Flowmeters and Their Apps:
An Overview

Here are 11 ways to measure flow—liquid, gas, and steam. One is sure to be just right for your application.

Jesse Yoder, Flow Research, Inc.

Nearly every type of flowmeter can be assigned to one of two categories: traditional and new technology. The traditional meters are:

- Differential pressure
- Positive displacement
- Turbine
- Open channel
- Variable area

These devices were introduced before 1950. Some of their performance characteristics, such as accuracy, are at a lower level than their newer counterparts and their maintenance requirements are greater. For instance, the orifice plates in differential pressure meters are subject to wear and can be knocked out of position by impurities in the flowstream. The various technologies represented in this group have been slow to incorporate recent advances in communication protocols such as HART, Foundation Fieldbus, and Profibus.

The new-technology flowmeters include:

- Coriolis
- Magnetic
- Ultrasonic
- Vortex
- Multivariable differential pressure
- Thermal

These were introduced after 1950. They take advantage of modern microprocessor-based technology. Their construction and operating principles avoid some of the problems inherent in the older meter types. And they generally outperform their precursors, particularly in their accuracy levels of ±1.0% or better.

Figure 1. Differential pressure flowmeters insert an obstruction in the flowstream to reduce the flow rate and thus the pressure. Flow rate is calculated by taking the difference between upstream and downstream pressures. (Photo courtesy of Honeywell

Traditional Flowmeters

Established, familiar flow measurement devices are still holding their ground in many applications, and their installed base is much larger than that claimed by the newer devices. In fact, the number of positive displacement and turbine meters sold in 2002 was about the same as the total number of new-technology flowmeters sold that year.

Differential Pressure. Differential-pressure (DP) flowmeters (see Figure 1) incorporate an obstruction in the flowstream that reduces flow velocity. This reduction has the effect of lowering the fluid pressure as well. The DP flowmeter measures the difference between upstream and downstream pressure, and computes flow rate based on that difference. The amount of pressure drop depends on the type of primary element used. Orifice plates cause substantial loss of line pressure, while averaging Pitot tubes cause less.

DP meters excel at measuring clean liquids, steams, and gases in applications that are not adversely affected by pressure drop, that require low-to-medium accuracy, and where price is a consideration. They are considerably less expensive than most Coriolis and ultrasonic meters.

Figure 2. Positive displacement flowmeters capture a liquid sample in a small container and calculate flow rate by counting the number of captures and fills. (Photo courtesy of FMC Measurement Solutions.)

Figure 3. The rotor in turbine flowmeters spins at a rate proportional to liquid flow rate. Shown here are an insertion (center) and an inline type (left). The small meters in the foreground are also turbines. (Photo courtesy of Hoffer Flow Controls Inc.)

Positive Displacement. Positive-displacement (PD) meters (see Figure 2) operate by capturing the fluid to be measured inside a small container of known capacity, and then counting the number of times this is done. The speed of flow therefore is not of consequence to these meters. They excel at measuring low flows and those with high viscosity.

Highly accurate, PD meters have been approved by various regulatory bodies for use in custody transfer operations such as commercial and industrial water, natural gas, and hydrocarbon liquids as they are transfered to and from delivery trucks. They also do well with liquids that would give other meters headaches—honey, oil, and syrup.

Turbine. These flowmeters (see Figure 3) incorporate a rotor whose blades spin in proportion to flow rate. They therefore are at their best with steady, high-speed flows. They are also are more adaptable to large pipe sizes (>12 in.) than are PD meters.

There are at least eight types of turbine meters, each designed for a specific set of applications. Among these are custody transfer of commercial and industrial water, hydrocarbon-based and other liquids, and natural gas.

Figure 4. Open-channel flowmeters are called for when the liquid of interest is not closely confined or pressurized. The Model 2150 area-velocity meter shown here monitoring flow at the bottom of a manhole does not require a weir or flume, although many such flowmeters do. (Photo courtesy of Isco, Inc.)

Open Channel. Open-channel flows are those in which a liquid flows in a stream or conduit that is not closed (e.g., a river), or in a partially filled pipe that is not pressurized. The open-channel meters that measure them (see Figure 4) come in different flavors. Some require hydraulic structures such as weirs or flumes, similar to the primary elements of DP meters. The liquid of interest passes through the structure, and flow rate is calculated based on the level or depth of the passing fluid.

Another popular method is velocity area, in which the velocity of the stream is computed by one method (e.g., electromagnetic), and the level or depth by another (e.g., radar). These values are then used to determine flow rate, although the area of the flow must also be known. There are also ultrasonic open-channel flowmeters.

These flowmeters are the only game in town when it comes to open-channel applications.

Variable Area. Most variable-area (VA) flowmeters (see Figure 5) consist of a tapered tube containing a float. Fluid passing through the meter exerts an upward force on the float that is counterbalanced by the force of gravity. The point at which the float stays constant indicates the volumetric flow rate, which is often read on a scale on the meter tube. The tubes are made of metal, glass, or plastic. Metal, the most expensive, is used for high-pressure applications.

Figure 5. Variable-area flowmeters typically contain a float that is forced upward by the fluid passing through. The point of equlibrium between this force and that of gravity indicates the volumetric flow rate. (Photo courtesy of ABB Inc.)

While most VA meters are read manually, some incorporate transmitters that generate an output signal, which can be sent to a controller or recorder. These meters are not a good choice for high-accuracy applications, but they do very well when a visual indication of flow is sufficient. They are quite effective at measuring low flow rates and can also serve as flow/no-flow indicators. Because they do not require electric power, they can safely be used in flammable environments.

New-Technology Flowmeters

Figure 6. As a liquid or gas passes through the (usually) bent vibrating tubes of a Coriolis flowmeter, the tubes twist to a degree proportional to the fluid's mass flow. The deflection is measured by a position sensor. (Photo courtesy of Foxboro)

Coriolis. In 1835, the French mathematician Gustave Coriolis demonstrated that an inertial force must be taken into account when describing the motion of bodies in a rotating frame of reference. The Earth is commonly used as an example of this Coriolis force. Because the planet is rotating, an object thrown from the North or South Pole toward the equator will appear to deviate from its intended path.

Coriolis flowmeters (see Figure 6) are composed of one or more, usually bent, vibrating tubes. Fluid passing through the tubes accelerates as it approaches the point of maximum vibration and decelerates as it leaves this point. The tubes twist to a degree directly proportional to the fluid's mass flow, and their deflections are detected by position sensors. Some manufacturers have introduced straight-tube models, often used for sanitary applications.

Figure 7. Magnetic flowmeters operate on Faraday's law of electromagnetic induction and therefore work only with conductive liquids. A current applied to coils mounted on or outside the flow pipe generates a magnetic field inside the pipe. The liquid passing through generates a voltage proportional to flow rate, which is detected by electrodes on either side of the pipe. (Photo by Flow Research, courtesy of Krohne)

Coriolis flowmeters work for both liquids and gases. They can also handle some fluids with varying densities that cannot easily be measured by other meters. While they are highly accurate, with a few exceptions they are limited in size to 6 in. dia.; more than 90% of those sold are 2 in. dia. Their high initial cost (although some models are now available in the $3000 range) is offset to some extent by low maintenance requirements.

Magnetic. Magnetic flowmeters (see Figure 7) are based on Faraday's law of electromagnetic induction, which posits that a voltage is generated in a conductive medium when it passes through a magnetic field. This voltage is directly proportional to the length of the conductor, the density of the magnetic field, and the velocity of the conductive medium. These three values are multiplied together, along with a constant, to yield the magnitude of the voltage.

Magnetic flowmeters, or magmeters, use wire coils mounted on or outside a pipe. A current applied to the coils generates a magnetic field inside the pipe. A conductive liquid passing through generates a voltage proportional to flow rate that is detected by electrodes mounted on either side of the pipe.

Figure 8. This multipath ultrasonic transit-time flowmeter uses four pairs of transducers to send and receive an ultrasonic signal over the same path length. The values given by the different paths are averaged to obtain gas flow-rate measurements more accurate than those provided by single-path meters. (Photo by Flow Research, courtesy of Emerson Daniel)

Magmeters are highly accurate and do not create a pressure drop. They can measure only liquids, not gases or steam. They are popular for use on conductive liquids and slurries, including paper pulp slurries and black liquor. Because they cannot measure hydrocarbons (which are nonconductive), they are not appropriate for most petroleum industry applications.

Ultrasonic. These flowmeters (see Figure 8), introduced to industry 1963, are available in two types: transit time and Doppler. Transit time meters incorporate a transducer that acts as both a sender and a receiver. An ultrasonic signal is sent across the pipe at an angle, and the time it takes to travel from one side of the pipe to the other is measured. The signal speed is greater traveling with the flow than against it. The difference between transit time across the pipe and that of the signal traveling in the reverse direction is proportional to flow rate. This type of ultrasonic flowmeter is used primarily for clean fluids, although some have been developed that can contend with impurities.

Doppler ultrasonic flowmeters also send an ultrasonic signal across the pipe, reflecting it off particles traveling in the flowstream at the same rate as the fluid. As the signal passes through the stream, its frequency shifts in proportion to the mean velocity of the fluid. A receiver measures the frequency of the reflected signal, and the flow rate is computed by comparing the generated and detected frequencies. These meters are used primarily on slurries and dirty liquids.

Multipath ultrasonic flowmeters use multiple pairs of transducers that alternate in their functions as senders and receivers over the same path length. By averaging the values given by the different paths, the flow rate is determined with greater accuracy than single-path meters can provide. These meters are used for natural gas custody transfer operations.

Vortex. Vortex flowmeters (see Figure 9) are based on the von Kármán effect. According to this principle, a flow will generate alternating vortices when passing by a bluff body. In a vortex meter, this bluff body is a piece of material with a broad, flat front mounted at right angles to the flowstream. Flow rate is calculated by multiplying the area of the pipe by the flow velocity, which is proportional to the frequency of the vortices generated by the bluff body. In some cases, vortex meters require straightening vanes or a specified length of straight piping upstream to eliminate distorted flow patterns and swirl. Low flow rates, which generate vortices irregularly, present a problem for these devices.

Figure 9. Vortex flowmeters measure flow by placing a bluff body across the stream. Flow rate is calculated by multiplying the pipe area by the flow velocity, which is proportional to the frequency of the vortices generated by the bluff body. These devices are used with liquid, gas, and steam. (Photo courtesy of Venture Measurement Co.)

Vortex flowmeters have medium to high accuracy, depending on model and manufacturer. In addition to liquid and gas, they are widely used to measure steam flow. Recent advances in vortex technology include the use of digital signal processing to better handle vibration problems.

Multivariable Differential Pressure. Multivariable DP flowmeters (see Figure 10) measure temperature and/or pressure in addition to flow. These values can then be used to calculate mass flow. Multivariable DP transmitters become flowmeters when they are attached to or integrated with a primary element. Some of these transmitters send their signals to a flow computer, which performs the mass flow calculation. Others perform this computation within the flowmeter.

Figure 10. Multivariable differential pressure transmitters, when attached to or integrated with a primary element, measure temperature and/or pressure and use these values to calculate mass flow. (Photo courtesy of Bristol Babcock)

These devices are used with steam and other applications requiring mass flow measurements.

Thermal. In contrast to most other types of flowmeter, thermal flowmeters (see Figure 11) measure mass flow directly. They can be based on a variety of operating principles, but most involve heat dispersion. Some put heat into a flowstream and measure the length of time required for dissipation. Others measure the amount of energy required to maintain a constant temperature in the flowstream. One type of thermal flowmeter, the mass flow controller, uses a bypass method to measure a portion of the flow.

Figure 11. Thermal flowmeters measure mass flow directly. Some of these devices put heat into the flow stream and measure how long it takes to dissipate; others measure the amount of energy required to maintain a constant temperature in the stream. They are used for low flows, primarily gas. (Photo courtesy of Sierra Instruments)

Thermal flowmeters excel at measuring low flows, primarily gas. They can handle some applications that defy Coriolis meters because of slow flow rate or insufficient fluid density. They are less expensive, but significantly less accurate than Coriolis meters. Thermal meters are the technology of preference when low to medium accuracy will do, and purchase price is a consideration.

Summary

Whatever the application, there is a flowmeter out there to satisfy it. In addition to the devices discussed here, there are target meters as well as some new designs based on sonic and photonic principles. Selection criteria will necessarily include theìcharacteristics of the fluid to be measured; the level of measurement acccuracy required; the extent to which the fluid can be confined, touched, or altered; accessibility for maintenance requirements; and, of course, purchase price.

This article was adapted from The World Market for Flowmeters*, published in February 2003.*

Jesse Yoder, Ph.D., is President, Flow Research, Inc., Wakefield, MA; 781-245-3200, jesse@flowresearch.com.

MORE!

For further reading on this and related topics, see these *Sensors* articles.

"A Miniature Flow Sensor with Electronic Temperature Compensation," April 2003
"A Mass Flow Controller that Semicon Can't Touch," January 2002
"Adapting Acoustic Monitoring Technology to Detect Bulk Solids Flow," September 2001
"Clamp-On Flowmeters for Fluids," August 2001
"A High-Precision Piezoresistive Flow Sensor for Microdosing Applications," September 2000
"Paddlewheel Flow Sensors: The Overlooked Choice," December 1999
"EMF Flow Measurement in Partially Filled Pipes," October 1999
"High-Temperature Flow Measurement with Wetted and Clamp-On Ultrasonic Sensors," October 1999
"Turbine Flowmeters," Part 1 and Part 2, October and November 1999
"Ultrasonic Flowmeter Basics," October 1997
"Single-Sensor Measurement of Flow in Filled or Partially Filled Process Pipes," September 1997