SwRI METERING RESEARCH FACILITY UPDATE

Edgar B. Bowles, Jr.
Dr. Darin L. George, P. E.
Eric Kelner, P. E.
Dr. Thomas B. Morrow, P. E.
Marybeth G. Nored

Metering Research Facility Program
Southwest Research Institute
6220 Culebra Road
San Antonio, TX 78238-5166 USA

Dr. Chip Letton
Letton-Hall Group
Houston, TX USA

INTRODUCTION

The Gas Technology Institute (GTI and formerly known as the Gas Research Institute or GRI) and the Pipeline Research Council International (PRCI) jointly sponsor a comprehensive flow measurement research, development, and commercialization program aimed, in large part, at improving natural gas metering performance in the field. Recent research has focused on developing new, more cost-effective technologies, as well as improving conventional measurement technologies. This article summarizes recent research efforts in support of the GTI/PRCI program conducted at the Metering Research Facility (MRF) located at Southwest Research Institute (SwRI) in San Antonio, Texas. The MRF is a high-accuracy natural gas flow calibration laboratory capable of simulating a wide range of operating conditions for the industry's research, calibration, and testing needs.

FIGURE 1. SwRI Metering Research Facility

SWRI FLUID PROPERTIES (ENERGY) METER

Since 1998, SwRI has conducted research and performed feasibility studies in the use of inferential techniques for determination of properties of pipeline fluids, in particular, those of natural gas. The goal of this effort has been to find ways of determining these properties – such as density and calorific value of the gas – using methods that are robust, inexpensive, and amenable to commercialization. A device called the Fluid Properties Meter (FPM) is the current result of this work.

Early studies showed that a regression model could be used to estimate gas properties with excellent accuracy, if five basic measurements were made on the gas:

- speed of sound
- pressure
- temperature
- mole percent of carbon dioxide
- mole percent of nitrogen

Patents covering the basic inferential method, as well as other innovations related to this work, are pending or have been issued.

The product niche this device will occupy lies somewhere between on-line gas chromatographs (GCs) that continuously monitor gas composition on-site and gas sampling systems that acquire spot or composite gas samples for off-site analysis. The simplicity of the SwRI device suggests that the total cost to the buyer should be significantly less than the price of a completely installed GC, thus, the technology has the potential to provide a low-cost alternative to gas chromatograph installations. It can also be used to provide gas properties at low-volume meter stations, where a gas chromatograph is not economically justified. Another potential application would be at locations where spot or composite samples are currently used to characterize gas quality. The device can also serve as a portable or on-line gravitometer/densitometer and can be used for natural gas engine control and protection. Local distribution companies can use the technology for grid management. Large industrial consumers can use it for monitoring gas consumption. The FPM can also serve as a low-cost back up for existing equipment.

Current developmental efforts are focused on commercialization of the technology. Field trials of advanced prototype units are currently in progress on gas transmission pipelines in the United States. A Joint Industry Project (JIP) - comprised of SwRI, several U.S. gas pipeline companies, and two measurement equipment manufacturers - has been organized to develop this technology for field use. The JIP held its first meeting at SwRI on April 8, 2004.

A photograph showing one of the prototype energy measurement modules is shown in Figure 2. Technical reports on this technology are available from GTI.[1],[2]

FIGURE 2. Energy Flow Rate Meter Prototype Measurement Unit

ULTRASONIC GAS FLOW METER RESEARCH

In June 1998, the American Gas Association (AGA) Transmission Measurement Committee (TMC) published its Report No.9, entitled *Measurement of Gas by Multipath Ultrasonic Meters*.[3] This document represents the first industry guidelines on the use of ultrasonic flow meters for natural gas applications. Since the publication of Report No.9 in 1998, the AGA Transmission Measurement Committee has been working to update the report to provide more specific guidance on the proper selection, installation, operation, and maintenance of ultrasonic flow meters. GTI/PRCI-funded research from the MRF is being used as the basis for some of the expected revisions to Report No.9.

During the past year, ultrasonic gas flow meter research at the MRF has focused on the effects of (1) line pressure variation, (2) very low gas velocity (e.g., nominal gas velocities <1 ft./sec.), and (3) temperature stratification of the flowing gas stream (which is most pronounced at nominal gas velocities <5 ft./sec.) on meter accuracy.

Figure 3 shows a flow meter skid used for part of the MRF research. This skid included three parallel meter runs containing an 8-inch diameter 4-path Daniel Flow Products ultrasonic flow meter, a 6-inch diameter 4-path Daniel ultrasonic flow meter, and a 3-inch diameter Instromet positive displacement (PD) flow meter. The two ultrasonic flow meter runs were fitted with perforated-plate type flow conditioners upstream of the meters.

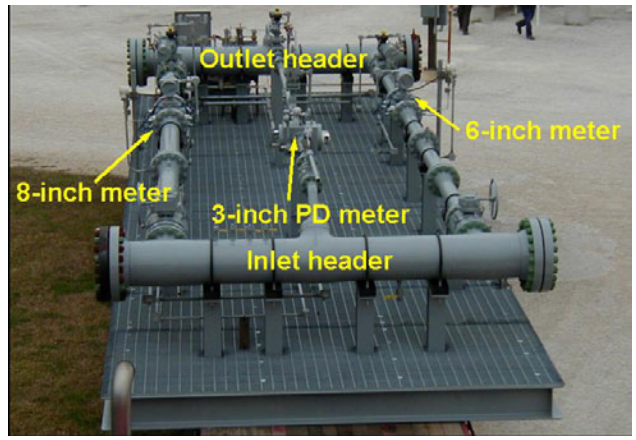

FIGURE 3. Ultrasonic Flow Meter Skid Package Tested at the SwRI Metering Research Facility

The flow meter skid shown in Figure 3 was used to test for various meter installation effects, including the effects of upstream and downstream headers. In addition, the low flow rate performance of the ultrasonic meters was compared to the performance of the positive displacement meter to help determine if the low-end range of the ultrasonic meters can achieve comparable measurement accuracy levels to that of a typical positive displacement meter. Other operational effects, such as line pressure variation, on meter performance were also investigated. At the time this article was written, the results of the MRF test work had not yet been compiled in a GTI Topical Report. However, a GTI report[4] documenting the findings of this MRF research work is scheduled to be published by September 2004.

TURBINE GAS FLOW METER RESEARCH

Due to advances in recent years in gas turbine flow meter technology, the AGA Transmission Measurement Committee is in the process of revising AGA Report No.7 – *Measurement of Gas by Turbine Meters*.[5] In support of this effort, MRF research recently investigated the effect of changes in line pressure and the effect of turbine meter cartridge change-outs on measurement accuracy.

To investigate the effects of line pressure changes on turbine meter accuracy, eight commercially-available gas turbine meters (both ‘standard’ and ‘extended-range’ designs) were tested using both natural gas (at the MRF) and air (at the Colorado Engineering Experiment Station) as the flowing medium. Performance changes due to fluid drag (related to Reynolds number) and non-fluid drag (related to gas density) were quantified in flowing conditions ranging from atmospheric air to natural gas at 700 psig. Shifts in meter calibration were observed with changes in flowing conditions for all the meters tested. The magnitudes of the changes in meter calibration were a function of meter design, but for all eight meters, the maximum changes were within ±2.5% of reading at flow rates above 20% of the maximum flow rate of each meter. The largest change below 20% of flow meter capacity exceeded 7% of reading.

Test results are summarized in Figure 4. Both single-rotor and dual-rotor designs were tested. For those dual-rotor meters where the second rotor was designed as an independent 'check rotor,' the second rotor calibration was recorded and analyzed separately. For other dual-rotor meter designs, the outputs from both rotors were combined mathematically to create an 'adjusted' calibration. Changes in the 'adjusted' calibration were also analyzed separately from the main rotor calibration. The brand and model of each meter were not identified in the study, in order to 'blind' the results. In Figure 4, the '4' series designation pertains to meters with a nominal diameter of 4 inches. The '8' series designation pertains to meters with a nominal diameter of 8 inches.

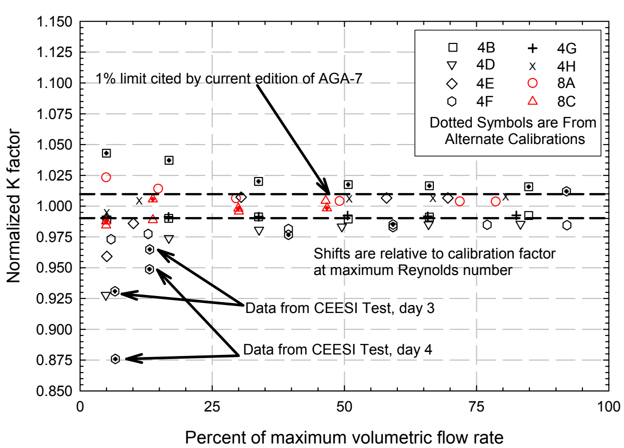

FIGURE 4. Maximum Observed Shifts in Turbine Meter Calibration with Changes in Reynolds Number and Gas Density. (All shifts are relative to the asymptotic calibration factor at maximum Reynolds number, i.e., at the maximum flow rate and line pressure tested.)

A complete technical report on the MRF turbine meter line pressure effects research can be obtained from GTI.[6]

For the cartridge change-out effects tests, four different brands and models of commercially-available natural gas turbine meters were evaluated. For each type of meter, two or three cartridges were flow calibrated in each of three different meter bodies. While analysis of the results was still in progress as of the time this article was written, some trends were clearly evident. The smallest changes were observed for a new, unused cartridge, tested with three bodies built especially for the test program. Larger changes were observed for cartridges and sets of bodies (provided by a gas transmission pipeline companies) that were in use for several years. Most variations due to cartridge changes between bodies were comparable in magnitude to values quoted by the meter manufacturers for their meters, but the largest variations (observed for the used meters) were significantly larger than specified by the meter manufacturer.

In several cases, a particular meter body consistently produced the highest or lowest calibration curve for all cartridges with which it was tested. Work is underway to determine if the calibration behavior correlates to variations in one or more internal dimensions of the body, or in clearances between the body and cartridge. Such information would give turbine meter users guidance for determining if particular meter bodies are prone to biasing flow rate measurements.

At the time this article was written, the results of the MRF test work had not yet been compiled in a GTI Topical Report. However, a GTI report documenting the findings of this MRF research work is scheduled to be published by September 2004.

ORIFICE GAS FLOW METER RESEARCH

Orifice flow meter discharge coefficient (C_d) data were recently collected at the MRF for two line sizes, 4-inch and 6-inch diameter, to experimentally determine the orifice meter expansion factor for a range of orifice meter diameter ratios (β) between 0.25 and 0.60. The purpose of this study was to provide information needed to formulate a decision on whether or not to revise the expansion factor equation in the North American orifice meter standard, i.e., AGA Report No.3, Part 1[7] (also, the American Petroleum Institute (API) Manual of Petroleum Measurement Standards (MPMS), Chapter 14.3, Part 1). In 2003, for its orifice flow meter standard (i.e., ISO 5167[8]), the International Standards Organization (ISO) adopted a new expansion factor equation based on orifice coefficient data taken since the early 1980s.

By convention, the orifice meter discharge coefficient, C_d, is the same in gas flows as in liquid flows for the same value of Reynolds number and β ratio. However, gas and liquid expand differently downstream of an orifice plate, and these differences can affect the pressure differential across the orifice plate. The differences are absorbed into the expansion factor. By definition, the expansion factor equals 1.0 in liquid, but is generally less than 1.0 in gas flow. Typically, the expansion factor, Y_1, is calculated from the Buckingham equation derived from experimental data taken in the Los Angeles tests of 1929,[9] and published in 1932. This equation was subsequently adopted for the North American orifice flow meter standard, AGA Report No.3, and the International Standards Organization (ISO) 5167 standard.

Example test results from the MRF research are shown in Figures 5 and 6. Figure 5 compares some expansion factor data for a 4-inch (100 mm) diameter meter tube with β = 0.50 (i.e., a ratio of orifice bore diameter to meter tube diameter of 0.5) to the expansion factor equation referenced in AGA Report No.3, Part 1 (i.e., the Buckingham equation). Note that these tests were run with natural gas and that while the MRF experimental data points for Y_1 lie above the values calculated from the Buckingham equation, they also lie completely within the uncertainty interval specified for the Buckingham equation. Also note that for these tests, a constant, perfect-gas value of the isentropic exponent, k = 1.3, was used instead of the real compressible fluid isentropic exponent, which is a function of pressure and temperature. This approach is accepted practice in accord with AGA Report No.3, Part 1.

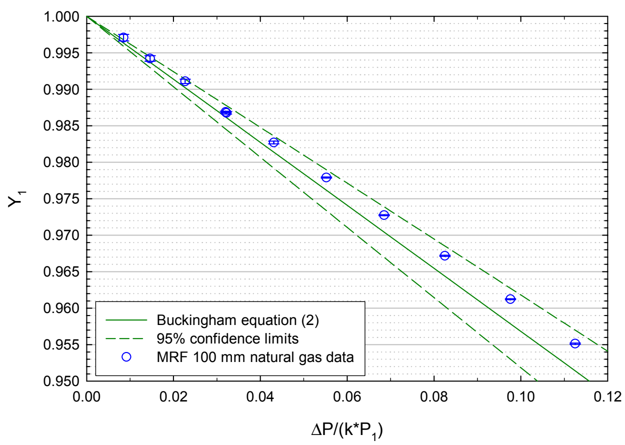

FIGURE 5. Example Plot of Orifice Meter Expansion Factor, Y_1, vs. $\Delta P/(k*P_1)$ Compared to the Buckingham Equation
(for line diameter = 4 inches and β = 0.50)

Where:

Y_1 = expansion factor

ΔP = (P_1 - P_2) is the pressure difference across the orifice plate

P_1 = static pressure upstream of the orifice plate

K = isentropic coefficient.

Figure 6 shows the same set of expansion factor data for Y_1 versus $\Delta P/(k*P_1)$ for a 4-inch (100 mm) meter tube with β = 0.50, but compares the data to the expansion factor equation referenced in ISO 5167-2:2003 (i.e., the version of the ISO orifice meter standard dated 2003).

Note that in Figure 6, the same MRF experimental data points for Y_1 now lie below the values calculated from the new ISO equation and that they also lie within the uncertainty interval specified for the ISO 5167-2:2003 equation. Therefore, the same set of experimental data can be seen as confirming both equations for expansion factor.

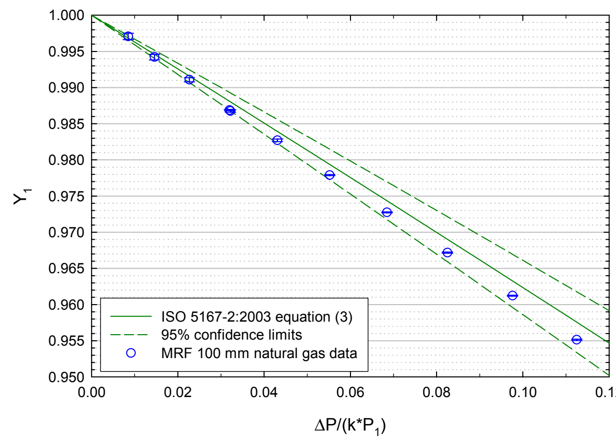

FIGURE 6. Example Plot of Orifice Meter Expansion Factor, Y_1, vs. $\Delta P/(k*P_1)$ Compared to the Buckingham Equation
(for line diameter = 4 inches and β = 0.50)

As of the time this article was written, the American Petroleum Institute Working Group responsible for maintaining API MPMS, Chapter 14.3/AGA Report No.3 had not made a final determination regarding any possible change to the expansion factor equation referenced in API MPMS, Chapter 14.3/AGA Report No.3. Contingent upon funding availability, additional MRF flow tests were planned by API. A complete technical report on the MRF expansion factor research to date can be obtained from GTI.[10]

NATURAL GAS SAMPLING RESEARCH

The research results from this program have led to a recent revision of the industry standard for gas sampling methods, i.e., the API Manual of Petroleum Measurement Standards (MPMS), Chapter 14. 1 - *Collecting and Handling of Natural Gas Samples for Custody Transfer*.[11]

In 2003, the MRF conducted research (see Figure 7) funded by the U.S. Minerals Management Service to evaluate a proposed API test protocol to verify the performance of natural gas sampling methods. This protocol is intended to serve as a means of assessing new gas sampling methods for the natural gas industry. The protocol was evaluated by using it to test some of the sampling methods currently referenced in GPA Standard 2166[12] that are known to provide accurate results when performed correctly. Experience with using the protocol led to several recommendations to API for improving the protocol, such as improving procedures to avoid sample contamination and to calibrate GCs beforehand. The need to correctly heat sampling equipment in cold conditions was demonstrated during the research. In addition, several newly proposed sampling methods were also tested. The methods were judged on repeatability of results, and on their ability to reproduce the composition and heating value of a flowing natural gas stream analyzed by an online GC. With proper equipment handling, one new sampling method was found to produce a representative sample of the flowing gas stream, when ambient conditions were both well above and well below the hydrocarbon dew point.

FIGURE 7. Proposed Natural Gas Sampling Method Verification Test Protocol Being Evaluated at the SwRI Metering Research Facility

As of the time this article was written, the American Petroleum Institute Working Group responsible for maintaining API MPMS, Chapter 14.1 was in the process of balloting the new verification test protocol for possible future inclusion in that API standard. A complete technical report on the sampling method verification test protocol research can be obtained from the United States Minerals Management Service.[13]

MRF personnel also recently assisted the natural gas industry by overseeing the preparation of an API industry standard for measurement of the hydrocarbon dew point of natural gas mixtures via the chilled mirror method. The Bureau of Mines chilled mirror device is the accepted method for field measurements of hydrocarbon dew point temperatures, particularly in settling custody transfer disputes. Although an ASTM standard (ASTM D1142[14]) exists for water dew point measurements via chilled mirror, no standard has existed until now for hydrocarbon dew point temperature measurements using this device. The standard, which is expected to eventually appear as an appendix to the next revision of API MPMS, Chapter 14.1, discusses the design requirements for chilled mirror devices, general considerations for accurate dew point temperature measurement, safety considerations, and uncertainties in dew point measurements. The procedures for operating the dew point tester include photos to help new users identify hydrocarbon dew points, water vapor dew points, and other condensations such as alcohol and glycol.

CONCLUSIONS

The GTI/PRCI applied flow measurement research program continues to address the priority needs of the natural gas industry. This paper summarizes some of the recent measurement research activities at the MRF. Ongoing or planned future research at the MRF includes the following technologies:

- fluid properties (energy) meters
- ultrasonic gas flow meters
- orifice gas flow meters
- water vapor sensing devices
- natural gas sampling methods/gas quality determination

A complete listing of all MRF research reports and technical papers is available from GTI (www.gri.org) or the MRF website (www.grimrf.org).

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