Let it flow

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Measuring the flow of liquids in industrial plants is critical. In some operations, the ability to conduct accurate flow measurements is so important it can make the difference between making a profit and taking a loss. In other cases, inaccurate flow measurements or failure to take measurements can cause serious or disastrous results.

With most liquid flow measurement instruments, the flow rate is determined inferentially by measuring the liquid's velocity or the change in kinetic energy. Velocity depends on the pressure differential that is forcing the liquid through a pipe or conduit. Because the pipe's cross-sectional area is knowable and remains constant, the average velocity is an indication of the flow rate.

The basic relationship for determining the liquid's flow rate in such cases is:

$Q = V*A$

Where: Q = Volumetric flow rate through the pipe (m^3/s)
V = Average velocity of the flow (m/s)
A = Cross-sectional area of the pipe (m^2)

Other factors that affect liquid flow rate include the liquid's viscosity and density and the friction of the liquid in contact with the pipe. Direct measurements of liquid flow happen using positive-displacement flowmeters. These units divide the liquid into specific increments and move it on. The total flow is an accumulation of the measured increments, which accumulate by mechanical or electronic techniques.

Numerous types of flowmeters are available for closed-piping systems. In general, they break down into four different flavors: differential pressure, positive displacement, velocity, and mass meters.

Differential pressure devices include orifices, venturi tubes, flow tubes, flow nozzles, pitot tubes, elbow-tap meters, target meters, and variable-area meters.

Positive displacement meters include piston, oval-gear, nutating-disk, and rotary-vane types.

Velocity meters consist of turbine, vortex shedding, electromagnetic, and sonic designs.

Mass meters include Coriolis and thermal types.
The measurement of liquid flows in open channels generally involves weirs and flumes.

Differential pressure meters

The use of differential pressure as an inferred measurement of a liquid's rate of flow is well known. Differential pressure flowmeters are, by far, the most common units in use. Estimates are that over 50% of all liquid flow measurement applications use this type of unit. The basic operating principle of differential pressure flowmeters is the pressure drop across the meter is proportional to the square of the flow rate. One ascertains the flow rate by measuring the pressure differential and extracting the square root.
Differential pressure flowmeters, like most flowmeters, have a primary and secondary element. The primary element causes a change in kinetic energy, which creates the differential pressure in the pipe. The unit must match up properly to the pipe size, flow conditions, and the liquid's properties. In addition, the measurement accuracy of the element must be good over a reasonable range.
The secondary element measures the differential pressure and provides the signal or read-out that translates to the actual flow value.

Orifices are the most popular liquid flowmeters in use. An orifice is a flat piece of metal with a specific-sized hole bored in it. Most orifices are of the concentric type, but eccentric, conical (quadrant), and segmental designs are also available. In practice, the orifice plate installs in the pipe between two flanges. Acting as the primary device, the orifice constricts the flow of liquid to produce a differential pressure across the plate. Pressure taps on either side of the plate detect the difference. Major advantages of orifices are they have no moving parts and their cost does not increase significantly with pipe size. Conical and quadrant orifices are relatively new. The units came about primarily to measure liquids with low Reynolds numbers. Essentially, constant flow coefficients are possible at Reynolds number values below 5000. Conical orifice plates have an upstream bevel, the depth and angle of which must be calculated and machined for each application. Integral wedge assemblies combine the wedge element and pressure taps into a one-piece pipe coupling bolted to a conventional pressure transmitter. No special piping or fittings are necessary to install the device in a pipeline. Metering accuracy of all orifice flowmeters depends on the installation conditions, the orifice area ratio, and the physical properties of the liquid.

Positive-displacement meters

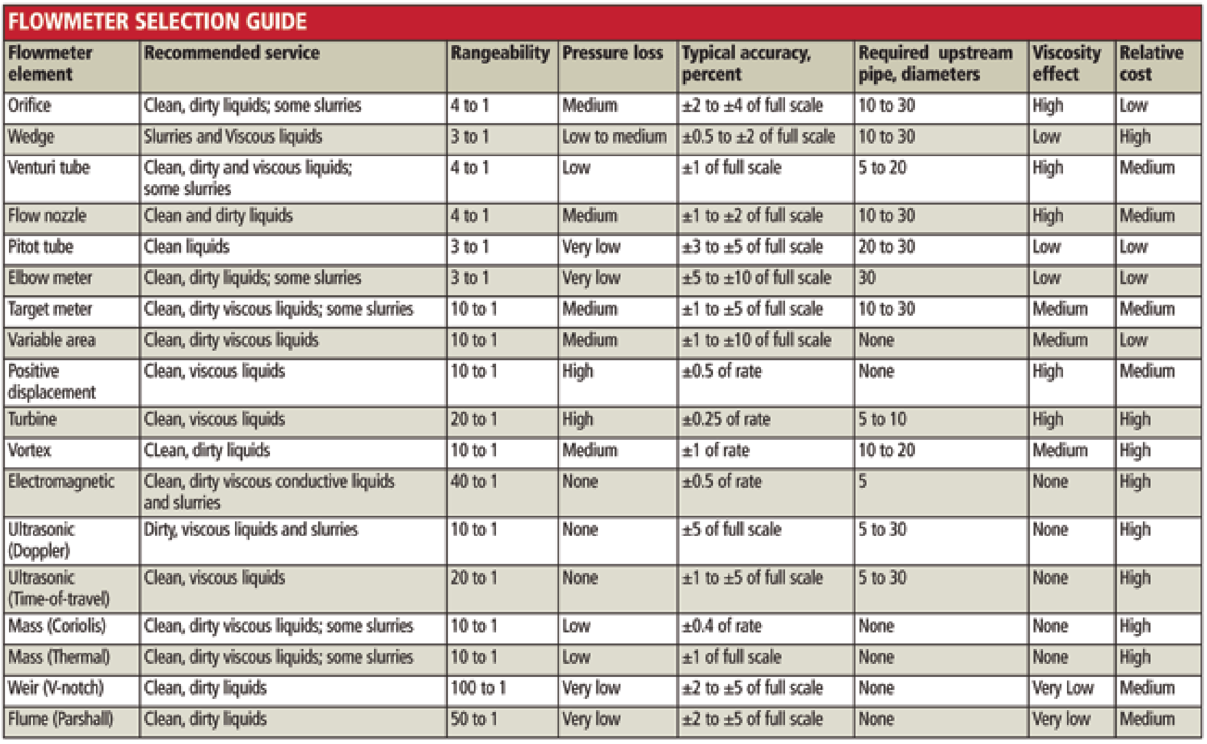
Positive-displacement meters operate by separating liquids into accurately measured increments and moving them on. Each segment connects register, which counts the increments one-by-one. Because every increment represents a discrete volume, positive-displacement units are popular for automatic batching and accounting applications. Positive-displacement meters are good candidates for measuring the flows of viscous liquids or for use where there's a need for a simple mechanical meter. Reciprocating piston meters are of the single and multiple-piston types. The specific choice depends on the range of flow rates required in the particular application. Piston meters can handle a wide variety of liquids. Liquid never encounters gears or other parts that might clog or corrode.

Velocity meters

Velocity meters operate linearly with respect to the 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 connect directly into pipelines. Turbine meters are one version of velocity meter that have found widespread use for accurate liquid measurement applications. The unit consists of a multiple-bladed rotor mounted with a pipe, perpendicular to the liquid flow. The rotor spins as the liquid passes through the blades. The rotational speed is a direct function of flow rate and a magnetic pick-up, a photoelectric cell, or gears can sense the speed.

Mass flowmeters

The continuing need for more accurate flow measurements in mass-related processes (chemical reactions, heat transfer, and the like) has resulted in the development of mass flowmeters. Various designs are available, but the one most commonly used for liquid flow applications is the Coriolis meter. Its operation is based on the natural phenomenon called the Coriolis force, hence the name. Coriolis meters are true mass meters that measure the mass rate of flow directly as opposed to volumetric flow. Because mass does not change, the meter is linear without having to be adjusted for variations in liquid properties. It also eliminates the 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 also available in various designs. A popular unit consists of a U-shaped flow tube enclosed in a sensor housing connected to an electronics unit. The sensing unit can install 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 vibrates at its natural frequency by a magnetic device located at the bend of the tube. The vibration is similar to that of a tuning fork, covering less than 0.1 in. and completing a full cycle about 80 times/sec. As the liquid flows through the tube, it takes on the vertical movement of the tube. When the tube is moving upward during half of its cycle, the liquid flowing into the meter resists the upward force by pushing down on the tube. The overall effect is a force that 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 amount of twist is directly proportional to the mass flow rate of the liquid flowing through the tube.



FLOWMETER SELECTION GUIDE

Flowmeter element	Recommended service	Rangeability	Pressure loss	Typical accuracy, percent	Required upstream pipe, diameters	Viscosity effect	Relative cost
Orifice	Clean, dirty liquids; some slurries	4 to 1	Medium	±2 to ±4 of full scale	10 to 30	High	Low
Wedge	Slurries and Viscous liquids	3 to 1	Low to medium	±0.5 to ±2 of full scale	10 to 30	Low	High
Venturi tube	Clean, dirty and viscous liquids; some slurries	4 to 1	Low	±1 of full scale	5 to 20	High	Medium
Flow nozzle	Clean and dirty liquids	4 to 1	Medium	±1 to ±2 of full scale	10 to 30	High	Medium
Pitot tube	Clean liquids	3 to 1	Very low	±3 to ±5 of full scale	20 to 30	Low	Low
Elbow meter	Clean, dirty liquids; some slurries	3 to 1	Very low	±5 to ±10 of full scale	30	Low	Low
Target meter	Clean, dirty viscous liquids; some slurries	10 to 1	Medium	±1 to ±5 of full scale	10 to 30	Medium	Medium
Variable area	Clean, dirty viscous liquids	10 to 1	Medium	±1 to ±10 of full scale	None	Medium	Low
Positive displacement	Clean, viscous liquids	10 to 1	High	±0.5 of rate	None	High	Medium
Turbine	Clean, viscous liquids	20 to 1	High	±0.25 of rate	5 to 10	High	High
Vortex	CLean, dirty liquids	10 to 1	Medium	±1 of rate	10 to 20	Medium	High
Electromagnetic	Clean, dirty viscous conductive liquids and slurries	40 to 1	None	±0.5 of rate	5	None	High
Ultrasonic (Doppler)	Dirty, viscous liquids and slurries	10 to 1	None	±5 of full scale	5 to 30	None	High
Ultrasonic (Time-of-travel)	Clean, viscous liquids	20 to 1	None	±1 to ±5 of full scale	5 to 30	None	High
Mass (Coriolis)	Clean, dirty viscous liquids; some slurries	10 to 1	Low	±0.4 of rate	None	None	High
Mass (Thermal)	Clean, dirty viscous liquids; some slurries	10 to 1	Low	±1 of full scale	None	None	High
Weir (V-notch)	Clean, dirty liquids	100 to 1	Very low	±2 to ±5 of full scale	None	Very Low	Medium
Flume (Parshall)	Clean, dirty liquids	50 to 1	Very low	±2 to ±5 of full scale	None	Very low	Medium