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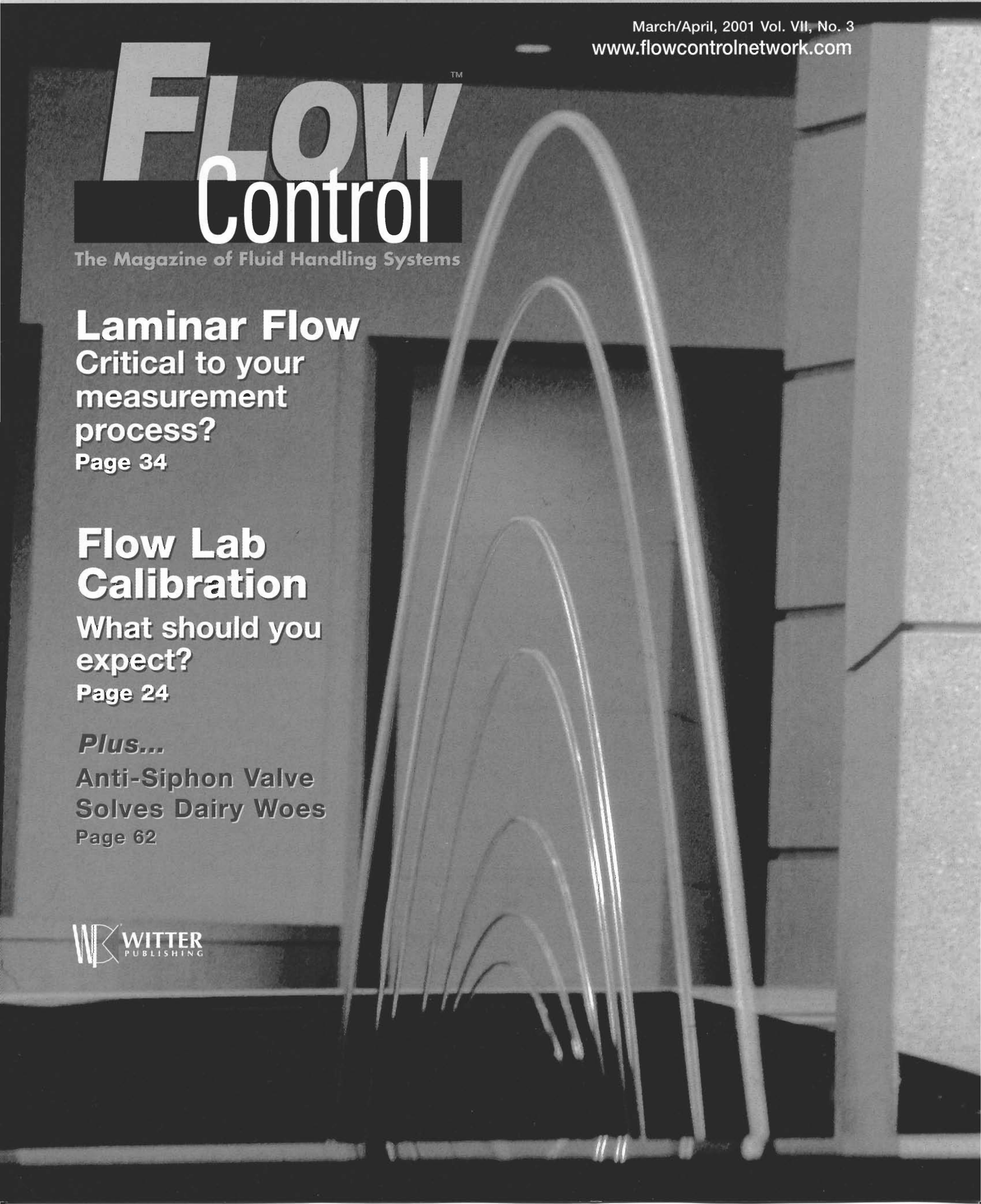

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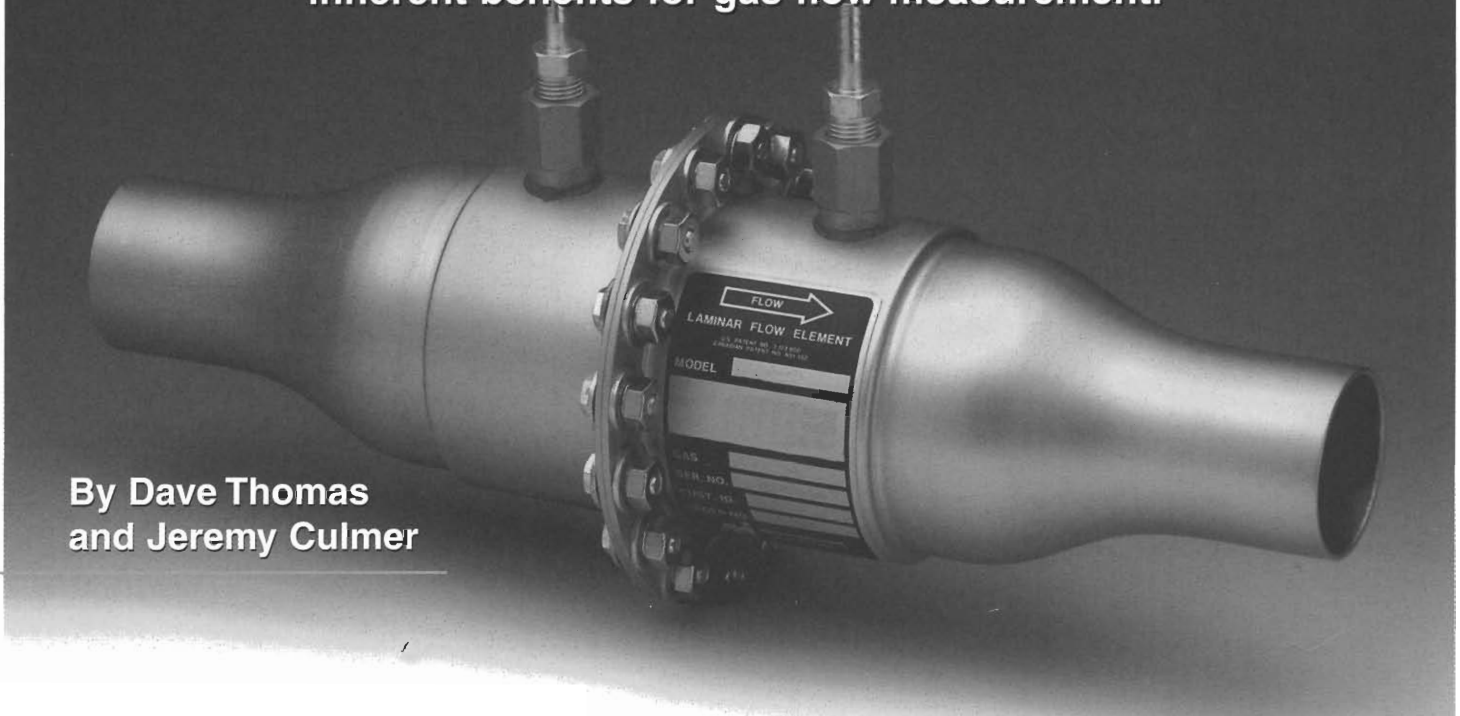
Laminar Flow Elements

How they work, where they're appropriate and their application's inherent benefits for gas flow measurement.



By Dave Thomas and Jeremy Culmer

Choosing the appropriate flowmeter for accurate gas flow measurement can be challenging when one takes into account a susceptibility to physical failure or calibration shift. An approach to dealing the more demanding of these applications is the laminar flow element (LFE). LFEs are primary flow elements designed to induce laminar flow through a capillary, and produce a differential pressure that is linear with respect to the volumetric flow rate. They are inherently accurate and repeatable, enhancing their applicability to critical gas flow measurement applications and even calibration of other flow measurement devices.

Manufacturers typically specify LFE calibration accuracy at better than ±0.9 percent of reading (not percentage of full scale), and usually offer traceability certification to the National Institute of Standards and Technology (NIST). (See Figure 1 on this page.) Independent test laboratories offer NIST traceable accuracy of ±0.5 percent of reading or better. Rigid construction and lack of any moving parts make the calibration stable. Only physical damage or particulate deposition in the element will cause a calibration shift. Cleaning and recalibration is typically recommended every 12 to 18 months.

The nearly linear relationship between produced differential pressure (DP) and flow rate (See Figure 2, page 35.) results in turndown ratios of 20:1, 50:1 or even greater, depending largely on the accuracy and resolution of the secondary device.

Standard models are available to measure as little as 0.2 standard cubic centimeters per minute (SCCM) (5.9 E-06 SCFM), to as

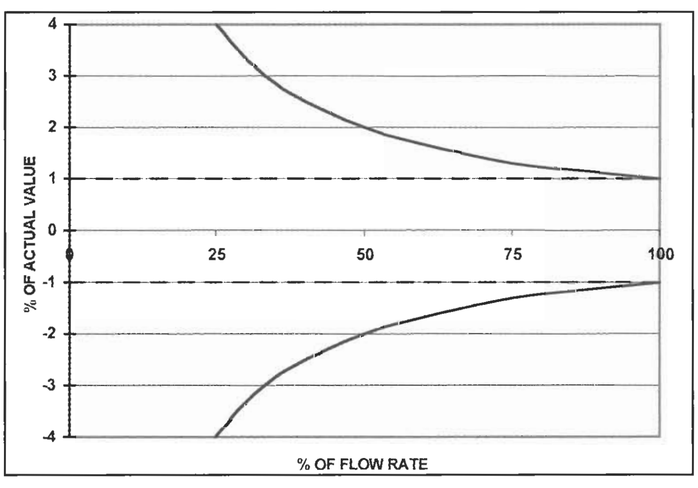


Figure 1. Comparison of ±1 percent of full scale (solid lines) vs. ±1 percent of reading (dotted lines).

much as 2,250 standard cubic feet per minute (SCFM) of airflow at standard conditions. Custom models are available for as much as 15,000 SCFM of air. Stainless steel or aluminum materials make LFEs compatible with most gases. The flow rate of gas mixtures can also be measured provided that the percentages of component gases and mixture properties are known. Common applications include precise measurement of gas flow rates in processes and test labs, calibration of other flow devices and leak detection.

How They Work

Laminar flow elements are designed to take advantage of the Hagen-Poiseuille relationship for energy loss under laminar flow conditions. In simplified terms, this relationship states that 'if a flow tube or capillary has small enough diameter relative to its length, the difference in pressure between the tube's inlet and outlet will be linearly proportional to the flow rate through the tube. (See Figure 3, page 35.) Flow in the gas supply pipe may be turbulent, transitional or laminar. By using small capillaries either individually or in a bundle (or matrix), the LFEs induce laminar flow through each capillary. Combining this feature with a sufficient capillary length results in a nearly linear relationship between DP and flow rate.

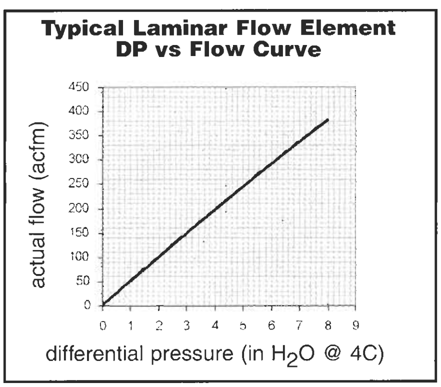


Figure 2. Typical calibration curve for laminar flow element.

LFEs are viscosity-dependent devices. When laminar flow exists, the fluid tends to behave as if it were divided into layers. Since viscosity is a measure of a fluid's resistance to change of shape, as layers of fluid move over each other, system energy is lost due to friction between the layers. The system energy loss is observed as DP across the inlet and outlet of the LFE matrix. Due to the dependence of the DP on viscosity (a function of temperature and gas media), and the velocity of the flowing fluid, LFEs measure actual volumetric flow rate. This makes it necessary to measure gas temperature and inlet pressure to calculate mass or standard volumetric flow rates.

Laminar flow elements can be fabricated from several materials. Housings are typically stainless steel or aluminum, and serve to hold the matrix of capillaries together in a stable configuration. They also provide process and DP connections. Process connections are available in threaded, hose or flange varieties. DP connections are made via NPT threads or hose barbs. The LFE matrix can be made from individual stainless steel tubes, windings of stainless steel foil or stainless steel slats installed through the length of the body. (See Figure 4, page 36.) More exotic materials are available when fluid compatibility is a concern.

The DP generated across the matrix responds within 16 milliseconds to changes in flow velocity. Response time of the meter (LFE and readout device) is generally limited to the capabilities of the DP readout device. Permanent pressure loss is associated with LFE use. Since the DP across the matrix of an LFE is a measure of system energy lost to overcoming friction between laminar flow layers, all produced DP is permanently lost pressure.

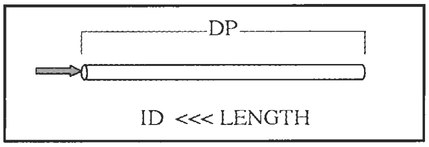


Figure 3. Application of Hagen-Poiseuille Law.

Due to the way they are sized, however, this can usually be mitigated. Full-scale flow rates are limited so that eight to 10 inches of water column is the maximum DP produced. When even less permanent loss is required, the LFE can be oversized to produce less DP at the required flow rate.

LFE Systems

With the proper instrumentation, LFEs can measure mass, standard volumetric or actual volumetric flow rates. Three measured flow parameters are required — differential pressure, absolute inlet pressure and flowing temperature. A fourth parameter, relative humidity, is often measured to correct for its effect on air viscosity and density. For manual measurement systems, the DP is often measured using inclined tube or micro-manometers. These instruments are capable of measuring to 0.01" and 0.001" of water column, respectively.

Mechanical gauges and electronic transducers can also be used. The inlet pressure of the LFE is usually measured by a gauge pressure manometer, indicator or electronic transducer. A barometric pressure reading must be made and added to gauge pressure readings to obtain absolute inlet pressure for use in flow calculations. A temperature device is needed to measure flow stream temperature, and, when desired, a relative humidity device is used to measure the air humidity. When all parameters are known, the user can manually calculate the flow rate or use calibration curves and

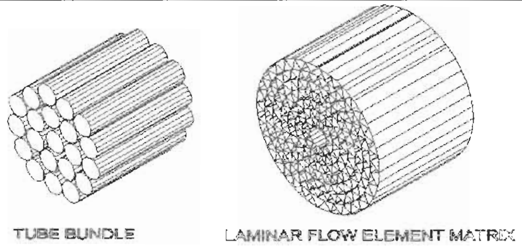


Figure 4. The LFE Matrix.

<u>Classical Calibration</u> (applicable when temp < 120°F and press < 45 psia):

$$\text{Actual Flow} = [(B \bullet DP) + (C \bullet DP^2)] \bullet (\mu_{CONSTANT}/\mu_{FLOWING})$$

<u>Universal Calibration</u> (for temp > 120°F and/or press > 45 psia)

$$\text{Actual Flow} = [(A0 + A1 \bullet (\rho \bullet DP/\mu^2) + A2 \bullet (\rho \bullet DP/\mu^2)^2] \bullet (DP/\mu)$$

Figure 5. LFE Flow Equations.

pressure, temperature and relative humidity correction curves to obtain flow rate information.

Manual data collection and calculation methods tend to be a low-cost solution for LFE's readout, but they can also be cumbersome and prone to error. Human factors, such as the correct observation of mechanical indicators, transcription of the data and accurately applying the data in the correct flow equations, can all be sources of error.

Automated systems address these problems, as well as offering data processing, archiving and presentation options. DP and absolute pressure transducers are used to measure the required pressures, and convert them to an equivalent analog signal. A thermocouple or RTD measures temperature. For the most demanding applications, relative humidity transducers can be used to correct for humidity's effect on gas density and viscosity. A flow algorithm in an automated system can use the transducer's signals to make real-time corrections for variations in flowing pressure, temperature and humidity.

Most automated LFE measurement packages come as plug-and-play systems, with wiring and piping complete. The user makes the DP connections to the LFE and connects it to the flow line. Output proportional to corrected flow rate and total flow is available in analog or digital formats. Typical accuracy of such systems (including LFE accuracy) ranges from ± 0.8 percent to ± 2.0 percent of reading for flow turndown up to 20:1 using a single LFE.

Automated systems support classic LFE equations and corrections, and newer calculation models that provide accurate flow rate when operating at high temperatures and pressures, are easily selected and applied. (See Figure 5, above.) PC-based systems with *Windows*-compatible software offer set-up, processing, documentation, archiving and presentation options. Software is available that is formatted with all of the coefficients and calculation options, uses digital data collection and executes complex equations in user-preferred units. Programmable logic controllers (PLCs) and microprocessor-controlled flow computers also offer computation speed and a variety of digital and analog outputs for a variety of control and data transfer purposes.

Summary

LFEs are applicable in most clean and non-condensing gas flow applications. They are used to calibrate turbine meters, variable area meters, flow regulators, mass flowmeters and thermal anemometers, to name a few. Gas flow measurement for process control is another common use. Other applications include leak detection and quantification, design and testing of discrete parts and automotive engine and emissions testing.

Standard LFEs measure the volumetric or mass flow rate of clean air from zero to 2,250 SCFM at standard conditions. A wide variety of gas and mixtures can be used with LFEs. NIST-traceable measurement systems with accuracy on the order of ± 0.8 percent to ± 2.0 percent of reading are achievable. A variety of process connection styles allow the user to connect to almost any flow line. Accurately measuring gas flow through an LFE requires measurement of DP, inlet pressure, flowing temperature and possibly relative humidity. The application requirements, accuracy goals and personal preference will determine whether manual or automated measurement systems are appropriate.

About the Authors

Dave Thomas, who holds a degree in petroleum engineering, is a technical service manager with Meriam Instrument (*www.meriam.com*), where he has been employed for the past 13 years.

Jeremy Culmer holds a degree in mechanical engineering, and has been a flow products engineer for Meriam for the past two years.

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