Case Study Results on Natural Gas Custody Transfer Measurement with Coriolis Meters in Saudi Arabia

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Introduction

Saudi Aramco has conducted a long-term trial of two Coriolis flow meters in an industry gate natural gas custody transfer application. The long-term measurement results of the Coriolis duty meter are compared to both a second reference Coriolis meter and an orifice meter.

The trial was conducted employing elements of the of American Gas Association Report No. 11 (AGA 11) Measurement of Natural Gas by Coriolis Meter - Second Edition that was published in February of 2013 (a.k.a, American Petroleum Institute Manual of Petroleum Measurement Standards Chapter 14.9 (API MPMS 14.9)). The Second Edition of AGA 11 includes many improvements and additions to the First Edition. One of the new additions describes how manufacturers can demonstrate that a meter designed for natural gas service has the flexibility to be calibrated with fluids other than natural gas (e.g., water). Another significant addition to AGA 11 describes how it is possible to perform a secondary verification check on a Coriolis meter in service without interrupting gas flow measurement.

Description of the Trial Application and Installation

Two Micro Motion CMF200 Coriolis meters were mounted together on the skid to allow gas to flow through both meters in series under normal operating conditions. Valves were installed and piping arranged as shown in Figure 1 to allow for either meter to be bypassed at any time. Additionally, two block valves were located on either side of each meter so that either meter could be blocked in on both the upstream and downstream side. High quality block valves were selected to ensure that no leakage through any of the valves would occur to influence the test results. The flow indication from the two meters was taken to a control room where an Emerson FB 107 flow computer calculated and recorded the flow totals from the meters on a daily basis.

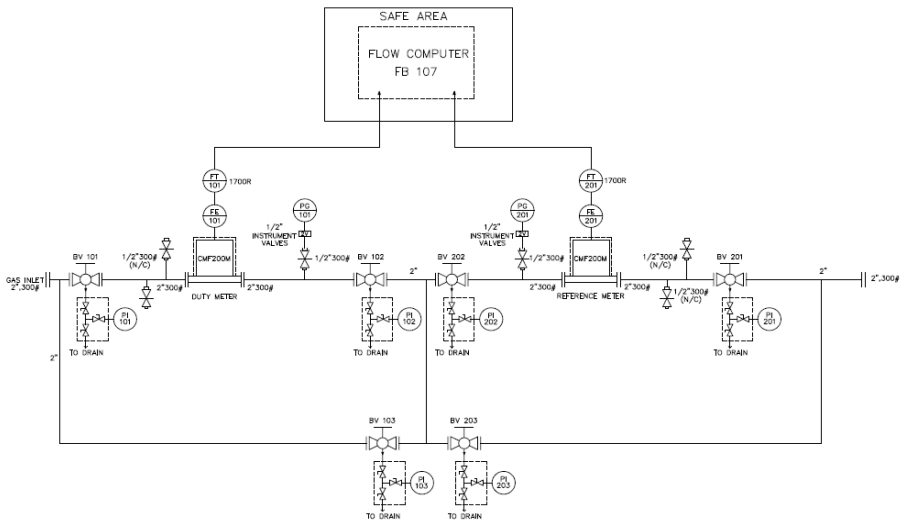

Fig.1. Diagram of the Trial Skid Piping Arrangement

With this arrangement it was possible to check the zero of either meter regularly without the need to interrupt the flow through the skid. It was also possible to remove either meter from service temporarily to allow the meters to be transported and tested in a calibration laboratory setting at another location without interrupting the functioning of the other meter during the course of the trial period.

The site of the test was a glass factory located in Dammam, Saudi Arabia. The skid shown in Figure 2 was delivered and installed in series with an existing orifice meter run at the point where natural gas is sold from a pipeline into the factory.

Fig.2. Trial skid with Two Micro Motion CMF200 Meters

The skid was designed to meet the following requirements:

- Gas flow rate: 700 - 1000 Nm^3/hr (0.6 - 0.85 MMSCFD)
- Mass flow rate at operating conditions: 560 - 800 kg/hr
- Operating pressure: 250 - 300 psig
- Gas temperature: 60 - 100 °C (140 - 212 °F)
- Pressure loss across each meter: 0.35 psi
- Maximum velocity passing through the meters: 18 m/s (57 fps or 0.04 Mach)

The trial period began May 25, 2011 and was successfully concluded on July 14, 2012 after a total duration of approximately 14 months. Toward end of trial period, the flow rates were allowed to increase to as high as 1180 Nm^3/hr (1.0 MMSCFD) with no appreciable adverse change observed in the results.

Determining Energy and Standard Volume Units from Coriolis Mass Flow Measurements

The standard practices for trading in natural gas are based on units of standard volume and energy. Standard volume is the volume of a fixed quantity of gas when it is at mutually agreed upon reference conditions of fixed pressure and temperature. It is necessary to work in units of standard volume instead of actual volume because the actual volume of a fixed amount of gas will change dramatically as actual pressure and temperature are changing.

To determine flow in energy units, a gas chromatograph or other method is needed to establish the heating value of the natural gas, which will vary with changing composition. The heating value can either be represented as energy units per unit of standard volume, such as BTU per standard cubic foot, or as energy units per unit of mass, such as MJ per kg.

The simplest and most accurate path to energy units is to multiply the mass by the heating value, expressed in energy units per unit of mass to arrive at units of energy (or energy flow).

$$Energy\ (MJ) = Mass\ (kg) \times H_c\ (MJ/kg)$$

OR

$$Energy\ Flow\ (MJ/day) = Mass\ Flow\ (kg/day) \times H_c\ (MJ/kg)$$

Where:

$Mass$ = Mass of gas (Coriolis flow meter measurement)

H_c = Heating Value (as determined by gas analysis)

If, instead, heating values are defined in units of energy per unit of standard volume, it is easy to make the conversion from mass to standard volume before multiplying by the heating value.

$$STD\ VOL\ (SCF) = \frac{Mass\ (lbm)}{\rho_b (lbm/ft^3)}$$ (AGA 11 Equation D.2) [1]

Where:

$STD\ VOL$ = Volume at reference temperature (T_b) and reference pressure (P_b)

$Mass$ = Mass of gas (Coriolis flow meter measurement)

ρ_b = Base density of gas at reference temperature (T_b) and reference pressure (P_b)

$$\rho_b = \frac{P_b \times M_{r\ (gas)}}{Z_b \times R \times T_b}$$ (AGA 8 Equation 7) [2]

P_b = Pressure at base conditions

M_r = Gas Molar Weight

Z_b = Base compressibility at reference temperature (T_b) and reference pressure (P_b)

R = Universal gas constant

T_b = Temperature at base conditions

The relationship between energy units and mass total or mass flow is also, therefore, straightforward as shown in the following equations.

$$Energy\ (BTU) = STD\ VOL\ (SCF) \times H_c\ (BTU/SCF) = \frac{Mass\ (lbm)}{\rho_b (lbm/ft^3)} \times H_c\ (BTU/SCF)$$

OR

$$Energy\ Flow\ (BTU/day) = STD\ VOL\ (SCFD) \times H_c\ (BTU/SCF) = \frac{Mass\ Flow (lbm/day)}{\rho_b (lbm/ft^3)} \times H_c\ (BTU/SCF)$$

Note that base density is a fixed constant that will not change unless the composition of the gas changes. Actual density will change, just as actual volume will change, when the actual pressure and temperature are changing. In contrast, base density will not change due to changes in actual pressure and temperature.

When the flow is measured directly by mass with a Coriolis meter it is still necessary to know the composition in order to convert to either energy or standard volume, but it is never necessary to know the actual pressure or temperature to convert units to base conditions because the mass of a fixed quantity or amount of gas will never change, even when the actual pressure and temperature are changing. For this reason, the trial skid did not include any pressure or temperature transmitters.

The initial gas molar weight in the trial installation was 16.42. The base density, ρ_b, was 0.78 kg/m^3 (0.044 lb/ft^3) at 14.7 psia and 15.5 °C. Therefore, the daily volume flow rate could be recorded in units of MSCFD in the FB107 by simply dividing the daily mass flow reading in kg/day by the base density, ρ_b (0.78 kg/m^3), and then multiplying by the conversion factor 0.035315 MSCF/m^3. As the trial progressed, the gas composition was sampled and updated in the flow computer on a weekly basis to calculate base density and standard volume (using the detailed method from AGA 8).

Measurement Traceability

Both the test (duty) and the reference Coriolis meters were installed and placed into service with the original factory water-based flow calibrations left intact.

AGA 11 states in the beginning of **Section 7 Gas Flow Calibration Requirements** that it may be valid to use an alternative calibration fluid, such as water, to calibrate Coriolis meters for gas measurement, so long as transferability of the calibration from the alternative fluid to gas has been demonstrated by the meter manufacturer through tests conducted by an independent flow calibration laboratory. Transferability of the calibration from an alternative fluid will include an added uncertainty relative to gas measurement that must be quantified by the manufacturer and verified by an independent flow calibration laboratory or laboratories. Coriolis meter designs that have not yet demonstrated calibration fluid flexibility are required to be flow calibrated on gas as prescribed in Section 7.1 of AGA 11.

Emerson has verified transferability of water calibration to gas flow measurement for the Micro Motion® ELITE® CMF series of flow meters through testing at multiple independent flow calibration laboratories. No linearization or adjustment was applied during this series of tests after the original factory calibration on water was performed other than compensation for the known effect of pressure on the meter that was applied. The maximum difference observed during testing between the original water calibration and the tests on natural gas and nitrogen was ±0.5%[3]. One of the Coriolis meters that were tested to verify the transferability of water calibrations is shown in Figure 3 as it was installed in an independent gas calibration laboratory during the testing.

Fig.3. Coriolis Meter Installed for Independent Gas Laboratory Testing[4]

The manufacturer's published gas measurement accuracy specification for the two Micro Motion meters used in the trial is ±0.35% of rate. This accuracy specification for gas measurement applies to the meters as they leave the factory calibration lab, after the standard flow calibration procedure that uses water as the fluid.

The measurement of the test (duty) Coriolis meter was confirmed on a daily basis during the trial by comparing the reading with that of the reference Coriolis meter. The two meters were required to agree by ±0.7% or better at all times or the test (duty) meter reading would not be used for custody transfer and the sale point would revert back to the orifice meter, which was left active.

The traceability of each of the Coriolis meters was also independently confirmed well into the trial period. The ability to remove each meter during operation was an important element of the design of the skid because the trial plan included provisions for testing each of the meters, one in a liquid calibration laboratory and one in a gas calibration laboratory, but only after both meters had already been in service at the trial site for some time.

After approximately 8 months in service, the test (duty) meter was removed from the skid and sent to the Emerson calibration laboratory in Abu Dhabi for a scheduled calibration test on water. The laboratory is CMC Certified by VSL. The original test plan called for agreement between the test (duty) meter and the water calibration standard of ±0.1% or better to pass. The meter passed this test and was returned to the skid and placed back into service the following month. During this time period, the reference meter acted as the duty meter.

As soon as the test (duty) meter had been returned into service, the plan then called for the reference Coriolis meter to be removed and sent to a third-party gas calibration laboratory to be checked against reference standards on natural gas flow in a controlled environment. The Southwest Research Institute (SwRI) natural gas laboratory in San Antonio, TX, USA was selected for this test and the plan called for agreement between the meter and the reference standards on natural gas of ±0.7% or better to pass. The data in Figure 4 from the test at SwRI shows that the meter agreed with the reference standards to within ±0.25%. The meter was returned to the skid and placed back into service as the reference meter on April 27, 2012.

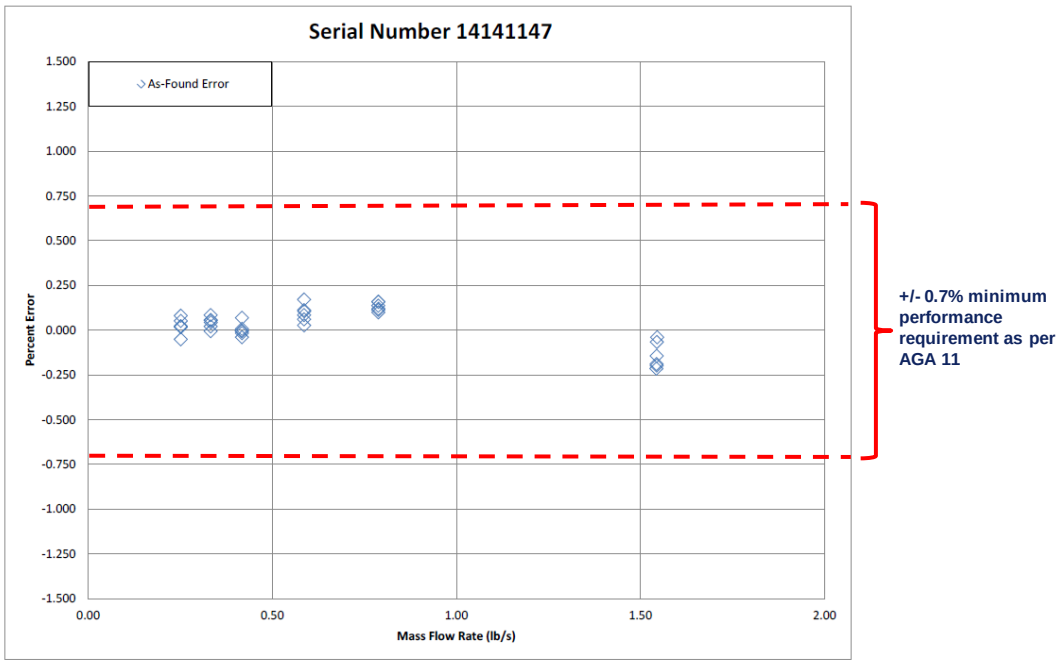

Fig.4. Reference Coriolis Meter Test Results at the Independent Gas Laboratory (SwRI)

Ongoing In-Situ Meter Verification

One of the most sought-after benefits of Coriolis meters is that the calibration remains very constant over time if nothing occurs to damage the meter structurally. This is why diagnostic tools that accurately monitor the structural health of a Coriolis meter are useful as a tool for secondary verification of the meter calibration that can be relied on, even after lengthy periods of time have passed since the most recent calibration against a primary or secondary flow reference standard.

Micro Motion ELITE CMF meters can be equipped with an optional diagnostic feature called Smart Meter Verification (SMV) that uses a sophisticated analysis the Coriolis meter flow tube vibration response characteristics to assess and trend the structural consistency of the meter flow tubes. If the structure of the meter is found by the SMV tool to be consistent over time, this result indicates that the meter's flow calibration has remained unchanged.

A Coriolis meter may be installed directly into service for natural gas custody transfer after the factory calibration on water, or it may be sent to an independent gas calibration laboratory for calibration. In either case, the value of the investment in equipment and calibration can be prolonged and preserved by using an automated secondary verification diagnostic tool like the Micro Motion SMV feature.

During the course of the trial, the SMV diagnostic test was used on a weekly basis as further confirmation of the integrity of the measurements. The SMV feature tested both the flow meter electronics (transmitter) and the sensor. In particular, the SMV test measured and recorded the stiffness of the flow tubes, which is the secondary attribute that is used to verify the structural integrity and calibration stability of the meter. The full history of the structural integrity flow tube stiffness tests for both of the Coriolis meters used in the trial is shown in Figure 5.

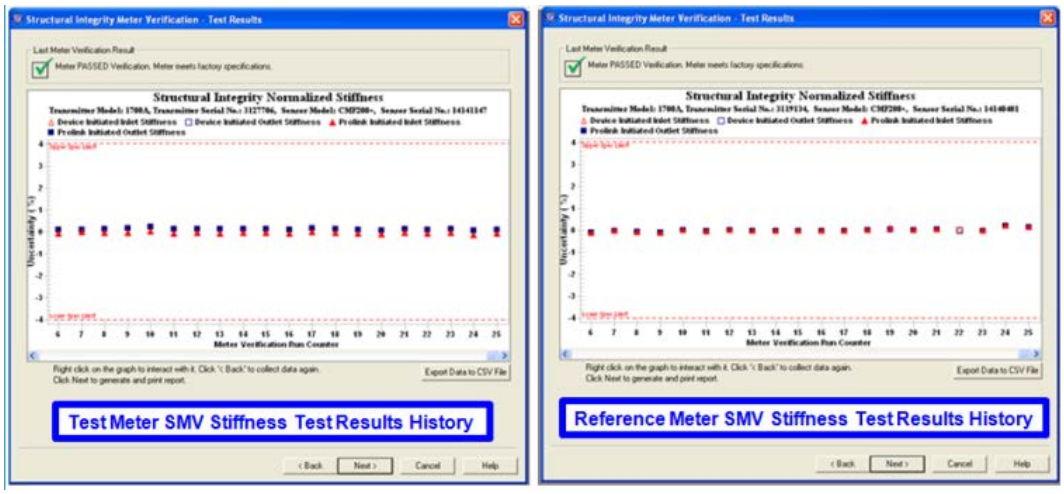

Fig.5. SMV Meter Structural Integrity Test Results History of the Two Coriolis Meters

The SMV test results showed that the both the meters were undamaged and that both of their original calibrations were intact. Therefore, it was no surprise when the test meter passed the liquid calibration test later in Abu Dhabi and the reference meter passed the gas calibration test at SwRI.

In addition to checking the calibration and health of the meters using the SMV test, the zero of each meter was checked on a weekly basis. To perform this check, one of the meters was shut in by closing both the upstream and downstream valves on either side of that meter and then confirming that the meter indicated zero flow properly. Then the flow through that meter was resumed while the same check was performed on the other meter. Both meters consistently passed this check.

Previous experiences in this application had identified a risk of coating by a black powder contamination. The Zero Check and SMV diagnostic test were used to protect against any undetected build-up of the black powder coating in the meter. No significant coating was detected while the meters were in service and this was verified by inspection with a borescope when the test meter arrived for calibration in water flow Lab in Abu Dhabi.

Summary Observations of the Trial

Confidence in the measurements made by both of the Coriolis meters was high. The weekly SMV and zero checks confirmed that the meters had not suffered any damage and that the calibrations of both meters were remaining stable over time as expected.

The planned removal of each of the Coriolis meters so that they could be sent to a laboratory offsite and tested against reference standards strengthened the confidence in the measurements even more. By first verifying that the test (duty) meter was still within ±0.1% of the Emerson lab when tested on water after 8 months in natural gas service, and then verifying that the reference meter was within ±0.25% when tested on natural gas at SwRI after 9 months in service, it was concluded that the meter calibrations had remained stable during the entire course of the trial.

Confidence in the calibration stability of the meters was also bolstered by the consistent agreement between the two meters to within ±0.7% during the entire trial period of 14 months.

Figure 6 shows this agreement between the two Coriolis meters in terms of daily captured flow rate averages. Note that the black line of the reference Coriolis meter is almost always completely obscured by the grey line of the test (duty) Coriolis meter. The only time the black line of the reference Coriolis meter is fully visible is during the one month period when the test meter was sent to Abu Dhabi for testing in the Emerson lab. During that time, the grey line was absent since the meter was not present in the skid.

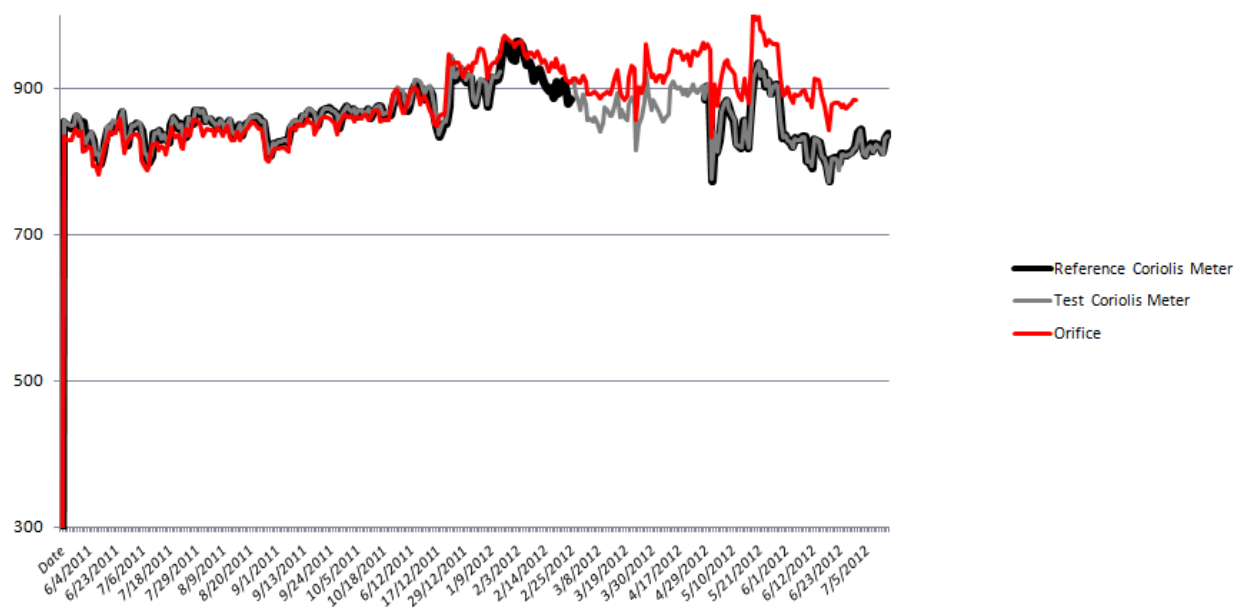

Fig.6. Daily Average Flow Rates of the Two Coriolis Meters and the Orifice Meter

It is easier to confirm the agreement between the two Coriolis meters in the plot of the deviation between the two meters shown in Figure 7. The green line, plotted as Deviation 2, represents the % difference between the two Coriolis meters and shows how well they agreed to within ±0.7% during the length of the trial period. A gap exists in the plot of Deviation 2 because during the time period where the gap appears is the time when either one or the other of the Coriolis meters was away at one of the offsite labs.

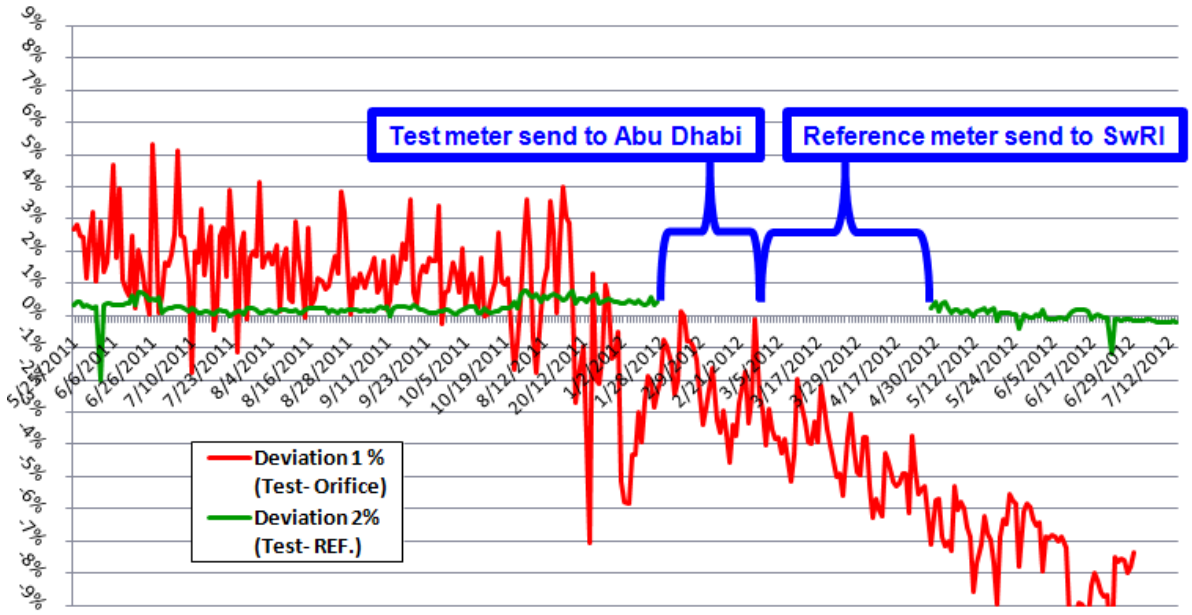

Fig.7. Deviations between the Two Coriolis Meters and the Orifice Meter

It can be seen in both Figures 6 and 7 that the orifice meter reading agreed reasonably well with the Coriolis meters up until roughly November or December of 2011. The red line, plotted as Deviation 1, indicates the difference between the test (duty) Coriolis meter and the orifice meter. It is plain to see that the orifice meter began to read higher and higher relative to both of the Coriolis meters from November 2011 until the end of the trial data collection in July of 2012. The orifice meter was over registering relative to the Coriolis meters and it eventually reached a point toward the end of the trial where it indicated higher than the Coriolis meters by roughly 10% of rate. The root cause of the orifice drift relative to the Coriolis meters has not yet been identified.

Conclusions

The trial has captured data demonstrating the long term performance of the test (duty) Coriolis meter. The results demonstrated the successful application of both calibration fluid flexibility with water and secondary meter verification diagnostics as described in the second edition of AGA 11.

The case study concluded that the Coriolis meters that were used are well suited for custody transfer measurement of natural gas. Furthermore, the Coriolis meters provided substantial benefits:

- improved system accuracy as a result of the long-term calibration stability
- quicker start-up straight from the factory due to the calibration fluid flexibility
- extended confidence in the measurements due to the secondary verification diagnostics
- confirmed water calibration for ongoing calibration tests with the results being transferable to gas flow measurement

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[1] AGA Report No. 11, API MPMS Chapter 14.9, ***Measurement of Natural Gas by Coriolis Meter***, American Gas Association, 400 N. Capitol Street, N.W., 4th Floor, Washington, DC 20001

[2] AGA Report No. 8, ***Compressibility Factor of Natural Gas and Related Hydrocarbon Gases***, American Gas Association, 400 N. Capitol Street, N.W., 4th Floor, Washington, DC 20001

[3] ***Test Report Number NMi-12200340-02***, Project Number 12200340, NMi Certin B.V., Hugo de Grootplein 1, 3314 EG Dordrecht, The Netherlands

[4] Wyatt, T., Stappert, K., ***Large Coriolis Meters and the Applicability of Water Calibrations for Gas Service***