METER SELECTION FOR VARIOUS LOAD REQUIREMENTS

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Introduction

This paper is intended to provide meter station designers with a basic methodology for selection of an appropriate flow meter (or meters) for a given application. Since many applications require that a meter station operate over a broad range of flow rates or loads, an example is provided on how to address system rangeability while maintaining accurate flow measurement. Detailed technical descriptions of the functionality of the various available gas metering technologies is beyond the scope of this paper, but information of that type can be found in other papers in these Proceedings.

General Considerations

There are several basic considerations that should always be kept in mind when designing a gas metering station. These include:

- Desired flow measurement accuracy
- Range of flow rate or load
- Quality and cleanliness of the gas stream
- Limits on the available space for the meter station installation
- Available infrastructure (e.g., electrical power, lighting, data communication, etc.)
- Environmental or atmospheric conditions
- Long-term maintenance requirements for the selected measurement equipment

The meter station designer should also keep in mind that there may be other, special considerations that can vary from application to application. However, regardless of the application − whether it is a meter installation for a residential application or a large, gas-fired electric power plant − the basic design methodology is essentially the same.

Measurement Accuracy

One of the first design considerations is measurement accuracy. The specification of the measurement accuracy will have a significant effect on the cost of the meter installation. The measurement accuracy might be specified in the gas sales contract or tariff or specified in an industry standard for the meter of choice. In any case, it is important to establish the required or desired measurement accuracy so that appropriate selections can be made for the flow meter and other, secondary instrumentation, such as pressure and temperature transmitters, which also contribute to the overall measurement accuracy of the installation or system.

Range of Flow Rate

Determination of the operating flow rate range is always critical to a successful meter station installation. Some applications, such as most residential metering sites, will have a relatively narrow range of flow rates. In those cases, a single meter should suffice. In other applications, such as gas-fired electric power plants or large industrial process plants, the load or flow rate can vary substantially over time. In many of those applications, a single flow meter may not suffice. It may be necessary, instead, to use multiple meters installed in parallel. Sophisticated flow control valving and switching logic may be necessary to ensure that, at any given time, the number of flow meters in operation is adequate for maintaining the desired measurement accuracy and flow rate. Also important in at least some of these cases is the *rate* at which the flow varies or changes. The meter station must be designed to be responsive to the expected changes in flow rate so as not to create undesirable operational upsets, such as flow starvation or flow surge.

An example of a multi-meter run is pictured in Figure 1. In this case, three flow meters of differing types and sizes are plumbed in parallel. This meter station skid is for a power plant application. Two ultrasonic flow meters (one 8 inches in diameter and one 6 inches in diameter) and one positive-displacement rotary flow meter (3 inches in diameter) are included. The positive-displacement rotary meter is sufficient to meter the power plant pilot flow during periods of low natural gas demand. The two ultrasonic meters are used either individually or in combination as the flow rate to the power plant increases with increasing electricity demand. Note the valves located upstream and downstream of each flow meter. These isolation valves are used to control flow to the various meters as operational demands dictate. The length of the meter skid was determined by the minimum piping length requirement for the larger ultrasonic flow meter.

One other important point for meter station designers to keep in mind is that flow meter accuracy typically degrades when the meter is operated at the lower end of its range. The point in the range at which the degradation becomes significant varies by meter type and configuration. In general, below about the lower 5 to 10 percent of the operating range of a gas flow meter, there will likely be less accurate flow rate measurement.

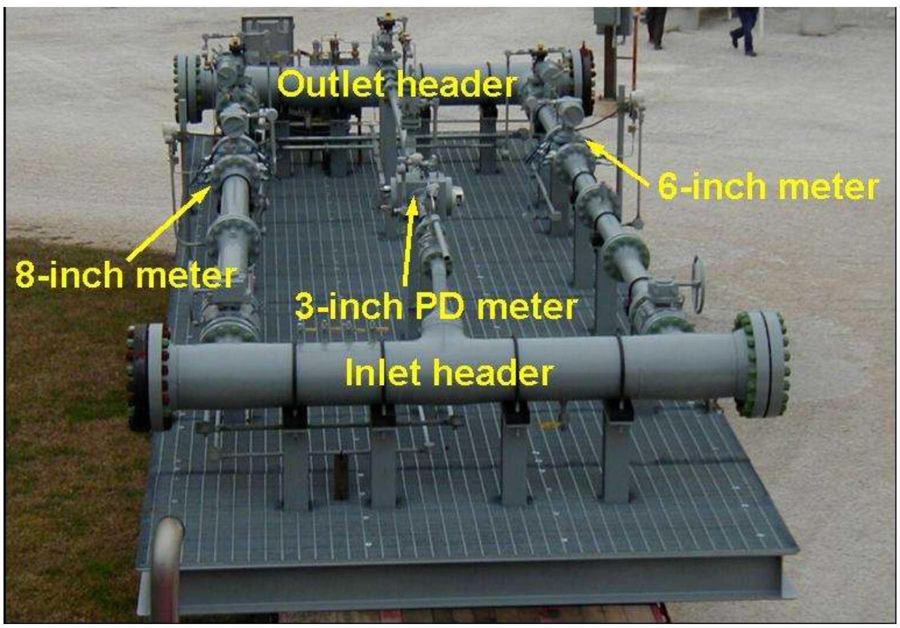

Figure 1. Power Plant Metering Skid Featuring Three Flow Meters in Parallel
(i.e., one 8-inch and one 6-inch-diameter ultrasonic flow meter and one 3-inch-diameter positive displacement (PD) rotary meter)

Quality and Cleanliness of the Gas Stream

The condition of the gas can also be important to meter selection. If liquids or particulates are known to be in the gas stream, special provisions may need to be made to eliminate these before they reach the flow meter. Some gas meters are robust enough to operate successfully in contaminated flow streams, but most are not. Most flow meters are adversely affected by flow stream contaminants and significant measurement biases (on the order of several percent of meter reading or more) may result. The magnitude of the effect of flow stream contamination on meter performance can vary, depending on the meter type. The meter manufacturer(s) should be consulted for detailed information on this subject. A filter or scrubber may need to be placed upstream of the meter station to handle flow stream contaminants.

Corrosive (e.g., hydrogen sulfide, carbon dioxide, water, etc.) or erosive (e.g., sand or water) elements in the flow stream can also present problems with meter performance. The presence of these types of contaminants may degrade meter performance or operational functionality over time. Again, the meter manufacturer(s) should be consulted if it is anticipated that corrosive or erosive elements may be present in the flow stream. Figure 2 show an example of an orifice flow meter tube subjected to flow contamination over a long period of time. In this instance, the contaminant buildup was found to have created a measurement bias of several percent of reading.

Figure 2. Contamination Buildup at the Plate Seat of an Orifice Flow Meter

Available Space and Infrastructure

The different flow meter types have varying requirements for installation configuration and electrical power. These should always be taken into account to help ensure that the flow meter(s) performs (perform) as desired. As examples, diaphragm flow meters with mechanical counters are "self-powered," extracting operational power from the flowing gas stream. Contrastingly, ultrasonic flow meters require electrical power to drive the ultrasonic transducers and associated microprocessor controllers.

Inferential flow meters (discussed in more detail later), such as orifice or ultrasonic flow meters, typically require some minimum amount of straight pipe immediately upstream and downstream of the meter to operate accurately. Contrastingly, positive displacement meters, such as diaphragm or rotary meters, typically do not require any straight pipe upstream and downstream of the meter. Thus, limits on available space for the meter installation may influence the type of flow meter selected for the application. Applicable industry standards for the various flow meter types, as well as flow meter manufacturers, can be consulted for guidance on the requirements for the piping configuration adjacent to the meter.

Environmental and Atmospheric Considerations

Most flow meters are influenced to at least some degree by the surrounding ambient conditions. Extreme weather conditions may bias meter output, so precautions should be taken to minimize or eliminate the influence of the surrounding environment. For instance, direct solar radiation on a flow meter body can cause asymmetric heating of the meter body. Under low flow conditions, this asymmetric heating can create secondary, buoyancy-driven flows inside a meter. Such a phenomenon with ultrasonic meters operating at nominal gas flow velocities less than 5 feet per second is known to bias the flow measurement. Consequently, some ultrasonic meter operators have chosen to shade their meter installations from the sun. In cold climates, such as in the northern United States and Canada, many high-volume meter stations are in enclosed, environmentally controlled buildings to minimize the effects of the cold and snow during the winter.

Long-Term Meter Station Maintenance

One often overlooked aspect to a meter station design is long-term maintenance. Some meter station designers make the mistake of minimizing initial capital cost of the installation only to find out the long-term maintenance costs are much greater than if a different meter type was chosen or if the meter station piping configuration was done differently at the outset. Not all flow meters have the same maintenance requirements; hence, the cost to maintain the various meter types can vary substantially. Furthermore, the meter installation configuration can be designed to accommodate the maintenance requirements in the most efficient manner possible. For instance, some gas pipeline companies have standardized on installing "inspection" tees upstream and downstream of ultrasonic flow meter runs to reduce the time and effort required to inspect the meter runs for contamination buildup − which is a typical source of measurement error for that type of flow meter. An example of such a meter installation configuration is shown in Figure 3.

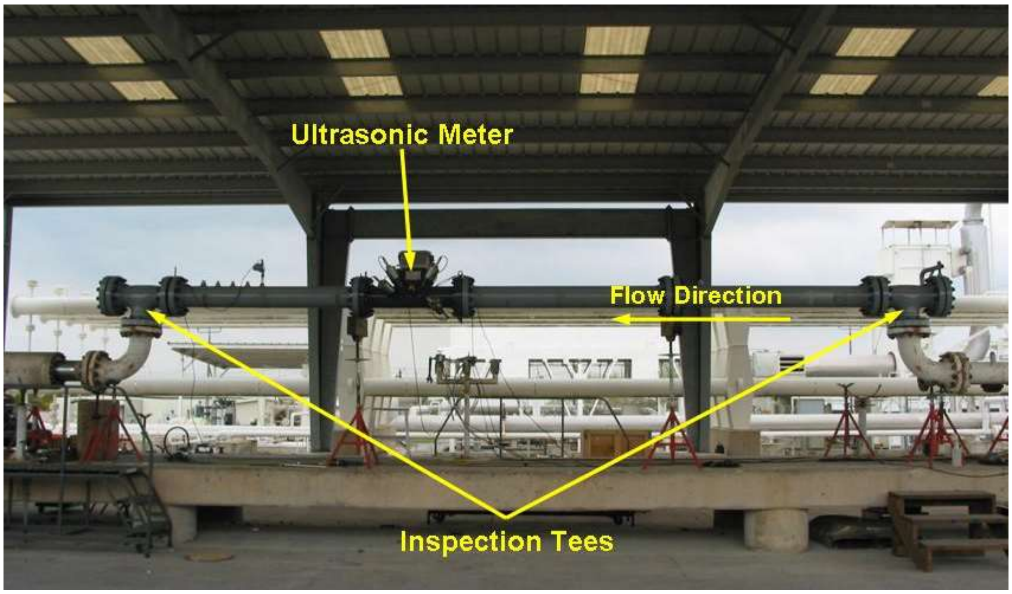

Figure 3. Ultrasonic Flow Meter Installation with Inspection Tees Upstream and Downstream of the Meter

Gas Flow Meter Types

Since different flow meter designs exhibit different sensitivities to *installation effect* errors (discussed in more detail later), it is important to understand how each meter design or type is influenced by the various flow field distortions that may occur at a meter station. There are essentially two types of gas flow meters − *discrete* and *inferential* devices. Discrete meters determine the volumetric flow rate of a gas stream by continuously separating the flow stream into discrete segments and then counting the number of segments measured per unit time. Diaphragm meters, rotary meters, and turbine meters are examples of discrete meters.

Inferential flow meters infer volumetric flow rate by measuring one or more dynamic properties of the flowing gas stream. Examples include the orifice meter, ultrasonic meter, and Coriolis meter. Inferential flow meters are generally more susceptible than discrete meters to measurement errors caused by installation effects or flow field distortions. However, since each meter type and design has unique sensitivities to installation effects, a meter station designer or operator must be aware of these sensitivities to eliminate or at least minimize measurement errors caused by installation effects.

Installation Effects

Research has shown that many meter types, particularly inferential meters such as orifice flow meters, are susceptible to errors when the flow field at the meter is distorted. The sources of flow field distortions are many. The piping geometry upstream of a flow meter can create flow distortions that may propagate several hundred pipe diameters downstream before completely dissipating. Sudden changes in the pipe diameter, either upstream or downstream of a meter, may also introduce flow field distortion. Branch flows, such as those produced by meter station headers, control valves, regulators, and other flow restrictions or expansions, can also create distortions in the flow.

Velocity profile asymmetry, swirl, and combined profile asymmetry and swirl are examples of flow field distortions that can result in meter bias errors (i.e., measurement errors that are of a fixed magnitude and sign). The effect of flow field distortion on meter error is commonly referred to as an *installation effect*. Most industry standards for gas meters do not adequately address installation effects, so it is often left to the meter station designer or operator to ensure that installation effects of this type are not significant.

Research performed in both North America and Western Europe has clearly demonstrated that typical meter station piping configurations and fittings generate a variety of flow distortions. Even simple piping elements, such as a 90° elbow, which produces two counter-rotating vortices (commonly referred to as Type 2 swirl[1]) and velocity profile asymmetry at its outlet plane, can create flow distortions that may result in meter bias errors. Research has also shown that a flow distortion may propagate through a series of piping elements (e.g., pipe bends, valves, contractions/expansions, etc.) without dissipating. In some instances, a flow distortion may actually increase in severity as it passes through a series of piping elements. This finding requires that a meter station designer or operator always be concerned about both nearby *and* distant piping elements from which flow distortions may propagate.

Figure 4 illustrates how a pipe flow distortion dissipates as it propagates downstream. In this example, pipe centerline velocity profiles were measured at several axial locations along a straight pipe downstream of a single 90° long-radius elbow. A fully-developed turbulent flow profile (denoted by the solid line on Figure 4) was provided at the inlet to the elbow. In this case, the test piping was 12-inch-diameter, schedule 40 carbon steel pipe. The axial locations where measurements were made downstream of the elbow are denoted in Figure 4 in terms of nominal pipe diameter, D. The velocity profiles were measured by traversing the centerline of the pipe (in the plane of the elbow) at 10, 40, 59, 78, and 97 pipe diameters downstream of the elbow. The test medium was distribution-grade natural gas (about 95% methane) at a line pressure of approximately 600 psia. Note that the velocity profile has nearly recovered to the fully-developed condition at 97 pipe diameters downstream. The measurements used in this example[2] were made in the High Pressure Loop at the Metering Research Facility (MRF) located at Southwest Research Institute in San Antonio, Texas.

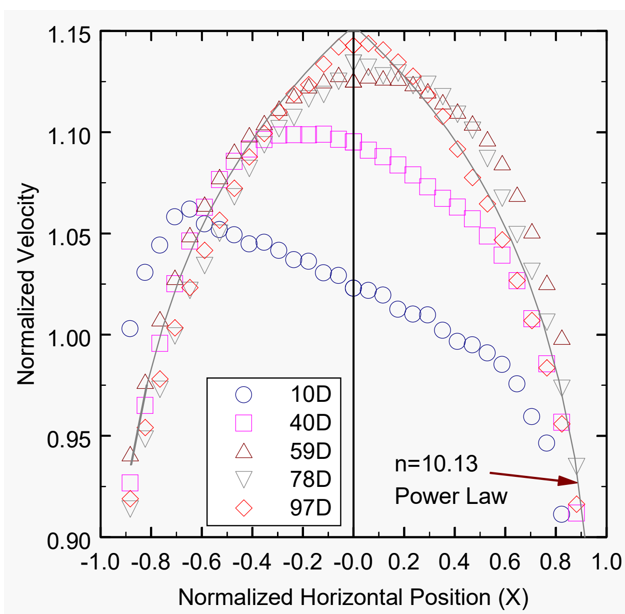

Figure 4. Centerline Velocity Profiles Measured Downstream of a Single, 90° Long-radius, Elbow[2]

Figure 5 illustrates how two 90° close-coupled elbows, oriented 90° out-of-plane, can dramatically distort the flow field as it passes through the elbow combination. This is a numerical simulation that was produced by the German gas company Ruhrgas. The flow profile (i.e., the velocity distribution across the cross section of the pipe at a given axial location along the length of the pipe) entering the upstream elbow was fully-developed, axi-symmetric, turbulent, and swirl free – i.e., the ideal profile desired at the inlet to an orifice flow meter. At the mid-point between the first and second elbows, note that the flow field has formed the classic counter-rotating vortices produced downstream of a single 90° elbow (i.e., the Type 2 swirl mentioned earlier). Downstream of the second elbow, note that the Type 2 swirl has dissipated and that the Type 1 swirl[1] (a.k.a., solid body rotation) has begun to form. If the flow continued along a straight pipe downstream of the elbow combination, the Type 1 swirl could persist for up to 200 pipe diameters or more. Many header configurations can produce a similar result.

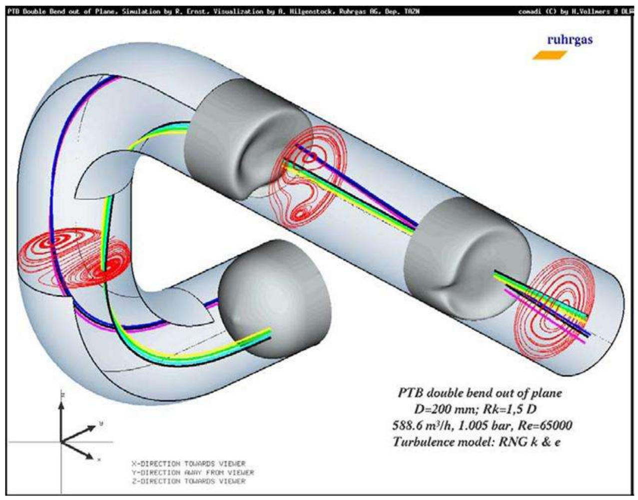

Figure 5. Flow Distortion Caused by Two Close-coupled 90° Elbows, 90° Out of Plane
(Image courtesy of Ruhrgas)

<u>Flow Conditioners</u>

Inferential flow meters use meter calibration factors or empirical coefficients to account for the effects of parameters that are not directly measured. For example, the velocity profile at the meter is not typically measured. However, the velocity profile does have an effect on meter error. As an example, the discharge coefficient for orifice flow meters has been experimentally determined from tests in which there was typically a fully developed, swirl-free turbulent flow field upstream of the test meter. Thus, the readings from an orifice meter installed at a field site will only produce unbiased results if the flow field upstream of the meter also produces a fully developed, swirl-free, turbulent velocity profile.

An effective way to minimize or eliminate the adverse influence of the fluid dynamics (e.g., velocity profile asymmetry, swirl, etc.) on meter performance is to install a *flow conditioner*. Flow conditioners are devices that "condition" the flow field at or near the meter inlet. Flow conditioners attempt to *isolate* a flow meter from flow field distortions that may propagate from upstream. There is *no* flow conditioner design that can truly isolate a meter from *all* possible flow field distortions, although some designs are quite effective at isolating a fairly broad range of distortions propagating from upstream.

Figure 6 shows several flow conditioners that are currently on the market. Flow conditioners can be grouped into three general classes based on their ability to correct velocity profile asymmetry, swirl, and turbulence structure. It is beyond the scope of this paper to provide a detailed treatment of flow conditioners and flow conditioning, but information of that type can be found in other papers in these Proceedings.

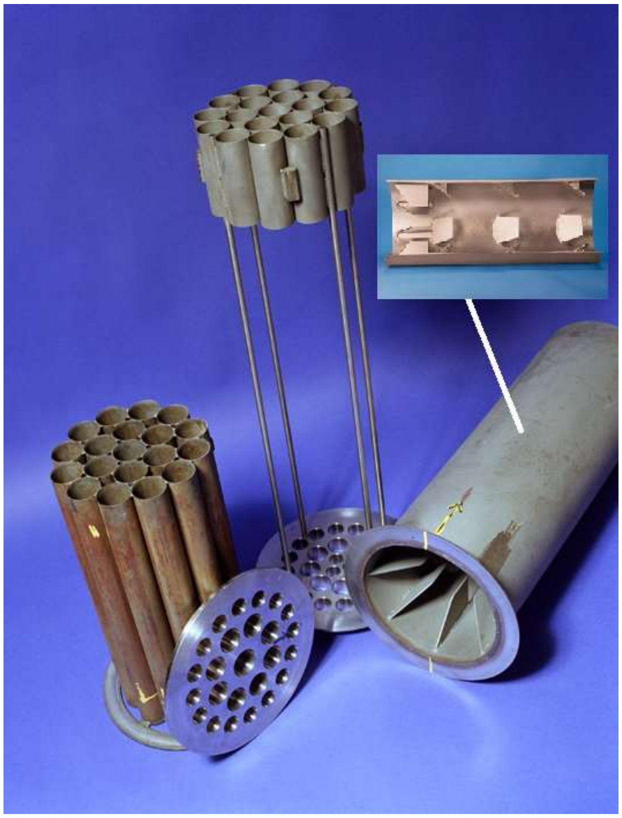

Figure 6. Example Flow Conditioners

Example Meter Selection Process

Following is an example of the basic process used to select a flow meter for a given application. The example is for an application with a broad flow rate range, so there are design tradeoffs in the selection process and multiple meters are required.

In the example, turbine flow meters are the meters of choice for an application in which the flow demand varies between 5 and 85 MMSCFD. The nominal actual gas density ranges from 2.1 to 2.3 lb_m/ft^3. The gas has a standard density of 0.046 lb_m/ft^3.

The available turbine meter sizes are:

Meter Diameter (in.)	Capacity (acfh)
4	18,000
6	30,000
8	60,000
12	140,000

Table 1. Available Turbine Meter Capacities

The first step in the meter selection process is to determine the actual volumetric flow rate range. The maximum flow rate is calculated to be 77,579 acfh, and the minimum flow rate is 4,167 acfh, which is a turndown ratio of approximately 18.6:1. Turbine meters typically have maximum turndown ratios on the order of 10:1, so multiple meters will be required for this application.

One 12-inch-diameter turbine meter could handle the maximum flow rate, but measurement accuracy would be degraded at the minimum flow rate. One 8-inch-diameter meter could not handle the maximum flow rate. Therefore, the preferred installation configuration would be two meters run in parallel. If two 8-inch-diameter meters are used, then the minimum flow through one 8-inch meter would be at about 6.9% of capacity. At this rate, the meter accuracy would be relatively poor. The meter registration might also be affected by the condition of the turbine rotor bearings as they age and wear over time.

A better configuration would be to use one 8-inch-diameter meter and one 6-inch-diameter meter run in parallel. The 6-inch unit will be designated as the primary flow element. The 8-inch meter will be used in combination with the 6-inch meter when the flow rate through the 6-inch meter reaches 80% of meter capacity. With this installation configuration, the 6-inch meter would be operating at about 13.9% of its capacity at the minimum flow rate. When flow is passing through both meters and the rate is reduced to the point that the rate reaches 15% of the capacity of the 8-inch meter, the entire flow will be diverted through the 6-inch meter.

With the selected meter sizes, the ratio of flow rates will be approximately 57.75% for the 8-inch meter and 42.25% for the 6-inch meter (assuming the pressure drop across both meter runs is balanced). Table 2 summarizes how the combination of an 8-inch meter and a 6-inch meter meets the flow range requirements. A 4-inch-diameter meter plumbed in parallel with an 8-inch meter could also handle the full flow rate range. However, with that configuration, there would only be 421 acfh "extra" capacity, and the need to balance the flows between the two meters would be quite challenging. Therefore, the combination of one 8-inch meter and one 6-inch meter is the optimum configuration for this application.

Condition	**Variable**	**6" Meter (30,000 acfh)**	**8" Meter (60,000 acfh)**
Minimum Flow	Flow Rate (acfh)	4,167	0
	% of Capacity	13.9	0
Before Switch to Two Meters	Flow Rate (acfh)	24,000	0
(80% capacity of 6" meter)	% of Capacity	80.0	0
After Switch to Two Meters	Flow Rate (acfh)	10,140	13,860
	% of Capacity	33.8	23.1
Before Switch to One Meter	Flow Rate (acfh)	6,584	9,000
(15% capacity of 8" meter)	% of Capacity	21.9	15.0
After Switch to One Meter	Flow Rate (acfh)	15,584	0
	% of Capacity	51.9	0
Maximum Flow	Flow Rate (acfh)	32,777	44,802
(Unrestricted)	% of Capacity	109.3	74.7
Maximum Flow	Flow Rate (acfh)	28,500	49,079
(Restricted)	% of Capacity	95.0	81.8

Table 2. Operational Summary of Tandem Turbine Meter Installation

Conclusions

As noted at the outset, this paper provides a basic methodology for selecting flow meters for any given application, particularly when the flow rate range exceeds the range of a single meter. Regardless of the meter type selected, the basic process of selecting a flow meter installation is essentially the same. Keen attention to detail will make the difference between a meter station that provides accurate, cost-effective flow measurement, and one that does not.

One final consideration to keep in mind is the flow calibration of the meter(s). Flow meters obviously perform best when flow calibrated (using an accurate flow reference for the calibration) prior to installation at the field site. Virtually all flow meters will require periodic recalibration over their operational life to sustain optimum performance. The required recalibration interval will be a function of meter type and service application.

It is also important to note that flow meter calibrations can be sensitive to line pressure effects. If a meter is calibrated at a particular line pressure and then operated in the field at a substantially different line pressure, a meter calibration "shift" or measurement bias error may result. Turbine meters, for instance, are known to be sensitive to line pressure effects. If a turbine meter is initially flow calibrated at atmospheric pressure, but operated in the field at a line pressure of 1,000 psia, a measurement bias would likely result, unless the line pressure effect was accounted for in some manner. It is beyond the scope of this paper to explain the various methods used to compensate flow meters for line pressure effects, but that information can be found elsewhere in these Proceedings.

It is sometimes possible to perform in-situ flow meter calibrations at a meter station. In-situ meter calibrations (or recalibrations) can be accomplished most cost effectively when such calibrations are considered during the meter station design stage. A good meter station design will provide for ease of installation and operation of reference meters during the in-situ calibrations. The associated in-situ meter calibration costs may be significantly less than if no forethought had been given to in-situ calibrations during the meter station design.

A number of the technical topics discussed in this paper are covered in much greater detail in other papers in these Proceedings. The interested reader is strongly encouraged to study the other technical information available in these Proceedings.

References

1. Mattingly, G. E. and T. T. Yeh, "Effects of Pipe Elbows and Tube Bundles on Selected Types of Flowmeters," Journal of Flow Measurement and Instrumentation, Vol. 2, Butterworth-Heinemann, Ltd., January 1991.

2. Grimley, T. A., "Performance Testing of 8-inch Ultrasonic Flow Meters for Natural Gas Measurement," Topical Report to Gas Research Institute, GRI Contract No. 5097-270-3937, November 2000.