



TRACKING NATURAL GAS WITH FLOWMETERS



SPECIAL APPLICATION SERIES

Feature Report

ENERGY EFFICIENCY: Tracking Natural Gas With Flowmeters

Thermal mass flowmeters provide advantages over other options for metering the consumption of natural gas by individual combustion units throughout the facility

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With today's increased emphasis on strategic energy management, many throughout the chemical process industries (CPI) and elsewhere are attempting to obtain better information on the natural gas consumption in their facilities. While custody-transfer flowmeters are typically in place at the property line (to track total gas consumption throughout the facility), the flow to individual combustion sources, such as heaters, furnaces, boilers and so on, generally remains unknown. When armed with better information on actual natural gas utilization, users can optimize the combustion performance by operating combustion processes at peak efficiency.

Similarly, when users measure actual natural gas flow, they are able to determine which of their units is the most efficient. The operating efficiency of furnaces or dryers will vary. Knowing which process unit is the most efficient can result in significant cost savings. For instance, if more than one furnace,

dryer or other type of gas-consuming unit is available, the user will be able to choose the combustion unit that provides the highest efficiency.

The first step to energy management and reducing the energy usage is to obtain good measurements of the flowrates of each individual combustion source. In addition to providing tools for improving energy management, the measurement of the natural gas utilized by individual combustion sources may also permit users to meet the regulatory requirements for determining emissions by reporting actual (rather than estimated) natural gas usage for each individual combustion source within the facility.

In general, the pipe size for natural gas flow to individual combustion sources typically ranges from 1 to 6 inches (25 to 150 mm). The temperature of natural gas is typically at ambient conditions; rarely will you find natural gas at elevated temperatures.

However, the pressure varies with the application. Because of this, flow-

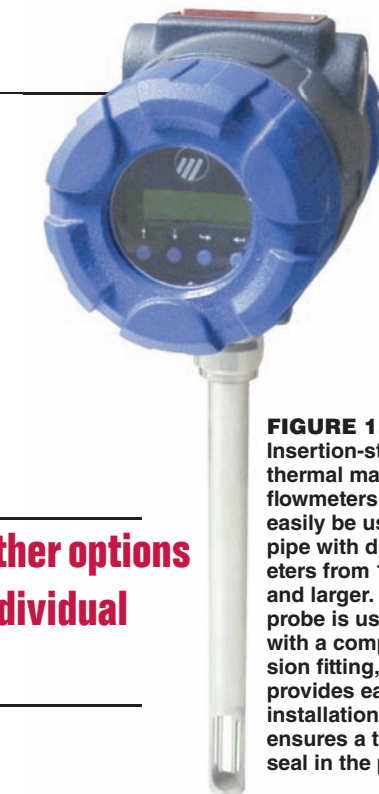


FIGURE 1. Insertion-style thermal mass flowmeters can easily be used in pipe with diameters from 1.5 in. and larger. The probe is used with a compression fitting, which provides easy installation and ensures a tight seal in the pipe

meters are generally located downstream of a pressure regulator. Line pressures typically range from 5 to 10 psig, and occasionally are as low as 1 to 2 psig. Even though the flowmeter is downstream of a pressure regulator, the actual pressure of the natural gas in the pipe may vary depending on the gas consumption. As the consumption increases, the line pressure may decrease.

Flowmeter options

There are many different ways to measure the flow of gases. A brief description of the leading options follows (see also Evaluating Industrial Flowmeters and Advances in Industrial Flowmetering, *CE*, April 2007, pp. 54–64). The difficulty in obtaining good, gas-flow measurements is the simple fact that gases are compressible, and thus the volume of the gas is dependent upon the pressure and temperature at the point of measurement. Chemical engineers will recall the basic concepts of the Ideal Gas Law, whereby gas volume is propor-



FIGURE 2. In this thermal mass flowmeter, the sensors are an integral part of the body construction. This design can be used in pipe sizes from 0.5 to 4 in., and may be used with an optional, built-in flow-conditioning element

tional to the temperature and inversely proportional to the pressure. This complicates gas flow measurement because, with the exception of thermal mass and Coriolis flowmeters, many gas-flow-measurement technologies measure the flow at the actual operating pressure and temperature. These units of measurement are typically expressed as either actual cubic feet per minute (acfm) or cubic meters per hour (m^3/h).

When comparing natural gas usage at various combustion sources for energy-management systems, on the other hand, the desired goal is to measure the flow relative to a defined pressure and temperature — at standard conditions (standard temperature and pressure; STP). While the definition of standard conditions will vary with different industries and in different geographic areas, when the flow is referenced to standard conditions, a mass flow measurement is obtained with units of measurement that are expressed as standard cubic feet per minute (scfm), standard cubic feet per hour (scfh), or normal cubic meters per hour (Nm^3/h).

Flow measurement via orifice plate. This is the traditional method of flow measurement for both gas and liquids. In simplest terms, an orifice is a plate with a hole that is smaller in diameter than the pipe diameter. The orifice plate is positioned between two flanges. As the gas is accelerated through the smaller orifice, the pressure decreases, creating a lower pressure on the downstream side of the orifice plate. The flowrate is proportional to the square root of the pressure drop.

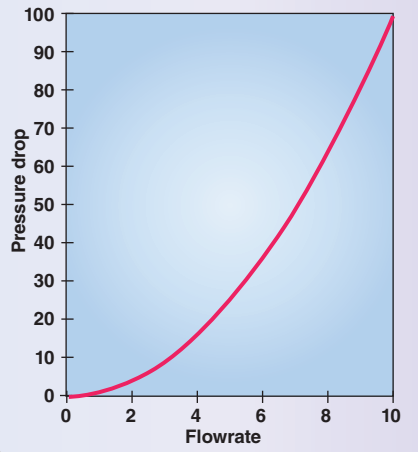


FIGURE 3. Shown here is a typical curve showing the square root relationship between pressure drop and flow for differential-pressure-type flowmeters. At very low flowrates, there is little signal, which limits the ability to accurately measure low flowrates. Similarly, pressure drop increases with the square of the flowrate, and this may limit the turndown or range of this particular type of flowmeter for certain applications

Flow is therefore determined by measuring the pressure drop across the orifice plate.

The important thing to consider is that the pressure drop is based on the flowrate at the gas density at the actual operating conditions. In order to get a mass flow measurement whereby the temperature and pressure are referenced to standard conditions, it is necessary to also have a temperature transmitter, a pressure transmitter, and a flow computer or multi-variable transmitter. As a result, while the cost of the orifice plate itself is relatively inexpensive, the installed price of the complete system becomes substantially more expensive when one considers the additional instrumentation that is required to obtain an accurate mass flow measurement.

Another factor with orifice plates is their range and turndown. With the orifice plate or any flow measurement based on differential pressure, the signal (pressure drop) is at zero at no flow and then increases with the square of the flow as shown in Figure 3. Thus, if the user has an application requiring a 5-to-1 turndown in flow, a differential pressure transmitter with a turndown of 25-to-1 is required. This issue of turndown can create limitations with the application of orifice flowmeters. Similarly, when sizing an orifice to handle the maximum flowrate, it may not be possible to also measure the flow at the lower end of the range, due to loss of signal.

The pressure drop across a flow element may be a consideration when looking at competing flow-measure-

ment devices for natural gas. Generally, the flowmeter is installed downstream of the pressure regulator with line pressures potentially as low as 1 psig. Under these situations there may not be adequate pressure in the pipe to provide sufficient pressure drop to ensure accurate flow measurement.

Vortex flowmeters. In a vortex flowmeter, a bluff object or shedder bar is placed in the flow path. As gas flows around this shedder bar, vortices are cyclically generated from opposite sides of the bar. This principle is seen every day when looking at a flag fluttering in a breeze. The flag pole is the bluff object and the fluttering of the flag is a visual indication of the vortices as they move across the surface of the flag.

The frequency of vortex generation is a function of the gas velocity. Various methods, frequently relying on piezoelectric crystals, are used to detect and count the number of vortices.

The relationship between the number of vortices shed from the bluff object with the flow is considered to be linear after some minimum flowrate has been reached, as determined by the Reynolds number. It is also important to realize that the measured flow is based on the actual gas density at the operating pressure and temperature. Thus, to convert the flowrate measured by a vortex meter to mass flow, the pressure and temperature must be measured (to adjust for changing gas density).

When applying vortex flowmeters to applications involving natural gas flow, it is important to get complete process information including the minimum and maximum flowrate, the gas pressure and gas temperature. Because of the Reynolds number influence, when sizing a vortex meter to measure the minimum flowrate, it is often necessary to reduce the pipe size in order to increase the velocity to a range that ensures that vortices will be generated. This may complicate the installation of a vortex flowmeter in existing installations and may also increase the pressure drop.

Turbine flowmeters. Turbine flowmeters have wide application for natural gas flow measurement. The operation of a turbine is based on a free-spinning rotor. As the fluid flows past the rotor, the rotor is turned with each revolution that corresponds to a given quantity of gas. There is a magnet in the rotor. The number of rotations are

counted using an external pickup that provides a series of electronic pulses with each pulse equivalent to one rotation. The pulses are then sent to the transmitter.

The manufacturer provides a K factor to relate each rotation to a given gas volume. The number of pulses that are counted over a given time period provide both the flowrate and the totalized flow.

Turbine meters have relatively high turndown capabilities with corresponding high measurement accuracy. Like the previously mentioned flowmeter types, the turbine flowmeter is a volumetric device that measures the actual flow at the operating conditions and thus requires pressure and temperature correction to obtain accurate mass flow. Considerations when applying turbine meters include the cleanliness of the gas and the fact that there are moving parts in the gas stream.

Ultrasonic flowmeters. This technology measures the difference in transit time of pulses that travel from a downstream transducer to the upstream transducer, compared to the time from the upstream transducer back to the downstream transducer. While this technology is accurate and accepted by AGA (American Gas Assn.) for the custody transfer of natural gas, the suitability of this technology for measuring the flow of natural gas to individual combustion sources within a facility becomes questionable, considering the relatively low velocities, and more importantly, the high cost of this device compared to other technology options. (Note that AGA also accepts orifice plate, turbine and Coriolis flowmeters.) Flowrate is measured at the actual operating conditions, requiring pressure and temperature to obtain mass flow. Some ultrasonic flowmeters will require a higher pressure (for instance, some units require a minimum of 150 psi operating pressure).

Coriolis mass flowmeters. Coriolis flowmeters provide a direct mass flow measurement by measuring the deflection of a vibrating tube. This is a true mass flowmeter, as it is insensitive to changes in pressure, temperature, density or gas composition. The Coriolis flowmeter is very accurate, with high turndown capabilities.

Coriolis flowmeters often require the pipe size to be reduced in order to obtain the desired range measurement. While suitable for measuring flow to

FIGURE 4 (top). In this installation of a thermal mass flowmeter in a 6-in. pipe, the device measures and totalizes the flow of natural gas to a combustion source such as a boiler, heater, furnace or other combustion unit

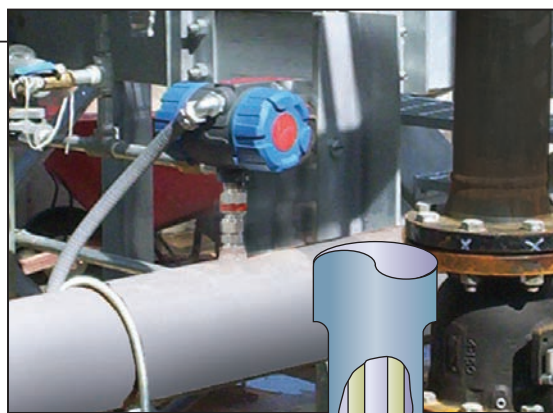
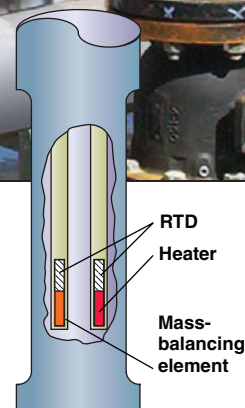


FIGURE 5 (bottom). Thermal mass flowmeters include a sensor such as the one shown here. It consists of two pins. Each has an RTD. One has a heater and the other has a mass-balancing element to ensure equal thermal mass between the two pins. A small temperature difference is maintained between the two RTDs. The amount of power applied to the heater to maintain this temperature difference is then used to obtain a mass flow measurement



individual combustion sources, this approach becomes rather expensive and is rarely used for the in-plant measurement of natural gas.

Thermal mass flowmeters. Thermal mass flowmeters (Figures 1, 2 and 4) provide an inferred measurement of the mass flow of the gases passing through them. Specifically, thermal mass flowmeters measure heat transfer that is caused as the molecules (hence, the mass) of gas flow past a heated surface. The relationship between heat transfer and mass flow is obtained during the calibration of the instrument.

In addition to providing a mass flow measurement without the need for additional devices to correct for pressure and temperature (as is required with the other flowmeters, with exception of Coriolis devices), thermal flowmeters also provide the following advantages:

- **Lower flow sensitivity.** A thermal mass flowmeter will easily measure flowrates that are much lower than those that can be measured using orifice plates or vortex flowmeters. This permits a thermal flowmeter to be retrofitted into existing natural gas pipes using a simple NPT (national pipe thread) thread or flange connection on the pipe. This simplifies installation compared to other flowmeters, which may require a reduction in the pipe size in order to obtain the desired rangeability
- **Higher turndown capabilities.** A range of 100-to-1 is easily obtained with a thermal mass flowmeter. Some combustion systems may have a high natural-gas firing rate during initial warm-up operation and then, once the desired temperature has

been obtained, the flowrate of the gas is typically reduced to maintain the desired operating temperature. A thermal mass flowmeter can easily handle this range, which may be difficult to obtain with other technologies

- **Simplified installation.** An insertion device permits simplicity of installing the flowmeter using NPT connection, flange, compression fitting or even a complete retractable probe assembly. Using a "hot tap" permits the user to install the flowmeter without having to shut down the operation. The insertion design also permits the use of the same instrument in different pipe sizes. Some use the insertion probe as a semi-portable instrument and reconfigure the transmitter for the different pipe sizes
- **Lower pressure drop.** There is virtually no pressure drop when using a thermal mass flowmeter. This is advantageous in low-pressure applications where other technologies would consume operating pressure

Today, thermal mass flowmeters from different manufacturers rely on different methods of operation and sensor designs. All methods accomplish the same thing, which is to provide a mass flow measurement.

A cutaway of a typical sensor is shown in Figure 5. The sensor consists of two elements, one providing a temperature measurement of the gas, with the other element heated to maintain a desired temperature difference between the two RTDs (resistance temperature detectors). Some manufacturers use self-heated RTDs, while others use a separate heater.

Because there is a heated element in

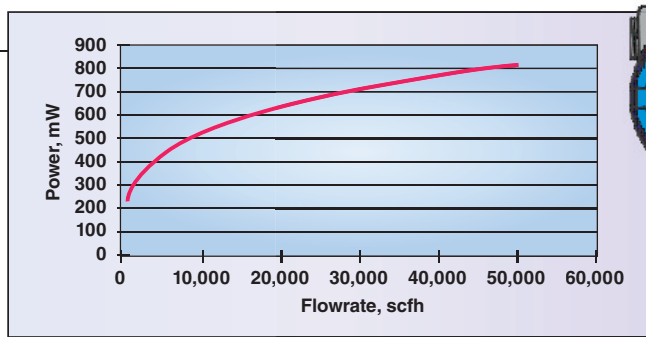


FIGURE 6 (top left). This curve shows the relationship between the power and the mass flowrate for a thermal mass flowmeter in a 4-in. pipe. Such a curve is developed during the calibration of the instrument

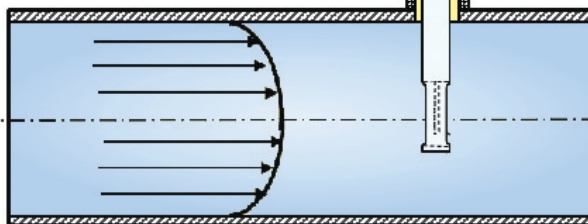


FIGURE 7 (bottom right). This figure shows a fully developed flow profile in a pipe. It also shows the use of a compression fitting for positioning the probe in the pipe. This installation provides considerable flexibility and easy installation

contact with the natural gas, the user should ensure that the temperature rise of the sensor is less than the auto-ignition temperature of natural gas, and that the instrument has all appropriate agency approvals for use in hazardous areas.

With this design, the electronics maintain a desired temperature difference between the two pins. At no flow, there is little heat loss and it takes little energy to maintain the desired temperature difference.

As flow increases, heat is transferred from the heated sensor into the gas stream, the electronics detect the reduction in the temperature difference and apply more power to the heater to maintain the desired temperature difference. The typical relationship between mass flow and power is shown in Figure 6.

The shape of this curve is very different from the comparable curve that was previously discussed for an orifice plate flowmeter (Figure 3). For instance, with a thermal mass flowmeter, there is a signal at low flow, and that signal increases rapidly, providing a great deal of sensitivity at low flowrates. This is why the thermal mass flowmeter is able to reliably measure much lower flowrates compared to competing flow-measurement technologies.

Meanwhile, as the flowrate continues to increase, the amount of power required to maintain the desired temperature difference continues to increase — but not as rapidly — thus providing the higher turndown capabilities mentioned earlier. However, as the flowrate continues to increase, the sensor will eventually reach a state where it becomes saturated and unable to transfer any more heat into the gas.

Calibration of the thermal mass flowmeter is required to establish this relationship between mass flow and heat transfer. Calibration involves placing the flowmeter in a test bench, flowing a known amount of gas past the sensor, measuring the signal, and repeating the process at different flowrates. At least ten calibration points should be obtained over the calibration range of the instrument for best results. These data are analyzed and the calibration data are then loaded into the instrument. After calibration, the flowmeter will provide a linear output signal over the calibration range.

Because of the heat-transfer characteristics of the sensors, each individual sensor must be calibrated. Once calibrated, the user can reconfigure the instrument for a lower flow range to accommodate those situations where the initial flow may be low, and then increase over time as production in the facility increases.

We have previously shown that thermal mass flowmeters provide a mass flow measurement based on the thermal properties of the gas, and thus, temperature correction for density adjustments are not required when going from actual operating conditions to standard conditions. However, it is recognized that the thermal properties of the gas will change with gas temperature. Thus it is important that the thermal flowmeter have real-time temperature compensation, to continually adjust the flow measurement for variations in the process gas temperature.

Various manufacturers deal with the issue of temperature compensation differently, with some manufacturers providing temperature compensation as a standard offering; with these de-

signs, the instrument also measures the gas temperature and adjusts the flow measurement for variations in the thermal properties of the gas with temperature.

Thermal flowmeters will provide a 4–20-mA output signal that is linear with the flowrate. A built-in software totalizer is also available, with the totalized flow shown on the display for those users who want to obtain the total consumption of the natural gas over a given time period. Those designs that also measure the gas temperature as part of the realtime temperature compensation also have the ability show the temperature on display of the flowmeter. Units with HART communication have the ability to transmit the mass flow, temperature and totalized flow as part of the HART data stream. Other units may also provide a pulse output and a milliamp signal of the temperature.

Changing gas composition will affect the heat transfer characteristics of the gas and potentially create an error in flow measurement. This is most prevalent when a significant change is made in the type of gas that is flowing through the unit — for instance, using a thermal mass flowmeter that was originally calibrated for air in natural gas service.

Fortunately, minor changes in the composition of natural gas, such as a reduction of methane content with a corresponding increase in the ethane content, will have very minor changes on the overall flow measurement that is produced by a thermal mass flowmeter. Using this example, the density of methane and ethane are considerably different, which will have a significant effect on other flowmeter technologies (such as those based on the measurement of differential pressure) where the gas density is directly used in the flow measurement.

With thermal mass flowmeters, the gas density is only one of the factors that affect convective heat transfer. Variations in methane and ethane content of the natural gas can create a change in the heat transfer characteristics of the natural gas (and slightly affect the flow measurement). However,

the relative change in heat transfer is comparatively less than the change in gas density, which is directly used by other flowmeters.

Installation considerations

Nearly all flowmeters require some straight run of pipe ahead of the flow sensor. Thermal mass flowmeters follow the same basic guidelines. The flow calculations used with an insertion-type flowmeter assume the presence of this fully developed flow profile and the placement of the sensor on the centerline of the pipe as shown in Figure 7. Theoretically the velocity at the wall is zero and the velocity on the centerline of the pipe is 20% higher than the average velocity.

This illustration also shows the use of a compression fitting that is commonly used for inserting the probe into the pipe. Because the flow profile at the centerline is relatively flat, minor variations in the insertion depth of the sensor will not have any impact on the flow measurement.

Theoretically, this desired flow profile occurs with a straight run of pipe whose length is the equivalent of approximately 20 pipe diameters. This is the general guideline for the amount of straight run following a single elbow, while longer lengths are required following a double elbow.

In many cases, this amount of straight run may not be available. When this is the case, options that are available include the use of a flow body with a flow conditioner as shown in Figure 8. This design ensures that the desired flow profile at the sensor is obtained. The use of a flow conditioner reduces the straight-run requirements. Or, the user may accept a reduction in the absolute accuracy due to the presence of the non-uniform flow profile, realizing that the flow measurement will continue to be repeatable.

If using an insertion probe, another installation effect that is not frequently realized is the correctness in pipe size. The inner diameter (ID) of the pipe or the pipe area is entered into the transmitter. Users will frequently specify pipe size such as 4-in. Schedule 40 in which case the manufacturer utilizes the pipe dimensions from the standard pipe tables. What many users may not realize is that the dimensions in the pipe tables are nominal dimensions,

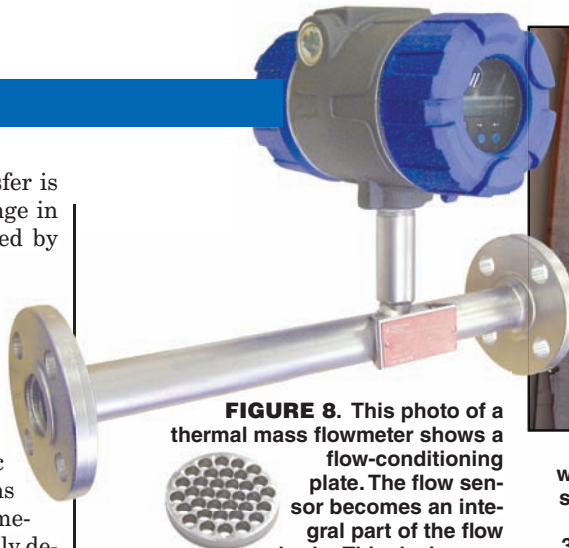


FIGURE 8. This photo of a thermal mass flowmeter shows a flow-conditioning plate. The flow sensor becomes an integral part of the flow body. This design can be used in pipes as small as 0.5 in. and up to 4 in. The optional flow conditioning is used for those applications where there is insufficient straight run to obtain the expected flow profile

and in reality, the wall thickness of the pipes may vary, resulting in corresponding variations in the pipe ID. Since the pipe area is a critical factor in calculating the mass flow, any deviation between actual pipe size and the nominal dimensions will cause errors in the flow measurement.

It is generally possible to enter correction factors in the transmitter to adjust for non-uniformity of the flow profile, pipe size or other installation effects. However, this requires that the user have a valid basis for comparing the measured mass flow with the expected flow.

Biogas measurement

Considerations related to the measurement of biogas using thermal mass flowmeters are very similar to those for natural-gas flow measurement. The primary difference is that biogas composition is typically a mixture of methane and carbon dioxide, with the potential trace concentration of other gases depending upon the application. Typically, this ratio is 65% methane and 35% carbon dioxide. Biogas can come from a number of sources including anaerobic digesters, landfill operations, and organic-industrial-waste processing. Other distinguishing issues with biogas is that the gas is often wet and may also be dirty.

Biogas measurement systems frequently operate at relatively low pressures and low flowrates. The combination of low flow, low pressure, and a wet and dirty gas rules out most other technologies, due to lack of sensitivity at low flowrates and difficulties with



FIGURE 9. A thermal mass flowmeter with remote electronics is used to measure the biogas flow from an anaerobic digester. The probe is located roughly 3 ft from the floor, and the remote head permits the operator to view the display. A retractable probe assembly is used to permit the removal of the probe from the pipe to ease maintenance while minimizing leakage of a combustible gas

the potential buildup of particulate matter on the flow element. By comparison, thermal mass flowmeters (Figure 9) are particularly well-suited for biogas/digester gas-flow measurement, due to the low flow sensitivity and low pressure drops. The use of an insertion probe with a retractable probe assembly eases the periodic removal of the probe for cleaning.

There are many flow-measurement technologies that can be used for the measurement of natural gas and biogas. However, thermal mass flowmeters provide certain advantages in terms of mass flow measurement, turndown, flow sensitivity, low pressure drop and ease in installation. In fact, thermal mass flowmeters tend to allow for very economical installations, thereby providing the lowest installed cost compared to other technologies that require pressure and temperature compensation. ■

Edited by Suzanne Shelley

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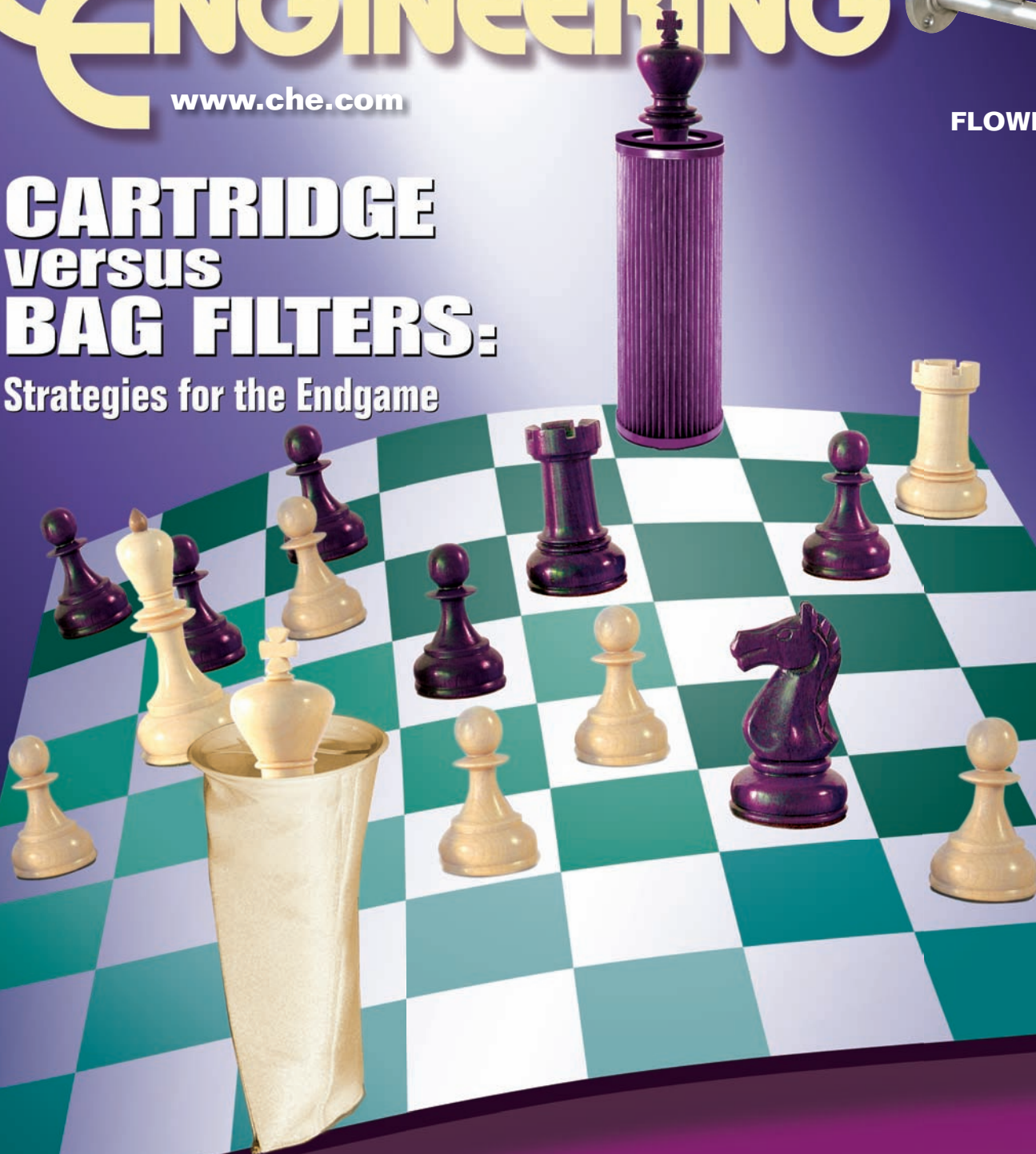
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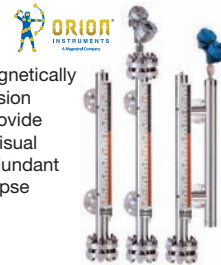
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PLEASE NOTE: The instruments recommended in this bulletin are based on field experience with similar applications and are included as a general guide to flow control selection. However, because all applications differ, customers should determine suitability for their own purposes.



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