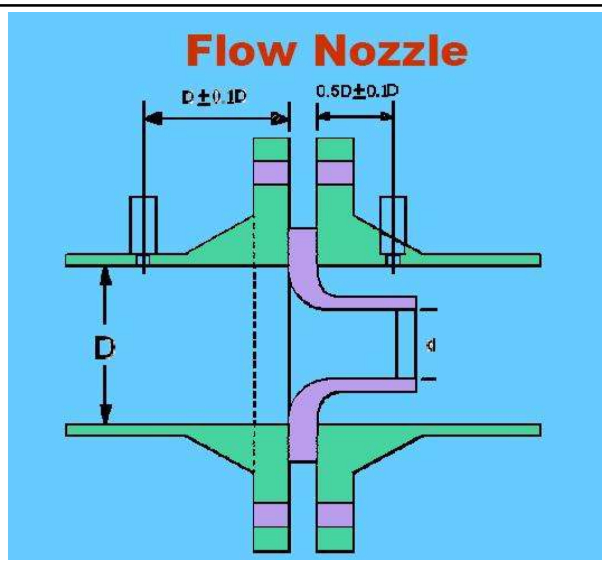
Nozzle flow meter

- Nozzle inserted instead of orifice
- Guided smoothly to the section of minimum area of stream from which the stream issues as a parallel jet
- Lesser pressure loss so higher discharge coefficient than the plate orifice; around 0.95
- Superiority lies in the absence of any mechanical feature

Nozzle flow meter

- Dust clogging could affect orifice meter, which can be avoided using flow nozzle.
- Uniform velocity exists over the greater part of the cross section.

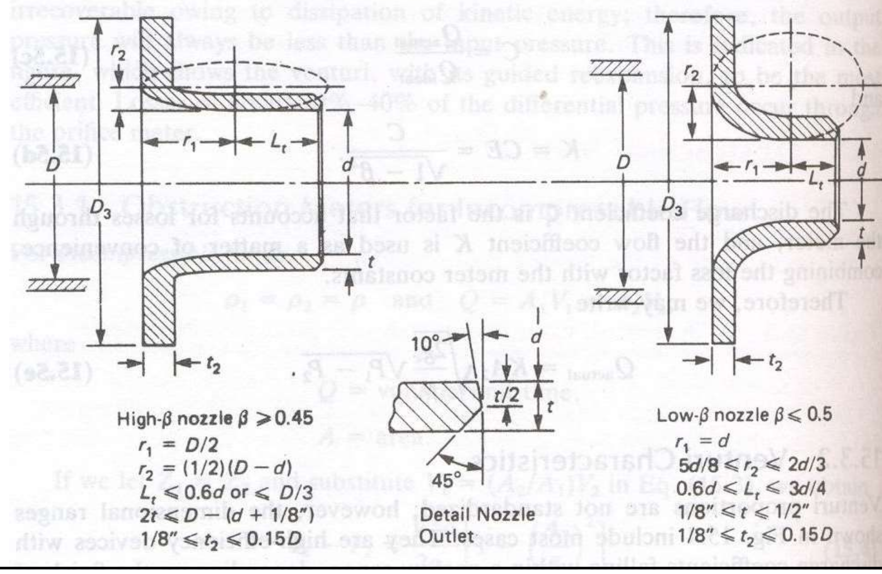




$$C_d = 0.99622 + 0.00059D - \frac{(6.36 + 0.13D - 0.24\beta^2)}{R_e}$$

Design of Nozzle

Dimensional relations for ASME long-radius flow nozzles (Source: ASME, Fluid Meters, 6th ed., 1971)

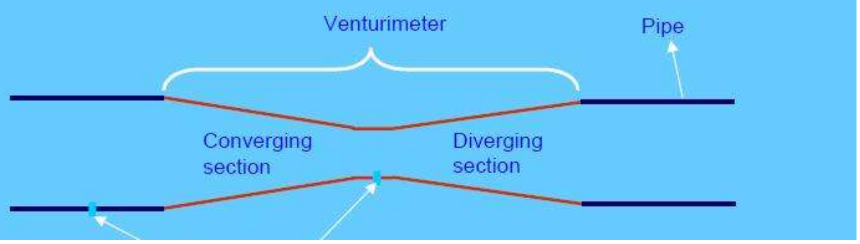


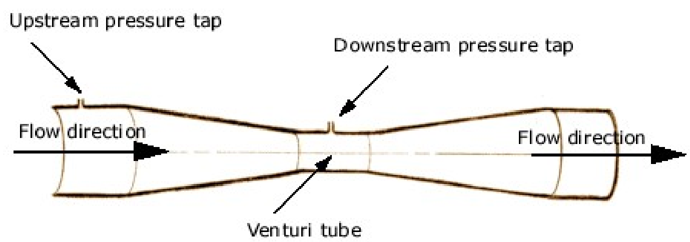
Venturi Tube

- Unrecoverable loss of pressure with an orifice or a nozzle due to the sudden increase of area
- We can recover most of the pressure by guiding the stream by means of a conical length pipe
- Arrangement with a conical entry of sharper taper preceding the throat is known as venturi tube

The changes in cross section area cause changes in velocity and pressure of the flow

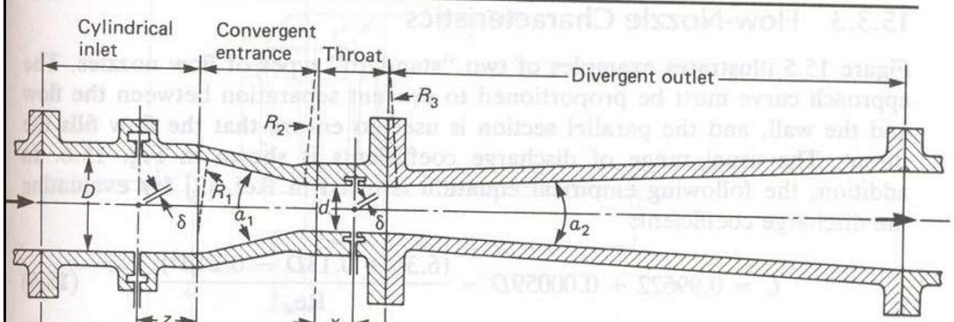
- Angle of the divergence not to exceed 6^0 or 7^0
- Slope of the inlet cone can be steeper
- Cone angles up to 15^0 - 21^0





Design of Venturi Tube

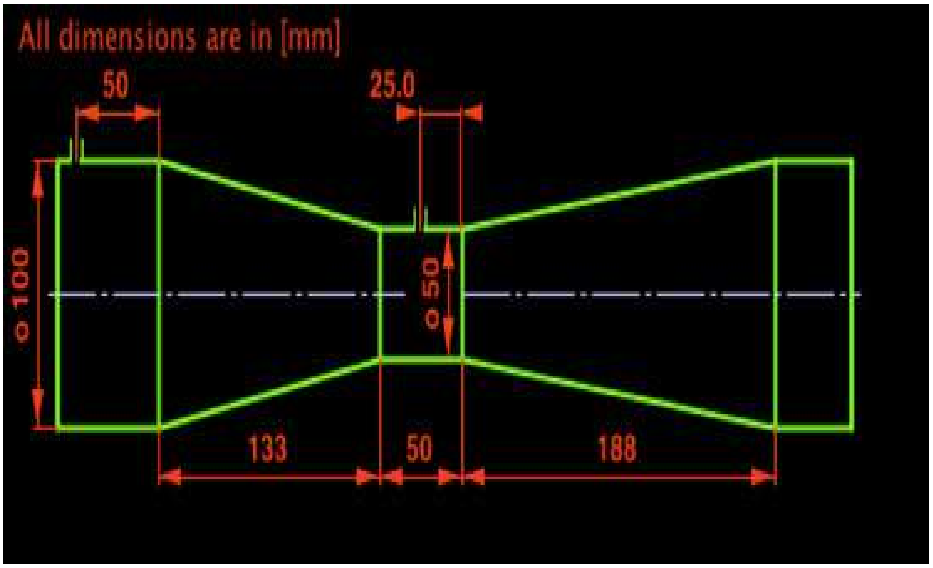
Recommended proportions of Herschel-type venturi tubes (Source: ASME, Fluid Meters, 6th ed., 1971)



$L_i \leqslant D$ or $L_i \leqslant (D/4 + 1'')$
$z \leqslant D/2 \pm D/4$ for $4'' \leqslant D \leqslant 6''$
$D/4 \leqslant z \leqslant D/2$ for $6'' \leqslant D \leqslant 32''$
$L_t \geqslant d/3$
$y \geqslant d/6$
$5/32'' \leqslant \delta \leqslant 25/64''$ and
$\delta < 0.1D$ or $0.13d$

$R_1 = 1.375D \pm 20\%$
$R_2 = 3.625d \pm 0.125d$
$5d \leqslant R_3 \leqslant 15d$
$\alpha_1 = 21^\circ \pm 1^\circ$
$7^\circ \leqslant \alpha_2 \leqslant 8^\circ$ or $7^\circ \leqslant \alpha \leqslant 15^\circ$

Simple Design



Advantages of obstruction flow meters

- Advantages:Simple construction, relatively inexpensive, No moving parts, low maintenance, wide application of flowing fluid, range selection, Extensive experience and performance data base, readily available standards and codes of practice
- Disadvantages: Flow rate is a nonlinear function of the differential pressure, low flow rate rangeability problems

Nozzle require lesser physical length, but relatively difficult to install in the flow stream compared to venturi

Measurement of compressible fluid flow using obstruction flow meters

$$\dot{m} = a_2 Y \frac{C_d}{\sqrt{1-\beta^4}} \sqrt{2\rho_1 (P_1 - P_2)}$$

Y **is the expansion factor, which is given by**

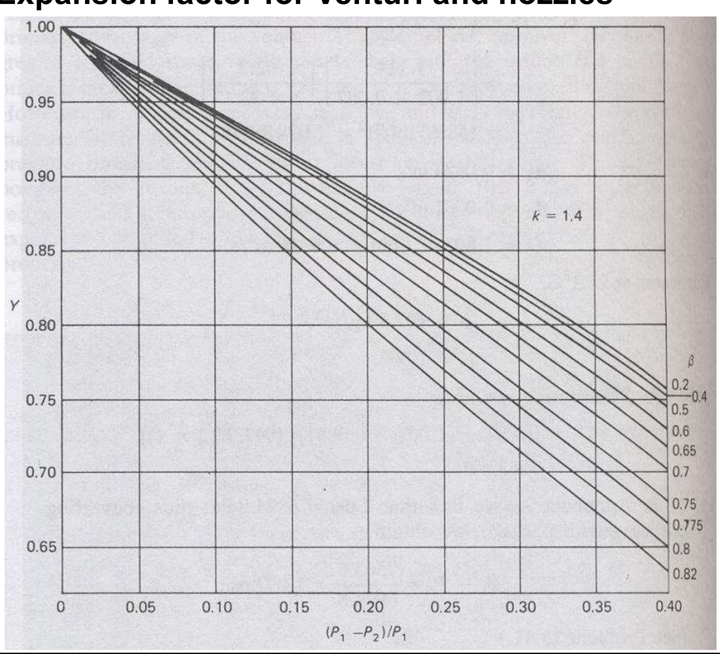
For Nozzles and Venturi's

$$Y = \left[\left(\frac{P_2}{P_1} \right)^{2/\gamma} \right] \left(\frac{\gamma}{\gamma - 1} \right) \left(\frac{1 - \left(\frac{P_2}{P_1} \right)^{(\gamma-1)/\gamma}}{1 - \left(\frac{P_2}{P_1} \right)} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 \left(\frac{P_2}{P_1} \right)^{2/\gamma}} \right)$$

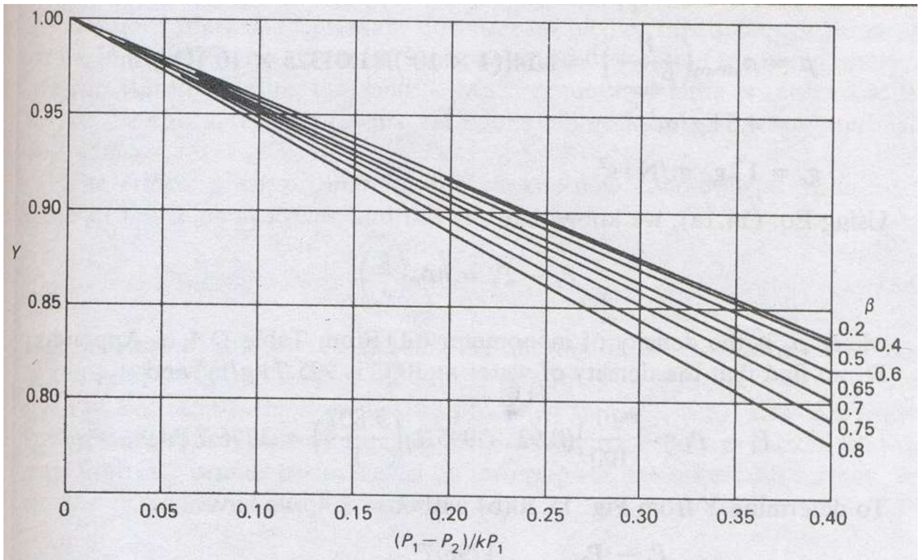
For Square –edged orifices

$$Y = 1 - \left[0.41 + 0.35\beta^4 \right] \left(\frac{P_1 - P_2}{\gamma P_1} \right)$$

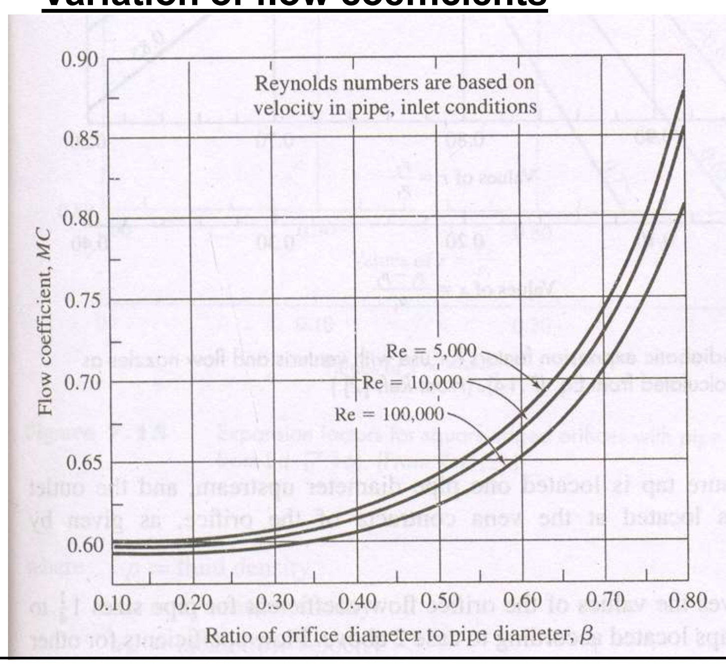
Expansion factor for Venturi and nozzles



Expansion factor for square edged orifices



Variation of flow coefficients



Choked flow

While considering isentropic flow of compressible fluids,
If $M \geq 1.0$ at the throat, the variation in pressure downstream of the throat no longer influences the mass flow rate.

The ***critical pressure ratio for the choked flow*** is expressed in terms of static upstream and throat pressure as:

$$\frac{P_2}{P_1} = \left(\frac{1+\gamma}{2}\right)^{\gamma/(1-\gamma)}$$

So long as the ratio P_2/P_1 is greater than the value given in above expression, the flow may be predicted.

Laminar flow meters

Relationship between flow rate and pressure drop in a laminar flow is linear

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} = \frac{P_2}{\rho} + \frac{V_2^2}{2} + gh_{L1,2}$$

$h_{L1\text{-}2}$ given by Darcy-Weisbach relationship

$$gh_{L1-2} = f\frac{L}{D} \times \frac{\overline{V}^2}{2}$$

Designed to operate within Re = 2000

Capillary tubes ensure that Re does not exceed the laminar region

For NR ≤ 2000, Hagen-Poiseuille Viscous flow relation

$$Q = \frac{\pi D_1^4}{128\mu} \frac{p_1 - p_2}{L}; \quad \mathrm{Re}_{D_1} < 2000$$

- A high sensitivity even at extremely low flow rates
- The ability to measure pipe system flows in either direction
- A wide usable flow range
- The ability to indicate an average flow rate in pulsating flows
- Susceptible to clogs, restricting to clean fluids

Laminar flow meters

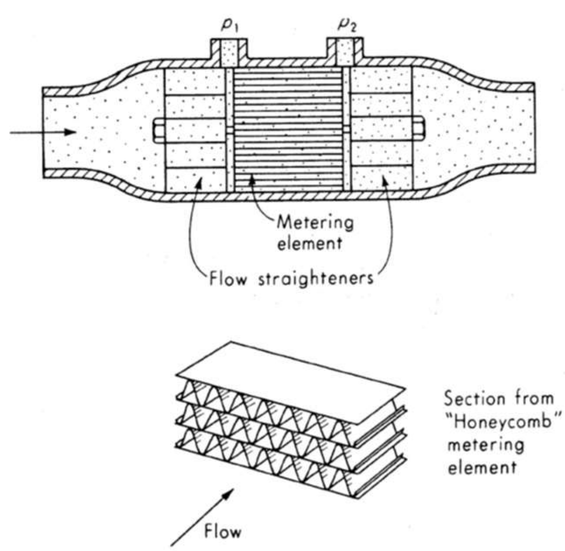


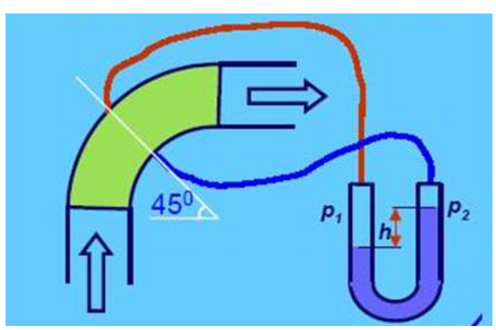
Fig. 7.32 *Laminar-flow element.*

MAIN FEATURES

- A 900 mm length, 0.1 mm dia. tubing measuring of 50 mm of H_2O column of inclined manometer gives a sensitivity of 0.003 cm^3/hr of hydrogen.
- Capacity enhancement may be done by increasing the no of capillary tubes.
- Honeycomb structure also used for low flow measurements.
- Mainly used to measure low pressure air flow rate ranges from 0.1 to 57 m^3/min at pressure drops of 100 – 200 mm of H_2O
- Widely used in pulsating flow conditions like in intake and exhaust manifolds of IC engines, reciprocating compressors, etc.

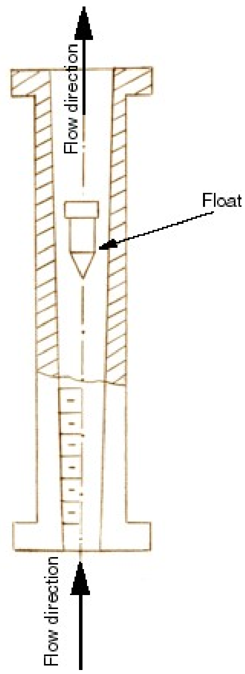
Elbow Flow Meter

As fluid passes through a pipe elbow, the pressure increases at the outside radius of the elbow because of centrifugal force. The pressure taps are located at the outside and inside of the elbow either at 25° or 45°



Rotameter

- Float within a vertical, tapered tube
- Flow entering from bottom passes over the float, which is free to move
- Principle of the device is simple balance between the drag force, gravity, and buoyancy
- Drag varies with the average velocity



Rotameter

- In operation, the float will rise to some position within the tube at which such a force balance exists, $F_y = 0$

$$\sum F_y = 0 = -F_D + W - F_B$$

$$\boxed{F_D = \frac{1}{2} C_D \rho A V^2}$$

$$\boxed{W = \rho_b g V_b}$$

Density of float

$$\boxed{F_B = \rho V_b}$$

Density of fluid

Rotameter

For a given design, the surface area of the float A_{float}, the densities of the float and flowing fluid ρ_f and ρ_{ff} and the volume of the float V_f are known. By the measuring the position (x) of the float in the rotameter, A_t is obtained. The volume flow rate Q can be calculated from the formula:

$$Q = \frac{(A_t - A_{float})}{\sqrt{1 - \left\{ \frac{A_t - A_{float}}{A_t} \right\}^2}} \sqrt{2gV_f \frac{\rho_f - \rho_{ff}}{C_d A_{float} \rho_{ff}}}$$

- **The variation of C_d with float position is less, hence Q becomes**

$$\boxed{Q = K(A_t - A_f)}$$

- If tube is so shaped that A_t varies linearly with x, flow rate varies linearly with position.
- Floats are made from corrosion resistant materials
- Rotameters sensitive to viscosity
- Floats shaped so as to induce turbulence to give viscosity insensitivity
- Float motion can be measured with a suitable displacement transducer for remote measurement

Rotameter

- The constant "K" of the ratometer should be calibrated/ calculated for each fluids separately.
- The tubes often made of high strength glass to allow direct observation of the float position.
- Typical accuracy : ± 2 %
- Effectively used for large flow ranges and gives the direct measurement.
- Flow range can be easily modified by changing the float.

<u>Disadvantages:</u>

Should be kept at vertical position.Cannot be used with liquid carrying large % of solids. Not suitable for low flow rate.

Effect of Fluid Density

Error due to the variation of fluid density

For a given flow rate;

$$\cancel{Q = Ky\sqrt{(\rho_f - \rho_{ff})\rho_{ff}}}$$

$$Q = Ky\sqrt{\frac{\rho_f - \rho_{ff}}{\rho_{ff}}}$$

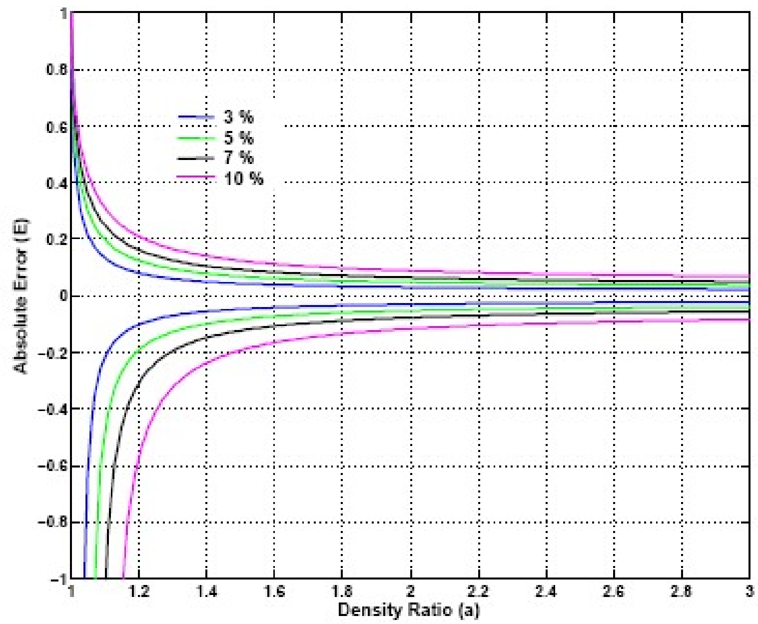
Let a = ρ_f/ρ_{ff}; In order to accommodate 5 % in the fluid density variation

$$Q_1 = Ky\sqrt{a(1 \pm 0.05) - 1}$$

$$Q_2 = Ky\sqrt{a - 1}$$

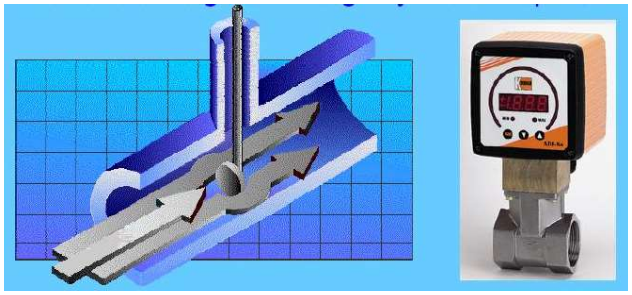
$$\frac{Q_1 - Q_2}{Q_1} = \frac{\sqrt{a(1 \pm 0.05) - 1} - \sqrt{a - 1}}{\sqrt{a(1 \pm 0.05) - 1}}$$

Effect of Fluid Density On the Absolute Error



TARGET FLOWMETERS

Target flow meters, also known as drag force flow meters, insert a target (drag element), usually a flat disc or a sphere with an extension rod, into the flow field. They then measure the drag force on the inserted target and convert it to the flow velocity.



Pipe sizes 15 ~ 150 mm (0.5 ~ 6 inch)

Drag Flowmeter

- Body immersed in fluid drag force F_d

$$F_d = \frac{C_d A \rho V^2}{2}$$

- For sufficiently high Reynolds number drag is reasonably constant
- F_d is proportional to V^2 and to square of the volume flow rate

C_d is the drag coefficient to be determined experimentally based on the flow conditions and the geometry of the drag element.

Turbine flowmeter

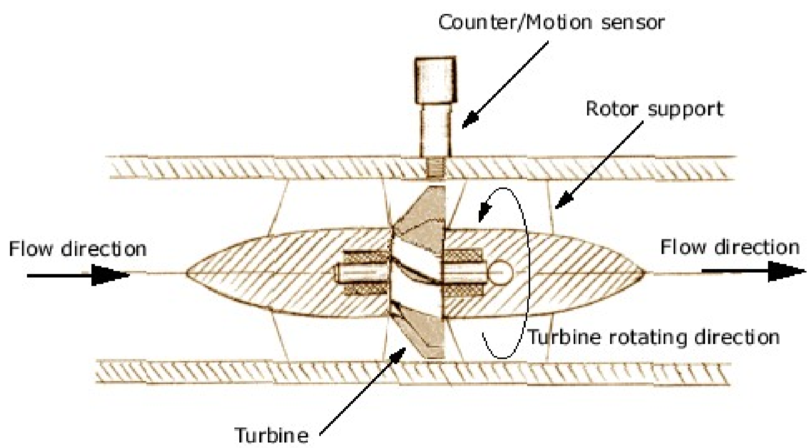
If a turbine wheel is placed in a pipe containing a flowing fluid, its rotary speed depends on the flow rate of the fluid.

By reducing losses like bearing friction, fluid viscosity or inertial effect, etc, a turbine can be designed whose speed varies linearly with the flow rate.

The speed can be measured by a magnetic proximity sensor where the rate t which the turbine blade passes a particular point is counted. (usually gives voltge pulses as o/p)

$$Q = A \times V \times \textbf{Constant.}$$

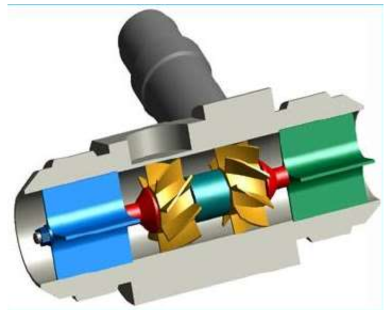
TURBINE FLOWMETERS



Pros: Medium initial set up cost, Reliable, time tested proven technology, Fast response, Remote sensing

Cons: For clean fluid only, Low to medium pressure drop.

TURBINE FLOWMETERS



Performance of Turbine flow meters

$$\frac{Q}{nD^3} = \frac{nD^2}{\nu} = \frac{\pi L}{4D}\left[1-\alpha^2 - \frac{2m(D_b - D_h)t}{\pi D^2}\sqrt{1+\left(\frac{\pi D_b}{L}\right)^2}\right]$$

Q- Volume flow m^3/s

n - rotor angular velocity rad/s

D – Bore diameter, m

ν - kinemetic viscosity, m^2/s

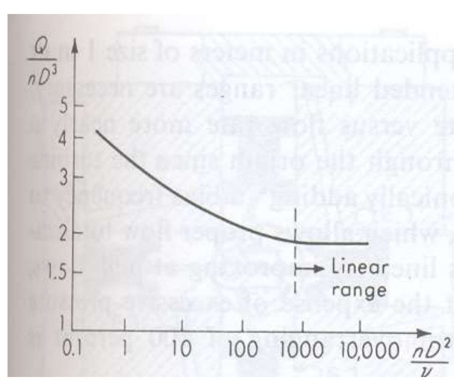
L – rotor lead, m

m – no. of blades

D_b- rotor blade tip diameter,m

D_h- rotor hub diameter, m

t – rotor blade thickness, m



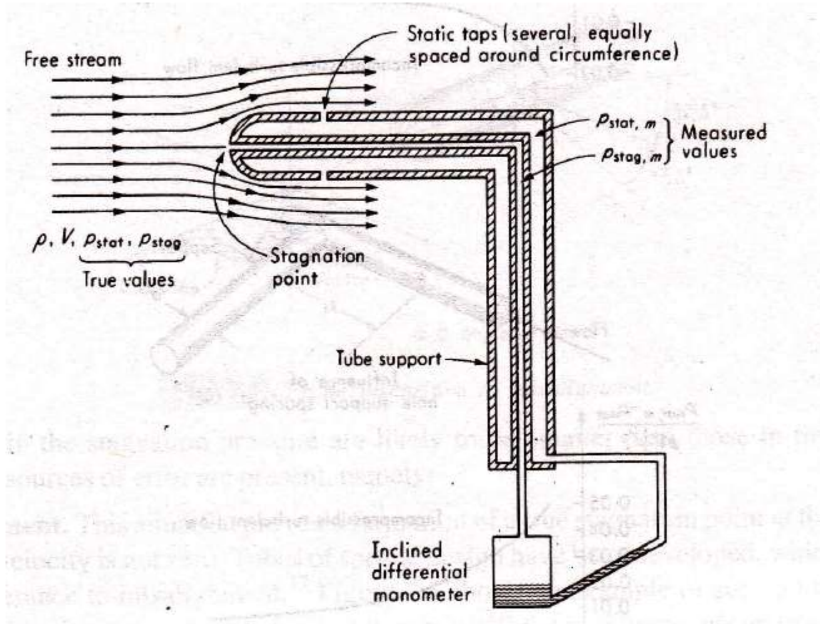
Main Features of Turbine flow meters

- First order instrument has the time constant of 2 – 10 ms at maximum flow.
- Accuracy up to ± 0.5 %
- Available pipe sizes from 0.125 to 8 in
- Rages from 0.01 to 30,000 gal/min for liquids and 0.078 to 112208 gal/min for gas.
- Special care to be given for bearing maintenance
- Poor accuracy at low flow rates (At low flow rates, linearity is degraded by both viscous and magnetic pickup drag.

Methods of Flow metering

- Vortex shedding flow meter
- Electromagnetic flowmeter
- Mass Flowmeters
  - Direct-Coriolis mass flowmeter
  - Indirect- Thermal mass flowmeter
- Ultrasonic flow meter
  - Insertion type
  - Clamp type
- Cross correlation flowmeter.

Pitot-static tube



Velocity from Pitot-Static Tube

- Pitot-static tube aligned with flow direction
- Assuming steady one-dimensional flow of an inviscid, incompressible fluid

$$V = \sqrt{\frac{2(p_{stag} - p_{stat})}{\rho}}$$

V - flow velocity

ρ - Fluid density

p_{stag} - stagnation or total pressure

p_{stat} - static pressure, free stream.

If ρ is accurately known, the errors can be inaccurate measurement of p_{stag} and p_{stat}

Possible errors in velocity measurements

- The difference between true and measured (p_{stat}) due to
  - Misalignment of the tube axis and velocity vector
  - Pitot-static tube employed in a compressible fluid.

For sub sonic flow,

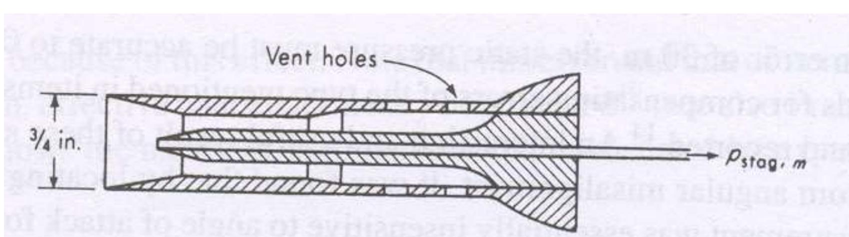
$$V = \sqrt{\frac{2k}{k-1}\frac{p_{stat}}{\rho_{stat}}\left[\left(\frac{p_{stag}}{p_{stat}}\right)^{(k-1)/k} - 1\right]} \qquad k = \frac{C_p}{C_v}$$

The above equation can be rewritten as

$$p_{stag} = p_{stat}\left\{1 + \frac{k-1}{2}(V/c)^2\right\}^{\frac{k}{k-1}}$$

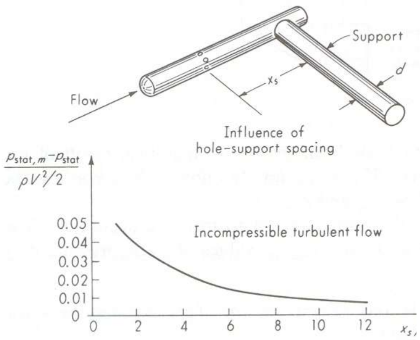
For supersonic flow

$$\frac{p_{stag}}{p_{stat}} = M^2\left(\frac{k+1}{k}\right)^{\frac{k}{k-1}}\left\{\frac{2kM-k+1}{M^2(k+1)}\right\}^{1-\frac{1}{k-1}}$$

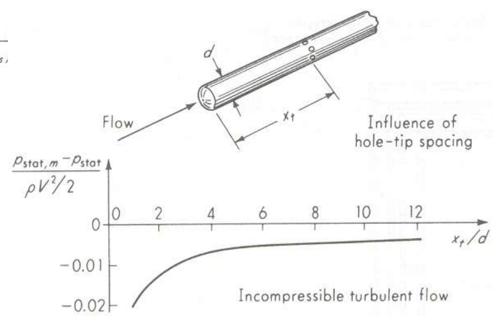


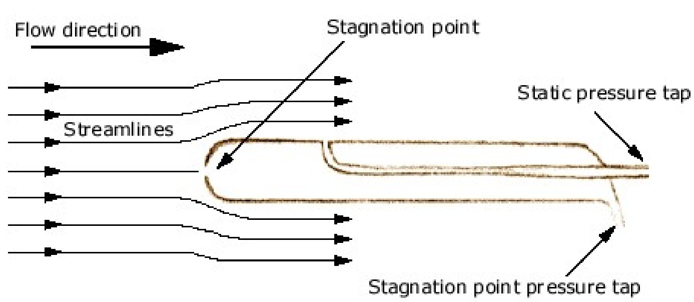
Stagnation probe for measuring error less than 1% of the velocity pressure for up to ±38° misalignment

Influences of position of static holes



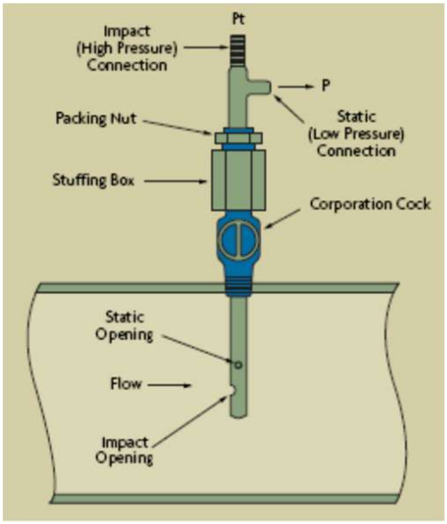
IF the static taps are too close to the tube support, reading will be high

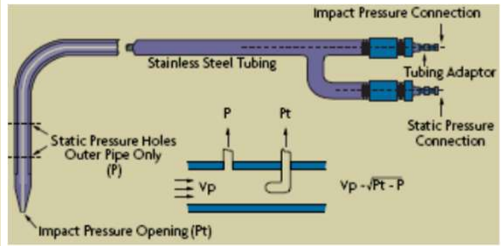




- Low to medium initial set up cost.
- Can be used in wide ranges of fluid phases and flow conditions.
- Simple and sturdy structures
- Medium to high pressure drop.

DIFFERENT TYPES OF PITOTS TUBE





CORIOLIS FLOW METERS

G.G. Coriolis, a French engineer, developed the concept of Coriolis acceleration.
When a fluid is flowing in a pipe and it is subjected to Coriolis acceleration through the mechanical introduction of apparent rotation into the pipe, the amount of deflecting force generated by the Coriolis inertial effect will be a function of the mass flow rate of the fluid.

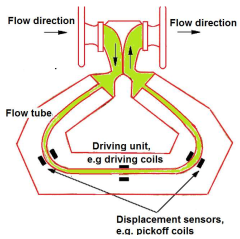
The main feature of Coriolis flowmeters is that it measures the mass flow rate directly which eliminates the need to compensate for changing temperature, viscosity, and pressure conditions.

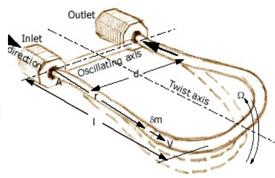
CORIOLIS FLOW METERS

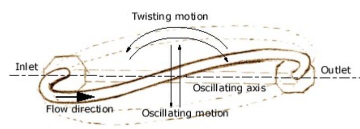
The two parallel tubes are counter-vibrating, to make the measuring device less sensitive to outside vibrations.

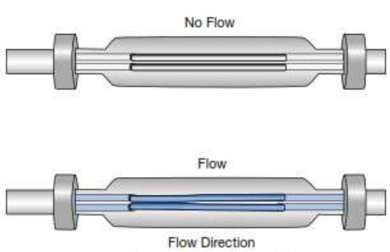
The actual frequency of the vibration (80 to 1000 Hz) depends on the size of the mass flow meter.

The flow is guided into the U-shaped tube which will induce a rotation or twist to the tube because of the Coriolis acceleration acting in opposite directions on either side of the applied force.

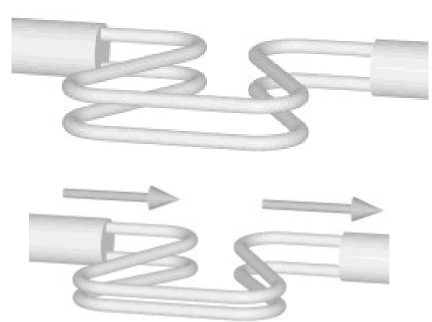






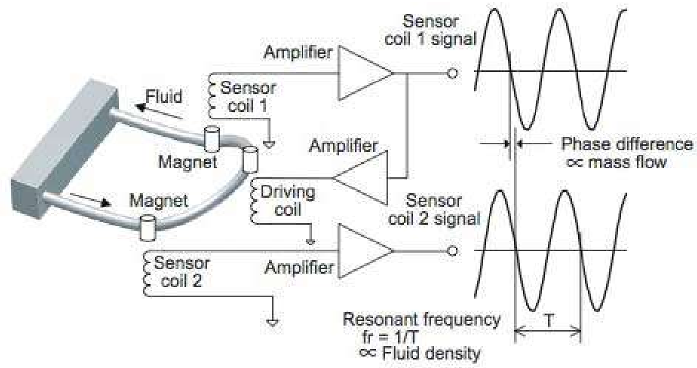


No flow, vibration is symme



As material flows through the tubes, the Coriolis effect causes the upstream side of the loop to fall slightly behind the downstream side. This motion is sensed by the motion sensors as a time shift.

https://www.youtube.com/watch?v=XIIViaNITIw– for videos



CORIOLIS FLOW METER

$$Q_m = \frac{K_s\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]}{2Kd^2}\tau$$

where

Q_m - Mass flow rate (kg/s)
τ - Measured time lag
ω - Vibrating frequency
ω_n – Natural frequency

K- Compensation factor for U shape
Ks – temp dependent stiffness of the tube
d- width of the U tube

CORIOLIS FLOW METER

TRANSMITTER

SENSOR

6 ~ 200 mm (0.25 ~ 8 inch)

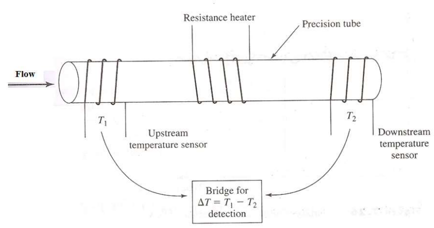
Advantages

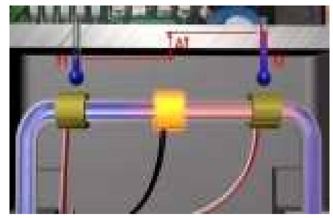
- Higher accuracy than most flow meters. Measures both directions.
- Can be used in a wide range of liquid flow conditions.
- Capable of measuring hot (e.g., molten sulphur, liquid toffee) and cold (e.g., cryogenic helium, liquid nitrogen) fluid flow.
- Low pressure drop. Measure mass flow rate of any flowing medium.

Disadvantages

- High initial set up cost.
- Clogging may occur and difficult to clean.
- Limited line size availability

THERMAL FLOWMETERS





$$\dot{m} = \frac{k\dot{q}}{C_p(T_2 - T_1)}$$

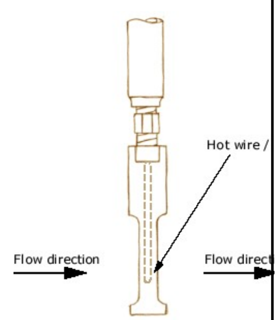
q – electric heat rate

<u>Hot wire anemometers</u>

Measure the heat carried away from the sensor by passing the flow to determine the mass flow rate.

As the flow passes over the hot wire, it carries away heat. The heat loss depends on the mass flow rate, the heat capacity of the fluid, and the temperature difference between the wire and the fluid.

Since the heat capacity of the fluid is known and the temperatures are monitored in real-time, the mass flow rate can be determined from the heat loss (related to the electric resistance of the wire via the Ohm's law) and the thermal expansion coefficient of the wire.



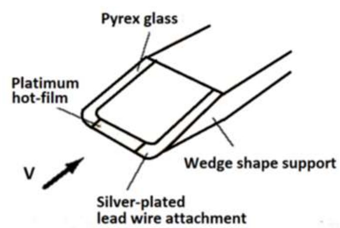
6 ~ 100 mm (0.25 ~ 4 inch)

- The core of the anemometer is an exposed hot wire either heated up by a constant current or maintained at a constant temperature. In either case, the heat lost to fluid convection is a function of the fluid velocity.
- The heat lost can be obtained by measuring either the change in

i. wire temperature under constant current or

ii. the current required to maintain a constant wire temperature.

The heat lost can then be converted into a fluid velocity.



Consider a wire that's immersed in a fluid flow. Assume that the wire, heated by an electrical current input, is in thermal equilibrium with its environment. The electrical power input is equal to the power lost to convective heat transfer,

$$I^2 R_w = hA_w(T_w - T_f) = m_f C_f (T_w - T_f) \qquad (1)$$

- I is the input current, R_w is the resistance of the wire,
- T_w and T_f are the temperatures of the wire and fluid respectively,
- A_w is the projected wire surface area,
- h is the heat transfer coefficient of the wire.
- m_f is mass flow rate of the fluid.

The wire resistance R_w is a function of temperature according to,

$$R_w = R_{ref}(1 + \alpha(T_w - T_{ref}) \qquad (2)$$

$$R_w = R_{ref}(1+\alpha(T_w - T_{ref})) \qquad (2)$$

The heat transfer coefficient h is a function of fluid velocity v_f according to King's law, $h = a + bV_f^c$ (3)

a, b, and c are coefficients obtained from calibration ($c \sim 0.5$).

Combining the above three Eqs., fluid velocity is given by

$$v_f = \left[\left[\frac{I^2 R_{ref}[1+\alpha(T_w - T_{ref})]}{A_w(T_w - T_f)} - a\right]/b\right]^{1/c}$$

Medium initial set up cost, Low pressure drop , measures mass flow directly, remote sensing, high accuracy for constant density fluids

Limitations:- High repair cost, For (clean) gas only, Can not take pressure and density variation during measurement.

Two types of thermal (hot-wire) anemometers are commonly used: constant-temperature and constant-current.

Constant Temperature

- For a hot-wire anemometer powered by adjusting current to maintain a constant temperature, T_w and R_w are constants. The fluid velocity is a function of input current and flow temperature,
- Furthermore, the temperature of the flow T_f can be measured. The fluid velocity is then reduced to a function of input current only.

$$a + bv_f^c = \left[\frac{I^2 R_w}{A_w(T_w - T_f)}\right] = f(I, T_f)$$

Constant-Current Hot-Wire Anemometers

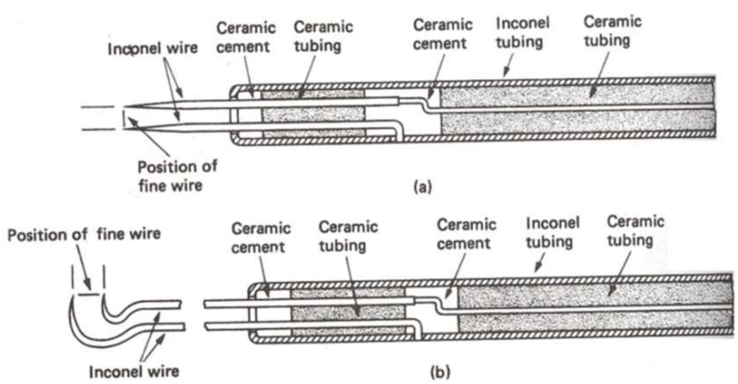
For a hot-wire anemometer powered by a constant current I, the velocity of flow is a function of the temperatures of the wire and the fluid,

$$a + b v_f^c = \left[\frac{I^2 R_{ref}(1 + \alpha(T_w - T_{ref}))}{A_w (T_w - T_f)} \right] = f_1(T_w, T_f)$$

If the flow temperature is measured independently, the fluid velocity can be reduced to a function of wire temperature T_w alone. In turn, the wire temperature is related to the measured wire resistance R_w.

Therefore, the fluid velocity can be related to the wire resistance

Constant Temperature Type



Platinum or Tungsten wire of 4 to 10 μm and length of 1mm

THERMAL MASS FLOW METER