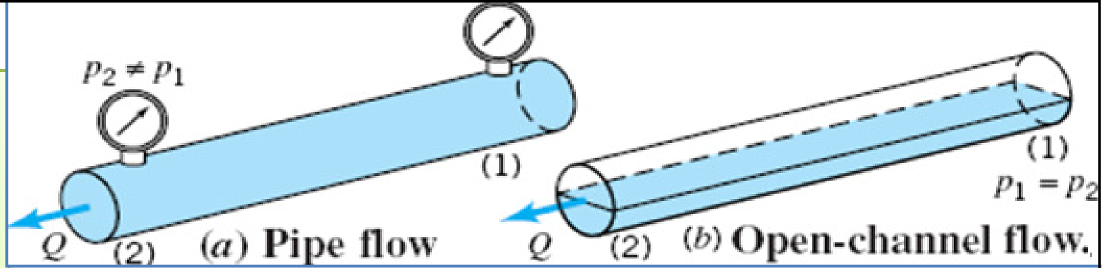
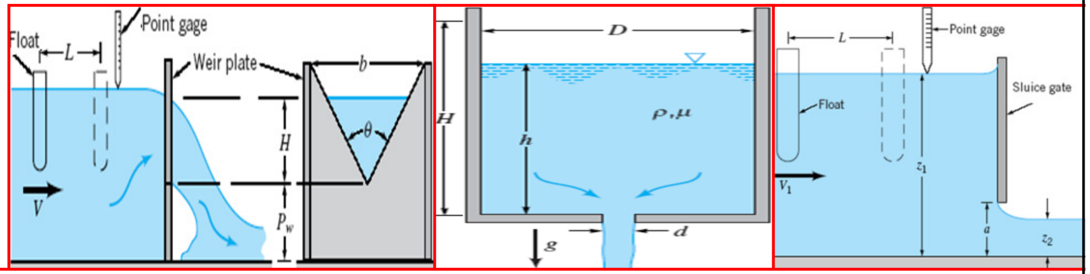
Flow Measurements

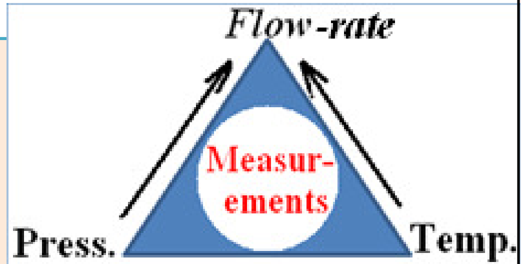


Types of Flow: 1-pipe/duct flow ($P_2 \neq P_1$) any area; 2-open channel flow ($P_2 = P_1$). For flow in pipe/duct we may have any type of fluid: liquid/gas/multi-phase but we can not have gas/gas-liquid mixture in open channel flow. More than 95% of flow measurements are for pipe/duct flow. Less than 5% is for open channel flow(rivers, open gates, open-in tank, triangle/rectangular weirs..)



Flow measurements are essential for all process control & practical engg systems.
Flow measurements must be made in chemical plants, refineries, power plants, and any other place where the quality of the product or performance of the plant depends on having a precise flow rate. Flow measurements also enter into our everyday lives in the metering of water and natural gas into our homes and gasoline into our cars.

Accuracy of measurement: some applications may need only crude data while others require accurate/precise measurement such as in research projects & control systems (e.g., water bill/cost depends on data of water-home meter &profits of gas service station is related to accuracy of the gasoline pumps).



Note that: 1-cost & complexity of flow measurements is directly proportional to accuracy of results. 2-overall efficiency of flow-rate measuring devices will depend on accuracy of some of associated measurements of pressure & temperature data.

Q = $
For custody transfer, flow measurement equals dollars.

Good Flow Measurement Fluids — Good fluids:

1. Are not near flash point (for liquids) or condensing points (for gases)
2. Are clean fluids without other phases present, with a composition whose PVT (pressure/volume/temperature) relationships are well documented with industry-acceptable data;
3. Are not exceptionally hot or cold since temperature may limit the ability to use certain meters;
4. Have minimal corrosive, erosive, or depositing characteristics.

Bad Flow Measurement Fluids — Bad fluids include:

1. Two or more phases in the flow stream; 2. Dirty mixtures;
3. Flows near fluid critical points;
4. Flows with temperatures over 120 or under 32ºF;
5. Highly corrosive or erosive fluids;
6. Highly disturbed flows; 7. Pulsating flows;
8. Flows that undergo chemical or mechanical changes;
9. Highly viscous flows.

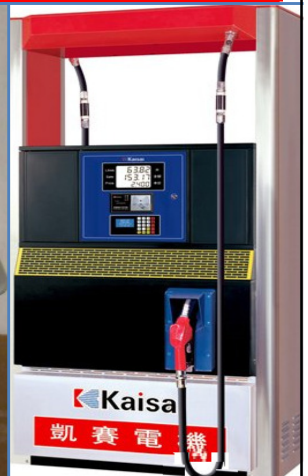
Many different types of meters are available for measureing flow Proper selection requires a full understanding of fluid and meter characteristics relative to a specific measurement job.

<u>Types of Flow Measurements/flow meters</u>:

1-Acumulated/total Flow quantity, units of volume (e.g., m^3,ft^3,Gallon, liters) at specific conditions of Press.&Temp.(e.g., gas/water home meters; conventional gasoline pumps at car service stations).

2-Flow rate meters in units of m^3/s, gpm, ft^3/min , cfm,..etc) or in units of mass/time.

nutating-disk meter




elster
Qn 1,5 m3/h
PN 16 bar
Δp 0,6 bar
0 9 6 2 3 m3
EM 2017
017087
G4
30066645
metrix
2014
IF YOU THINK YOU CAN SMELL GAS
0800 111 999
10141707
EAST-MAN
LITRES
Diesel Flow Meter,

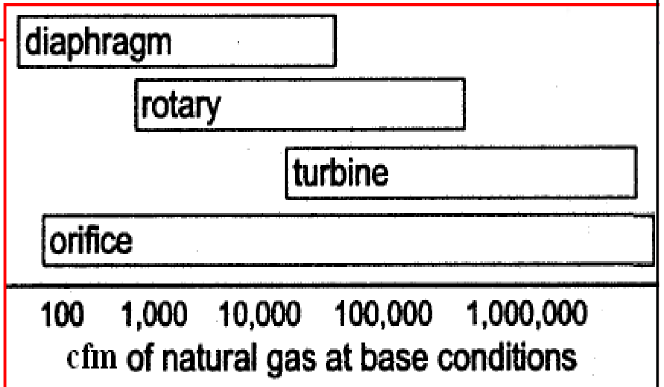
METER CHARACTERISTICS

Comparing Meters

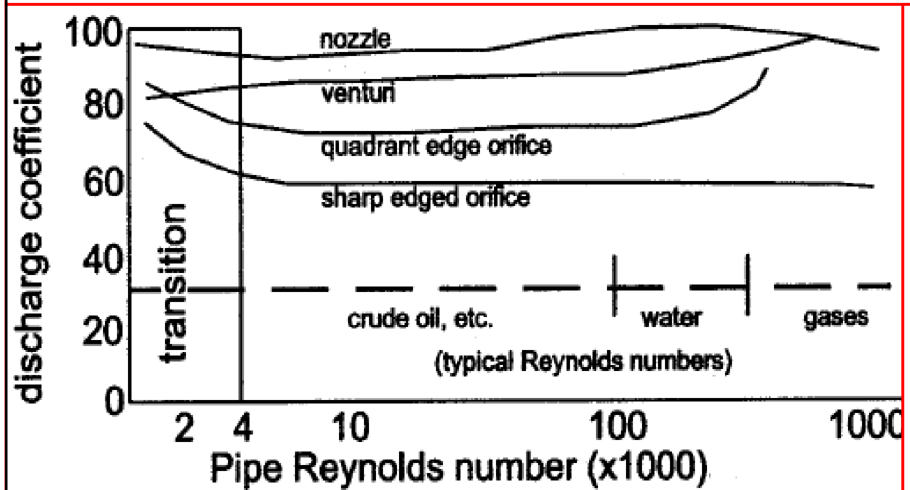
Characteristics to be considered when evaluating a meter include: achievable uncertainty, comparative cost, use acceptance and specific use, repeatability, maintenance costs, operating cost, few or no moving parts, ruggedness, service life, rangeability, style to meet fluid property problems, pressure and temperature ratings required, ease of installation and removal, power required, pressure loss caused by meter (running and stopped), and how well calibration can be proved.

No single meter will have all of the characteristics desired, but candidates can be evaluated by going through such a list for each meter under consideration and then deciding which of the factors are of prime importance for the particular flow measurement problem. A procedure something like the following may be helpful:

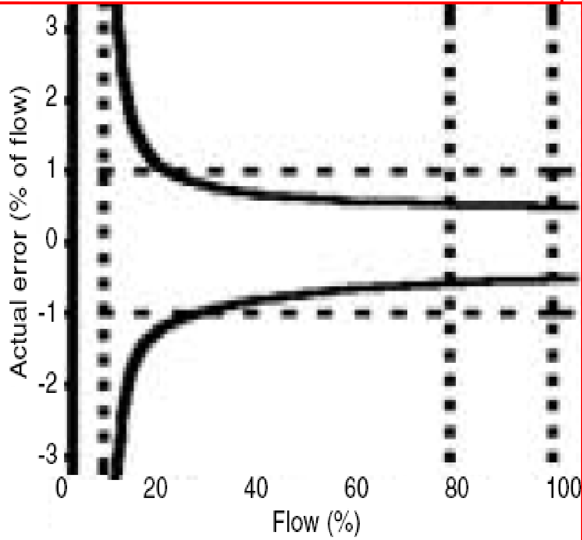
1. List, for each candidate meter, the characteristics of importance.
2. Define *how important* each is by assigning a weighting factor (such as from 10 for very important to 0 for no importance).
3. Assign a similar rating number to show how well the meter will *perform* to meet specific needs of the application.
4. Multiply the weight factor by performance factor, and add all totals.



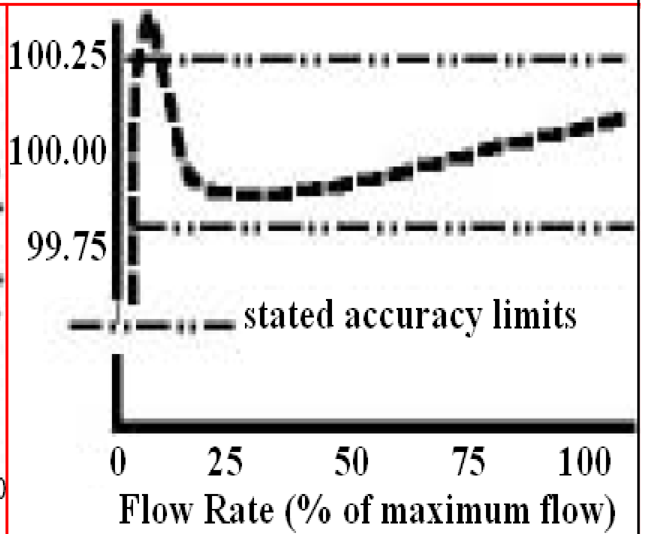
Comparison of flow ranges for various gas flow meters.



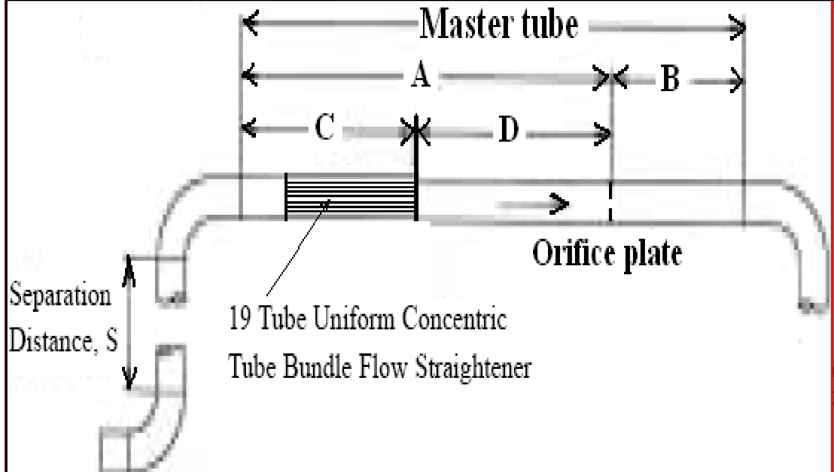
Shown are typical effects on discharge coefficient for various meters and bias error versus Reynolds number in measuring typical fluids.



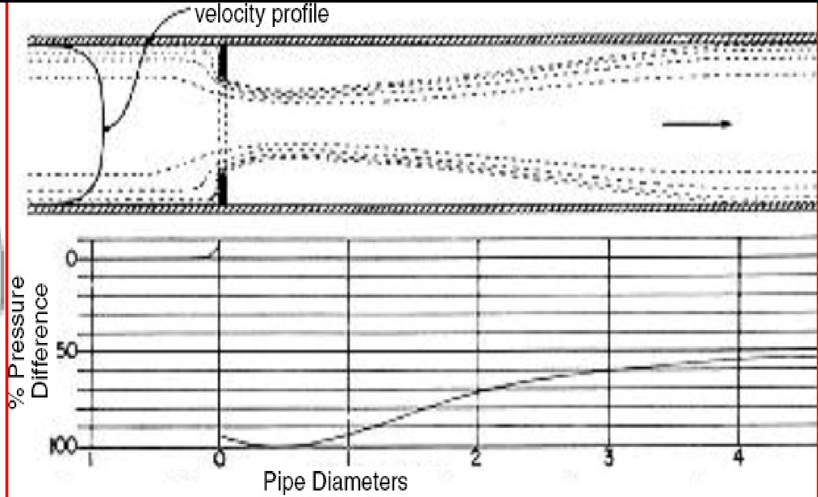
Variation of Accuracy of transducers



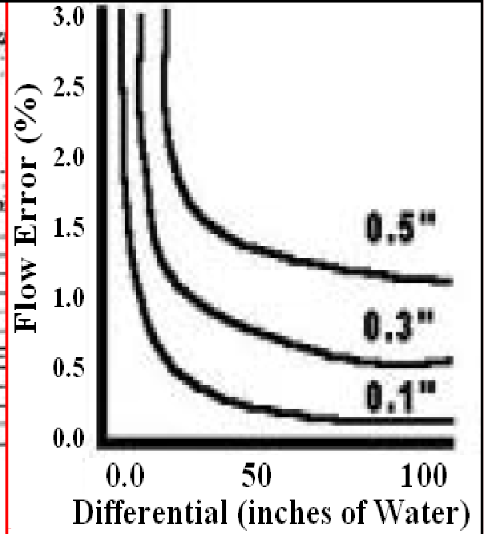
Variation of meter uncertainty with flow



International Standards, key orifice-meter document to help design appropriate meter piping & configurations.

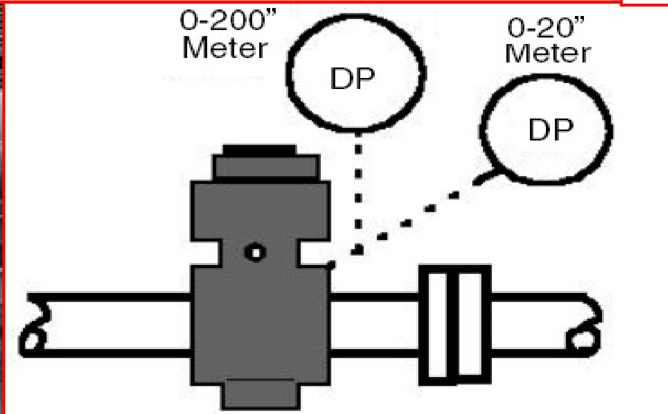


Sufficient pressure drop must be created by flowing conditions to be able to derive valid flow measurement

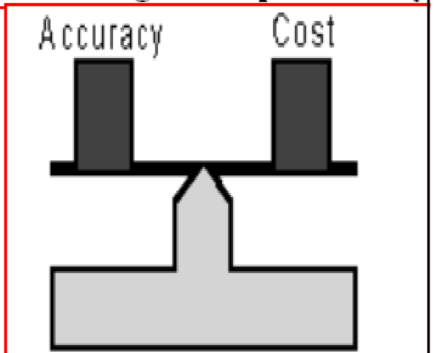


Effect of gas compressibility

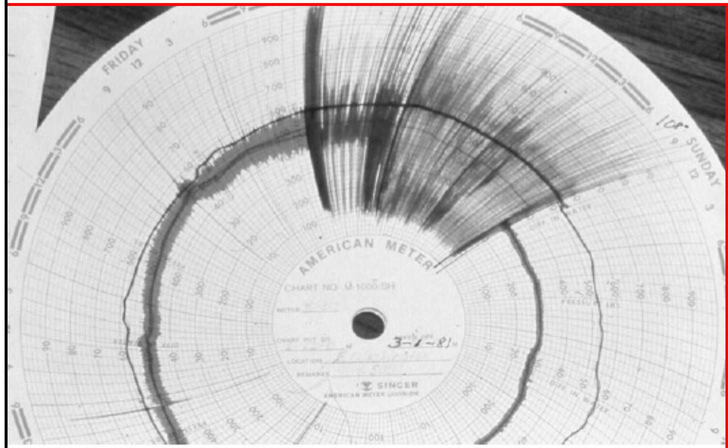

Good design calls for long, straight meter-tube lengths for the most accurate flow measurement with minimum uncertainty.



If meter's range not sufficient to measure flow, multiple transducer can be used or use a different type meter



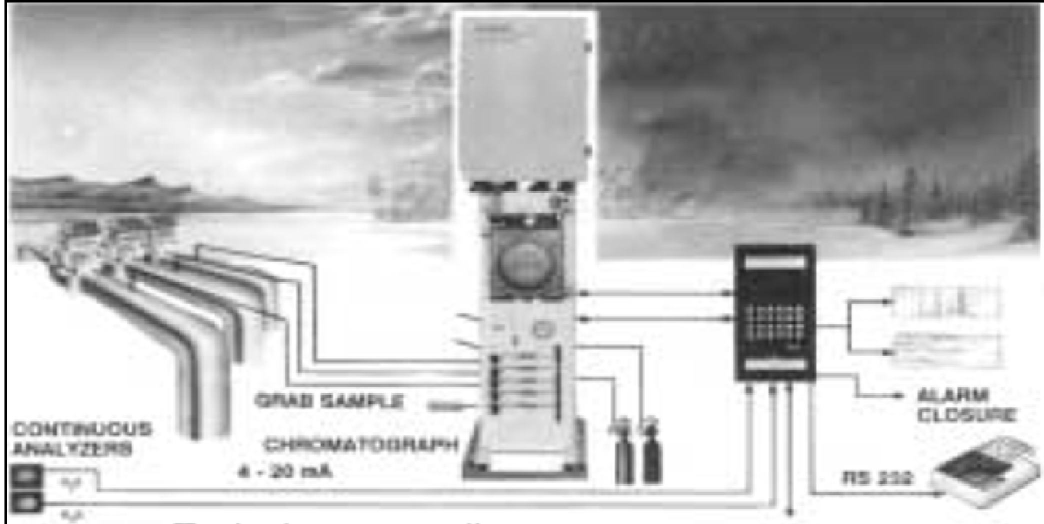
cost of accuracy should be compared with needed accuracy for the job



Unstable/Bad flow control signals causes improper metering


Maintenance of tubes & meters must be done for accutate flow measurements


Engineers/operators must understand equipment&measurement is must for maximum effectiveness to the user



Typical gas sampling system.

Typical orifice meter installation.

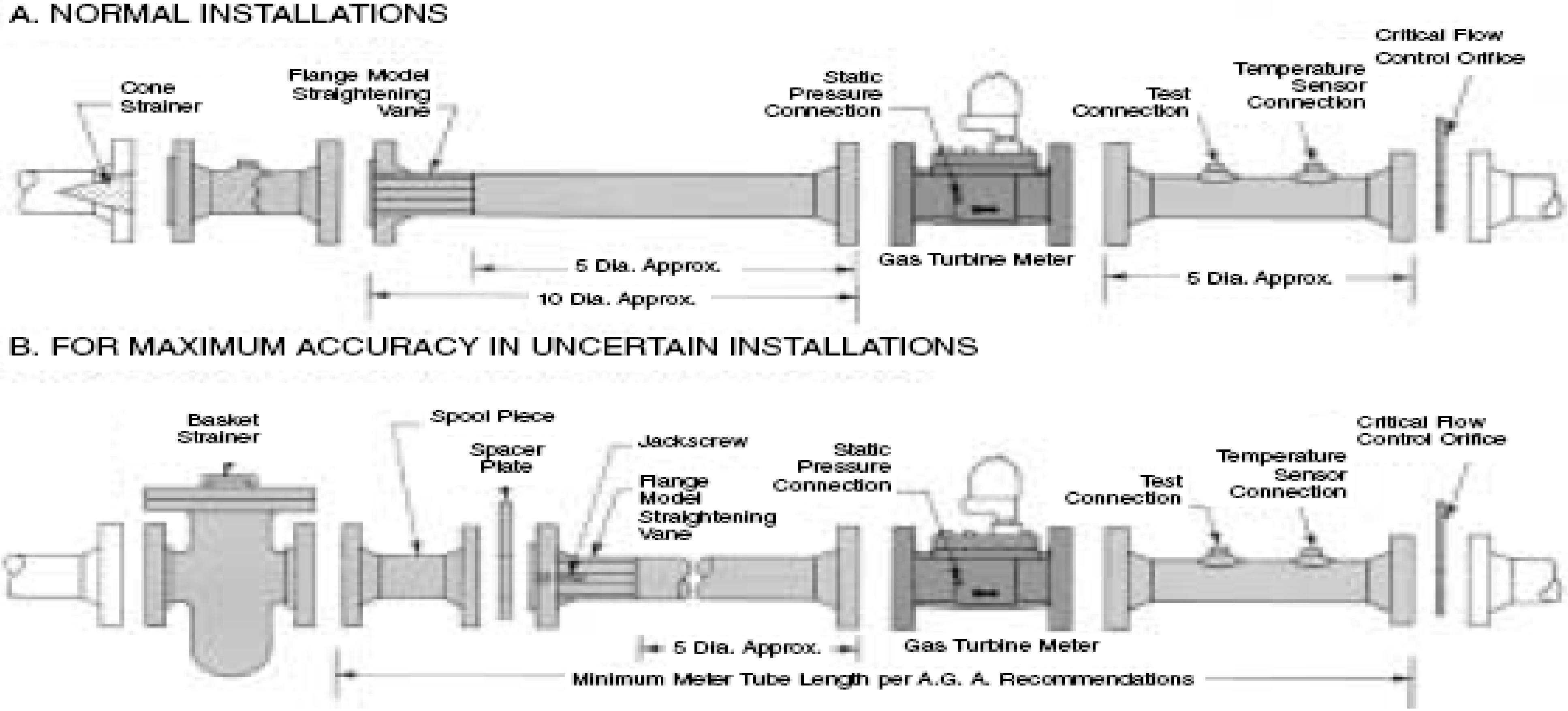
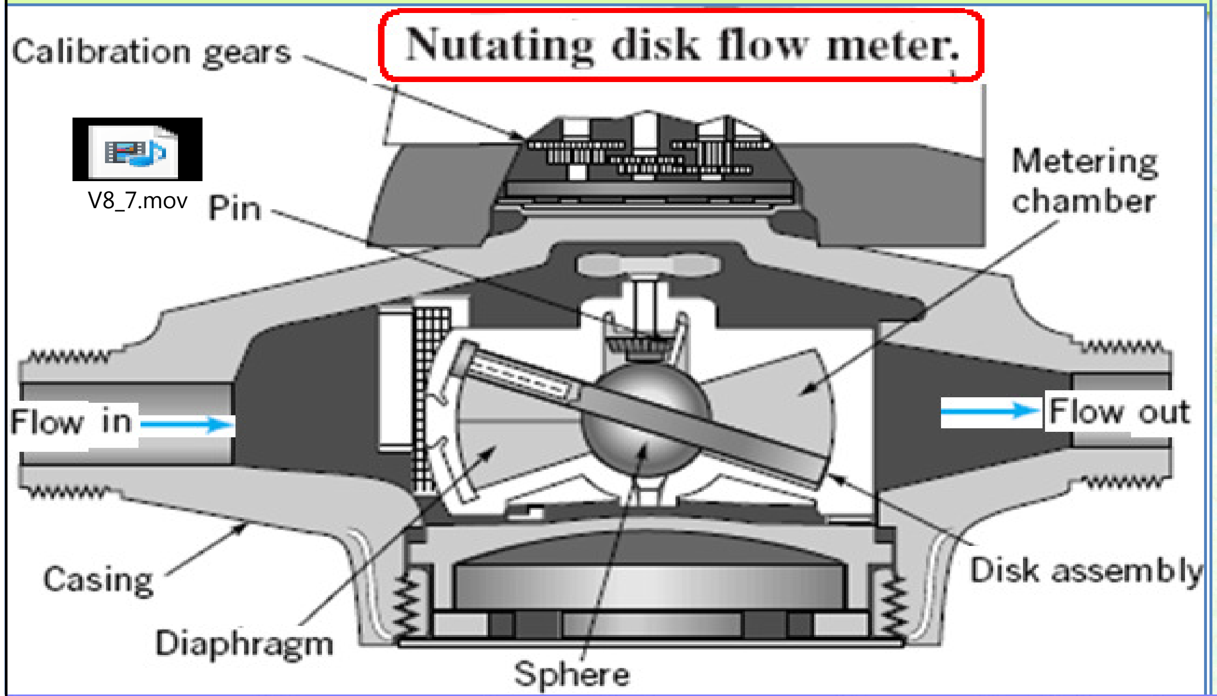


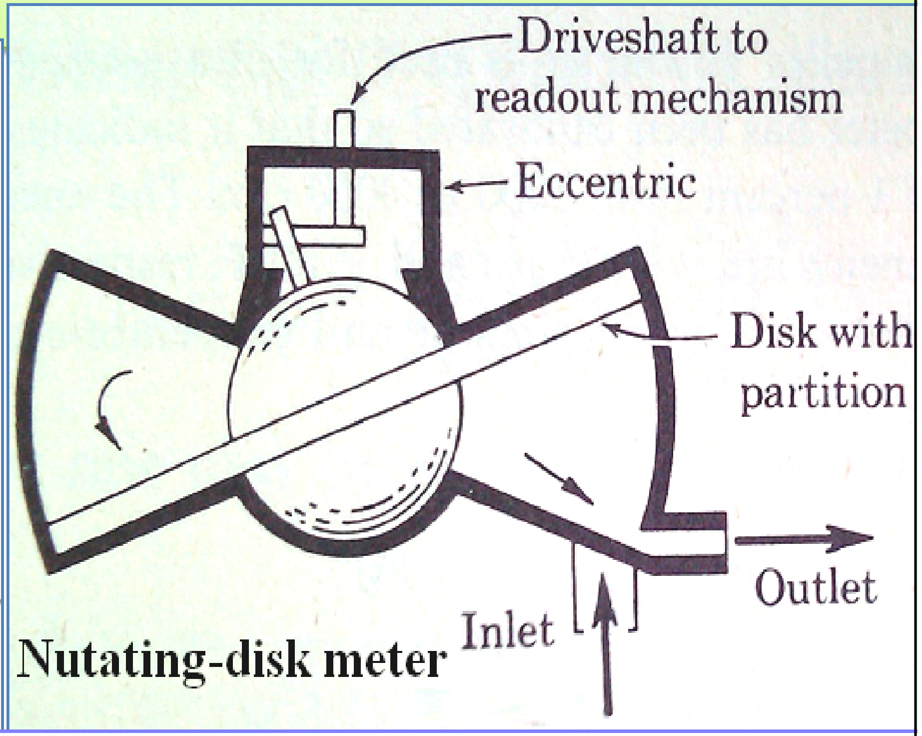
Figure 12-11 Installation of two- and three-section gas turbine meter tubes according to the AGA-7 requirements.

Volume Flow Meters

In many instances it is necessary to know the amount (volume or mass) of fluid that has passed through a pipe during a given time period, rather than the instantaneous flowrate. For example, we are interested in how many gallons of gasoline are pumped into the tank in our car rather than the rate at which it flows into the tank. There are numerous quantity-measuring devices that provide such information.

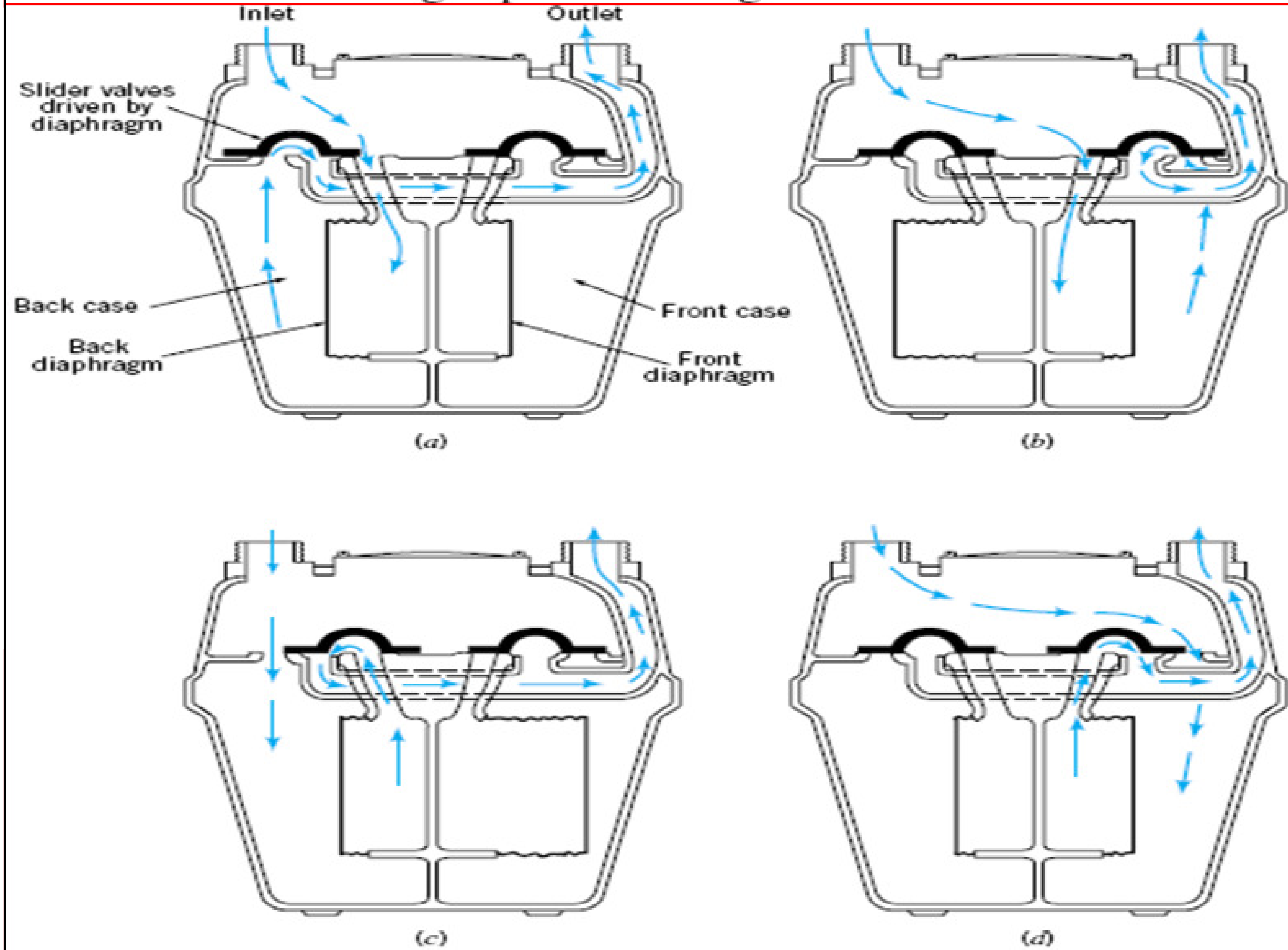
Positive-Displacement Meters: for gases or nonvolatile liquids ; highly accurate under steady flow conditions. Operation of these units consists of separating liquids into accurately measured increments and moving them on. Each segment is counted by a connecting register. Because every increment represents a discrete volume, positive-displacement units are popular for automatic batching and accounting applications. Positive-displacement meters are good candidates for measuring the flows of viscous liquids or for use where a simple mechanical meter system is needed.





The *nutating disk meter* shown in Fig. is widely used to measure the net amount of water used in domestic and commercial water systems as well as the amount of gasoline delivered to your gas tank. This meter contains only one essential moving part and is relatively inexpensive and accurate. Its operating principle is very simple, but it may be difficult

Another quantity-measuring device that is used for gas flow measurements is the *bellows meter* as shown in Fig. It contains a set of bellows that alternately fill and empty as a result of pressure of the gas and motion of a set of inlet and outlet valves. The common household natural gas meter is of this type. For each cycle [(*a*) through (*d*)] a known volume of gas passes through the meter.

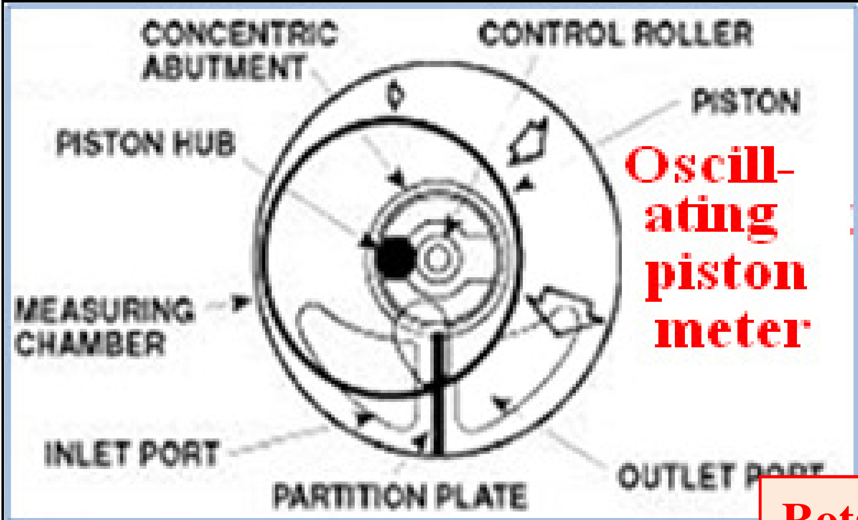


Bellows-type flow meter. (Courtesy of BTR—Rockwell Gas Products). (*a*) Back case emptying, back diaphragm filling. (*b*) Front diaphragm filling, front case emptying. (*c*) Back case filling, back diaphragm emptying. (*d*) Front diaphragm emptying, front case filling.

gas-meter of diaphragm style

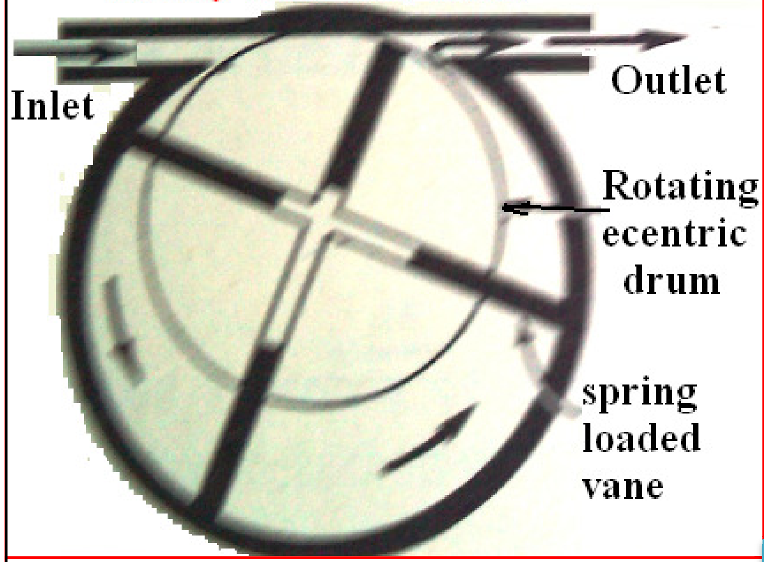
Indicator of a gas meter type

Many types/sizes of metalic bellows

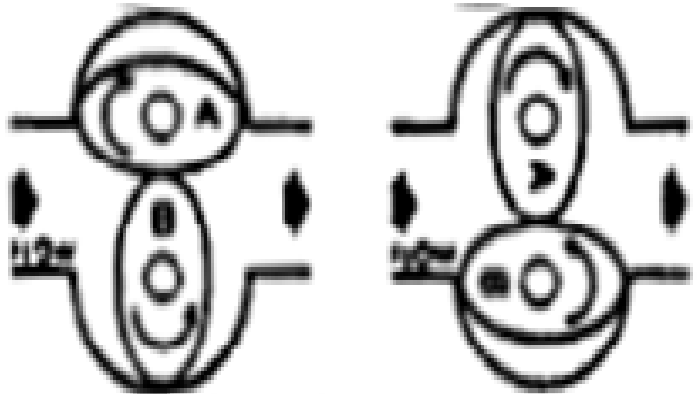


Oscillating-piston meter operates on magnetic drive principle so that liquid will not come in contact with parts. A partition plate bet. Inlet & outlet ports forces incoming liquid to flow around a cylinderical measuring chamber & through the outlet port. The motion of the oscillating piston in the unit is transferred to a magnetic assembly in the measuring chamber which is coupled to follower magnet on the other side of the chamber wall.

Rotary-vane flow-meter

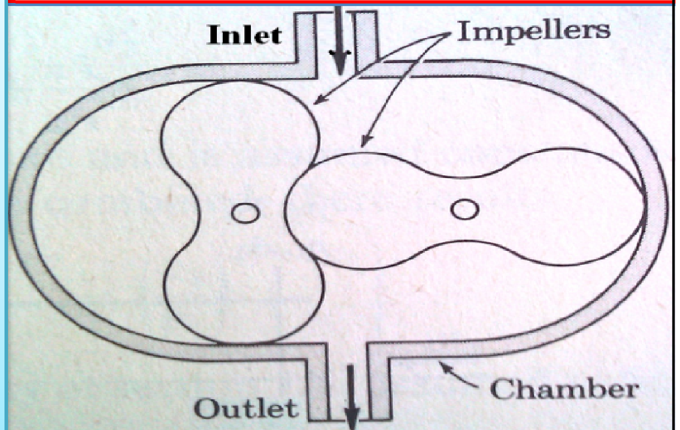


Rotary-vane meters are available in several designs, but they all operate on the same principle. The basic unit consists of an equally divided, rotating impeller (containing two or more compartments) mounted inside the meter's housing. The impeller is in continuous contact with the casing. A fixed volume of liquid is swept to the meter's outlet from each compartment as the impeller rotates. The revolutions of impeller are counted and registered in volumetric units. Helix flowmeters consist of two radically pitched helical rotors geared together, with a small clearance between the rotors and the casing. The two rotors displace liquid axially from one end of the chamber to the other

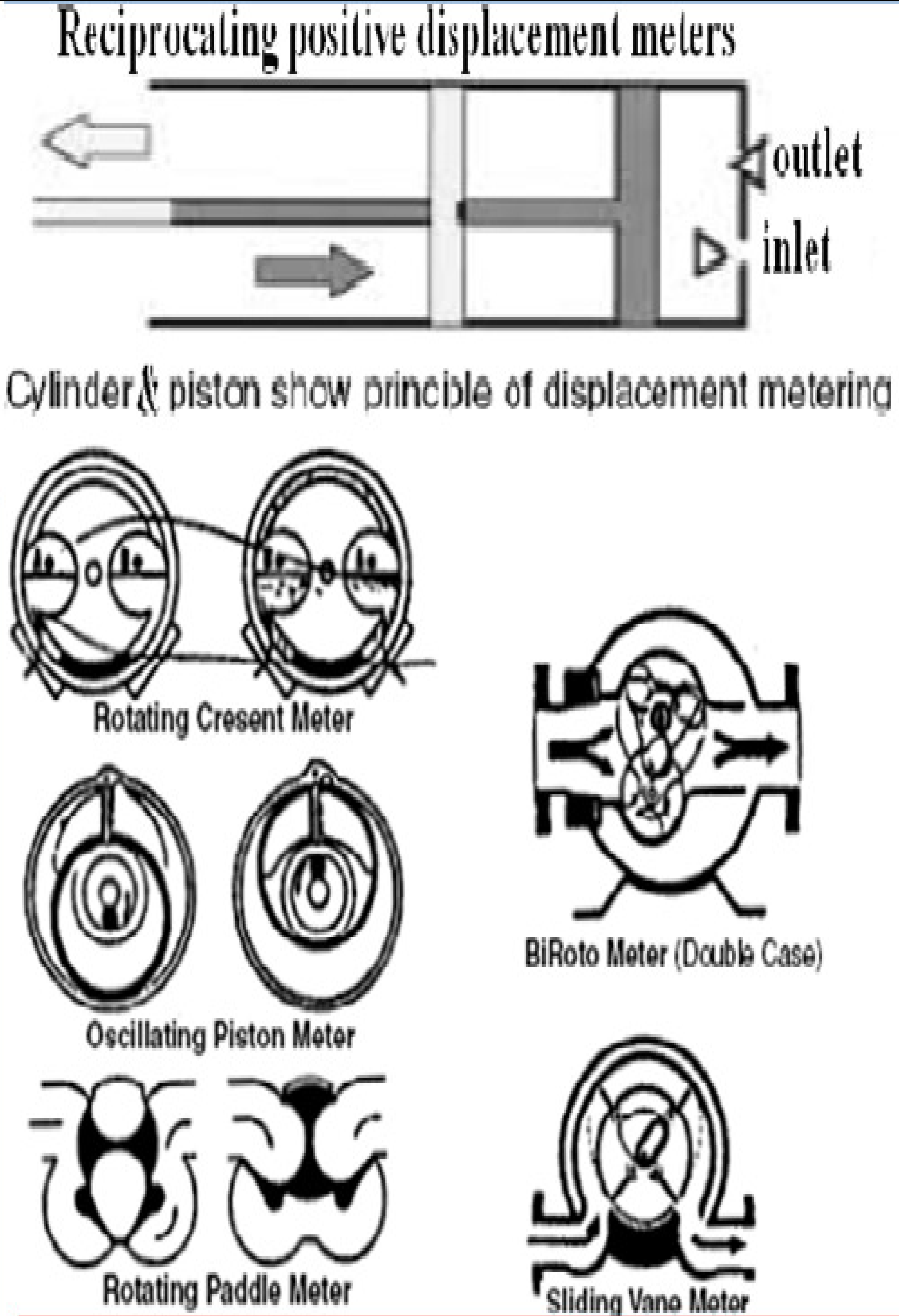


Oval Gear Meter

Oval-gear meters : have two rotating, oval-shaped gears with synchronized, close fitting teeth. A fixed quantity of liquid passes through the meter for each revolution. Shaft rotation can be monitored to obtain specific flow rates.



lobed-impeller flowmeter



Major types of positive displacement meters for liquids

Advantages of PD meters:

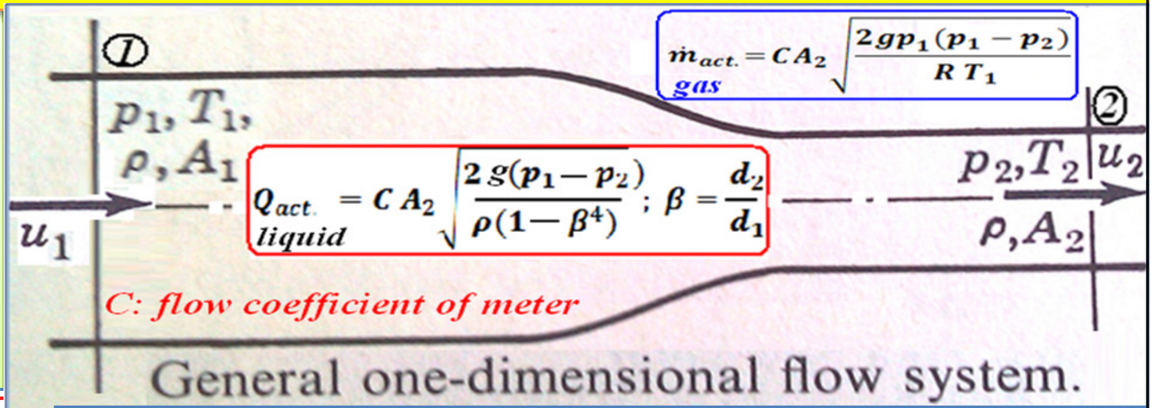
1. Insensitive to upstream and downstream piping effects so that no or minimum lengths are required;
2. Operating principle straightforward, easy to understand;
3. Rangeability among highest of liquid and gas meters available without loss of accuracy;
4. Even though valving and clearances require close tolerances, commercially available units are rugged and provide long and reliable service on clean fluids or with line filters; and
5. Simple to complex readout systems available for simple flow equation.

Disadvantages of PD meters:

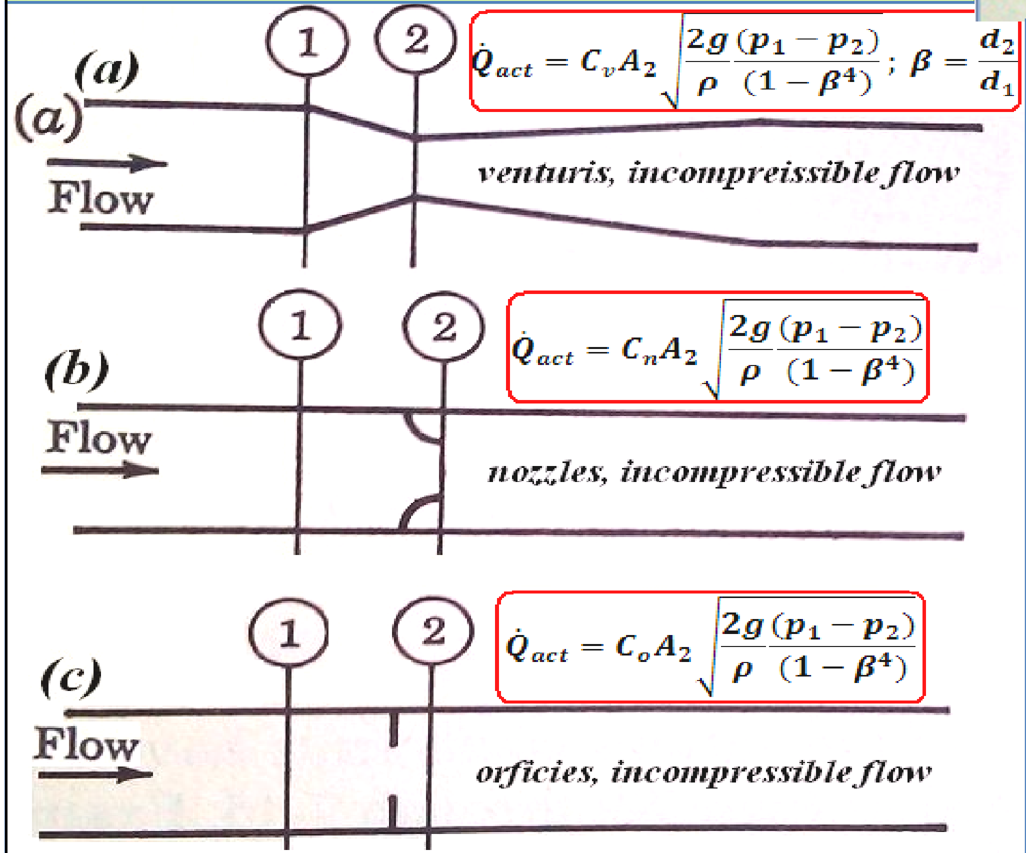
1. Because of clearances required, pressure, temperature, and viscosity ranges are limited and special care may be required for installation (meter specifications in this regard vary between manufacturers and should be examined carefully);
2. For larger sizes (above 10 inches), meters are large, heavy, and relatively expensive;
3. Head loss can be high, particularly if the meter jams; protection from flow shutdown and pressure overrange may be required;
4. Filtration or strainers may be required for fluids containing foreign particles to minimize meter wear; and
5. Maintenance costs are high on some larger meters; unit replacement is typical for smaller meters because of complexity and field-repair cost.

Flow-Rate Measurement: it is instantaneous measurement of average flow-rate over a specified cross-section or measurement of flow velocity at a point in the flow field (need to integrate velocity profile). Meters include: Head/obstruction meters (*Venturimeter, Orifice Plate, Nozzlemeter*), *Elbow-meters, Rota-meter, Segmental Wedge, V-Cone, Pitot Tube, Magnetic Flow-meters, Turbine-meters, Ultrasonic-meters, Hot Wire anemometer, Lazier Doppler anemometer (LDAN),….etc.*

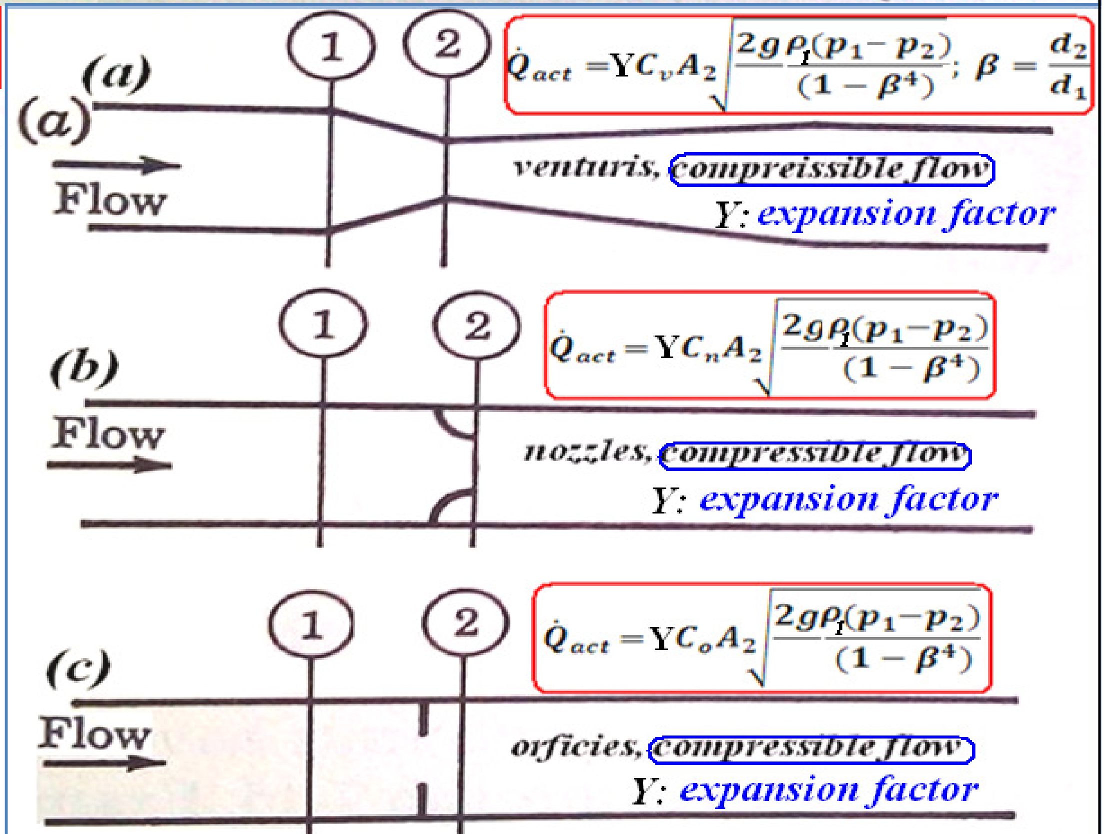
Flow-Obstraction or Head meters: used for all types of single phase fluids; accurate for steady flow conditions; depend on measuring ΔP; inexpensive; be used for automation if ΔP is measured be electric transducer type . They use adiabatic, frictionless, incompressible eqn.(Bernoulli's eqn., $\rho_1 = \rho_2 = \rho$) as shown in fig.



General one-dimensional flow system.

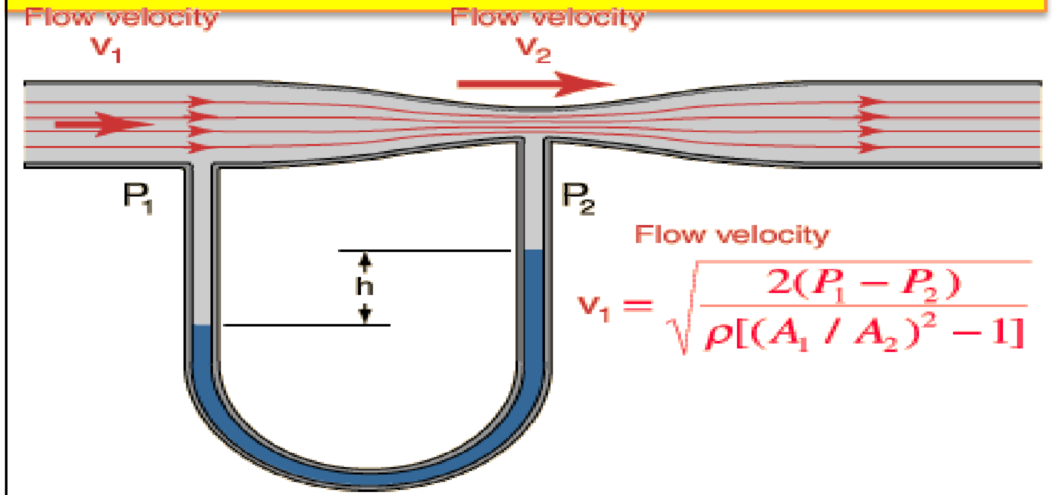


three typical obstruction meters



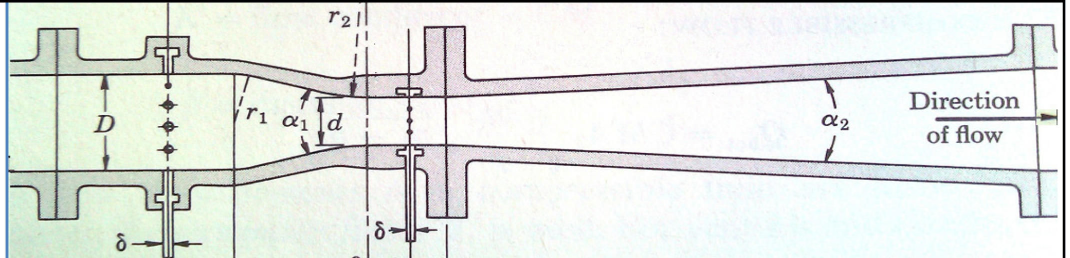
three typical obstruction meters

Practical considerations for Obstruction meters:

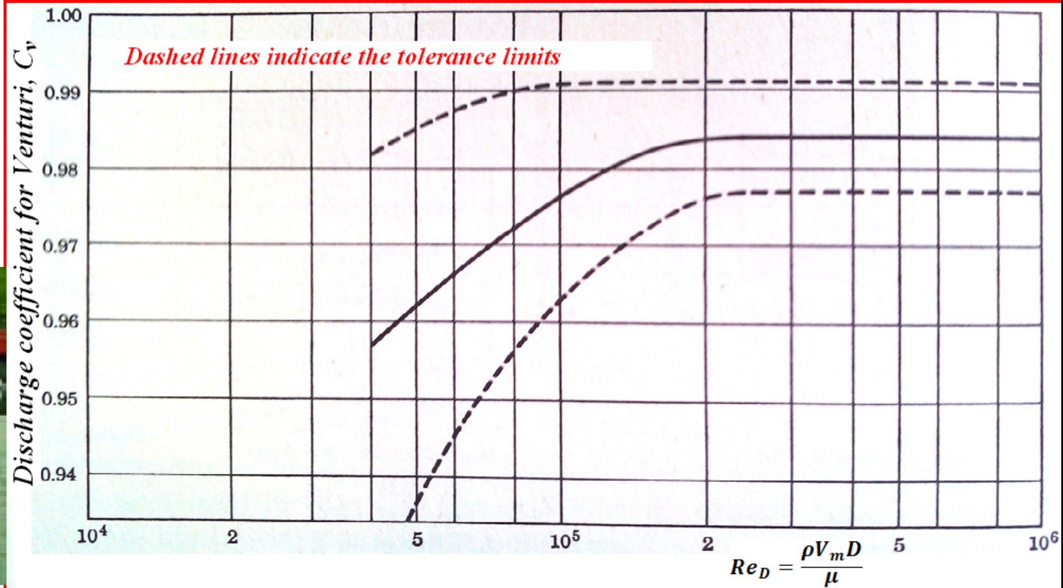


30" MODEL 2300 Westfall Venturi
30"x12.960 w/150 C.S. FLNG

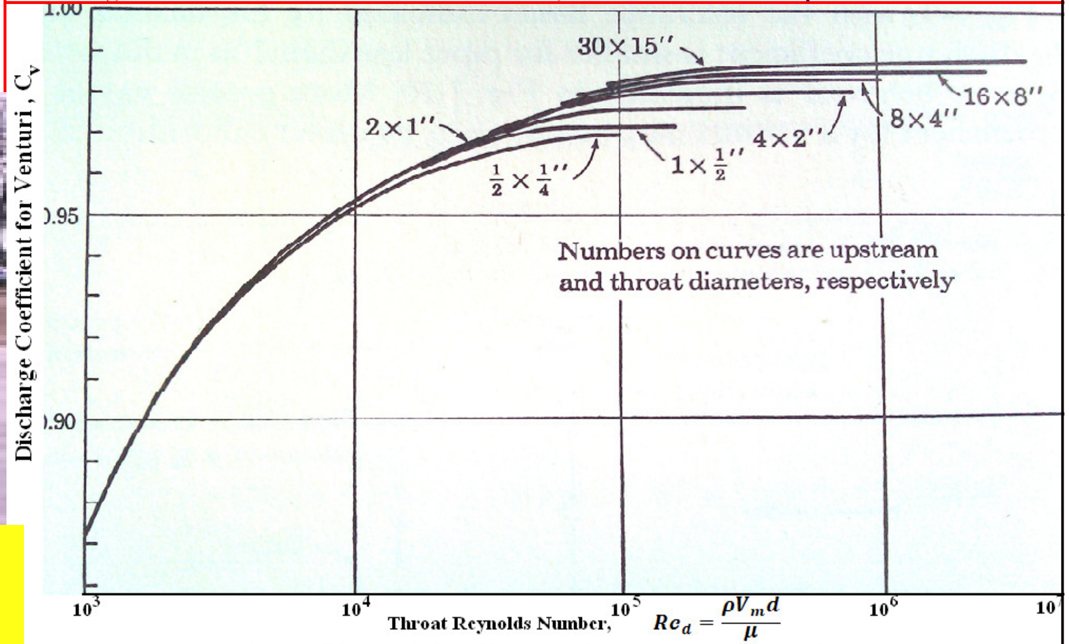
96" Vinyl ester fiberglass universal venturi tube
manufactured by Westfall Manufacturing Company for BIF. Pipe Size
96" S.S.Throat 60.9" Overall Length 186"



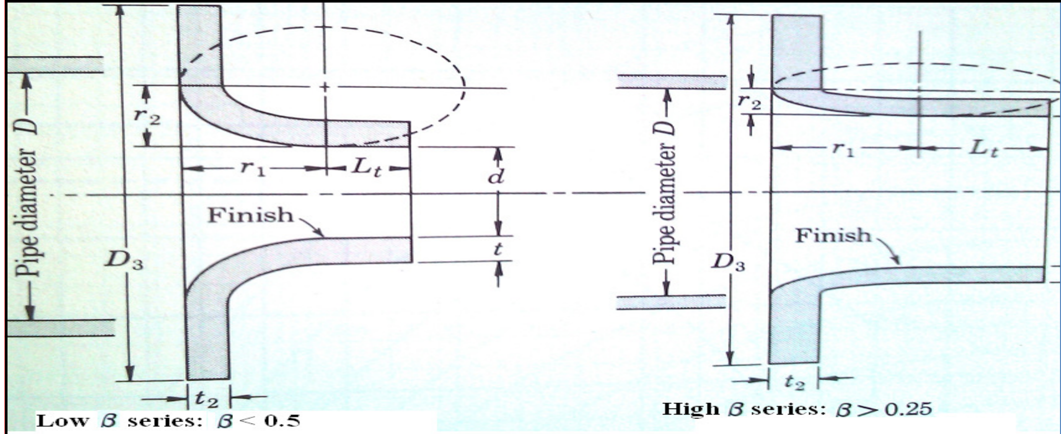
Some Recommended proportions of vinturi tubes



Discharge Coefficients for the Venturi tube shown; Values are for $0.25 < \beta < 0.75$ and $D > 2$ in.



Approximate Venturi Coefficients for various throat diameters



Recommended proportions of the ASME long-radius flow Nozzle meter.

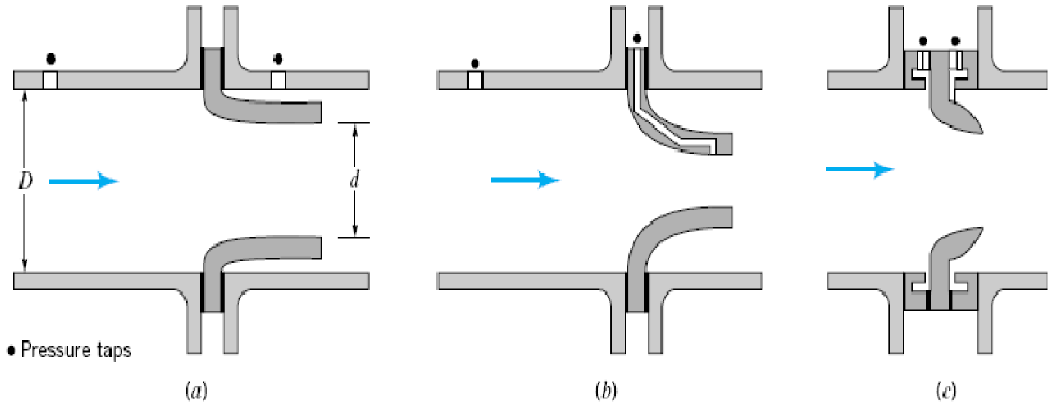
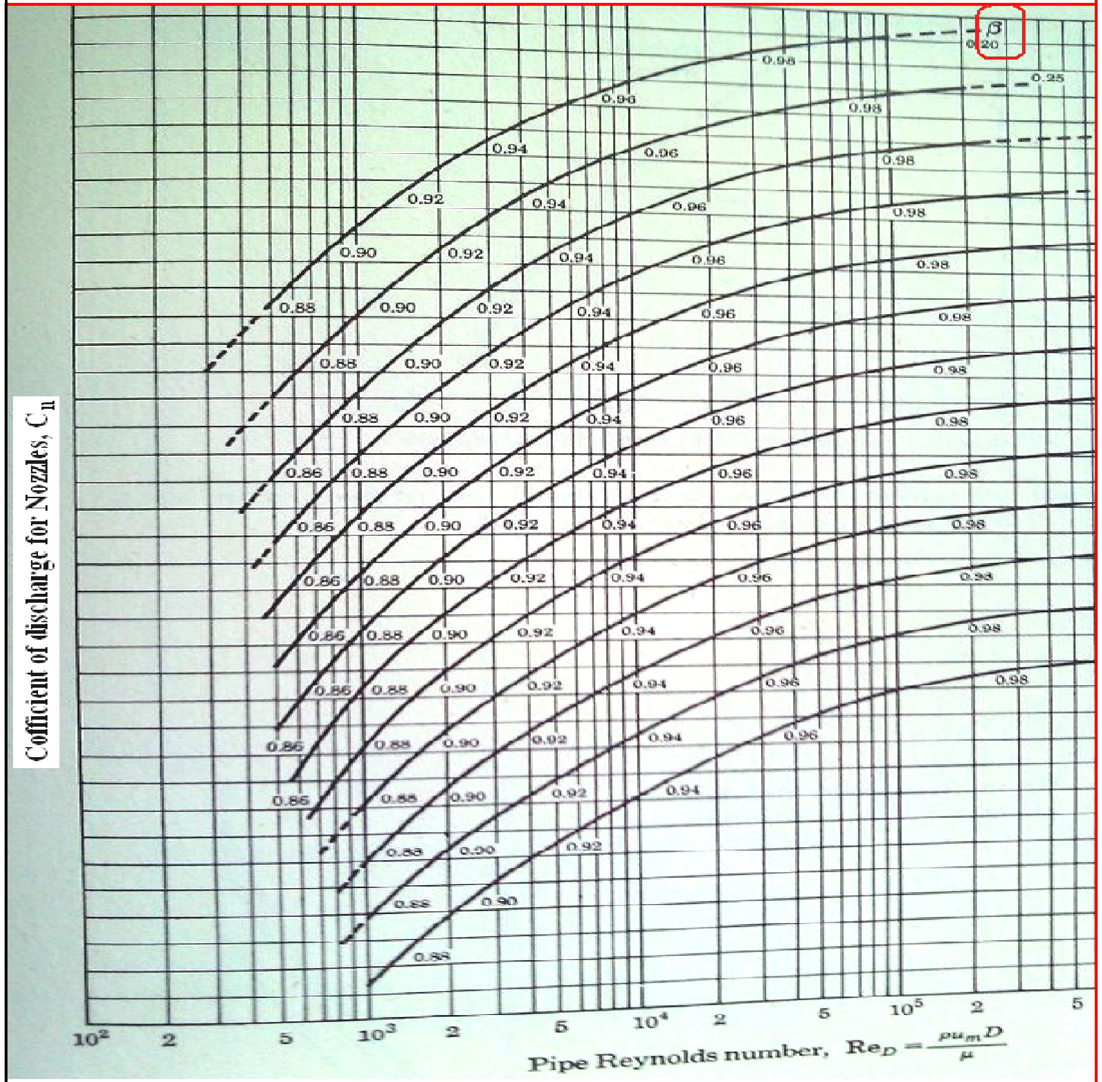
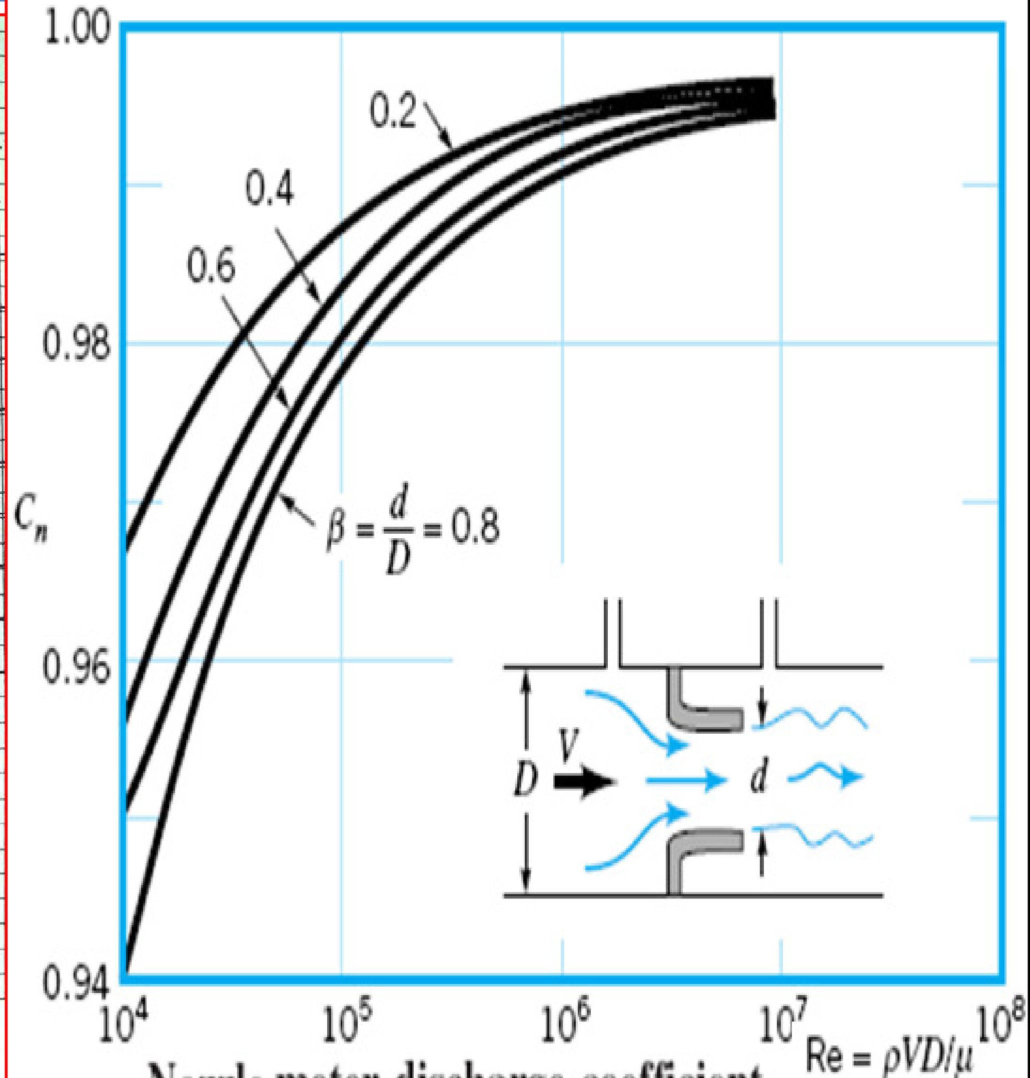


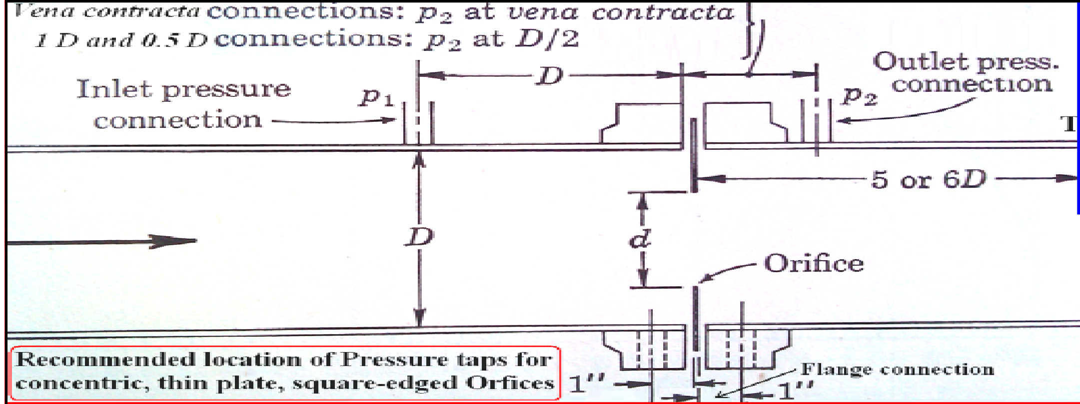
FIGURE 8.42 Typical nozzle meter construction.



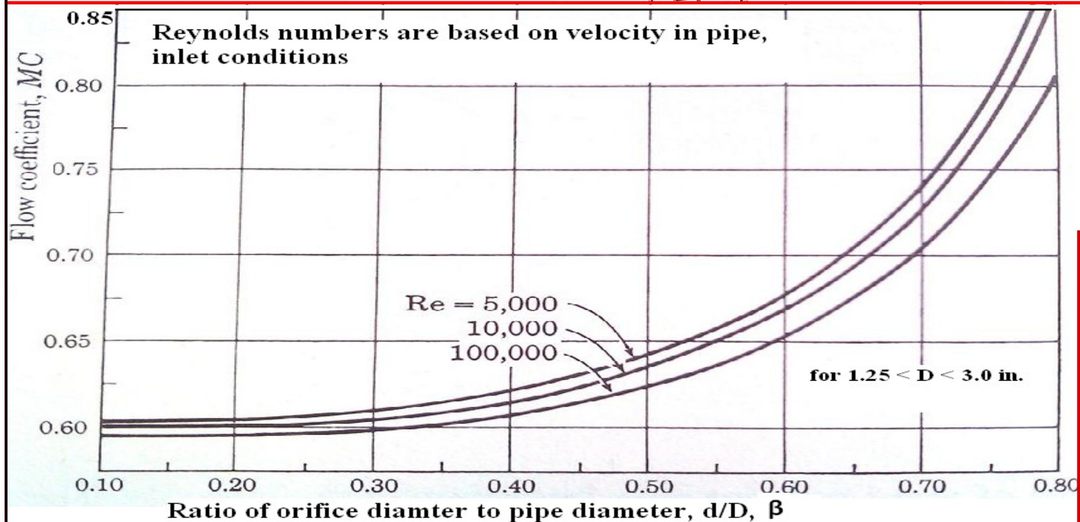
Discharge Coefficients for ASME long-radius nozzles



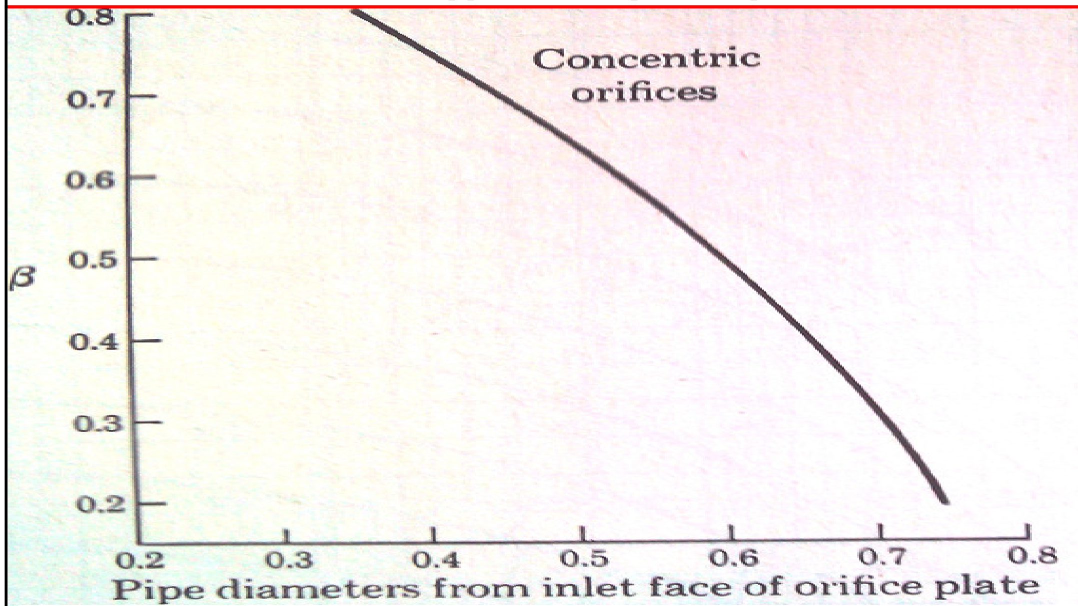
Nozzle meter discharge coefficient



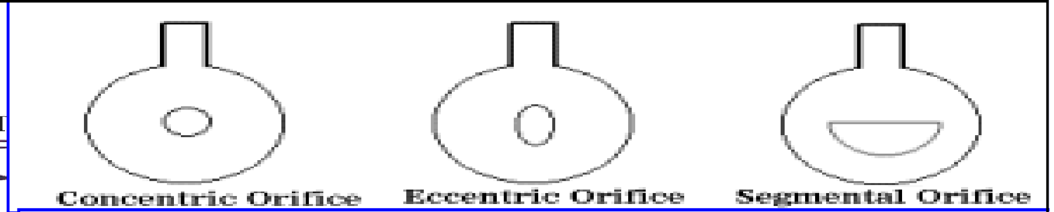
Recommended location of Pressure taps for concentric, thin plate, square-edged Orfices



Flow coefficients for concentric orifices in pipes. Pressure tapes one D upstream & 0.5D downstream.



Location of outlet pressure connectios for The Orifices



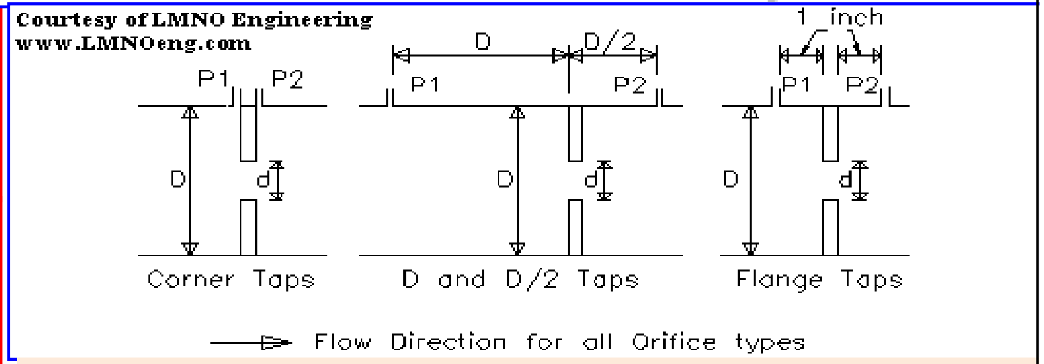
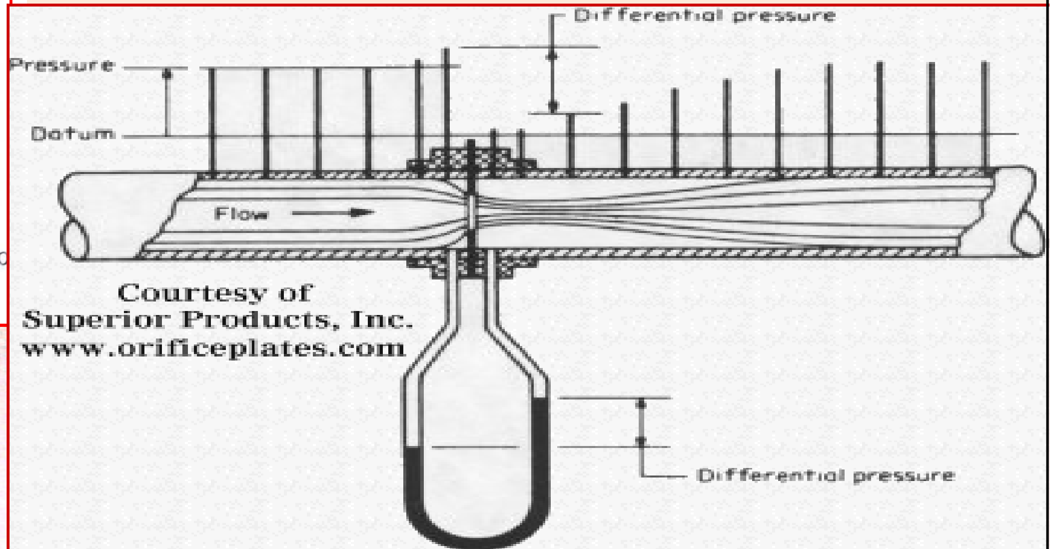
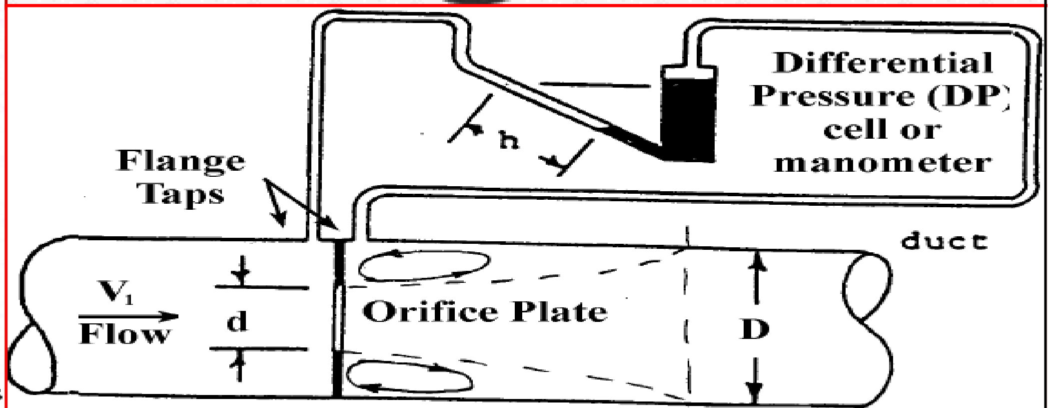


Figure 2: Various Tap Positions for Orifice Plates





Calibration of a Nozzle Flow Meter

Objective: volumetric flowrate, Q, of given fluid through a nozzle meter is proportional to the square root of the pressure drop across the meter. Thus, $Q = Kh^{1/2}$, where K is the meter calibration constant and h is manometer reading that measures the pressure drop across the meter (see Fig. P3.102). The purpose of this experiment is to determine the value of K for a given nozzle flow meter.

$$\boxed{Q_{act} = C\,A_2\sqrt{\frac{2\,g(p_1 - p_2)}{\rho(1-\beta^4)}}}$$

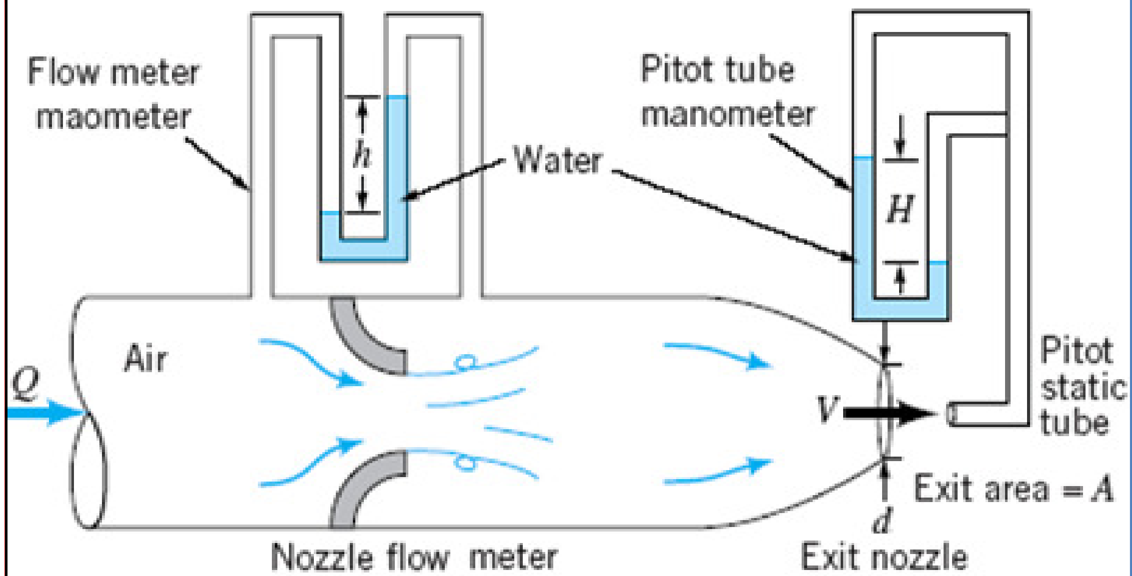
Equipment: Pipe with a nozzle flow meter; variable speed fan; exit nozzle to produce a uniform jet of air; Pitot static tube; manometers; barometer; thermometer.

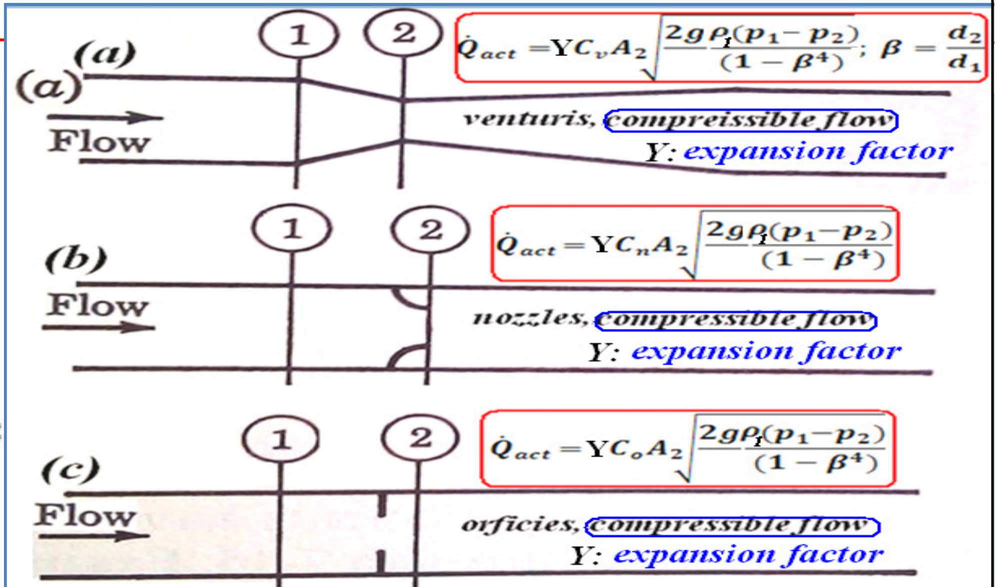
Experimental Procedure: Adjust the fan speed control to give the desired flowrate, Q. Record the flow meter manometer reading, h, and the Pitot tube manometer reading, H. Repeat the measurements for various fan settings (i.e., flowrates). Record the nozzle exit diameter, d. Record the barometer reading, H_{atm}, in inches of mercury and the air temperature, T, so that the air density can be calculated from the perfect gal law.

Calculations: For each fan setting determine the flowrate, $Q = VA$, where V and A are the air velocity at the exit and the nozzle exit area, respectively. The velocity, V, can be determined by using the Bernoulli equation and the Pitot tube manometer data, H

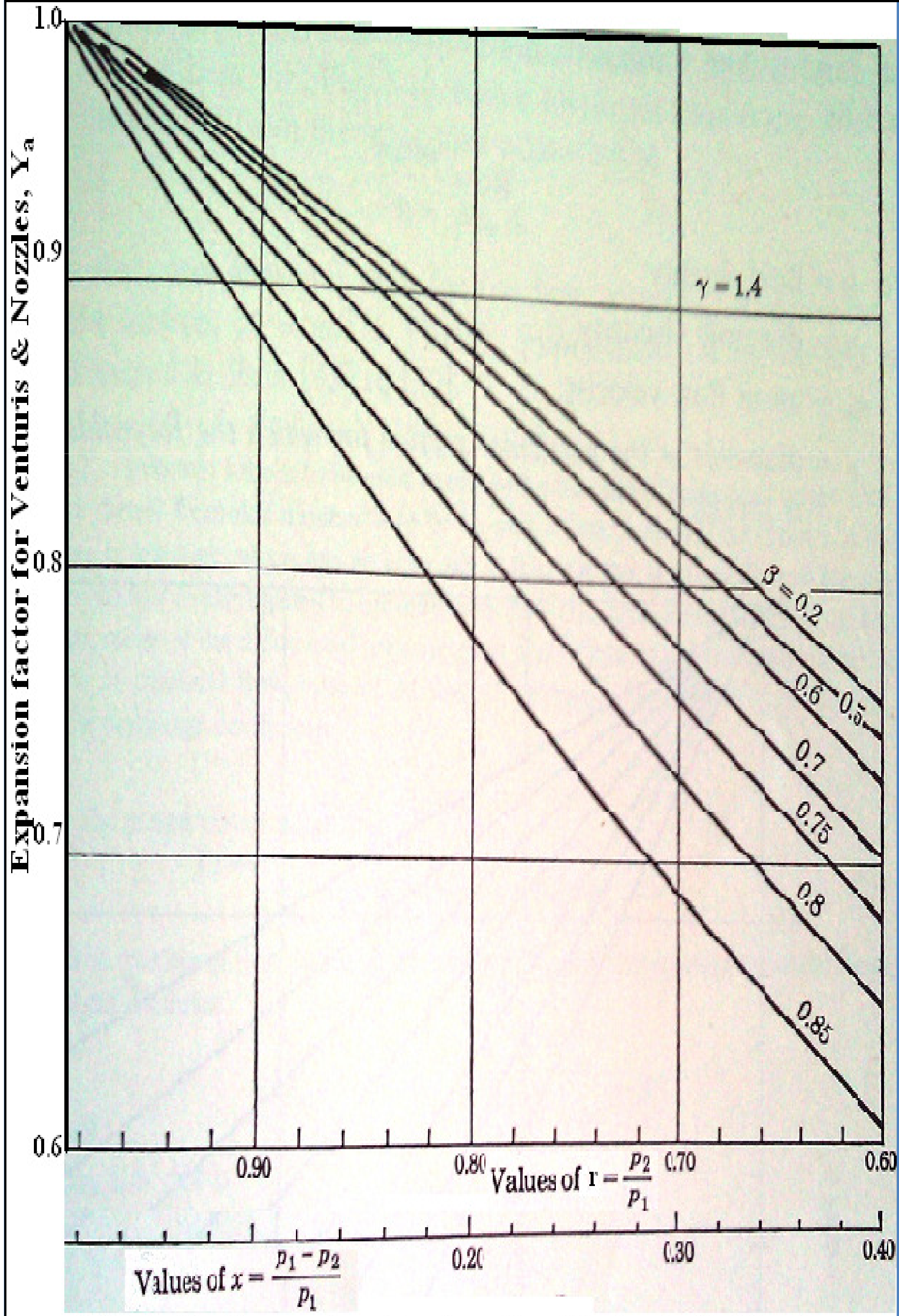
Graph: Plot flowrate, Q, as ordinates and flow meter manometer reading, h, as abscissas on a log-log graph. Draw the best-fit straight line with a slope of ½ through the data.

Results: Use your data to determine the calibration constant, K, in the flow meter equation $Q = Kh^{1/2}$.

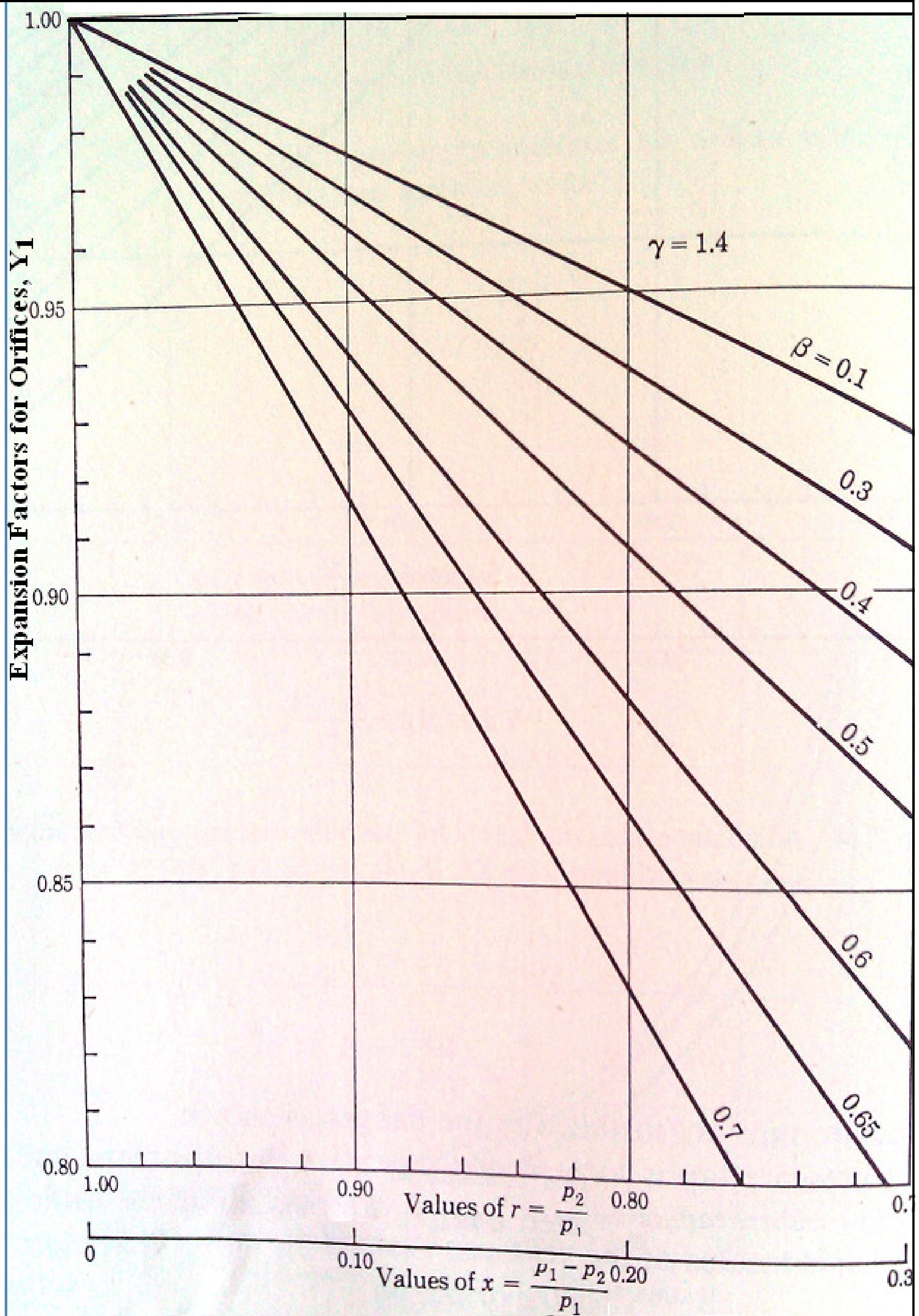




three typical obstruction meters



Adiabatic Expansion Factors for Venturis & Nozzles



Expansion Factors, Y_2 for square-edged orifices with pipe taps

Calibration of an Orifice Meter and a Venturi Meter

Objective: Because of various real-world, nonideal conditions, neither orifice meters nor Venturi meters operate exactly as predicted by a simple theoretical analysis. The purpose of this experiment is to use the device shown to calibrate an orifice meter and a Venturi meter.

Equipment: Water tank with sight gage, pump, Venturi meter, orifice meter, manometers.

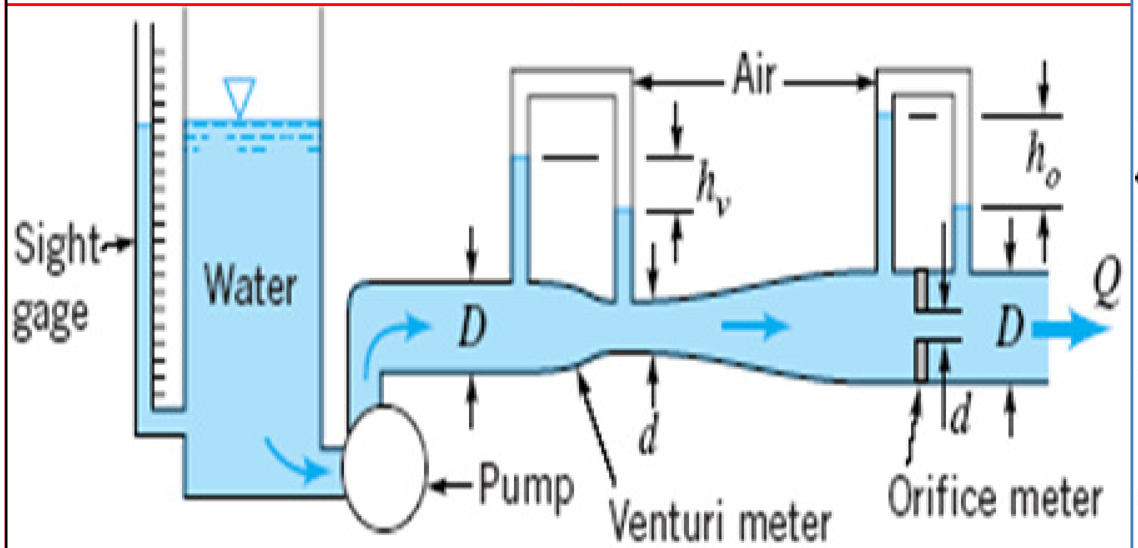
Experimental Procedure: Determine the pipe diameter, D, and the throat diameter, d, for the flow meters. Note that each meter has the same values of D and d. Make sure that the tubes connecting the manometers to the flow meters do not contain any unwanted air bubbles. This can be verified by noting that the manometer readings, h_v, and h_o, are zero when the system is full of water and the flowrate, Q, is zero. Turn on the pump and adjust the valve to give the desired flowrate. Record the time, t, it takes for a given volume, V, of water to be pumped from the tank. The volume can be determined from using the sight gage on the tank. At this flowrate record the manometer readings. Repeat for several different flowrates.

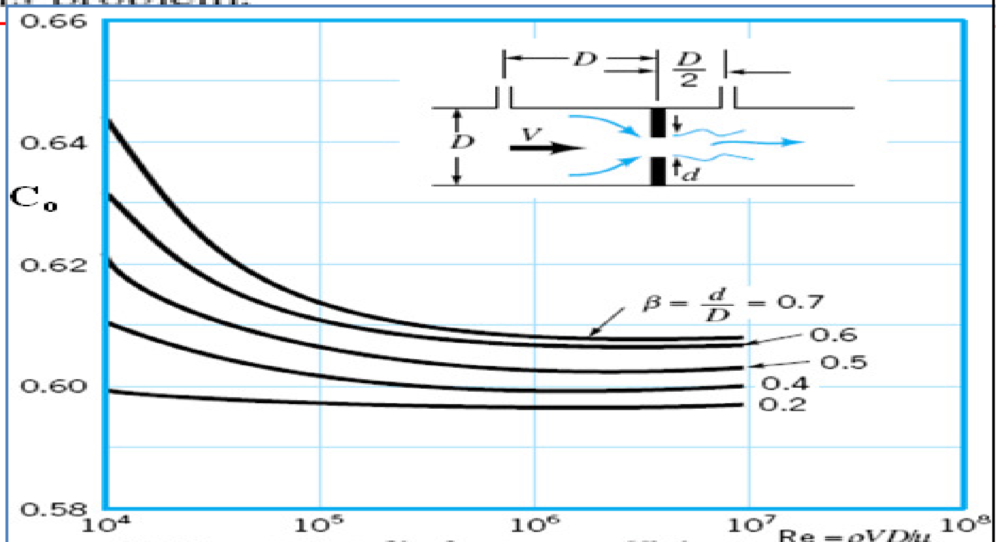
Calculations: For each data set determine the volumetric flowrate, $Q = V/t$, and the pressure differences across each meter, $\Delta p = \gamma_m h$, where γ_m is the specific weight of the manometer fluid. Use the flow meter equations (see Section 8.6.1) to determine the orifice discharge coefficient, C_o, and the Venturi discharge coefficient, C_v, for these meters.

Graph: On a log-log graph, plot flowrate, Q, as ordinates and pressure difference, Δp, as abscissas.

Result: On the same graph, plot the ideal flowrate, Q_{ideal} as function of pressure difference.

Data: To proceed, print this page for reference when you work the problem and *click here* to bring up an EXCEL page with the data for this problem.





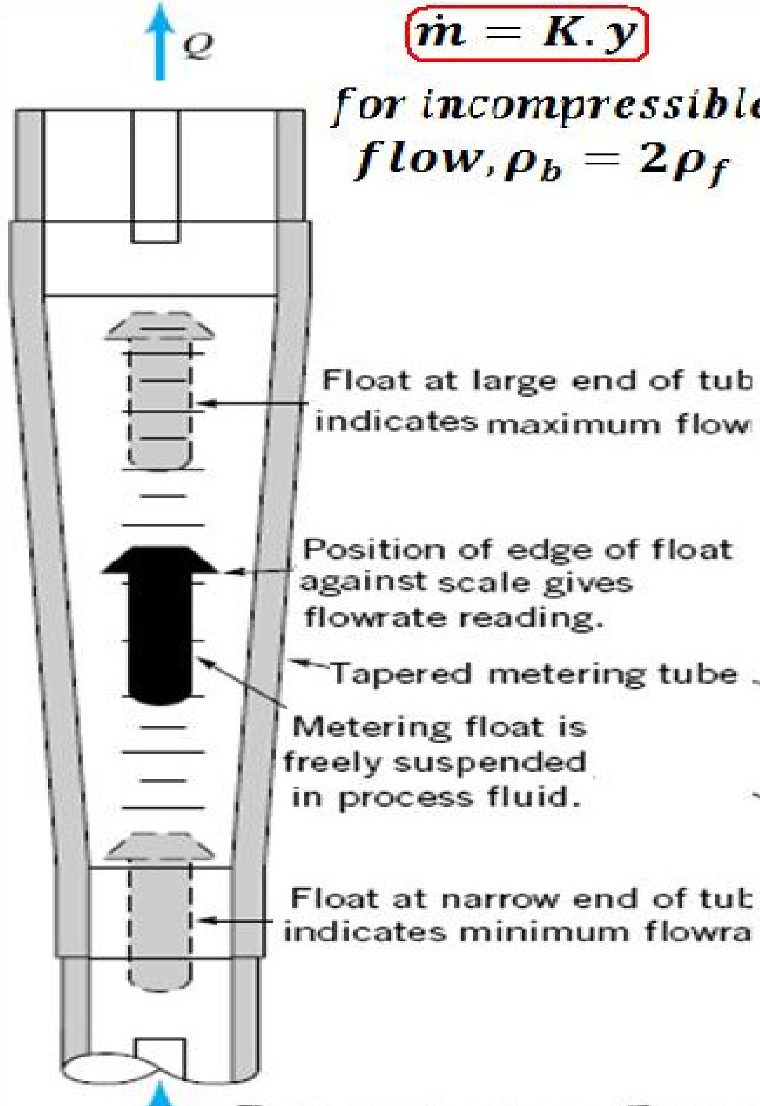
Orifice meter discharge coefficient

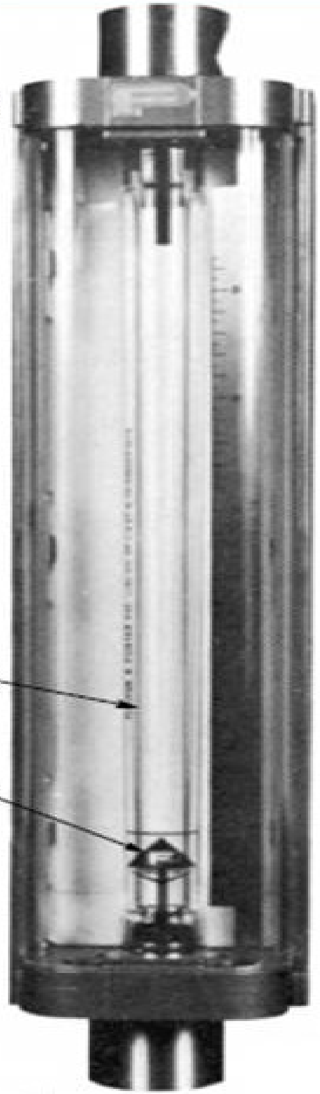
Flow Measurement by Drag Effects

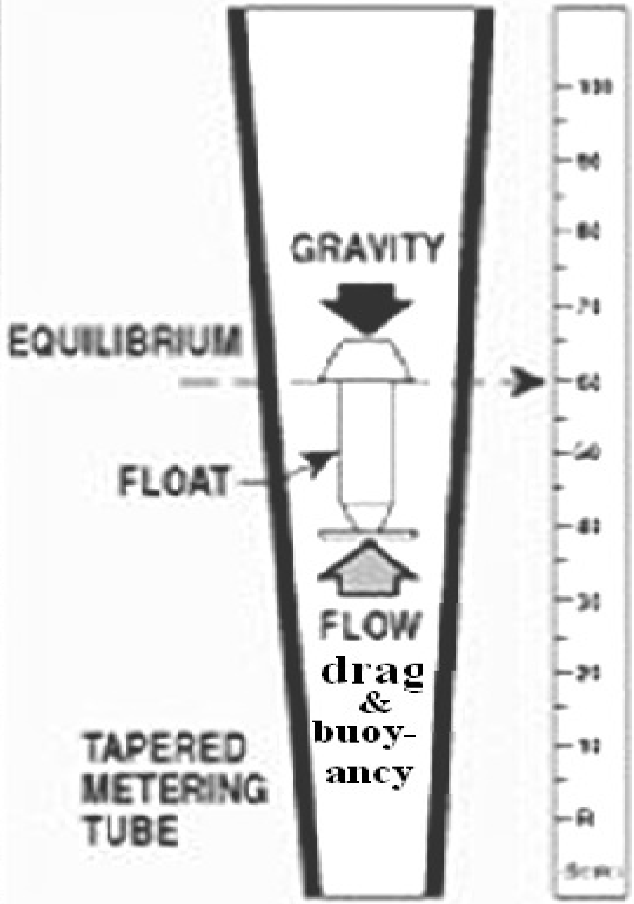
Rota-meter: **most widely, use variable area flow meter. cross section area available to flow varies with flow rate. Under (nearly) constant pressure drop, higher the volume flow rate, the higher flow path area. Variable-area meters, often called rotameters, consist essentially of tapered tube and float. Although classified as differential pressure units, they are, in reality, constant differential pressure devices. Flanged-end fittings provide an easy means for installing them in pipes. When there is no liquid flow, the float rests freely at the bottom of the tube. As liquid enters bottom of the tube, the float begins to rise. The position of the float varies directly with the flow rate. Its exact position is at the point where the differential pressure between the upper and lower surfaces balance the weight of the float.**

$\boxed{\dot{m} = K.y}$

for incompressible flow, $\rho_b = 2\rho_f$







Rotameter-type flow meter.

Calibration of a Rotameter

Objective: The flowrate, Q, through a rotameter can be determined from the scale reading, SR, which indicates the vertical position of the float within the tapered tube of the rotameter as shown in Fig. P7.75. Clearly, for a given scale reading, the flowrate depends on the density of the flowing fluid. The purpose of this experiment is to calibrate a rotameter so that it can be used for both water and air.

Equipment: Rotameter, air supply with a calibrated flow meter, water supply, weighing scale, stop watch, thermometer, barometer.

Experimental Procedure: Connect the rotameter to the water supply and adjust the flowrate, Q, to the desired value. Record the scale reading, SR, on the rotameter and measure the flowrate by collecting a given weight, W, of water that passes through the rotameter in a given time, t. Repeat for several flow rates.

Connect the rotameter to the air supply and adjust the flowrate to the desired value as indicated by the flow meter. Record the scale reading on the rotameter. Repeat for several flowrates. Record the barometer reading, H_{atm}, in inches of mercury and the air temperature, T, so that the air density can be calculated by use of the perfect gas law.

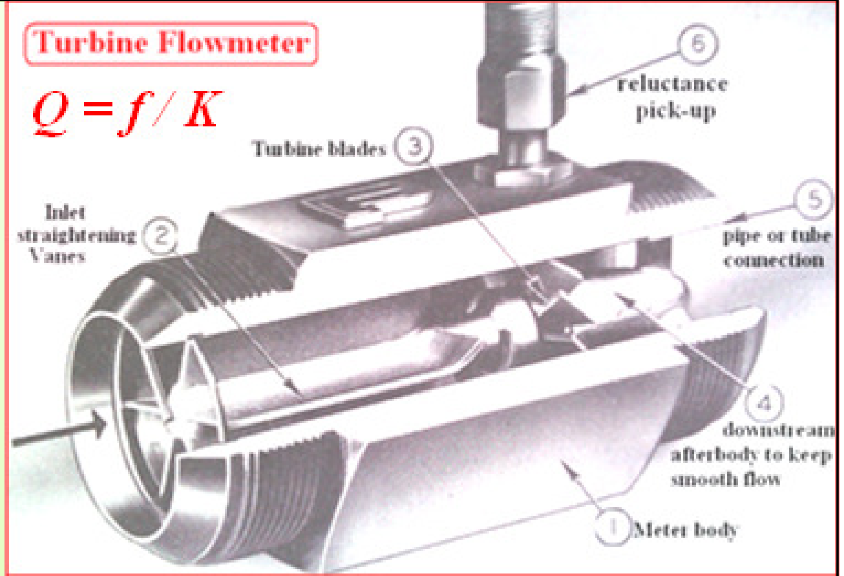
Calculations: For the water portion of the experiment, use the weight, W, and time, t, data to determine the volumetric flowrate, $Q = W/\gamma t$. The equilibrium position of the float is a result of a balance between the fluid drag force on the float, the weight of the float, and the buoyant force on the float. Thus, a typical dimensionless flowrate can be written as $Q/[d(\rho/Vg(\rho_f - \rho))^{1/2}]$, where d is the diameter of the float, V is the volume of the float, g is the acceleration of gravity, ρ is the fluid density, and ρ_f is the float density. Determine this dimensionless flowrate for each condition tested.

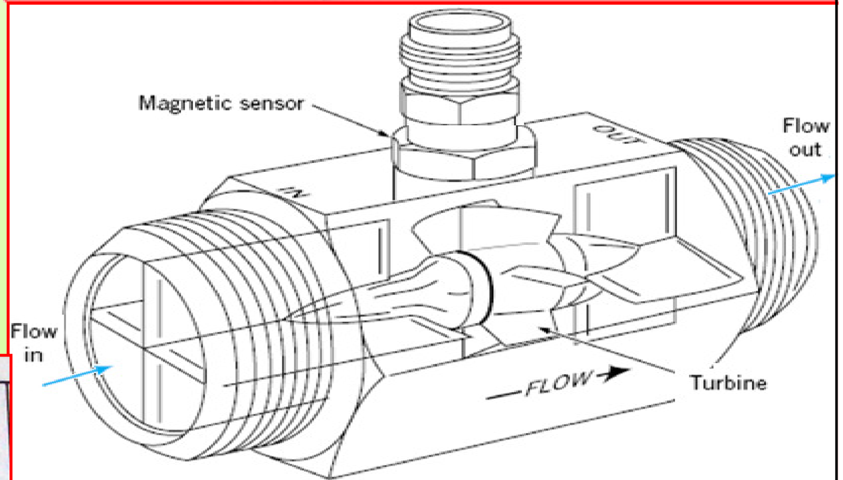
Graph: On a single graph, plot the flowrate, Q, as ordinates and scale reading, SR, as abscissas for both the water and air data.

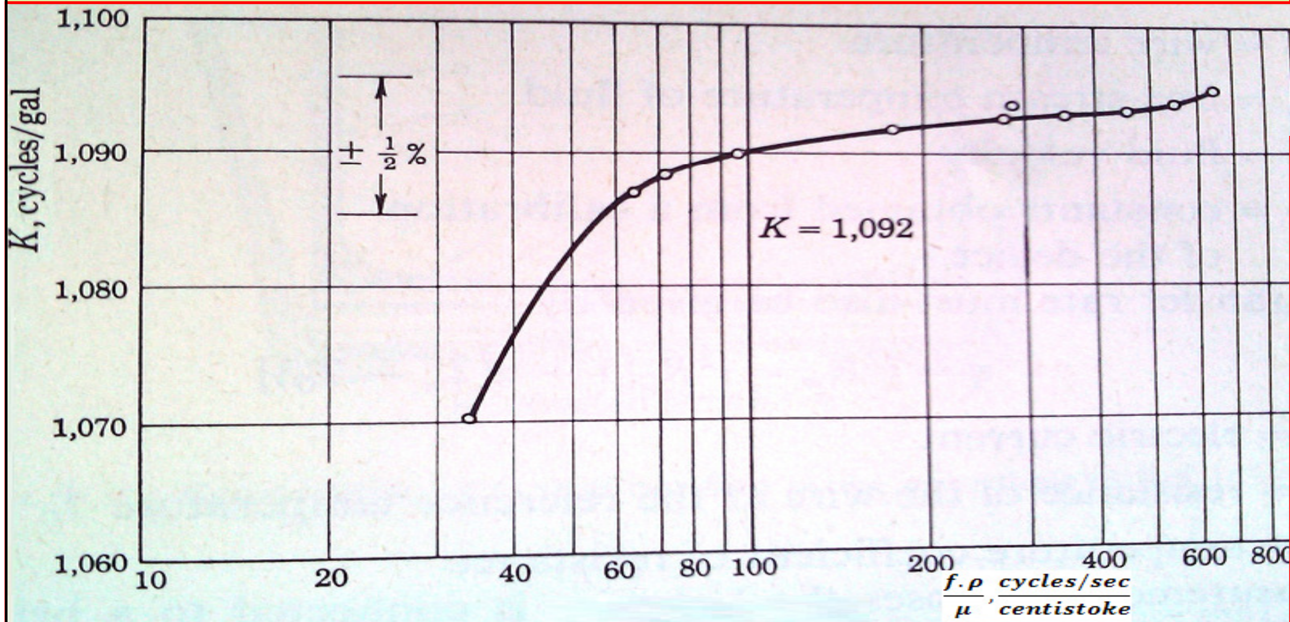
Results: On another graph, plot the dimensionless flowrate as a function of scale reading for both the water and air data. Note that the scale reading is a percent of full scale and, hence, is a dimensionless quantity. Based on your results, comment on the usefulness of dimensional analysis.

Data: To proceed, print this page for reference when you work the problem and *click here* to bring up an EXCEL page with the data for this problem.

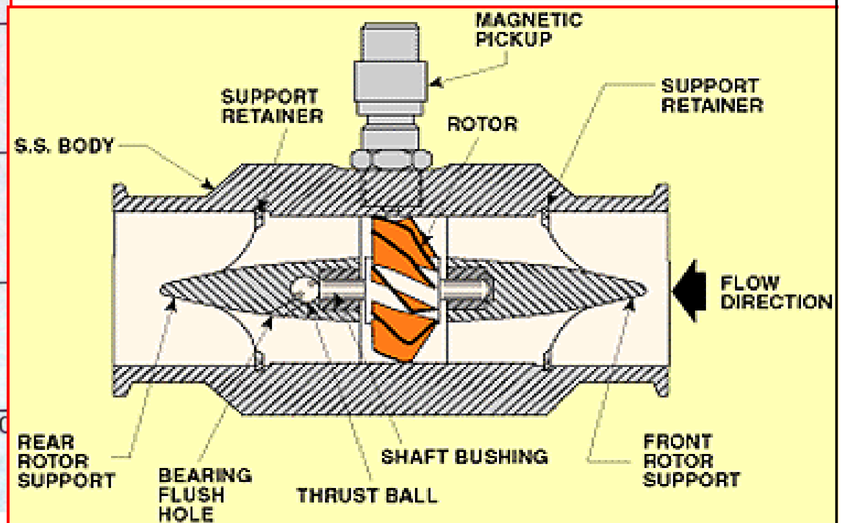
Turbine-meter: has a wide spread usage for an accurate liquid measurements. Rotational speed is direct function of flow rate and sensed by magnetic pick-up, photoelectric cell, or gears. Electrical pulses can be counted and totalized. The Number of electric pulses counted for given period of time is proportional to flow rate. Tachometer can be used to measure turbine's speed to determine flow rate. Turbine meters, when properly specified and installed, have good accuracy, particularly with low-viscosity liquids. A major concern with turbine meters is bearing wear. A "bearing-less" design has been developed to avoid this problem. Liquid entering meter travels through the spiraling vanes of stator that imparts rotation to liquid stream that acts on sphere, causing it to orbit in space between 1st stator and similarly spiraled 2nd stator. Orbiting movement of sphere is detected electronically. Frequency of pulse output is proportional to flow rate.



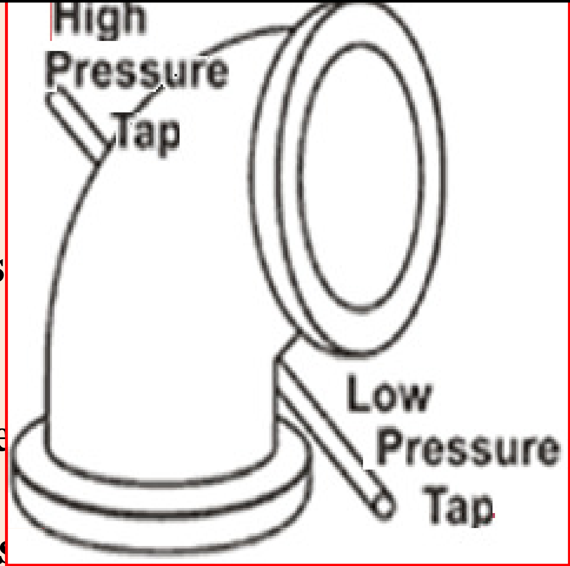


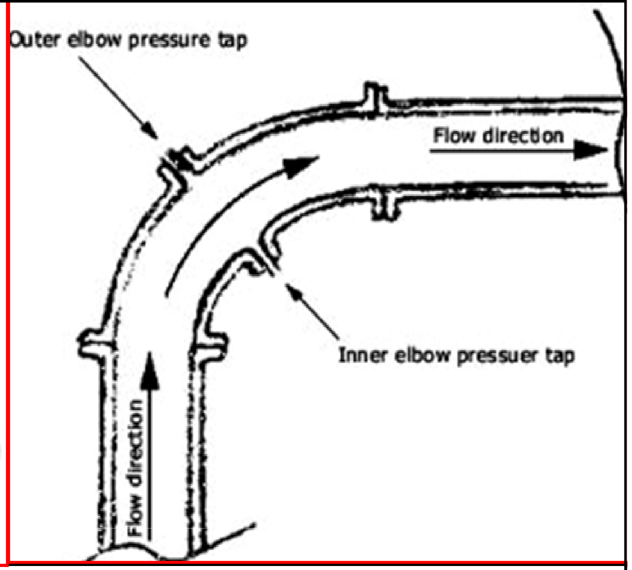


Calibration curve for 1-in Turbine flowmeter with water flow

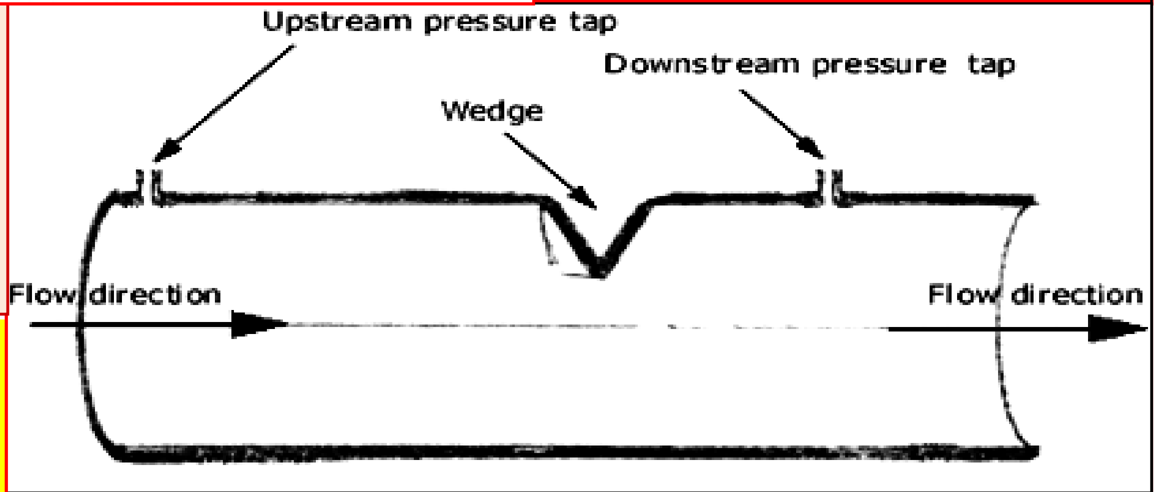


Elbow meters: **if a liquid travels in a circular path, centrifugal force exerted along outer edges. Thus, when liquid flows through pipe elbow, force on the elbow's interior surface is proportional to the density of the liquid times square of its velocity. In addition, the force is inversely proportional to the elbow's radius. As the fluid passes through the pipe elbow,the pressure at outside radius of elbow increases due to the centrifugal force. The pressure taps located at the outside & inside of the elbow at 22.5 or 45 degrees will generate reproducible measurement. The taps located at angles > 45º are not recommended as flow separation may cause erratic readings.**

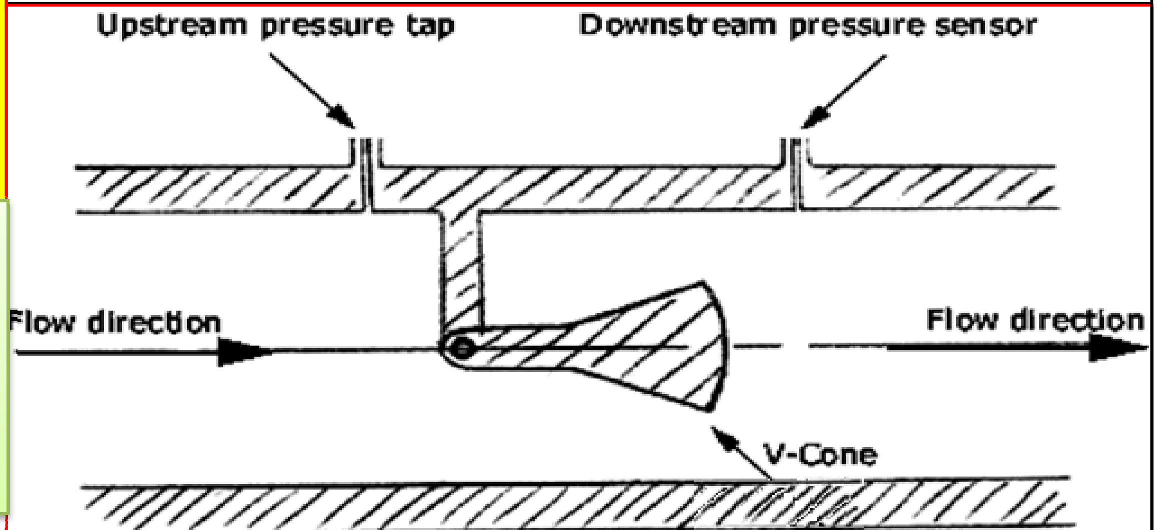




Segmental Wedge: **it consisted of a wedge-shaped segment is inserted perpendicularly into one side of the pipe while the other side remains unrestricted. The change in cross section area of the flow path creates pressure drops used to calculate flow velocities.**



V-Cone meter : **A cone shaped obstructing element that serves as the cross section modifier is placed at the center of the pipe for calculating flow velocities by measuring the pressure differential.**



Target meters sense&measure forces caused by liquid impacting on a target or drag-disk suspended in the liquid stream. A direct indication of liquid flow rate is achieved by measuring force exerted on target. In its simplest form, the meter consists only of a hinged, swinging plate that moves outward, along with the liquid stream. In such cases, the device serves as a flow indicator. A more sophisticated version uses a precision, low-level force transducer sensing element. The force of the target caused by the liquid flow is sensed by a strain gage. The output signal from the gage is indicative of the flow rate. Target meters are useful for measuring flows of dirty or corrosive liquids.

Vortex meters : make use of a natural phenomenon that occurs if liquid flows a around bluff object. The eddies or the vortices are shed alternately downstream of the object. Frequency of vortex shedding is directly proportional to velocity of the liquid flowing through the meter, Fig. 6. There components of flow meter are bluff body strut-mounted across flow meter bore, a sensor to detect the presence of vortex and to generate electrical impulse,& signal amplification and the conditioning transmitter whose output is in direct proportional to flow rate, Fig. 7. The meter is equally suitable for flow rate or flow totalization measurements. Use for slurries or high viscosity liquids is not recommended.

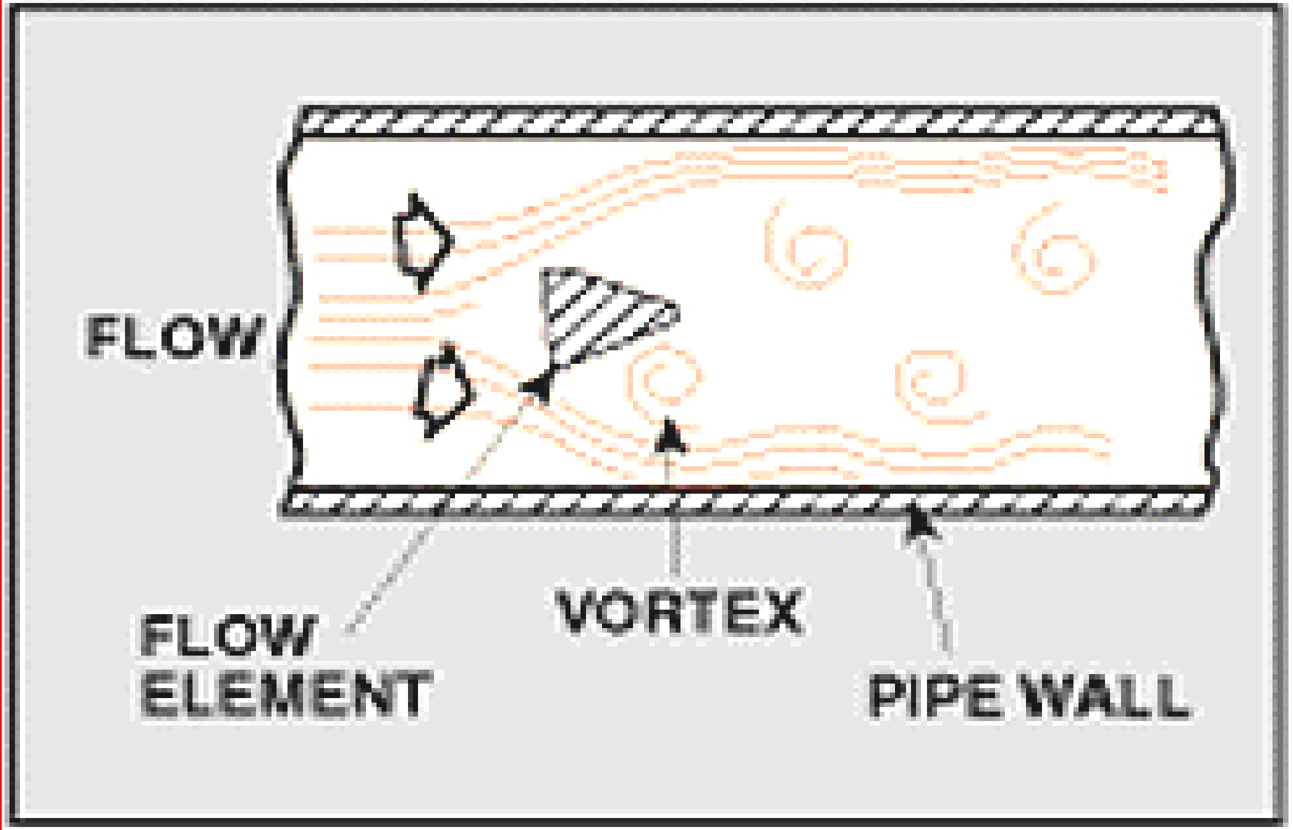
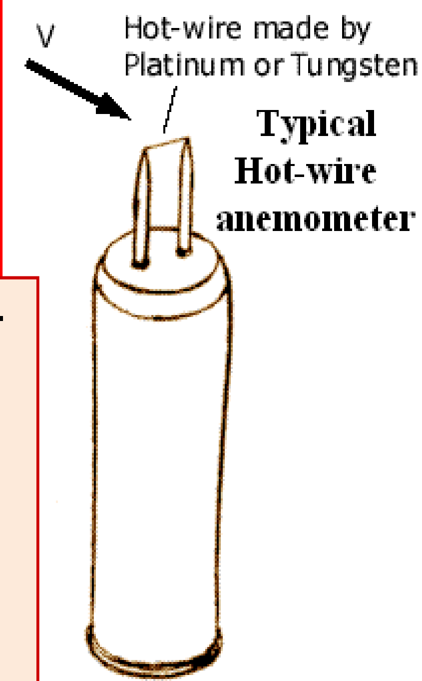


Figure 6: Vortex meters operate on the principle that when a nonstreamlined object is placed in the middle of a flow stream, a series of vortices are shed alternately downstream of the object. The frequency of the vortex shedding is directly proportional to the velocity of the liquid flowing in the pipeline

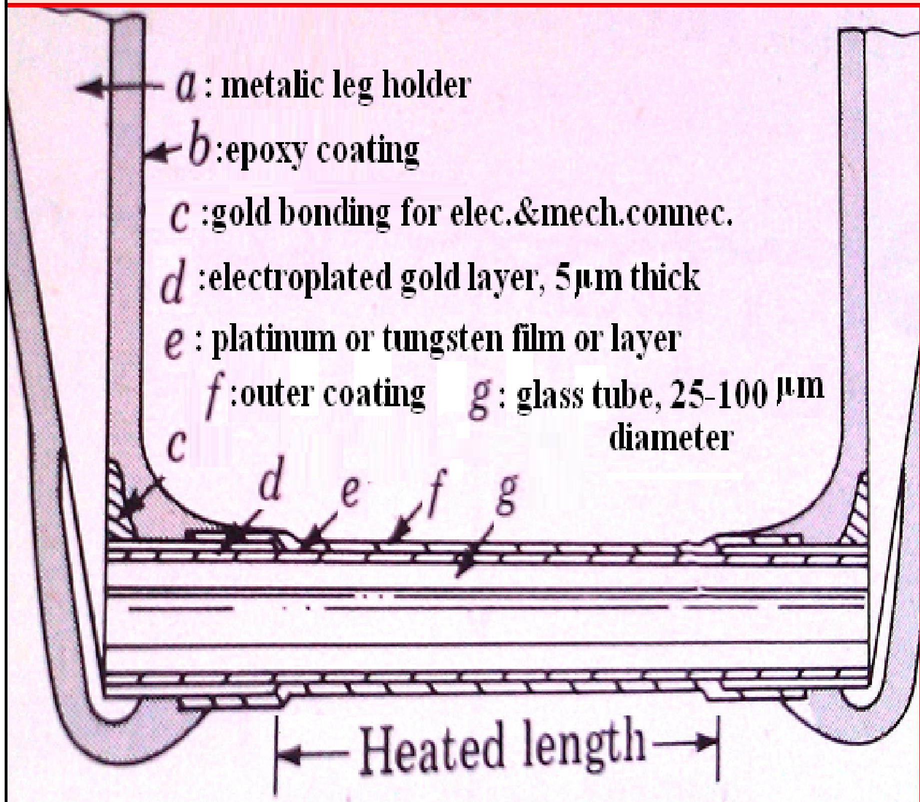
Figure 7: Vortex Flowmeter is designed to be installed directly into pipelines without the need for special tools or complicated installation procedures. Unit is precalibrated and ready for use.

Figure 8: Wafer-type electromagnetic flowmeter is lightweight, compact, and can be easily installed between existing pipe flanges. The no-moving-part instrument has negligible pressure drop and can handle numerous liquids and slurries, provided they are conductive.

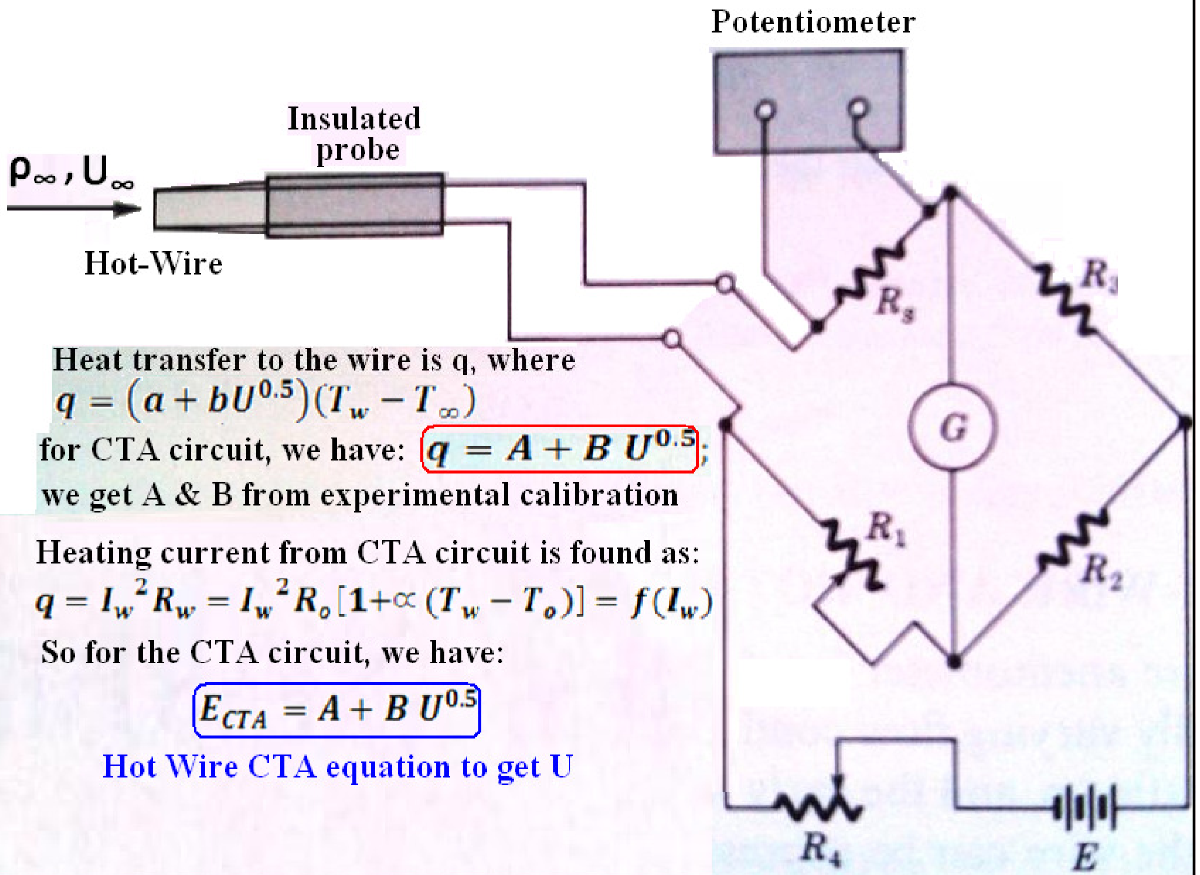
Velocity Meters : **These instruments operate linearly with respect to volume flow rate. Because there is no square-root relationship (as with differential pressure devices), their rangeability is greater. Velocity meters have minimum sensitivity to viscosity changes when used at Reynolds numbers above 10,000. Most velocity-type meter housings are equipped with flanges or fittings to permit them to be connected directly into pipelines..**



Hot-Wire & Hot-Film Anemometers: **used in research applications to study turbulence. The Hot-Wire Anemometer is the most well known thermal anemometer, and measures a fluid velocity by noting the heat convected away by the fluid. The core of the anemometer is an exposed hot wire either heated up by a constant current or maintained at a constant temperature (refer to the schematic below). In either case, the heat lost to fluid convection is a function of the fluid velocity. By measuring the change in wire temperature under constant current or the current required to maintain a constant wire temperature, the heat lost can be obtained. The heat lost can then be converted into a fluid velocity in accordance with convective theory .**



Construction of typical fot-film probe



Heat transfer to the wire is q, where

$$q = (a + bU^{0.5})(T_w - T_\infty)$$

for CTA circuit, we have: $\boxed{q = A + B\,U^{0.5}}$;

we get A & B from experimental calibration

Heating current from CTA circuit is found as:

$$q = I_w^{\,2} R_w = I_w^{\,2} R_o[1 + \propto (T_w - T_o)] = f(I_w)$$

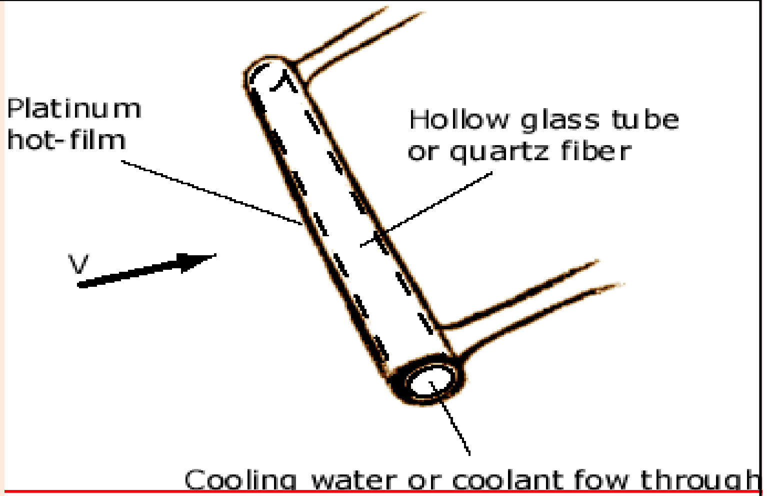
So for the CTA circuit, we have:

$$\boxed{E_{CTA} = A + B\,U^{0.5}}$$

Hot Wire CTA equation to get U

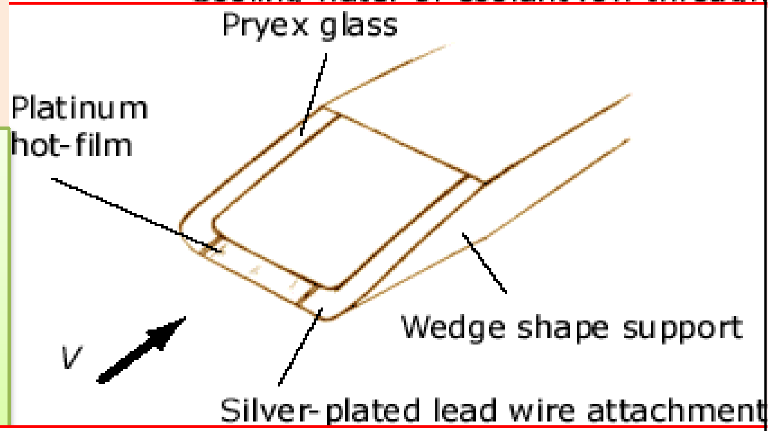
Further Information

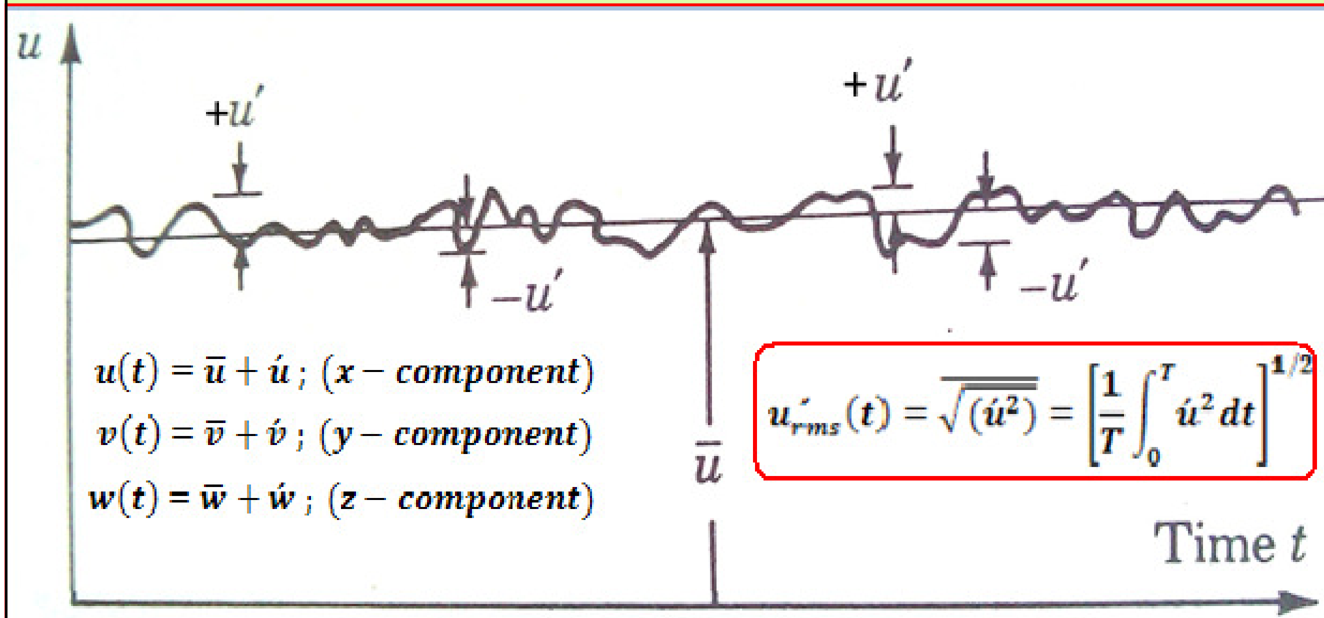
Typically, anemometer wire is made of platinum or tungsten and is 4~ 10 μm diameter& 1 mm length. Typical commercially available hot-wire anemometers have a flat frequency response (< 3 dB) up to 17kHz at average velocity 9.1 m/s, 30 kHz at 30.5 m/s, or 50 kHz at 91 m/s. Due to tiny size of wire, it is fragile & thus suitable only for clean gas flows. In liquid flow or rugged gas flow, a platinum hot-film coated on a 25 ~ 150 mm diameter quartz fiber or hollow glass tube can be used instead, as shown in schematic. Another alternative is a pyrex glass wedge coated with a thin platinum hot-film at the edge tip, as shown schematically below.



Pros: **Excellent spatial resolution, High frequency response, 10 kHz (up to 400 kHz). X-wire can be used to measure *u* & *v*.**

Cons: Fragile, can be used only in clean gas flows, Needs to be recalibrated frequently due to dust accumulation (unless the flow is very clean), High cost.

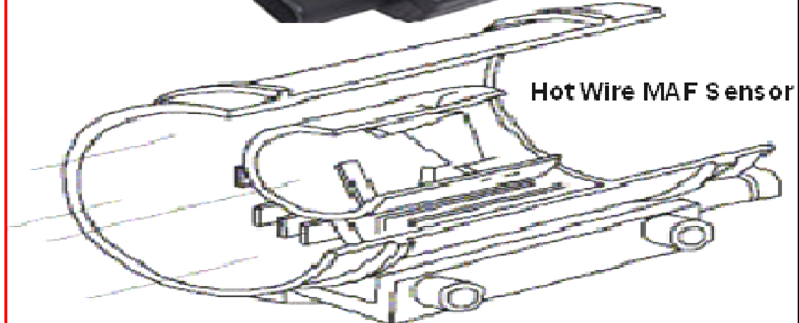




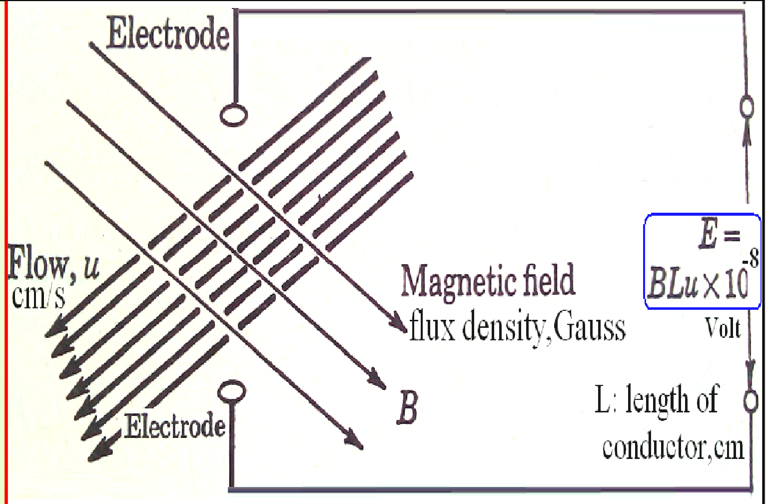
$$u(t) = \bar{u} + \acute{u}\,;\ (x-component)$$
$$v(t) = \bar{v} + \acute{v}\,;\ (y-component)$$
$$w(t) = \bar{w} + \acute{w}\,;\ (z-component)$$

$$\boxed{u'_{rms}(t) = \sqrt{\overline{(\acute{u}^2)}} = \left[\frac{1}{T}\int_0^T \acute{u}^2\,dt\right]^{1/2}}$$

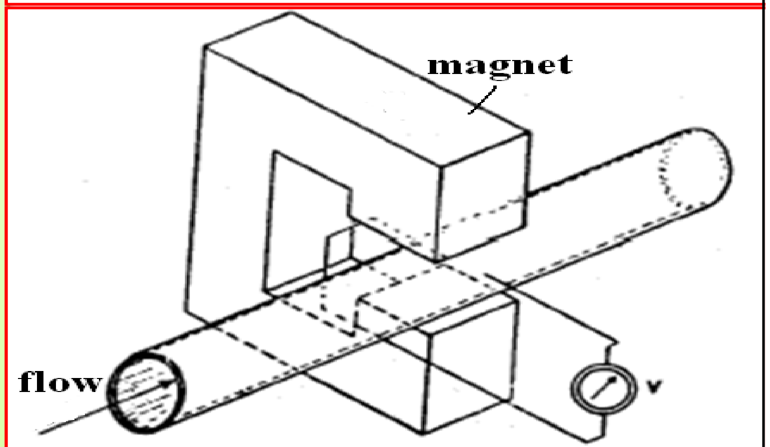
Turbulent fluctuations in direction of flow



Magnetic Flowmeters: useful to measure conductive liquids or slurries. Due to the material conductivity they require for operation, they are not used in petroleum industry for measuring hydrocarbons. The operation of magnetic meters is based on Faraday's law of electromagnetic induction. Magnetic meters can detect flow of conductive fluids only. Early designs required a minimum fluidic conductivity of 1-5 micro siemens/centimeter for operation. Newer designs have reduced requirement hundredfold to between 0.05 &0.1. Magnetic meter consists of non-magnetic pipe lined with insulating material. A pair of magnetic coils is situated as shown, and pair of electrodes penetrates pipe and its lining. If a conductive fluid flows through pipe of diameter(D) through magnetic field density (B) generated by the coils, amount of voltage (E) developed across electrodes--as Faraday's law--will be proportional to the velocity (V) of liquid. Because magnetic field density&pipe diameter are fixed values, they can be combined into calibration factor (K) and the equation reduces to: $E = K\,V$



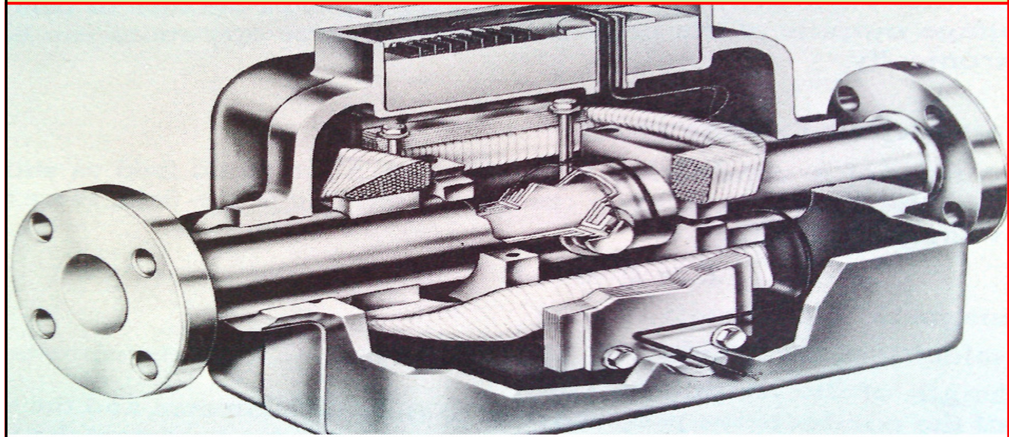
Flow of conducting fluid through a magnetic field



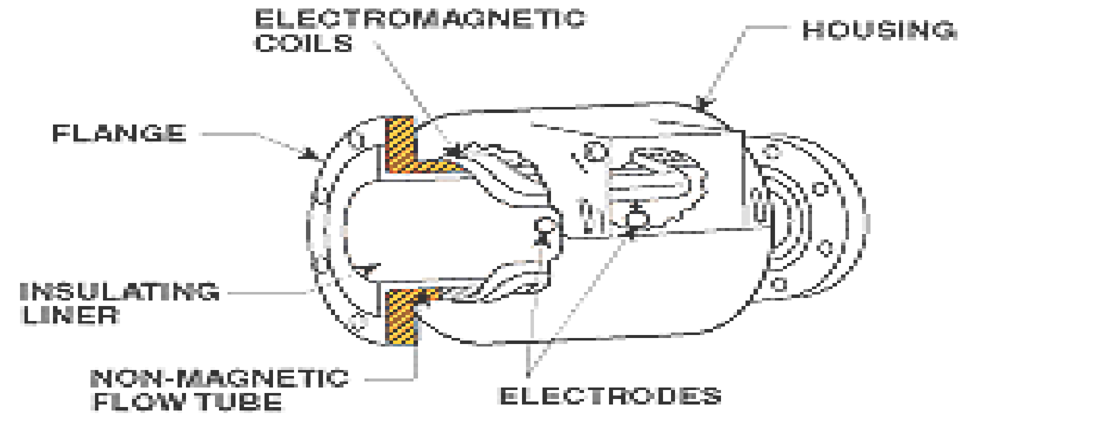
Elements of electromagnetic flow meter

Velocity differences at different points of flow profile are compensated for by a signal-weighing factor. Compensation is provided by shaping magnetic coils such that magnetic flux will be greatest where signal weighing factor is lowest, and vice versa. Manufacturers determine each magmeter's K factor by water calibration of each flowtube. The K value thus obtained is valid for any other conductive liquid and is linear over the entire flowmeter range. For this reason, flowtubes are usually calibrated at only one velocity. Magmeters can measure flow in both directions, as reversing direction will change the polarity but not the magnitude of the signal. The K value obtained by water testing might not be valid for non-Newtonian fluids (with velocity-dependent viscosity) or magnetic slurries (those containing magnetic particles). These types of fluids can affect the density of the magnetic field in the tube. In-line calibration and special compensating designs should be considered for both of these fluids.

Advantages of electromagnetic fmeters: can measure difficult and corrosive liquids and slurries; and can measure forward as well as reverse flow with equal accuracy. **Disadvantages** of earlier designs high power consumption, and the need to obtain a full pipe and no flow to initially set meter to zero. Recent improvements have eliminated these problems. Pulse-type excitation techniques have reduced power consumption, because excitation occurs only half the time in the unit. Zero settings are no longer required.



Commercial magnetic flowmeter for low-conductivity fluids



Major components of obstruction-free electromagnetic flowmeter's flow tube include electrodes and coils.

They are very useful, however, for measuring such things as water slurries, which most other meters cannot measure. They are made in sizes from fractions of an inch through almost 100 inches. Since they operate on velocity, their equations to convert from flowing to base conditions are the same as for turbine meters.

Density and viscosity do not directly affect meter operation. The meter operates bidirectionally, provided upstream lengths are used on both sides of the meter to control the velocity pattern. Since the meter is full line size, there is no pressure drop caused by the meter other than normal pipe loss. The meters are fairly expensive and have a high operating cost because of the high power requirements. In the large sizes, they are quite heavy and require special considerations for installation and removal.

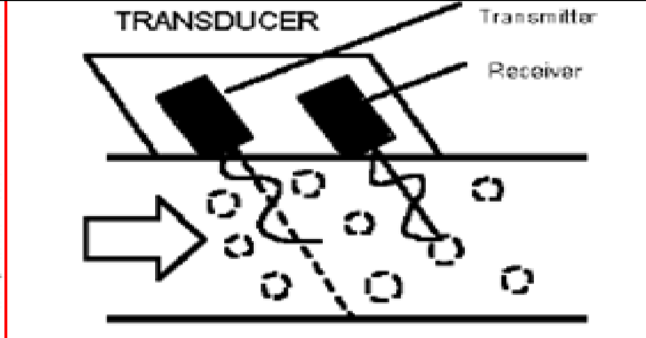
Advantages of magnetic meters:

1. Performance not affected by changes in viscosities and densities;
2. Full-bore opening means no head loss;
3. Meters will operate bidirectionally with required upstream lengths installed on both sides of meters; and
4. Available with insert liners that allow use on some corrosive and erosive fluids.

Disadvantages of magnetic meters:

1. Installation and operating costs relatively high because of size, weight, and electrical power costs;
2. Fluids must have at least the minimum conductivity specified by manufacturer of the specific meter; and
3. Used for liquids or slurries but *not* gases.

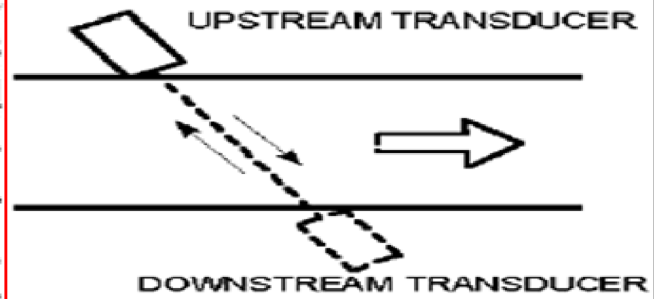
Ultrasonic Meters category contains a number of different designs for measuring an average velocity in a flowing system. They are all based on an ultrasonic signal being changed by or reflected from the flowing stream velocity. Meter accuracy relates to the ability of the system to represent the average velocity over the whole stream passing through the meter body's hydraulic area. This ability affects installation requirements and accuracy of results obtained.



Media with scatters (dirt, air, etc.), and ultrasonic wave refelct

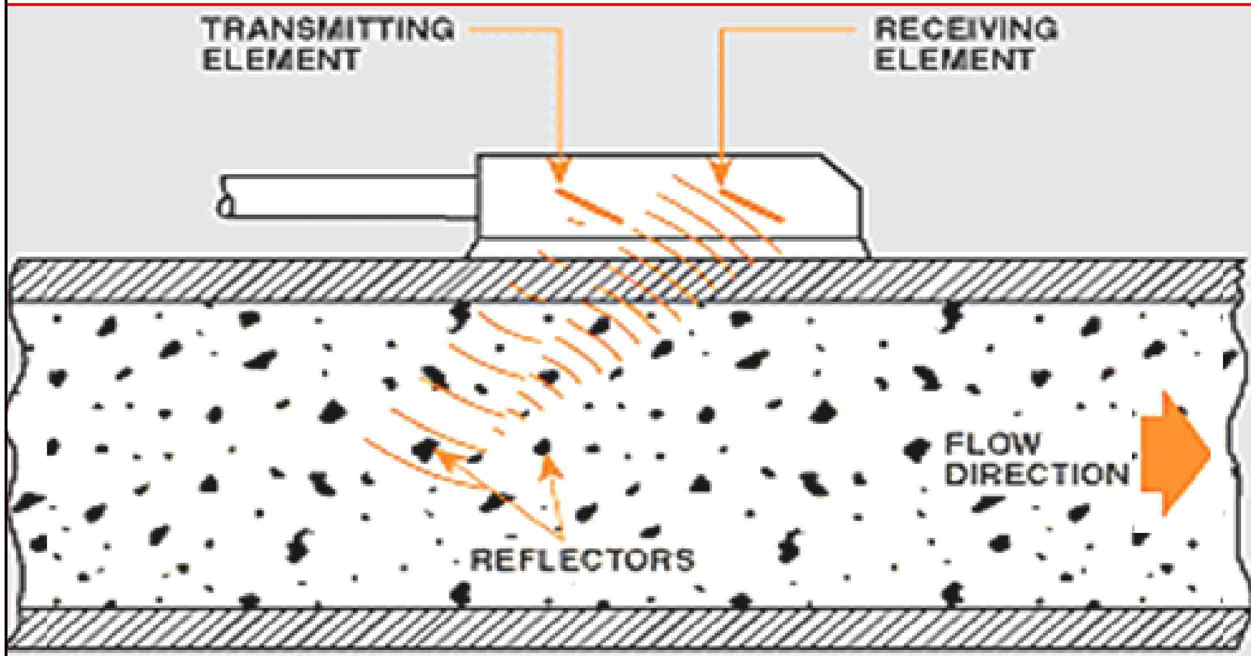
Doppler reflection meter

Dopplers two main types of ultrasonic meters are Doppler frequency shift and the transit-time change. The Doppler meter is used on liquids and gases with some types of entrained particles that are traveling at the same speed as main body of flow. The ultrasonic signal is reflected from these traveling particles across stream, and the shift in frequency is related to the average velocity of these particles over time. Meters are made in several types; one type requires installation of transducers into the flowing stream, the other is a strap-on model that can be installed without shutting down the flow stream.

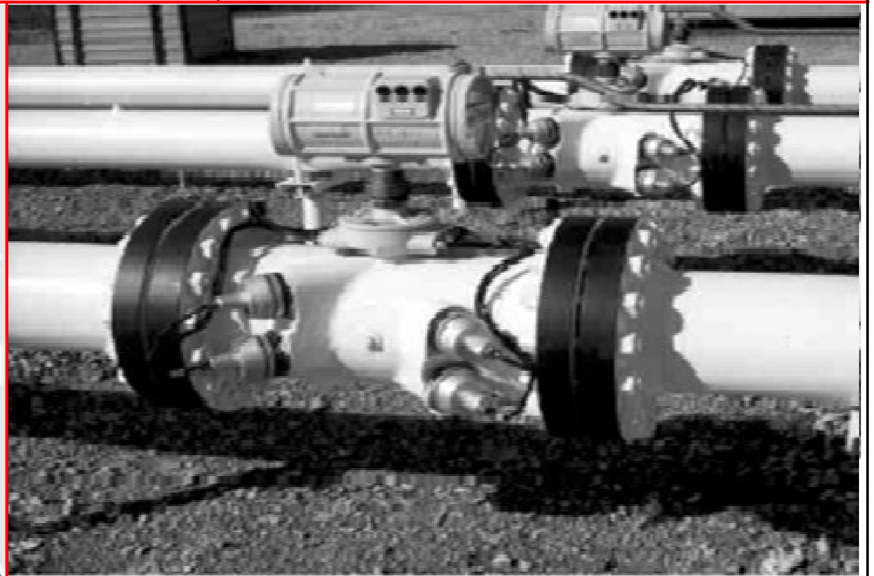


Each transducer alternately acts as a transmitter and receiver.

Transit-time ultrasonic meter.



Doppler meters use sound pulse reflection principle to measure liquid flow rates, Solids or bubbles in suspension in the liquid reflect the sound back to the receiving transducer element.


Transducers in multipath ultrasonic meter are mounted so that sound travel path crosses pipe body at set angle. Four pairs transducers are used for high accuracy with many flow profiles.

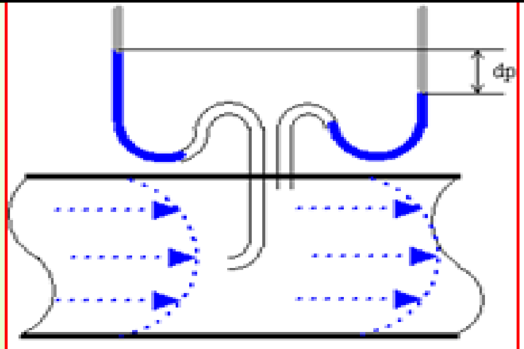
Ultrasonic flowmeters can be divided into Doppler meters & time-of-travel (or transit) meters. Doppler meters measure frequency shifts caused by liquid flow. Two transducers are mounted in case attached to one side of pipe. A signal of known frequency is sent into liquid to be measured. Solids, bubbles, or any discontinuity in liquid, cause pulse to be reflected to receiver element. Because liquid causing reflection is moving, frequency of returned pulse is shifted. The frequency shift is proportional to the liquid's velocity. A portable Doppler meter capable of being operated on AC power or from a rechargeable power pack has recently been developed. The sensing heads are simply clamped to outside of the pipe, and the instrument is ready to be used. Total weight, including the case, is 22 lb. A set of 4 to 20 millampere output terminals permits unit to be connected to a strip chart recorder or other remote device. Time-of-travel meters have transducers mounted on each side of the pipe. The configuration is such that the sound waves traveling between the devices are at a 45 deg. angle to the direction of liquid flow. The speed of the signal traveling between the transducers increases or decreases with the direction of transmission and the velocity of the liquid being measured. A time-differential relationship proportional to the flow can be obtained by transmitting the signal alternately in both directions. A limitation of time-of-travel meters is that the liquids being measured must be relatively free of entrained gas or solids to minimize signal scattering and absorption.

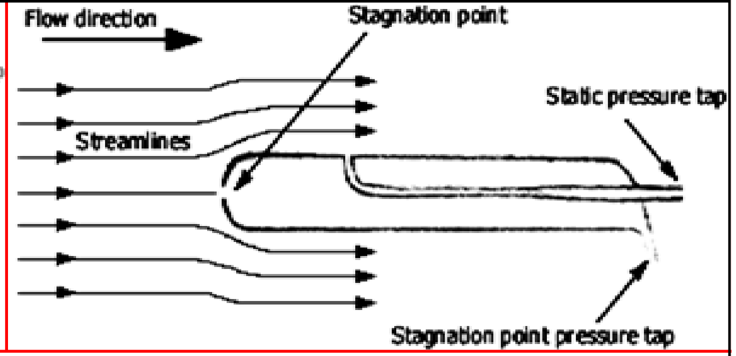
Transit-Time Ultrasonic Meters

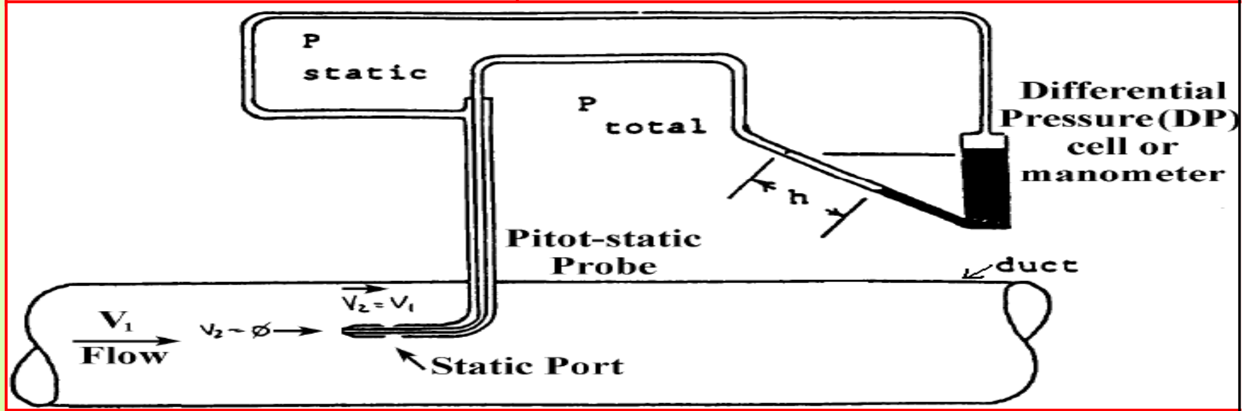
A transit-time unit is installed directly into the flowing stream and can be made with single or multiple transducers for establishing average velocity. These units can be used on liquids or gas, although the large majority of pipeline applications are for gas. The multiple transducer units can handle velocity profile distortions so that installation requirements are reduced. But meter complexity (i.e., cost) goes up because of the multiple transducer units and the more complex electronics required to compute average velocity and flow. Some manufacturers offer spool piece single and multiple path meters plus insertion ("hot tap") types for surface or underground installation.

The multipath meter uses transducers set at an angle to the flow axis. In one company's four-path design, each transducer in a pair functions alternately as transmitter and receiver over the same path length. When equations for transit times "upstream" and "downstream" are used to determine mean transit time, the speed of sound in the medium "drops out." Consequently, gas velocity through the meter can be determined from only transit times and physical dimensions of the spool piece.

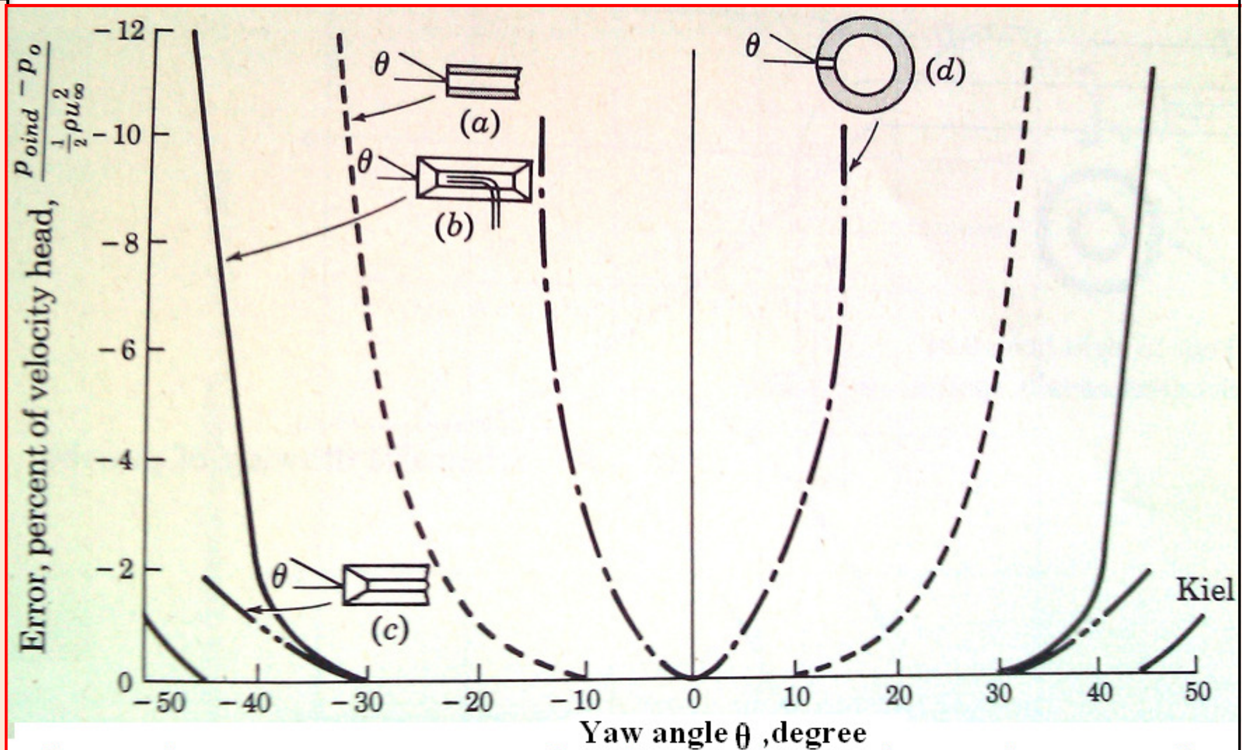
Pitot tubes: sense two pressures simultaneously, impact and static. The impact unit consists of a tube with one end bent at right angles toward flow direction. Static tube's end is closed, but a small slot is located in side of unit. The tubes can be mounted separately in a pipe or combined in a single casing. Pitot tubes are generally installed by welding coupling on pipe and inserting probe through coupling. Use of most pitot tubes is limited to single point measurements. Units are susceptible to plugging by foreign material in liquid. Advantages of pitot tubes are low cost, absence of moving parts, easy installation, and minimum pressure drop.







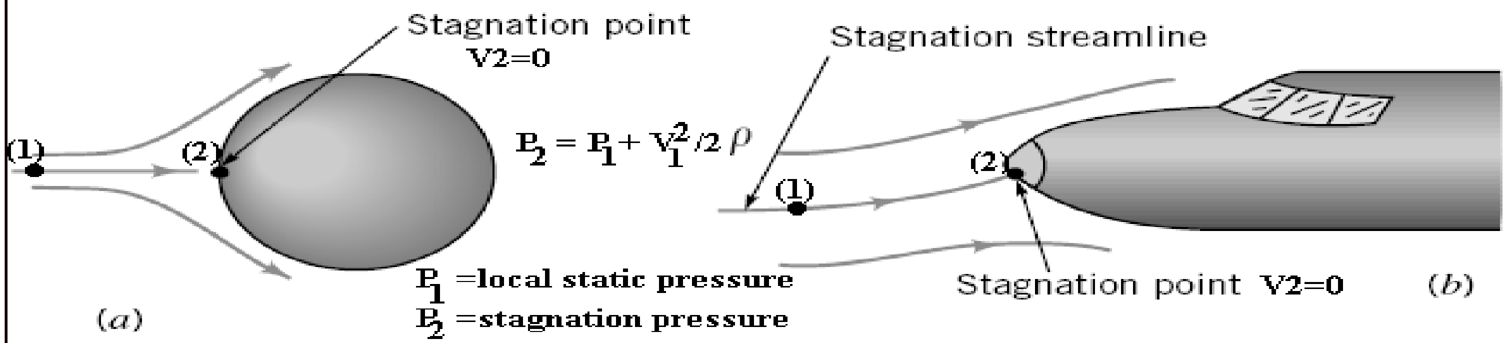
Pitot tubes are most used & cheapest ways to measure velocity, especially air applications as ventilation and HVAC systems, even used in airplanes for the speed measurement. Pitot tube measures velocity by converting kinetic energy of flow into potential energy. Use of pitot tube is restricted to point measuring **(θ=0, it must be in direction of U_∞)**. With annubar or multi-orifice pitot probe, dynamic press. is measured across the velocity profile, and annubar obtains averaging effect. A probe with open tip (Pitot tube) is inserted into flow field. The tip is stationary (zero velocity) point of flow. Its pressure, compared to static pressure, is used to calculate flow velocity. Pitot tubes can measure flow velocity at the point of measurement.



Stagnation pressure response of various probes to changes in yaw angle.
(a)Open-ended tube; (b)channel tube; (c)chamfered tube; (d)tube with orific in side

Errors in calculating Stagnation Pressure (compressibilty effects):

V3_4.mov



■ FIGURE 6.2 Stagnation points on bodies in flowing fluids.

We consider the stagnation point flow of **figure** 6.2 to illustrate the difference between the incompressible and compressible results.

$$\boxed{\frac{p_2 - p_1}{p_1} = \left[\left(1 + \frac{k-1}{2}\mathrm{Ma}_1^2\right)^{k/k-1} - 1\right] \quad \text{(compressible)}}$$

where (1) denotes the upstream conditions and (2) the stagnation conditions. We have assumed $z_1 = z_2$, $V_2 = 0$, and have denoted $\mathrm{Ma}_1 = V_1/c_1$ as the upstream *Mach number*—the ratio of the fluid velocity to the speed of sound, $c_1 = \sqrt{kRT_1}$.

A comparison between this compressible result and the incompressible result is perhaps most easily seen if we write the incompressible flow result in terms of the pressure ratio and the Mach number. Thus, we divide each term in the Bernoulli equation, $\rho V_1^2/2 + p_1 = p_2$, by p_1 and use the perfect gas law, $p_1 = \rho RT_1$, to obtain $\frac{p_2}{p_1} = \frac{V_1^2}{2RT_1}$

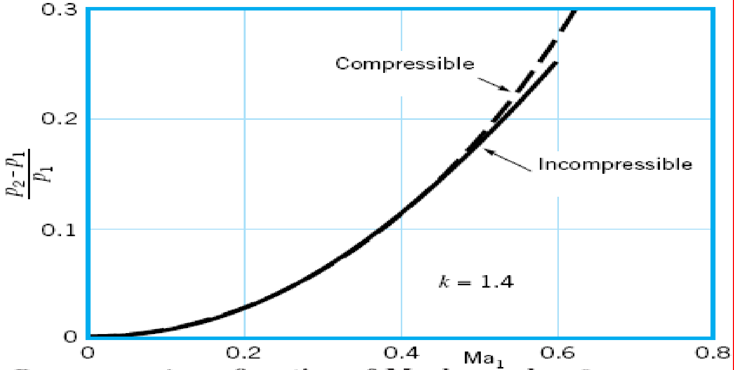
Since $\mathrm{Ma}_1 = V_1/\sqrt{kRT_1}$ this can be written as

$$\boxed{\frac{p_2 - p_1}{p_1} = \frac{k\mathrm{Ma}_1^2}{2} \quad \text{(incompressible)}}$$

In the low-speed limit of $\mathrm{Ma}_1 \rightarrow 0$, both of the results are the same.
This can be seen by denoting $(k-1)\mathrm{Ma}_1^2/2 = \tilde{\varepsilon}$ and using the

binomial expansion, $(1 + \tilde{\varepsilon})^n = 1 + n\tilde{\varepsilon} + n(n-1)\tilde{\varepsilon}^2/2 + \cdots$, where $n = k/(k-1)$, to write

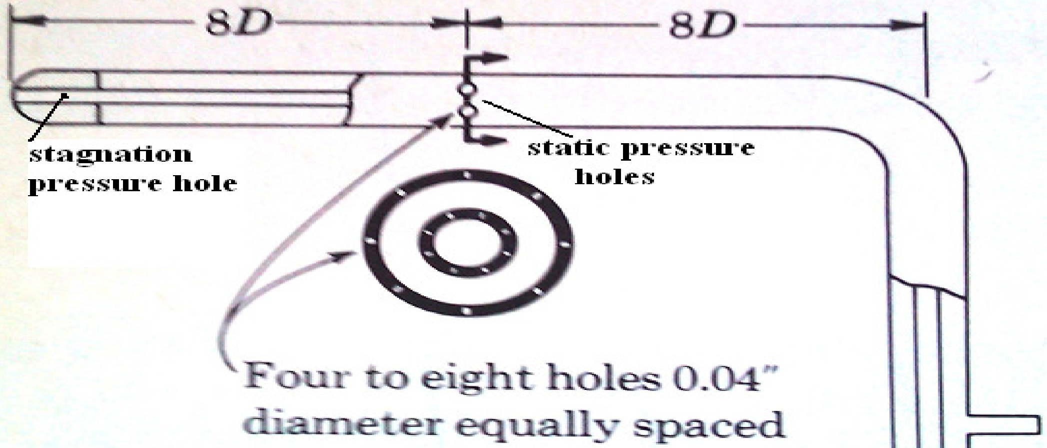
$$\boxed{\frac{p_2 - p_1}{p_1} = \frac{k\mathrm{Ma}_1^2}{2}\left(1 + \frac{1}{4}\mathrm{Ma}_1^2 + \frac{2-k}{24}\mathrm{Ma}_1^4 + \cdots\right) \quad \text{(compressible)}}$$



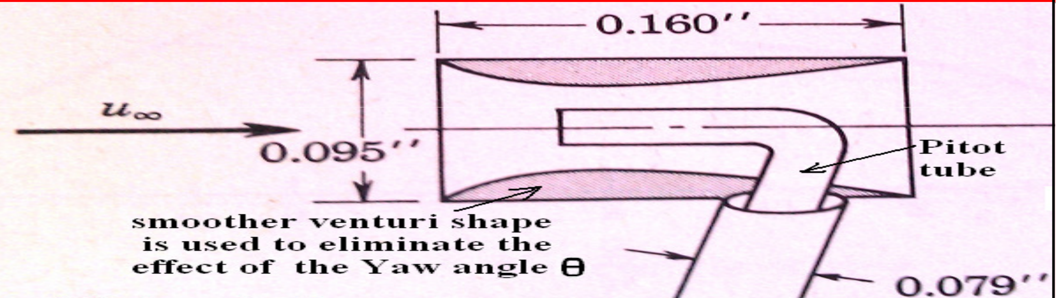
Pressure ratio as function of Mach number for compressible (isentropic) flow and incompressible flow.

For $Ma_1 \ll 1$ compressible flow result agrees with incompressible flow. The incompressible & compressible equations agree to within about 2% up to a Mach number of approximately $Ma_1 = 0.3$. For larger Mach numbers the disagreement between the two results increases.

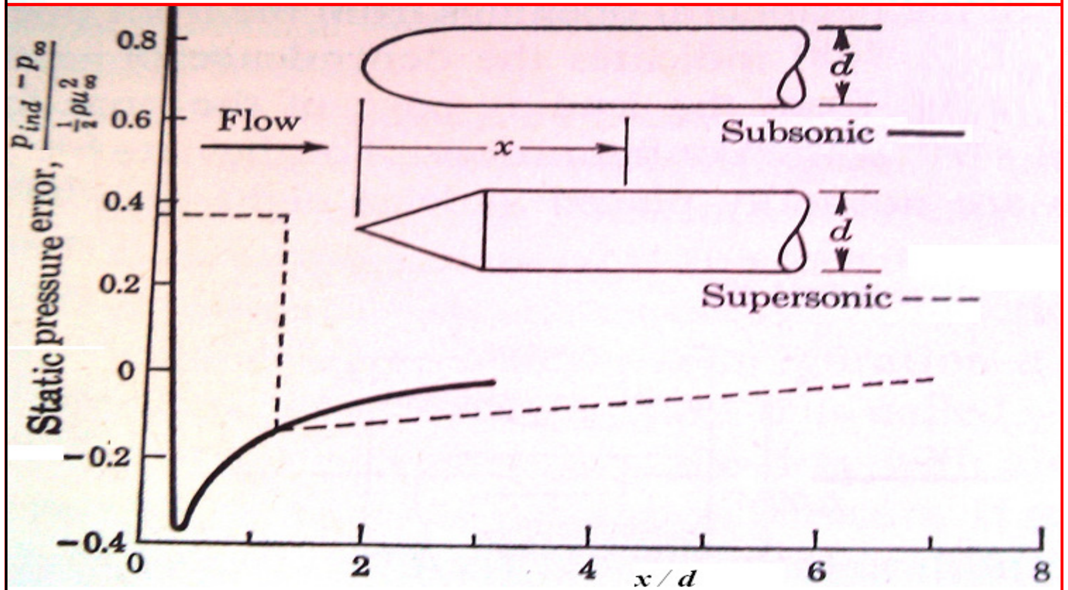
Thus, a "rule of thumb" is that the flow of a perfect gas may be considered as incompressible provided the Mach number is less than about 0.3. In standard air (T_1 =288 K, $c_1 = \sqrt{kRT_1} =$ 340 m/s) this corresponds to a speed of $V_1 = c_1 Ma_1 = 0.3($ 340 m/s $)=102$ m/s = 367.2 km/hr. At higher speeds, compressibility may become important.



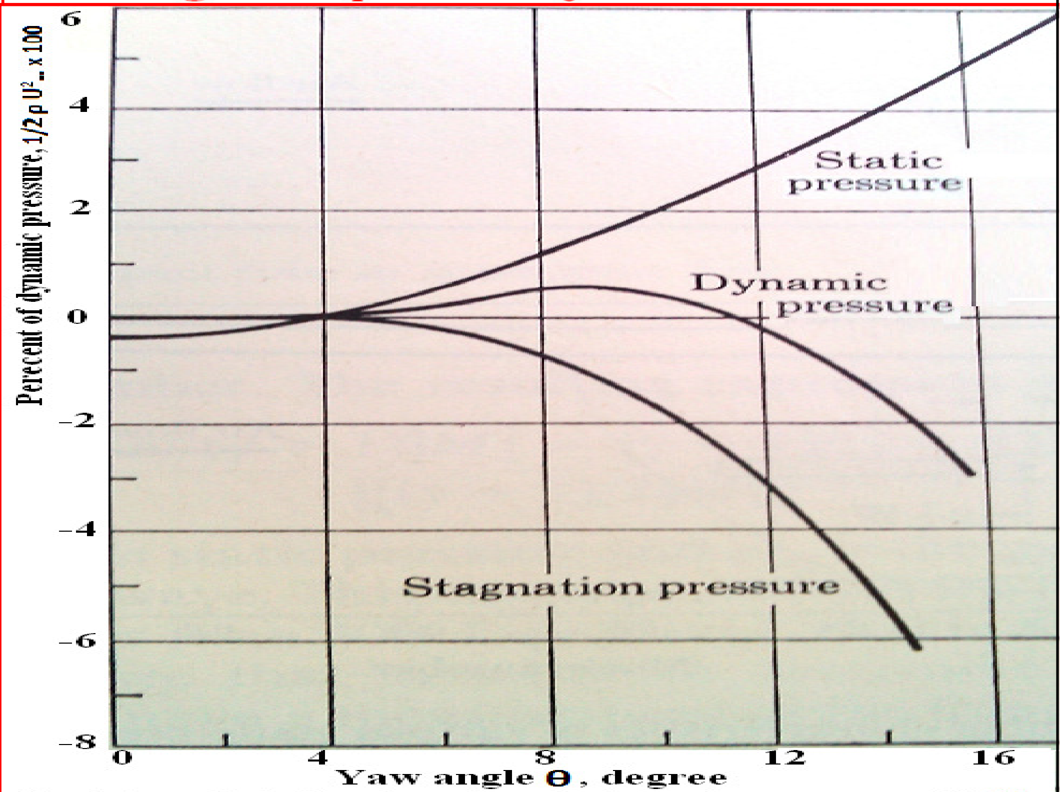
Typical Pitot Tube for measuring static & stagnation pressures



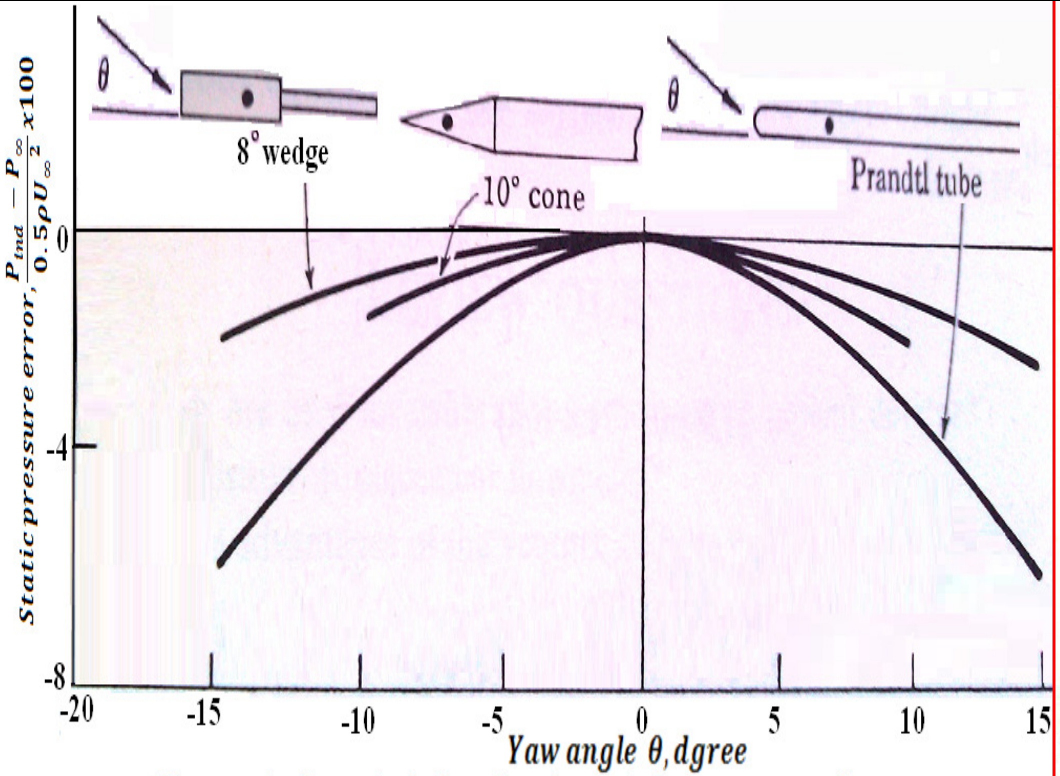
Kiel probe for measurement of stagnation pressure P_o



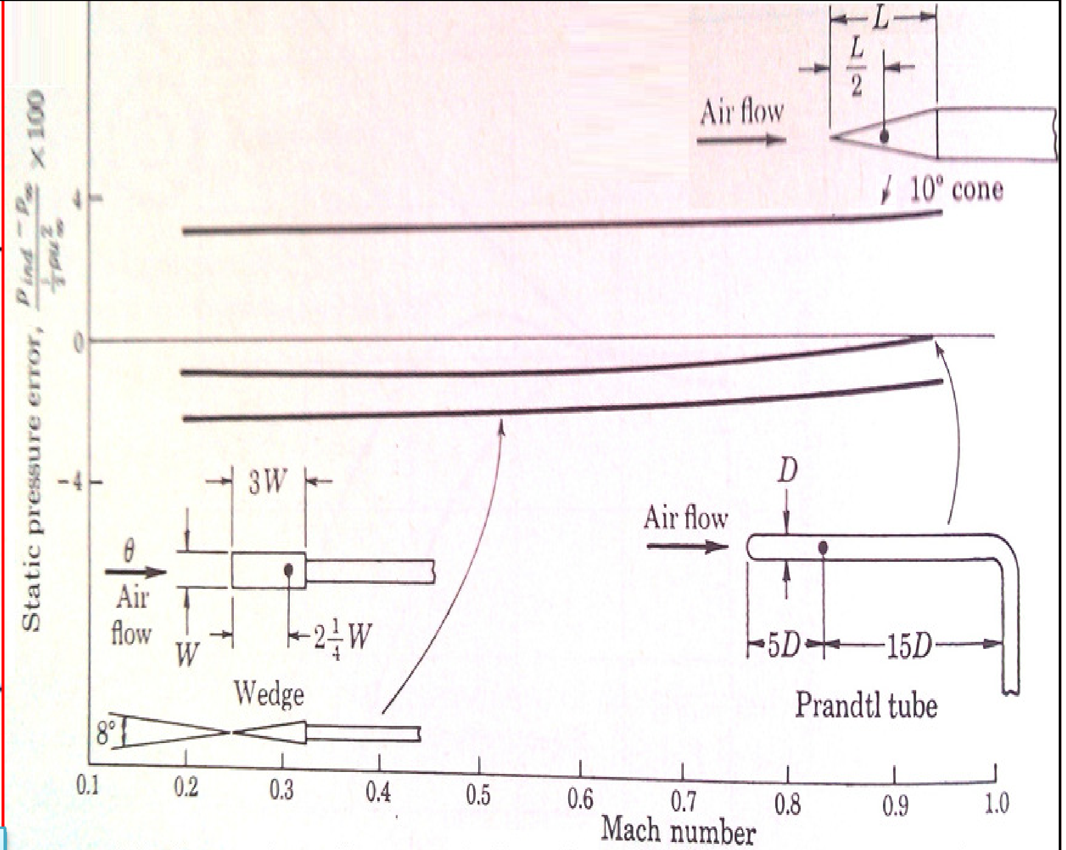
Variation of static pressure along standard subsonic&supersonic probes



Variation of static, stagnation & dynamic pressure with θ

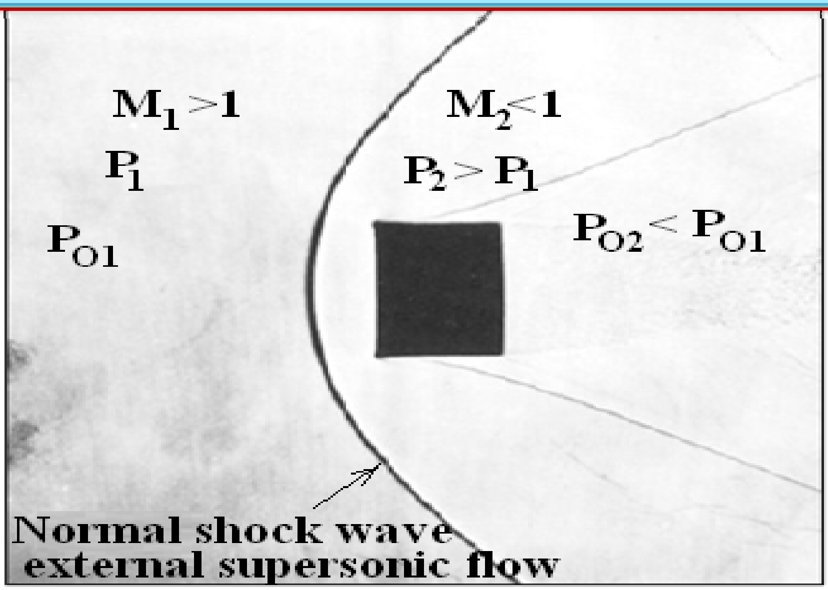


Yaw-angle characteristics of various static-pressure probes

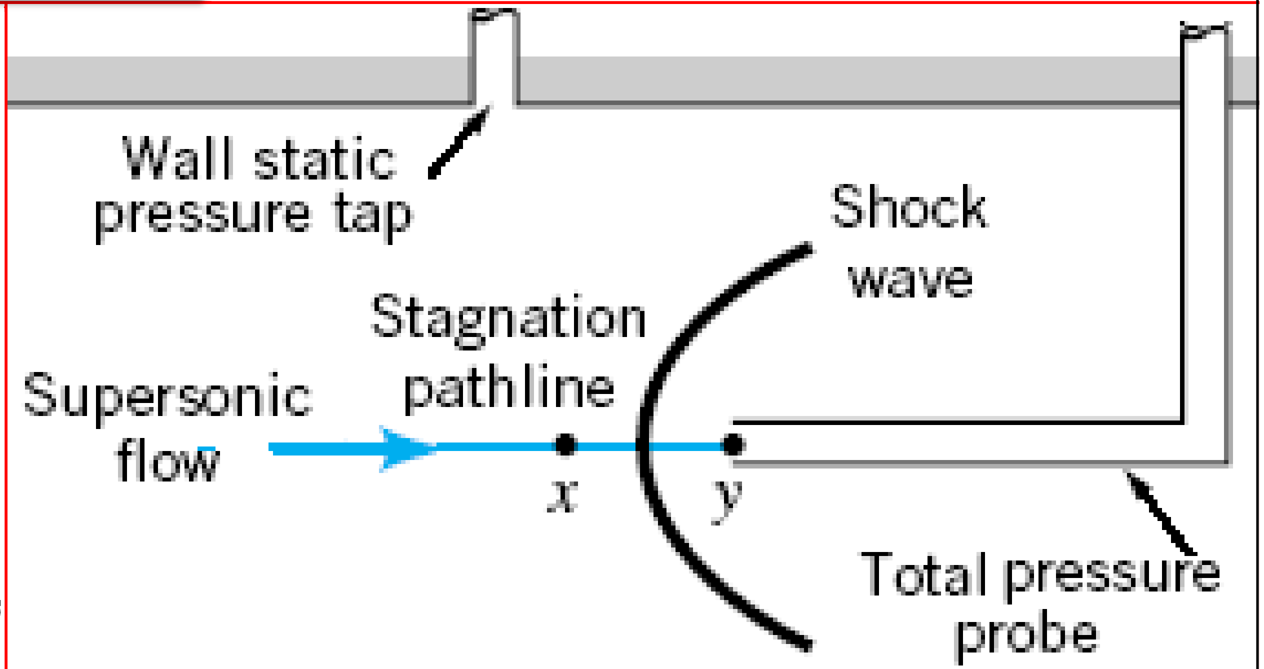


Mach-number characteristics of various static pressure probes

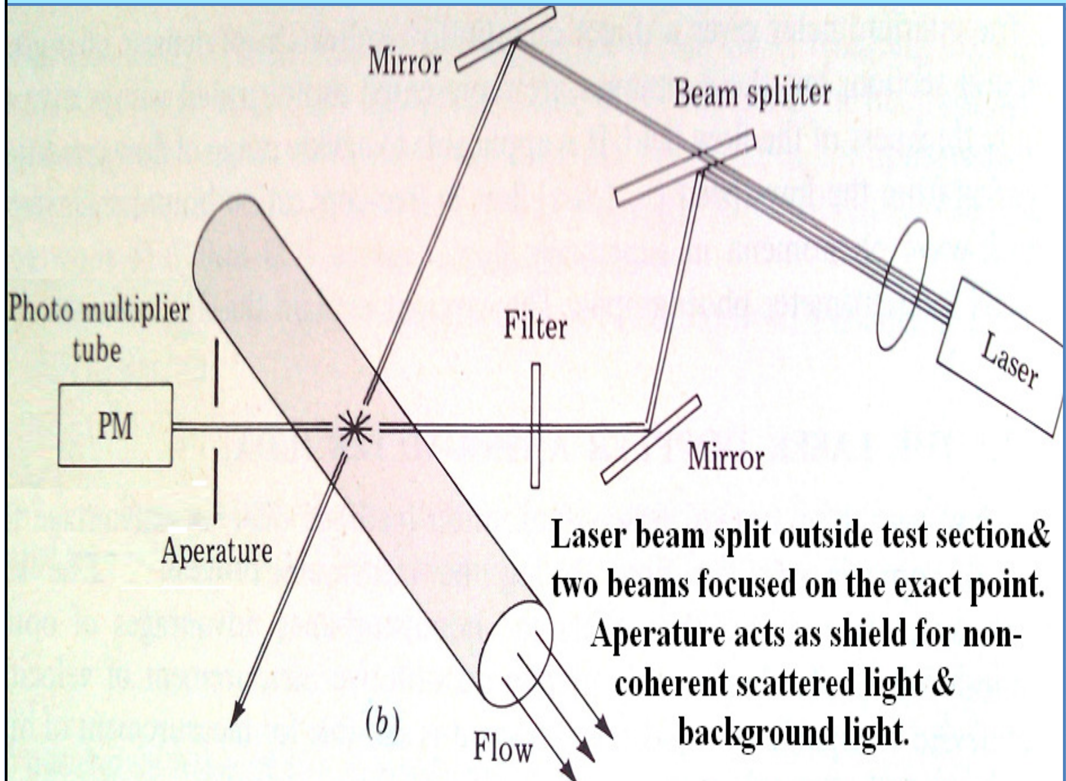
Pitot tubes for supersonic flow measurements:

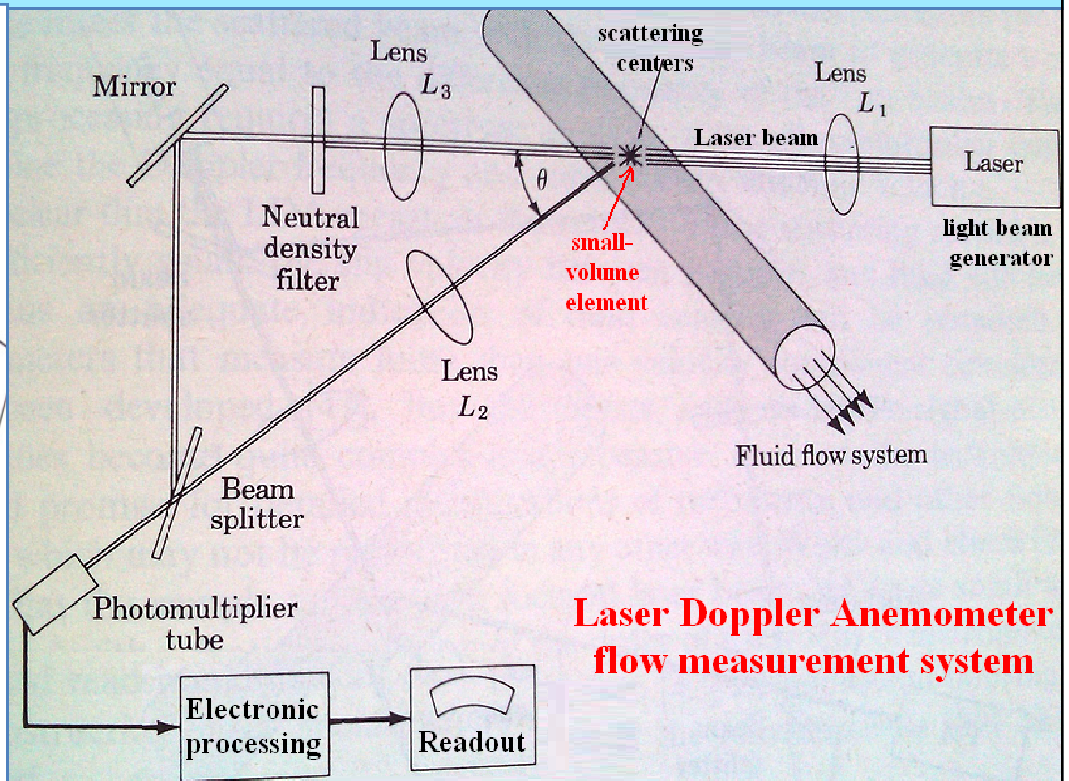


Super sonic flow past blunt body creates NSW at nose changing P & Po at body



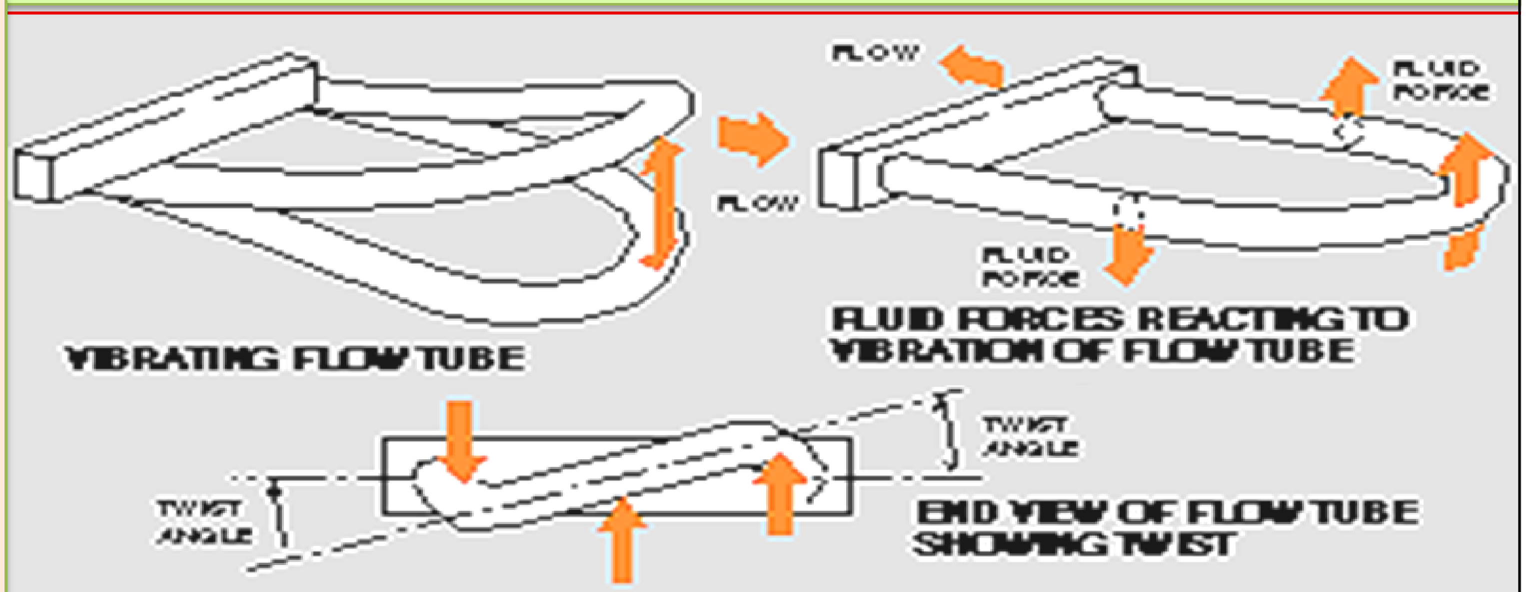
<u>The Laser Doppler Anemometer (LDA) measurements</u>: is device offers optical & non-disturbing flow field method for very precise &quantitative measurement of velocities of non-obaque clean gases. LDA is capable of rapid response&is suited for measurement of high-frequency turbulent fluctuations. Laser beam is focused on small-volume element in the flow through lenses. Flow has to contain some type of very small particles (called seeding) to scatter the light, but the particles concentration required is very small & should have no effect on flow field. Optical arrangements are made (as seen) so that scattered light, at small-volume element, experiences a Doppler shift in frequency is directly proportional to flow velocity. Un-scattered portion of beam is reduced in intensity by neutral density filter & recombined with scattered beam through beam splitter. LDA device must be so constructed that direct & scattered beams travel same optical path so that an interference will be observed at photomultiplier tube that is proportional to frequency shift. This shift then gives an indication of the flow velocity. In order to retrieve the velocity data from the photomultiplier signal, very sophisticated electronic techniques must be employed for signal processing. A spectrum analyzer may be used to determine velocity in steady laminar flow as well as mean velocity & turbulence intensity in turbulent flows.





Mass Flowmeters: need for more accurate measurement in mass-related processes(chemical reactions, etc) has resulted in developing mass flowmeters. Many designs are available, but most commonly used for liquid flow applications is Coriolis meter. Its operation is based on natural phenomenon called Coriolis force, hence name.
Coriolis meters: are true mass meters that measure mass rate of flow directly as opposed to volumetric flow. Because mass does not change, meter is linear without having be adjusted for variations in liquid properties. It also eliminates need to compensate for changing temperature and pressure conditions. The meter is especially useful for measuring liquids whose viscosity varies with velocity at given temperatures and pressures.

Coriolis meters are available in various designs. Popular unit consists of U-shaped flow tube enclosed in sensor housing connected to an electronics unit. Sensing unit can be installed directly into any process. The electronics unit can be located up to 500 feet from the sensor. Inside the sensor housing, the U-shaped flow tube is vibrated at its natural frequency by a magnetic device located at the bend of the tube.



Vibrating, U-shaped flow tube is heart of popular Coriolis mass flowmeter: Tube vibration, coupled with the fluid's force, causes tube deflection that is directly proportional to the mass flow rate

Vibration is similar to that of tuning fork, covering less than 0.1in. &completing full cycle about 80 times/sec. As liquid flows through tube, it is forced to take on vertical movement of tube. When tube is moving upward during half of its cycle, liquid flowing into meter resists being forced up by pushing down on tube. Having been forced upward, liquid flowing out of the meter resists having its vertical motion decreased by pushing up on the tube. This action causes the tube to twist. When the tube is moving downward during the second half of its vibration cycle, it twists in the opposite direction. The ammount of twist is directly proportional to the mass flow rate of the liquid flowing through the tube. Magnetic sensors located on each side of the flow tube measure the tube velocities, which change as the tube twists. The sensors feed this information to the electronics unit, where it is processed and converted to a voltage proportional to mass flow rate. The meter has a wide range of applications from adhesives and coatings to liquid nitrogen

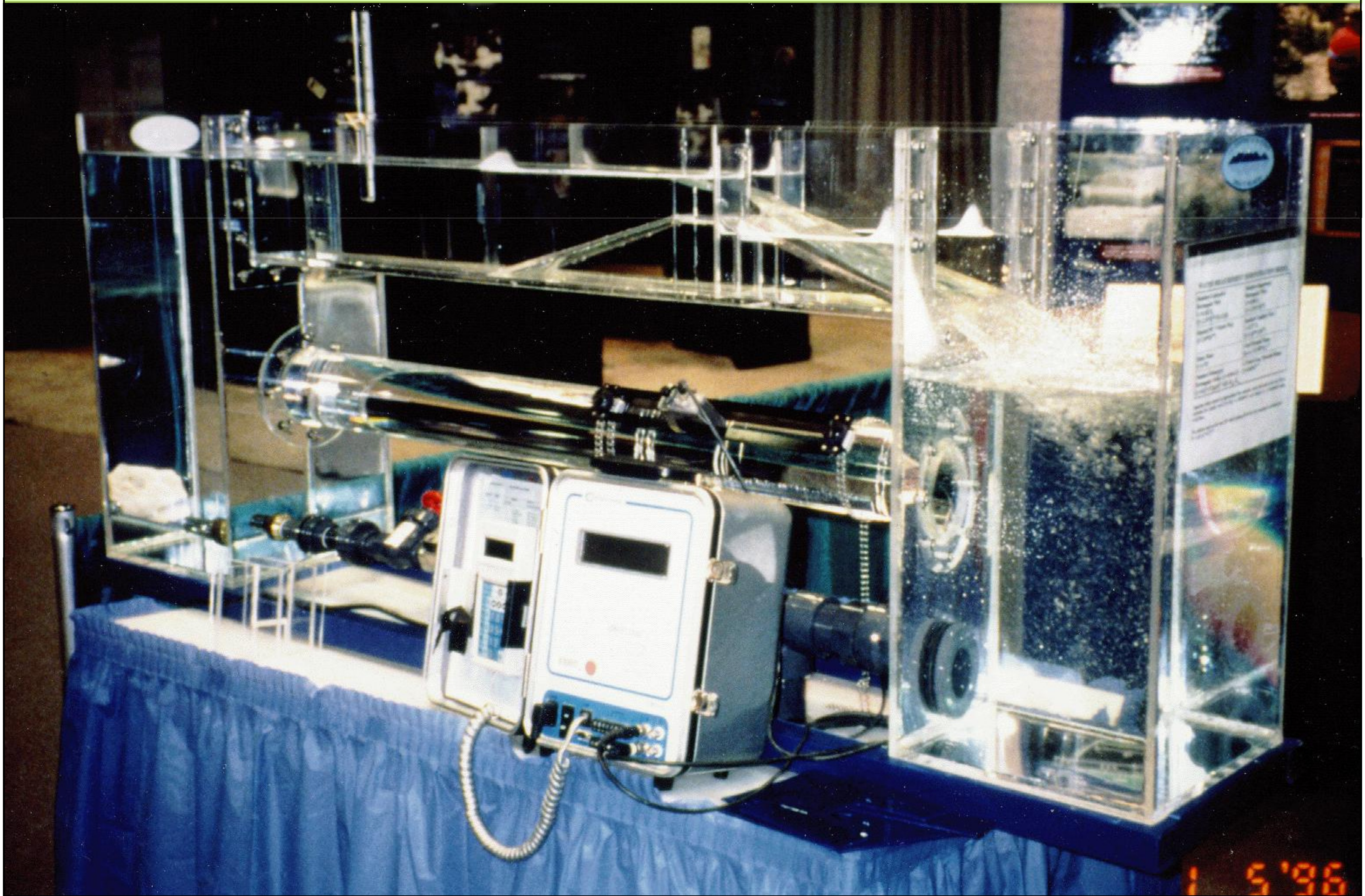
Open Channel Meters :refers to any conduit in which liquid flows with a free surface. Included are tunnels, nonpressurized sewers, partially filled pipes, canals, streams, and rivers. Of the many techniques available for monitoring open-channel flows, depth-related methods are the most common. These techniques presume that the instantaneous flow rate may be determined from a measurement of the water depth, or head. Weirs and flumes are the oldest and most widely used primary devices for measuring open-channel flows.

Weirs: operate on principle that obstruction in channel will cause water to back up, creating a high level (head) behind barrier. Head is function of flow velocity & the flow rate through the device. Weirs consist of vertical plates with sharp crests. The top of the plate can be straight or notched. Weirs are classified in accordance with the shape of the notch. The basic types are V-notch, rectangular, and trapezoidal.

Flumes: are generally used when head loss must be kept to a minimum, or if the flowing liquid contains large amounts of suspended solids. Flumes are to open channels what venturi tubes are to closed pipes. Popular flumes are the Parshall and Palmer-Bowlus designs. The Parshall flume consists of a converging upstream section, a throat, and a diverging downstream section. Flume walls are vertical and the floor of the throat is inclined downward. Head loss through Parshall flumes is lower than for other types of open-channel flow measuring devices. High flow velocities help make the flume self-cleaning. Flow can be measured accurately under a wide range of conditions. Palmer-Bowlus flumes have a trapezoidal throat of uniform cross section and a length about equal to the diameter of the pipe in which it is installed. It is comparable to a Parshall flume in accuracy and in ability to pass debris without cleaning. A principal advantage is the comparative ease with which it can be installed in existing circular conduits, because a rectangular approach section is not required.

Discharge through weirs and flumes is a function of level, so level measurement techniques must be used with the equipment to determine flow rates. Staff gages and float-operated units are the simplest devices used for this purpose. Various electronic sensing, totalizing, and recording systems are also available. A more recent development consists of using ultrasonic pulses to measure liquid levels. Measurements are made by sending sound pulses from a sensor to the surface of the liquid, and timing the echo return. Linearizing circuitry converts the height of the liquid into flow rate. A strip chart recorder logs the flow rate, and a digital totalizer registers the total gallons. Another recently introduced microprocessor-based system uses either ultrasonic or float sensors. A key-pad with an interactive liquid crystal display simplifies programming, control, and calibration tasks.

Water Measurement Demo Flume- weirs, submerged orifices, vortex meters, transit time pipe flow meters, flow measurement flumes.Velocity Measurement Devices- ADCP, transit time open channel flow meter, ADV, ADFM, electromagnetic velocity meter, propeller velocity meter.



Calibration of a Triangular Weir

Objective: The flowrate over a weir is a function of the weir head. The purpose of this experiment is to use a device as shown in Fig. P10.98 to calibrate a triangular weir and determine the relationship between flowrate, Q, and weir head, H.

Equipment: Water channel (flume) with a pump and a flow control valve; triangular weir; float; point gage; stop watch.

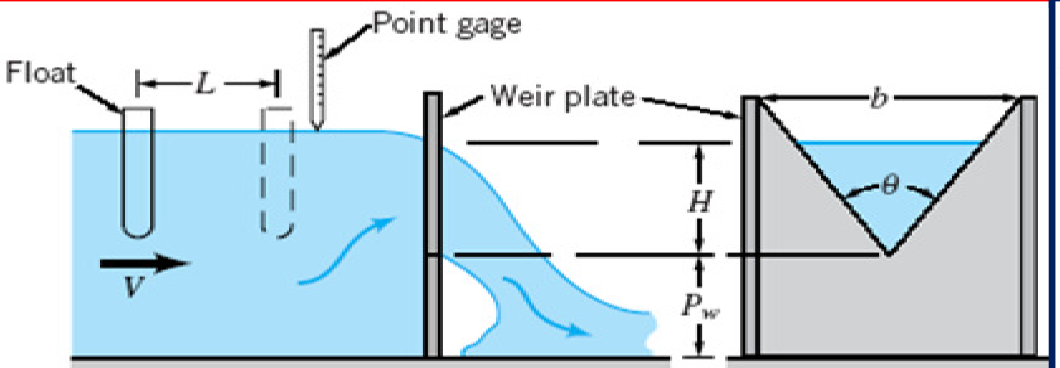
Experimental Procedure: Measure the width, b, of the channel, the distance, P_w, between the channel bottom and the bottom of the V-notch in the weir plate, and the angle, θ, of the V-notch. Fasten the weir plate to the channel bottom, turn on the pump, and adjust the control valve to produce the desired flowrate, Q, over the weir. Use the point gage to measure the weir head, H. Insert the float into the water well upstream from the weir and measure the time, t, it takes for the float to travel a known distance, L. Repeat the measurements for various flowrates (i.e., various weir heads).

Calculations: For each set of data, determine the experimental flowrate as $Q = VA$, where $V = L/t$ is the velocity of the float (assumed to be equal to the average velocity of the water upstream of the weir) and $A = b(P_w + H)$ is the flow area upstream of the weir.

Graph: On log-log graph paper, plot flowrate, Q, as ordinates and weir head, H, as abscissas. Draw the best-fit line with a slope of 5/2 through the data.

Results: Use the flowrate-weir head data to determine the triangular weir coefficient, C_{wt}, for this weir (see Eq. 10.32). For this experiment, assume that the weir coefficient is a constant, independent of weir head.

Data: To proceed, print this page for reference when you work the problem and *click here* to bring up an EXCEL page with the data for this problem.



Calibration of a Rectangular Weir

Objective: The flowrate over a weir is a function of the weir head. The purpose of this experiment is to use a device as shown in Fig. P10.99 to calibrate a rectangular weir and determine the relationship between flowrate, Q, and weir head, H.

Equipment: Water channel (flume) with a pump and a flow control valve; rectangular weir; float; point gage; stop watch.

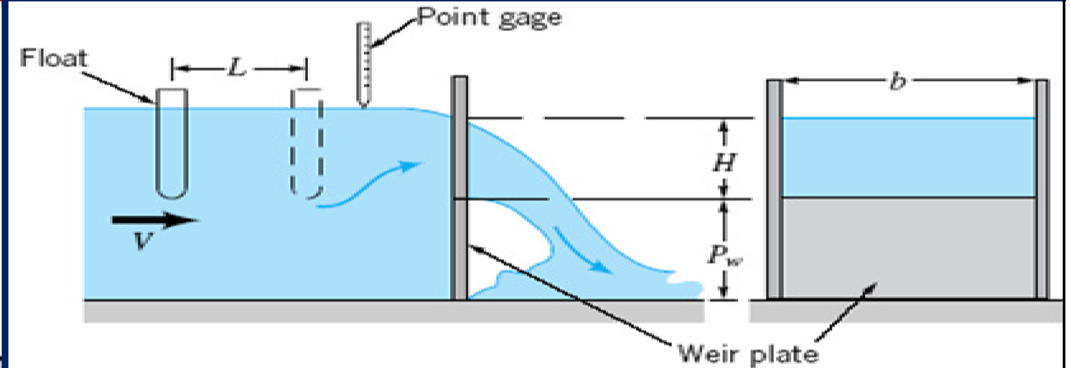
Experimental Procedure: Measure the width, b, of the channel and the distance, P_w, between the channel bottom and the top of the weir plate. Fasten the weir plate to the channel bottom, turn on the pump, and adjust the control valve to produce the desired flowrate, Q, over the weir. Use the point gage to measure the weir head, H. Insert the float into the water well upstream from the weir and measure the time, t, it takes for the float to travel a known distance, L. Repeat the measurements for various flowrates (i.e., various weir heads).

Calculations: For each set of data, determine the experimental flowrate as $Q = VA$, where $V = L/t$ is the velocity of the float (assumed to be equal to the average velocity of the water upstream of the weir) and $A = b(P_w + H)$ is the flow area upstream of the weir.

Graph: On log-log graph paper, plot flowrate, Q, as ordinates and weir head, H, as abscissas. Draw the best-fit line with a slope of 3/2 through the data.

Results: Use the flowrate-weir head data to determine the rectangular weir coefficient, C_{wr}, for this weir (see Eq. 10.30). For this experiment, assume that the weir coefficient is a constant, independent of weir head.

Data: To proceed, print this page for reference when you work the problem and *click here* to bring up an EXCEL page with the data for this problem.



٢-٤ عناصر قياس معدل التدفق:

معدل تدفق مائع متغير هام في المنظومات الصناعية، وقياسه يبين لنا كمية المائع المستخدمة في المنظومة، لذلك يمكن استخدامه كمتغير تحكم للحفاظ على مردودية المنظومة.

معدل التدفق الحجمي (m^3/sec) : $Q = \frac{\Delta V}{\Delta t}$ حيث: ΔV: فرق الحجم، Δt: فرق الزمن

أيضا: $Q = A.v$ حيث: A: مساحة مقطع الأنبوب، v: سرعة السريان

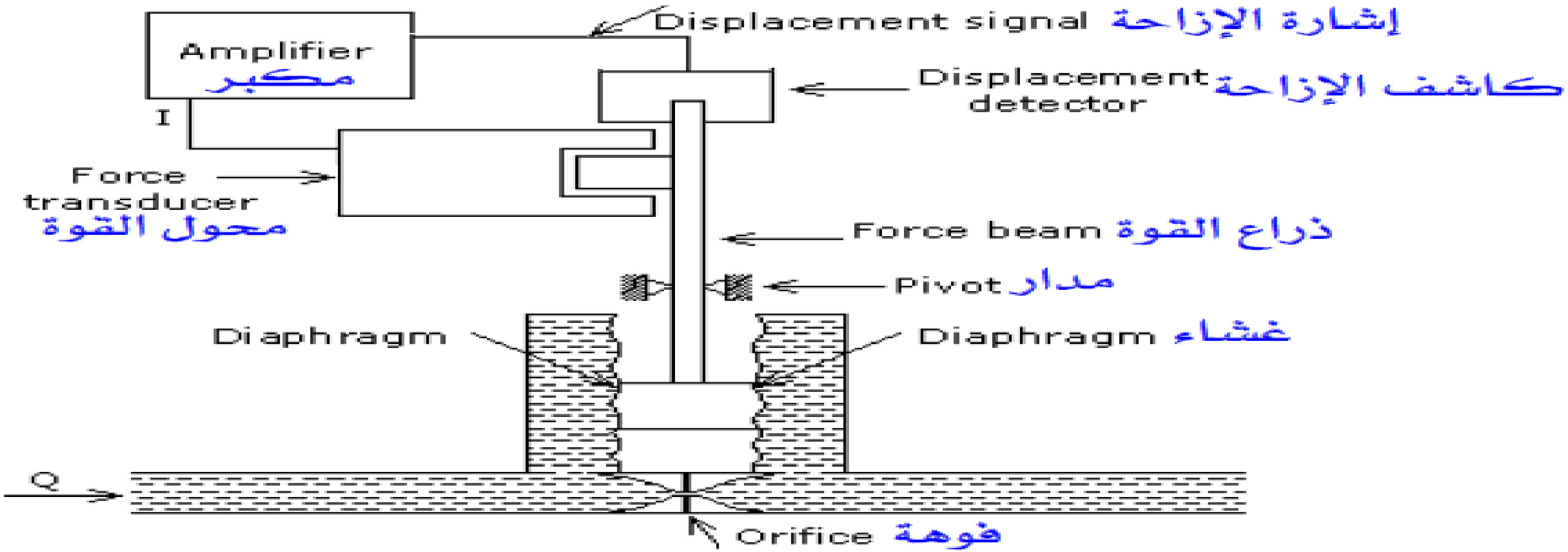
معدل التدفق الكتلي (kg/sec): $Q_m = \rho.Q$ حيث: ρ: كثافة المائع

٢-٤-١ عنصر حس معدل التدفق ذي الفوهة:

هذا العنصر يعمل على أساس قياس معدل التدفق باستخدام الفوهة Orifice في أنبوب تسبب نقصا محليا في الضغط ΔP يمكن قياسه وحساب معدل التدفق منه، ويسمى حساس معدل التدفق ذي الفوهة Orifice flow meter.

القانون الفيزيائي الذي يربط فرق الضغط بمعدل التدفق هو: $Q = K.\sqrt{\Delta P}$

هذه الفوهة وضعت داخل الأنبوب، كما هو مبين في الشكل التالي، بحيث كل السائل يمر عبر هذا الثقب، الذي يقوم بتحويله إلى ضغط على مستوى واجهتي غشاء وحدة ناقل الضغط التفاضلي. فرق الضغط المولد يتحول إلى قوة عند نهاية ذراع القوة، وهناك محول قوة في النهاية الثانية للذراع ينتج قوة توازن مساوية لها. كاشف الإزاحة يحس بأي حركة تنتج عن عدم توازن في القوى المسلطة على الذراع. المضخم يحول هذه الإزاحة إلى تعديل في تيار الدخل لمحول القوة. قوة التوازن الناتجة عن محول القوة تتناسب مع ضغطي الأنبوب وتيار الدخل. وبذلك فإن التيار يتناسب مع فرق الضغط عند الفوهة. نفس هذا التيار يستخدم كإشارة خرج لناقل الضغط التفاضلي.



A typical differential pressure flow transducer

شكل ٢-٣٤: عنصر حس معدل التدفق ذي الفوهة

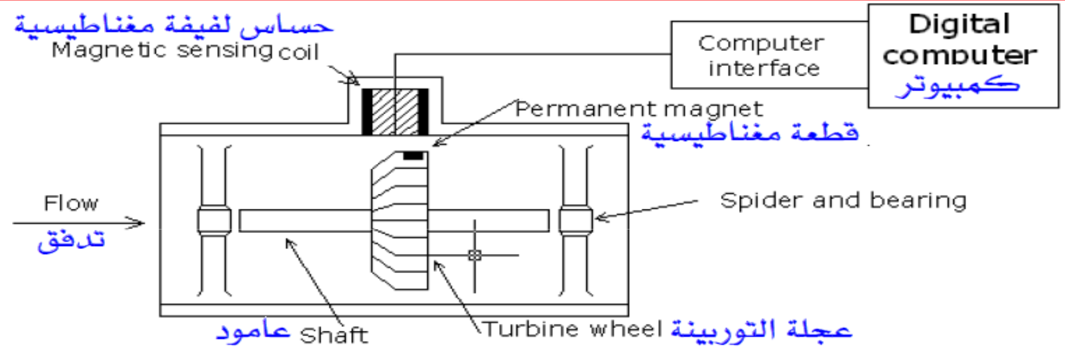
٢-٤-٢ عنصر حس معدل التدفق التوربيني:

نلاحظ في هذا الحساس كما هو مبين في الشكل التالي، وجود قطعة مغناطيسية صغيرة مثبتة على أحد ريش التوربينة. الحساس المغناطيسي magnetic sensing coil يولد نبضة كلما مرت به القطعة المغناطيسية. عدد النبضات له علاقة بحجم السائل الذي يمر عبر المقياس كالتالي: $V=K.N$

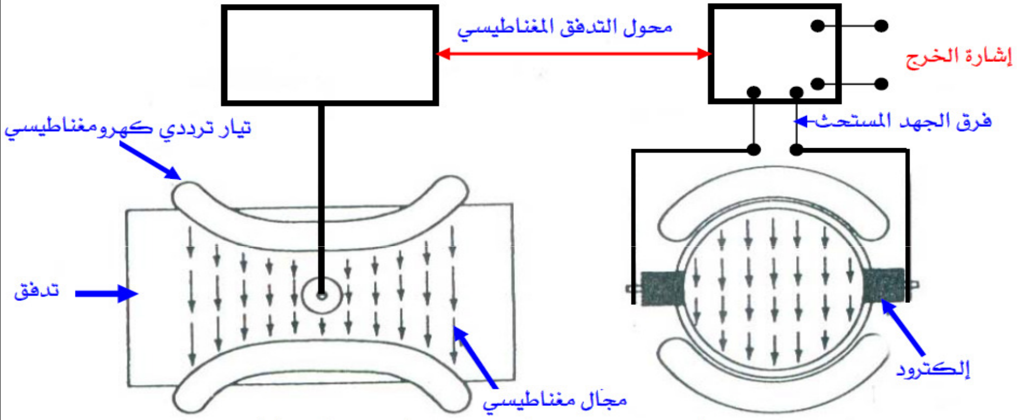
حيث: V: الحجم الكلي لسائل ، K: حجم السائل لكل نبضة

معدل التدفق Q يساوي الحجم الكلي على فرق الزمن: $Q=V/\Delta t=K.N/\Delta t=K.f$

حيث: f هي ذبذبة النبضات $f=N/\Delta t$



شكل٢-٣٥:مقياس معدل تدفق توربيني بدقة خطية وإشارة تدفق رقمية (يستعمل في البيتروكيمياويات وميادين صناعية أخرى)



شكل ٢- ٣٦: مقياس معدل التدفق المغناطيسي

٢-٤-٣ عنصر حس معدل التدفق المغناطيسي:

مقياس معدل التدفق المغناطيسي ليس له عناصر متحركة وليست هناك عوائق للسائل المتدفق. فهو يعمل على أساس فرق الجهد المستحث في الموصل المتحرك في المجال المغناطيسي كما هو مبين في الشكل التالي.

هناك ملف ذو شكل مركب موجود حول أنبوب التدفق ينتج مجال مغناطيسي يمثل زاوية قائمة مع اتجاه التدفق. السائل المتدفق هو الموصل، وتدفق السائل يزود حركة الموصل.

فرق الجهد المستحث عمودي بالنسبة للمجال المغناطيسي واتجاه حركة الموصل. هناك قطعتي إلكترود يستخدمان للكشف عن فرق الجهد المستحث، الذي يتناسب مع معدل التدفق.

محول التدفق المغناطيسي يحول فرق الجهد المستحث الترددي إلى تيار كهربائي مستمر مناسب للمنظم الإلكتروني.

٢-٥ عناصر قياس الوضع السرعة والقوة:

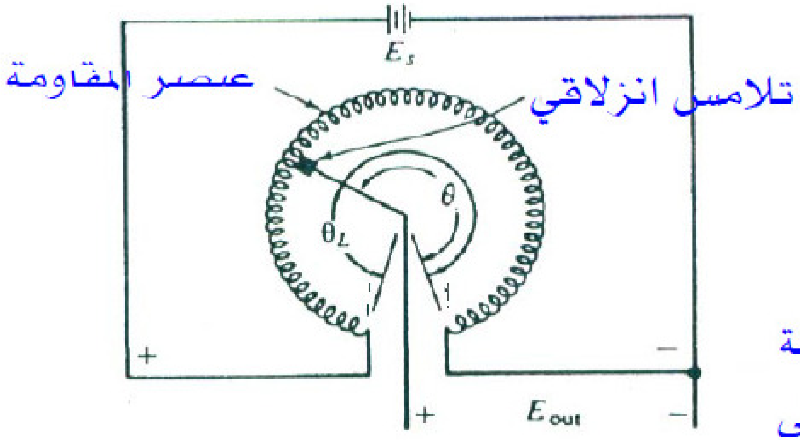
٢-٥-١ قياس الوضع والإزاحة:

قياس الوضع والإزاحة ينقسم إلى نوعين: خطي وزاوي. الوضع أو الإزاحة الخطية تقاس بوحدة الطول(المتر meter (m)). الوضع أو الإزاحة الزاوية تقاس بوحدة الزاوية (الدرجة degree أو الراديان radian حيث إن $1rad=1808/\pi$ حوالي ٥٧,٣درجة).

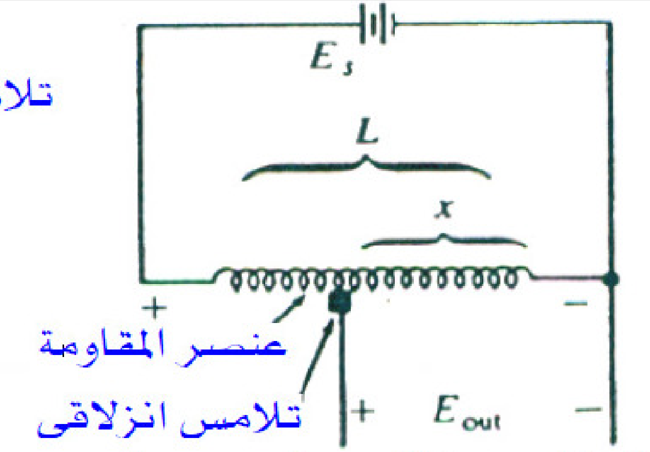
أ- مقياس الجهد Potentiometer:

مقياس فرق الجهد هو مقاومة بتلامس انزلاقي الذي يمكن أن يتحرك من النهاية الأولى إلى النهاية الثانية. ويستخدم مقياس الجهد لقياس الإزاحات الخطية والزاوية.

وكما هو معروف فإن فرق الجهد الملامس يتناسب مع المسافة X والزاوية υ كما هو مبين في الشكلين التاليين:



شكل٢-٣٧(ب): مقياس فرق الجهد
لإزاحة زاوية



شكل٢-٣٧(أ): مقياس فرق الجهد
لإزاحة خطية

العلاقة بين فرق جهد الدخل E_s وفرق الجهد الخرج E_{out} في مقياس الجهد الخطي: $E_{out}=(x/L).E_s$

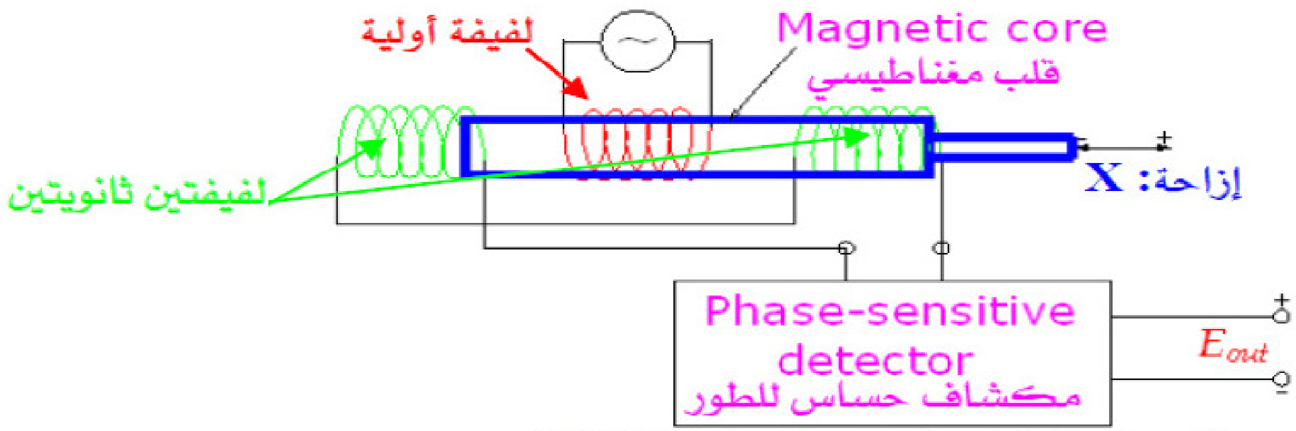
العلاقة بين فرق جهد الدخل E_s وفرق الجهد الخرج E_{out} في مقياس الجهد الزاوي: $E_{out}=(\theta/\theta_L).E_s$

انحلال مقياس الجهد resolution of potentiometer هو:

$Resolution\ (\%)=100/N$ ، حيث N عدد اللفات في مقياس الجهد

ب- المحول التفاضلي الخطي Linear Variable Differential Transformers (LVDT):

المحول التفاضلي الخطي هو محول الكترومغناطيسي يستخدم لقياس الإزاحات الخطية كما هو مبين في الشكل التالي.يتكون من لفيفة أولية موضوعة بين لفيفتين ثانويتين حول أسطوانة وهناك قلب مغناطيسي متحرك يولد علاقة متغيرة بين اللفيفتين. قضيب القياس متصل بالمغناطيس الرئيس ويمكن تحريكه لقياس الإزاحة.



شكل٢-٣٨: المحول التفاضلي الخطي LVDT ومكشاف حساس الطور
ينتج فرق جهد ثابت يتناسب مع إزاحة القلب المغناطيسي

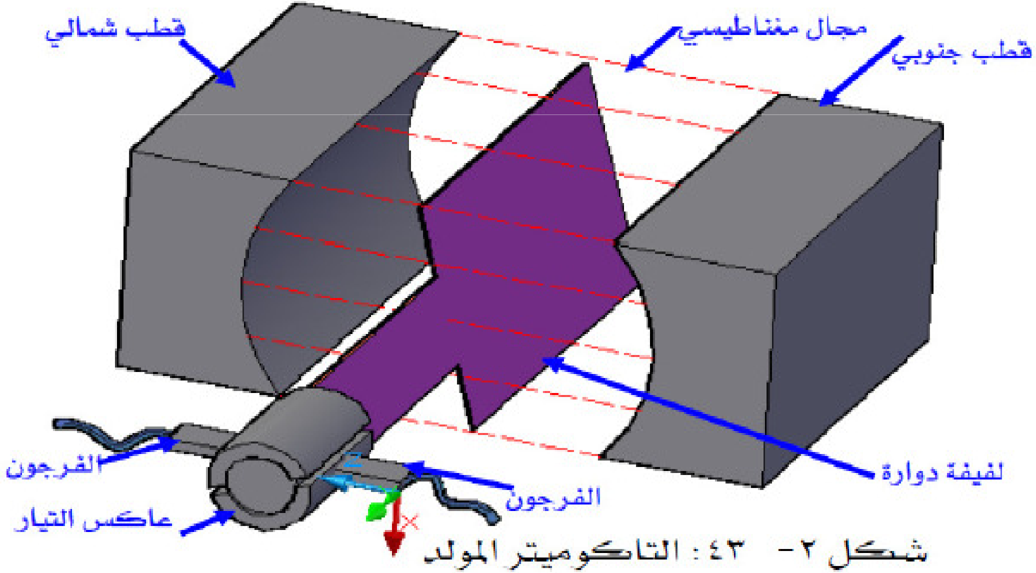
٢- ٥- ٢ قياس السرعة:

السرعة هي معدل تغير الإزاحة أو المسافة، وتقاس بوحدة الطول لكل وحدة زمن. السرعة الزاوية أو سرعة الدوران هي معدل تغير الإزاحة الزاوية، وتقاس بالرادين لكل وجدة زمن أو باللفة لكل وحدة زمن. قياس السرعة الخطية يمكن تحويله إلى سرعة زاوية وقياسه بمحول سرعة زاوية. هناك طريقتين لقياس السرعة الزاوية باستخدام التاكوميتر المولد والتاكوميتر الضوئي .

❖ **التاكوميتر المولد:** وهناك نوعان

أ- تاكوميتر التيار المستمر dc tachometer:

هذا التاكوميتر هو مولد كهربائي يستخدم لقياس السرعةالزاويةالشكلالتالي يبين مكوناتالتاكوميتر.



شكل ٢- ٤٣: التاكوميتر المولد

يتم تركيب اللفيفة الدوارة في أسطوانة مغناطيسية تسمى حافظة المغناطيس armature . للفيفة نهايتين موصولتين بعاكس التيار commutator وهناك قطعتين عند عاكس التيار لكل لفيفة، مثلا حافظة مغناطيس لها 11 لفيفة يجب أن يكون لديها 22 قطعة.

كل اثنان من الفرجون الكربوني يوصلان أسلاك من الرصاص بأجزاء عاكس التيار وبذلك فإن الفرجون الكربوني وعاكس التيار يعملان كزر عاكس لتوصيل اللفيفة لكل نصف لفة (1808) لحافظة المغناطيس. عملية التغيير تحول فولتية ترددية في اللفيفة الدوارة إلى فولتية مستمرة، وبذلك فإن عاكس التيار و الفرجون يكونان محول تيار متردد إلى مستمر.

التاكوميتر يولد فولتية مستمرة تتناسب مع السرعة الدورانية لحافظة المغناطيس، والمعادلة التالية تبين ذلك:

$$E=K_E.S=(30.K_E.\varpi)/\pi \qquad K_E=(2\pi RBNL)/60$$

حيث: E = خرج التاكوميتر بالفولت (Volt) ، K_E = ثابت التناسب بالفولت/لفة (volt/rpm)

S = سرعة الدوران باللفة/دقيقة (rev/min) ، ϖ = سرعة الدوران بالرادين/الثانية (rad/sec)

R = معدل نصف القطر بالمتر (m) ، B = كثافة الدفق المغناطيسي بالويبر/المتر مربع ($weber/m^2$)

N = العدد الفعلي للموصلات ، L = طول كل موصل بالمتر (m)

ب- تاكوميتر التيار المتردد Ac tachometer:

تاكوميتر التيار المتردد هو مولد كهربائي بثلاثة خطوط حارة three-phase مع مقوم(يحول تيار متردد إلى تيار طردي) rectifier عند الخرج . هذا التاكوميتر في سرعات عالية، ولكن الخرج يصبح غير خطي non linear عند سرعات منخفضة وذلك بسبب هبوط النولتية التي تمر عبر المقوم (حوالي 0.7V). لهذه الأسباب هذا التاكوميتر له نطاقات سرعة من 100 إلى 1 بالمقارنة مع 1000 إلى 1 في تاكوميتر التيار المستمر. تاكوميتر التيار المتردد ليس له فرجونات brushes .

مقارنة بين تاكوميتر التيار المستمر وتاكوميتر التيار المتردد			
	تاكوميتر التيار المستمر مزود بفرجونات	تاكوميتر التيار المستمر غير مزود بفرجونات	تاكوميتر التيار المتردد
نطاق السرعة	١/١٠٠٠	١/١٠٠٠	١/١٠٠
دارة كهربية	لا	حساس وضع وتحويل بدون صمامات الكترونية	مقوم

❖ التاكوميتر الضوئي:

محول شفرة تدرجي موصل إلى عمود دوار يولد سلسلة متعاقبة من النبضات والتي تمكننا من الحصول على إشارة رقمية للسرعة. مثلا لنفرض أن محول الشفرة له 1000 ثقب على المسار الخارجي، والعداد يولد مجموع جديد كل 10ms. عمود له سرعة بقيمة 600rpm (10 لفات في الثانية) يولد 10 x 1000 = 10000 نبضة في الثانية. العداد سوف يعد 0.01 x 10000 = 100 نبضة لكل 10ms . وبذلك فإن عد 100 يوافق سرعة دورانية 600لفة في الدقيقة. المعادلات التالية تبين العلاقة بين سرعة دوران عمود والعداد الزمني للتاكوميتر الضوئي: $S=(60.C)/(N.T_C)$ $C=(S.N.T_C)/60$

حيث: S = سرعة دوران عمود باللفة في الدقيقة N = عدد النبضات لكل لفة للعامود

C = العدد الكلي خلال الزمن T_C T_C = زمن العد بالثانية

٢-٥-٣ قياس القوة:

القوة كمية فيزيائية تولد تغيير في سرعة أو شكل الأشياء، لها قيمة واتجاه تم تعريفهما عن طريق قانون الحركة لنيوتن Newton's law of motion، كالتالي: $F = m.a$

حيث: F = القوة المسلطة على الكتلة M بالنيوتن (Newton)(N) m = الكتلة بالكيلوجرام (Kg)

A = تسارع الكتلة بالمتر/ثانية^2 (m/sec^2)

قيمة القوة F كما نلاحظ هي الكتلة ضارب التسارع، ولكن هذا لا يعني أنه ليس هناك قوة مسلطة على الجسم إذا لم يكن هناك تسارع.

كل طرق قياس القوة، تستعمل بعض وسائل إنتاج قوة موازنة قابلة للقياس، وهناك طريقتان لإنتاج قوة الموازنة:

- طريقة تصفير الموازنة null balance method
- طريقة الإزاحة displacement method.