Selecting Flowmeters to Minimize Energy Costs

Greg Livelli
ABB Measurement Products

Choosing a flowmeter with a low permanent pressure loss can reduce pump or compressor work requirements and increase steam boiler capacities — thereby trimming annual energy costs.

Fluid flowrate is an important measurement in the chemical process industries (CPI). Selecting an appropriate flow measurement technique can be a daunting task. If several technologies are suitable for a particular application, minimizing energy costs can help narrow the choice. This article describes several types of flowmeters and discusses ways to assess the energy costs associated with a particular flow-metering technology.

Flowmeter technologies

Figure 1 indicates the variety of flowmeter technologies available and their representation in the CPI.

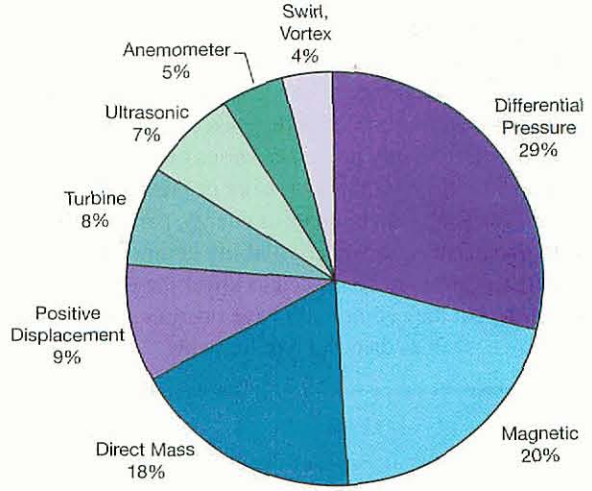
Table 1 shows the applicability of certain flowmeter technologies to various liquid and gas conditions. Green indicates that the technology is suitable for the application, while red rules it out. Yellow indicates that the flowmeter technology will sometimes be appropriate if certain conditions are met. When more than one technology is suitable for a particular set of fluid conditions, the flowmeter with the lowest energy cost may be the best choice.

Flow velocity

Many of the technologies, such as electromagnetic, vortex, turbine, ultrasonic, and anemometer flowmeters, actually measure the flow velocity of the fluid in the pipe. The volumetric flowrate may be calculated by multiplying the measured average velocity by the cross-sectional area of the meter or pipe. In the following sections, the dollar sign after the flowmeter technology indicates its relative capital cost.

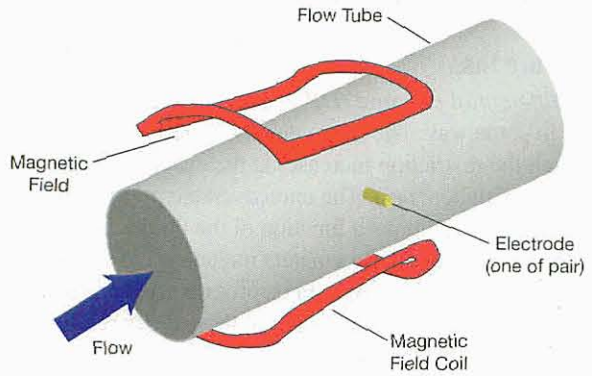
Electromagnetic flowmeters ($) impose alternating or pulsating direct current (DC) magnetic fields on a conductive liquid. Electrodes on either side of the pipe wall pick up the induced voltage (Figure 2). This small voltage (usually in millivolts) is proportional to fluid velocity. These meters do not obstruct liquid flow in any way, so they cause virtually no pressure loss.

Vortex meters ($$) have a bluff obstacle in the flow stream, which creates vortices or eddies with frequencies proportional to flow velocity (Figure 3). Sensors detect and count the pressure variations produced over a fixed

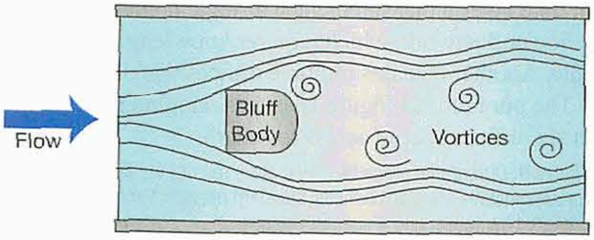


▲ **Figure 1.** In the chemical process industries (CPI), differential pressure devices are the most prevalent flowmeters, followed by electromagnetic flowmeters.

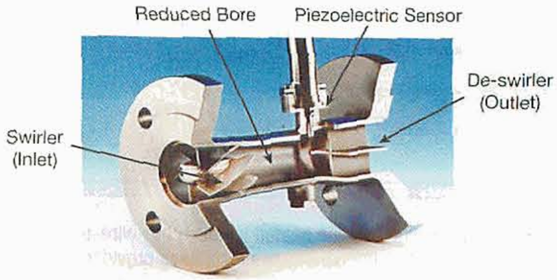
Table 1. Selection of flowmeter technologies depends on the application. Key: Green = Optimal; Yellow = Suitable; Red = Not suitable.							
	Magnetic	Vortex, Swirl	Thermal Mass	Coriolis	DP Orifice	Wedge	Rotameter
Liquids							
Conductive	Green	Green	Red	Green	Green	Green	Green
Non-Conductive	Red	Green	Red	Green	Green	Green	Green
High Solids	Green	Red	Red	Yellow	Yellow	Green	Red
Pulsating Flow	Green	Red	Red	Yellow	Yellow	Yellow	Red
High Viscosity	Green	Yellow	Red	Green	Yellow	Green	Yellow
Gases							
Dry/Clean	Red	Green	Green	Green	Green	Green	Green
Moist	Red	Yellow	Yellow	Yellow	Green	Green	Green
Corrosive	Red	Yellow	Yellow	Yellow	Yellow	Green	Yellow
Contaminated	Red	Green	Yellow	Yellow	Yellow	Green	Red
Steam	Red	Green	Red	Yellow	Green	Green	Green



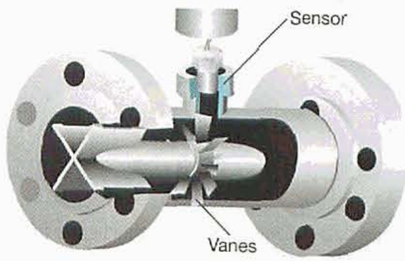
▲ **Figure 2.** Electromagnetic flowmeters send alternating or pulsating direct current (DC) magnetic fields through conductive liquids. Electrodes (shown in yellow) on either side of the pipe wall pick up the induced voltage.



▲ **Figure 3.** Vortex meters have an obstacle in the flow stream that creates vortices whose frequencies are proportional to flow velocity.



▲ **Figure 4.** Vanes at the inlet of a swirl meter cause the flow to swirl, which creates pressure variations for velocity measurement. Straightening vanes at the outlet de-swirl the flow.



▲ **Figure 5.** As fluid flows past the vanes in a turbine meter, the vanes rotate. A sensor detects the rate of rotation, which is proportional to fluid velocity.

time. The frequency of variations per unit time is a measurement of flow velocity.

Swirl meters ($$) are similar to vortex meters, except vanes at the inlet cause the flow to swirl, which creates pressure variations. Straightening vanes at the outlet de-swirl the flow (Figure 4). The straightening vanes reduce the need for long straight runs of pipe upstream from the meter.

Turbine meters ($) contain a turbine with vanes in the fluid flow path. As fluid flows past them, the vanes rotate (Figure 5). A sensor detects the rate of rotation, which is proportional to fluid velocity.

Ultrasonic meters ($$) are available in two varieties:

Doppler and transit-time. The Doppler flowmeter sends an ultrasonic beam into the flow and measures the frequency shift of reflections due to discontinuities in the flow (Figure 6). Transit-time flowmeters have an ultrasonic transmitter and receiver separated by a known distance. The difference between the transit times of a signal aided by the flow and the signal moving against the flow is a function of fluid velocity.

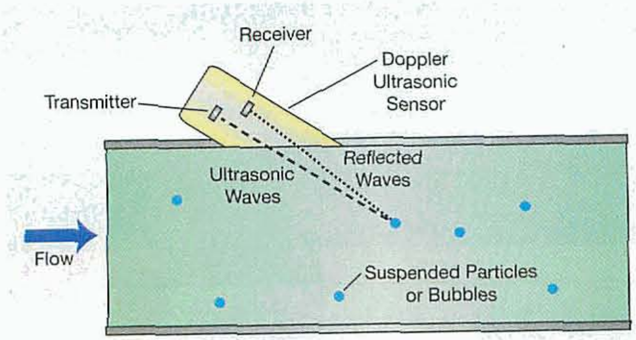
Hot-wire anemometers ($$) introduce a very fine wire that is electrically heated to some temperature above ambient into a gas stream (Figure 7). Gas flowing past the wire has a cooling effect on the wire. Because the electrical resistance of most metals depends on the metal's temperature, measuring the wire's resistance provides an indication of flow velocity.

Target meters ($) place a physical target within the fluid's flow path. The moving fluid deflects a force bar attached to the target (Figure 8). The amount of deflection depends on the target area, as well as the fluid density and velocity. Meters with different target sizes and construction materials are available to handle different fluids and flow ranges.

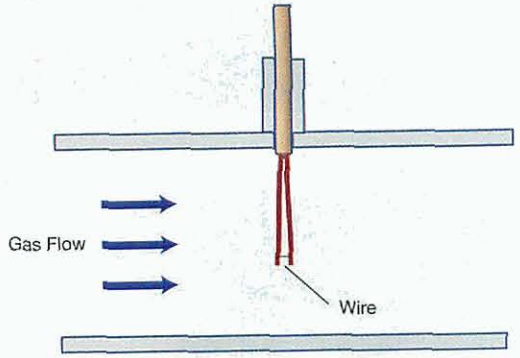
Pressure loss

Differential pressure (DP) meters ($) restrict the fluid flow in some way. The flow velocity (kinetic energy) through the restriction increases at the expense of fluid pressure (potential energy). The unrecoverable pressure drop across the restriction is a function of the fluid velocity, which can be calculated. DP flowmeters include standard orifices, standard nozzles, Venturi meters, proprietary flowtubes, and V-shaped wedges (Figure 9). All of these types require a differential pressure sensor and transmitter.

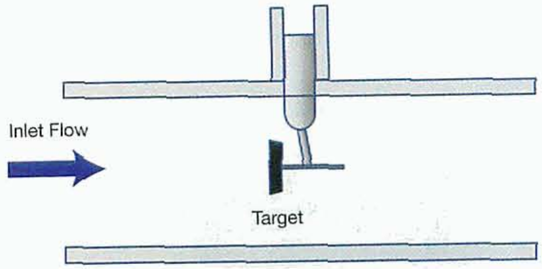
Pitot tubes ($) are low-cost DP elements that are especially suited to gas flow measurement. They are inserted into the flow path and convert the kinetic energy of the flow velocity into potential energy (pressure). One type of pitot tube takes a measurement at a single point within the pipeline or ductwork, which requires knowledge of the flow profile. Another contains multiple orifices that allow averaging. The pitot tube in Figure 10 is an averaging pitot tube with six orifices spaced across its length.



▲ **Figure 6.** A doppler flowmeter sends an ultrasonic beam into a flow path, and discontinuities reflect the wave. The frequency shift between the incident and reflected beams is proportional to flowrate.

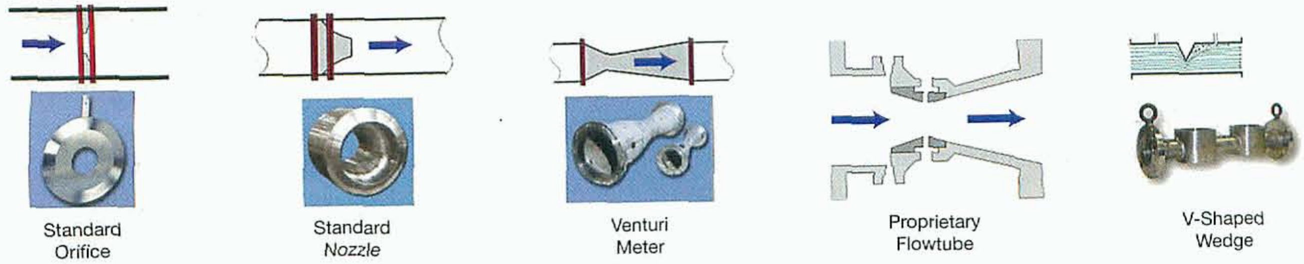


▲ **Figure 7.** Gas flowing past the heated wire in a hot-wire anemometer has a cooling effect. Measuring the wire's resistance provides an indication of flow velocity.

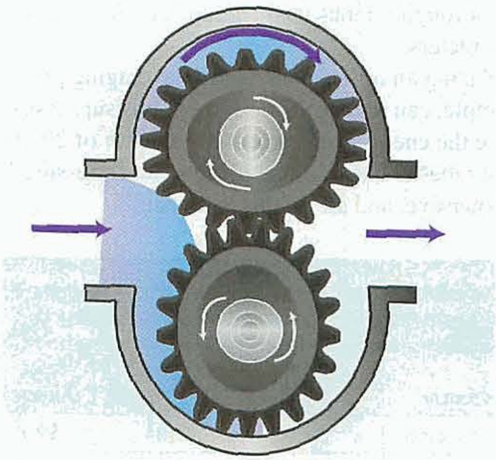


▲ **Figure 8.** Moving fluid deflects a force bar attached to the target meter. If the target area and fluid density are known, the fluid velocity can be determined.

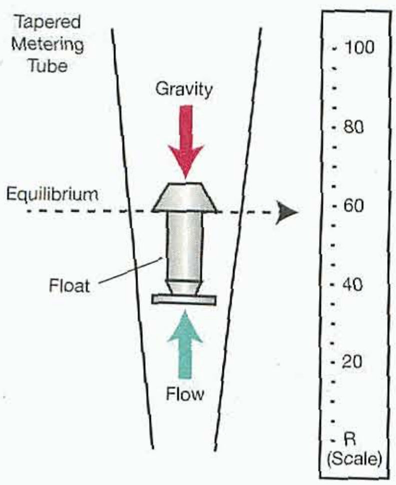
▼ **Figure 9.** Differential pressure (DP) meters restrict the fluid flow. DP flowmeters include standard orifices, standard nozzles, Venturi meters, proprietary flow tubes, and V-shaped wedges.



▲ **Figure 10.** Pitot tubes are suitable for gas flow measurement. This averaging pitot tube has six orifices spaced across its length.



▲ **Figure 11.** Positive-displacement meters capture a discrete volume of fluid and pass it to the outlet. The fluid pressure moves the mechanism that empties one chamber as another fills.



▲ **Figure 12.** With variable-area meters (rotameters), operators can take direct volumetric flow readings based on the float position inside a transparent tube.

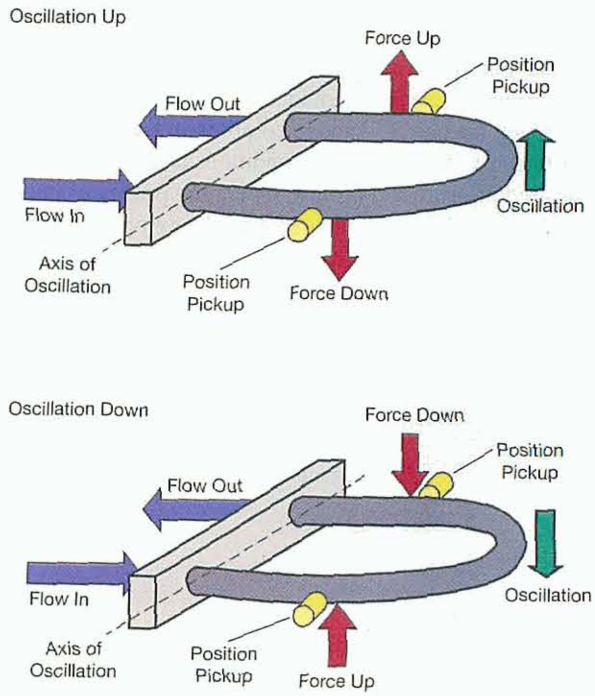
Volumetric flowrate

Positive-displacement meters ($$) directly measure volumetric flowrates and require no calculations. They capture a specific volume of fluid and pass it to the outlet. The fluid pressure moves the mechanism that empties one chamber as another fills (Figure 11). Counting the cycles of rotational or linear motion provides a measure of the displaced fluid. Positive-displacement flowmeters are commonly used for residential gas measurement.

Variable-area meters ($) (often called rotameters) are simple and inexpensive devices that consist of two components: a tapered metering tube and a float that rides within the tube (Figure 12). The float position is determined by the rate of upward flow and float weight, and is therefore a linear function of flowrate. Operators can take direct volumetric flow readings based on the float position inside a transparent glass or plastic tube. Rotameters with metal tubes have a magnetically coupled pointer to indicate the float position.

Mass flowrate

If the application requires a measure of the mass flowrate, volumetric flowmeters must be supplemented with additional instrumentation to measure fluid density, pressure, and/or temperature. Some multivariable flowmeters and transmitters incorporate an additional sensor to provide



▲ **Figure 13.** Coriolis meters measure mass flowrate directly. As fluid flows through the U-tube, Coriolis forces twist it. Sensors pick up the amount of twist, which is a function of mass flowrate.

this information. On the other hand, Coriolis flowmeters and thermal probes directly measure mass flowrate.

Direct mass flow — Coriolis flowmeters ($$$) measure mass flowrates directly and have few installation limitations (Figure 13). These flowmeters are not sensitive to velocity profile distortion and swirl. Additionally, Coriolis flowmeters handle all fluids regardless of their Reynolds number. Aside from measuring mass flowrates, Coriolis flowmeters can provide simultaneous outputs for fluid density and temperature, volumetric flowrate, total flow, and concentration.

Thermal mass flowmeters ($$) are similar to hot-wire anemometers. They introduce heat into a gas stream and measure its rate of dissipation with one or two temperature sensors. The heat dissipated by the flow stream is a measure of the mass flowrate. Thermal mass flowmeters have no moving parts, are easy to install, and provide a relatively unobstructed flow path. They are accurate over a wide range of gaseous flowrates. However, because they measure flow at a specific point within the gas stream, they require some upstream flow conditioning or knowledge of the flow profile.

Why minimize energy?

Many flow measurement technologies introduce pressure loss into a system. Some flowmeters require upstream reducers and downstream expanders to operate properly. Valves, reducers, expanders, and measuring devices, as well as pipe friction, all increase the permanent pressure loss (PPL) in the system. Pressure losses are energy losses and translate to increased pumping/compressing costs.

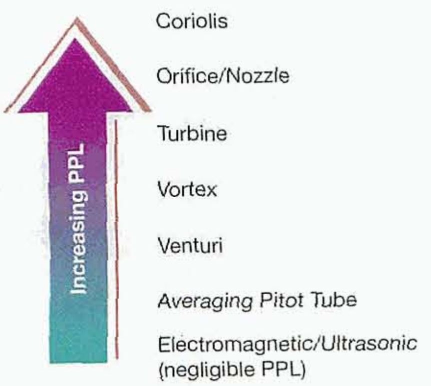
In designing a system, engineers often consider PPL when sizing the pump (liquids), compressor (gases), or boiler (steam) to meet process conditions and to deliver the desired pressure and/or flow. Operating processes must compensate for PPL by adding energy via pumping or compression, which can significantly increase annual operating costs. Minimizing pressure losses in a process reduces the need for top-up pumping or compression, and also reduces environmental impacts. In the case of steam boilers, the ability to retrofit existing flow-metering points with meters that have lower pressure losses can increase the effective boiler capacity.

By selecting flowmeters with low pressure losses, engineers can:

- reduce pumping/compressing costs
- increase capacity
- minimize compressor, pump, or boiler size.

The amount of pressure lost in a flowmeter depends on three factors: the fluid density, the square of the fluid velocity (V_f^2), and the degree of obstruction to fluid flow (K_{meter}). Figure 14 roughly ranks the magnitude of the PPL for various flowmeters.

Replacing an orifice plate with an averaging pitot tube, for example, can reduce the permanent pressure loss (and therefore the energy requirement) by a factor of 20. Averaging pitot tubes create minimal irrecoverable pressure losses, are inexpensive, and are simple to install.



▲ **Figure 14.** Electromagnetic and ultrasonic flowmeters have negligible permanent pressure losses, while Coriolis meters have the highest PPL.

Table 2. For a nitrogen gas application, the flowmeter with the lowest permanent pressure loss also has the lowest annual energy cost.

Flowmeter	PPL, in. H_2O	Power (ME 70%), W	Annual Cost
Orifice, $\beta = 0.65$	54	3,104	$2,719.10
Averaging Pitot	2.8	160	$140.16
Vortex	27.2	1,563	$1,369.19

Note: β is the ratio of the orifice hole diameter to the pipe inside diameter.

Table 3. In a liquid water system, electromagnetic flowmeters are the lowest-annual-cost option because they create no permanent pressure loss.

Flowmeter	PPL, in. H_2O	Power (ME 70%), W	Annual Cost
Orifice, $\beta = 0.65$	64.1	288	$252.29
Averaging Pitot	7.5	33	$28.91
Vortex	25.6	115	$100.74
Electromagnetic	0	0	$0

Table 4. In a steam system, the averaging pitot flowmeter creates the lowest permanent pressure loss and has the lowest annual cost.

Flowmeter	PPL, in. H_2O	Power (ME 90%), W	Annual Cost
Orifice, $\beta = 0.65$	83.7	9,141	$8,007.52
Averaging Pitot	5.23	571	$500.20
Vortex	47.12	5,146	$4,507.90

Calculating energy use and annual cost

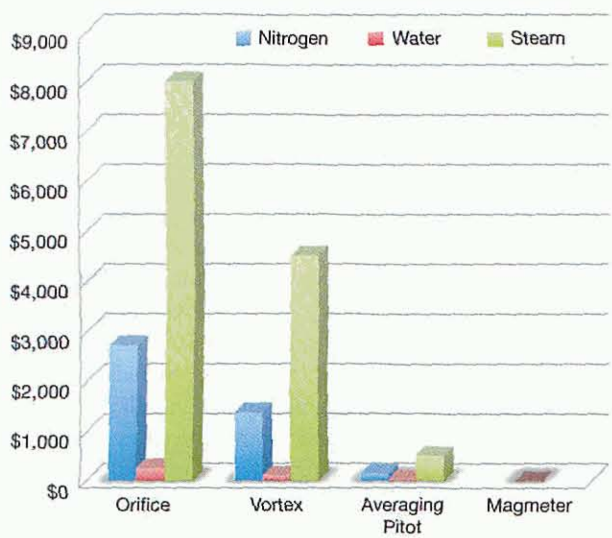
Energy usage per unit of time (*i.e.*, power) may be calculated by multiplying the permanent pressure loss (*PPL*) by the volumetric flowrate (Q), and dividing the product by the mechanical efficiency (*ME*) of the system:

$$Power = \frac{0.118 PPL \times Q}{ME} \quad (1)$$

Equation 1 must be used with the following units: *Power* in watts, *PPL* in in. H_2O, and Q in ft^3/min.

The system's mechanical efficiency is a product of the efficiencies of the electric motor and the pump or compressor. Boilers also have a system efficiency that relates the boiler's energy output to its energy input. The analyses in the example applications assume an efficiency of 0.70 for the compressor and pump in the nitrogen and water systems and 0.90 for the boiler system. The lower the system efficiency, the more power is required to make up for pressure losses in the process.

The annual cost can be calculated by multiplying the power by the local electricity cost ($/kWh) and the number of operating hours in a year (8,760 h/yr). The following examples assume a local electricity cost of $0.10/kWh, which is close to the national average (in 2010). Electric rates, however, differ by state and by residential, commercial, and industrial end uses, and can range from $0.06 to $0.25 per kWh.



▲ **Figure 15.** Annual energy costs for various flow-metering technologies and fluids based on the examples discussed. Selecting a flowmeter for minimum energy favorably affects pump and compressor sizing as well as boiler capacity.

GREG LIVELLI is the Senior Vice President, Global Product Group Flow Measurement for ABB, Inc. (Warminster, PA; Phone: (215) 674-6641; Email: greg.livelli@us.abb.com). He has more than 20 years of experience in the design and marketing of flow-metering equipment. He earned an MBA from Regis Univ. and a bachelor's degree in mechanical engineering from the New Jersey Institute of Technology. He is a member of the International Society of Automation (ISA).

Example applications

Nitrogen, water, and steam serve as representative gases and liquids for many materials in chemical plants. These examples compare the costs of several common types of flowmeters — orifice, averaging pitot, vortex, and electromagnetic (water only) — to monitor these fluids.

Nitrogen gas. Nitrogen gas is flowing in a 4-in. line at a flowrate of 1,500 scfm at standard conditions. At a pressure of 50 psig (64.7 psia), the flowrate may be calculated with the following equation:

$$\frac{1{,}500 \text{ scfm}}{64.7 \text{ psia} / 14.7 \text{ psia}} = 341 \text{ ft}^3/\text{min} \quad (2)$$

Table 2 compares the annual costs of an orifice, averaging pitot, and vortex flowmeter in nitrogen service. The averaging pitot flowmeter has the lowest PPL, and therefore also has the lowest compressor energy requirement and lowest annual cost.

Water. Liquid water is flowing in a 4-in. line at a flowrate of 200 gpm (26.74 ft^3/min) at a pressure of 100 psig.

Table 3 compares the annual costs of orifice, averaging pitot, vortex, and electromagnetic flowmeters for measuring water flow. Because the electromagnetic flowmeter does not obstruct flow, it has no permanent pressure loss. Therefore, it requires no extra power from the pump, and has virtually no annual operating cost.

Steam. Steam is flowing in a 4-in. line at a flowrate of 7,500 lb/h (125 lb/min). At 290°F and 50 psig, the steam's density is 6.66 ft^3/lb. Multiplying 125 lb/min by the density yields an average flowrate of 832.5 ft^3/min.

Table 4 compares the average cost of orifice, averaging pitot, and vortex flowmeters for this application. The averaging pitot tube has the lowest PPL, and therefore has the lowest power requirement and annual cost.

Closing thoughts

Figure 15 compares the annual energy costs required to overcome the permanent pressure losses associated with the flow-metering technologies discussed in the examples. A system with several flowmeters and other pressure-reduction devices served by a pump, compressor, or boiler would incur higher costs than indicated here. However, reducing the PPL can lead to lower electricity bills by minimizing the size and/or work requirement of the pump and/or compressor. Lowering the PPL can also be a low-cost way to expand steam boiler capacities. CEP