

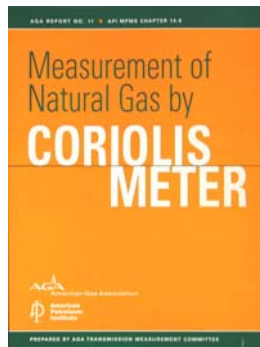
# CORIOLIS MASS FLOW METERS FOR NATURAL GAS MEASUREMENT

**Karl Stappert, Micro Motion, Inc.**

## **Abstract**

Coriolis meters have gained worldwide acceptance in liquid applications since the early 1980's with an installed base of more than 500,000 units. Newer designs have increased low-flow sensitivity, lowered pressure drop, and increased noise immunity enabling performance characteristics that are similar or better than traditional metering technologies. Coriolis also has attributes that no other fluid measurement technology can achieve. Some of these attributes are the meter's immunity to flow disturbances, fluid compositional change, and it contains no wearing parts. With more than 30,000 meters measuring gas phase fluids around the world, many national and international measurement organizations are investigating and writing industry reports and measurement standards for the technology.

In December of 2003 the American Gas Association and the American Petroleum Institute co-published American Gas Association (AGA) Report Number 11 and American Petroleum Institute (API) Manual Petroleum Measurement Standards, Chapter 14.9, Measurement of Natural Gas by Coriolis Meter.



An overview of theory, selection, installation, maintenance, and benefits of Coriolis meters will be presented. Application details will be presented to illustrate both the range of natural gas applications, including production, fuel flow control to gas power turbines, master metering, city/industrial gate custody transfer, and third-party test data. Laboratories include the Colorado Engineering Experiment Station Inc. (CEESI), Southwest Research Institute (SwRI), and Pigsar.

## **Introduction**

Coriolis is one of the fastest growing technologies in the Oil and Gas market. Newer designs and technology developments since the early 1990's have enabled Coriolis to measure gases that are extremely light, heavy, dirty, clean, sweet, sour, hot, cold, and/or in a partial two-phase state. AGA Report Number 11 specifically concentrates on the measurement of single-phase natural gas mixtures

within the normal and expanded compositional ranges called out by AGA Report Number 8, Compressibility Factors for Natural Gas and Other Hydrocarbon Gases.

The low flow sensitivity of Coriolis meters has dramatically improved in recent years allowing the technology to easily achieve flow turndowns of 30:1 or more at pressures of 300 psi with turndown increasing as pressure increases.

All in all, it can be argued that Coriolis technology solves more problems and offers even more value for gas than liquid measurement. This is due to gases being more compressible, and with more traditional gas technologies (i.e. Orifice, Turbine, Rotary, and Ultrasonic) process pressure, temperature, and gas composition must be accurately measured or controlled and the flow elements regularly maintained (i.e. Orifice plates, flow tubes, and transmitters checked on Orifice; Bearings, flow tubes, transmitters, and bearing oilers checked on Turbine; Gears, rotors, transmitters, and gear oilers checked on Rotary; flow tubes, flow conditioners, and transmitters checked on ultrasonic). Adequate gas flow testing performed on the technologies that are sensitive to gas density and/or flow profile; i.e Turbine, Ultrasonic. Since Coriolis measures the flowing mass of fluids its accuracy is independent of fluid composition, viscosity, flow pulsations, and flow profile/swirl. The meter is more accurate over a wider range of operating conditions and is less costly to install and maintain and many applications and especially in 300 ANSI applications and higher.

Coriolis is a smaller line-size technology: the largest offering from any vendor for gas applications is a 150mm (6") pipe flow diameter. The pressure drop and flow range of a Coriolis meter draws a direct relationship to the actual flow area through the meter when comparing it to other metering technologies; i.e. the flow area through a turbine meter is area not displaced by the turbine internals and rotor, the flow area of an orifice meter is that of the orifice diameter. Because of this relationship a Coriolis meter will typically be one pipe size smaller than a turbine meter and several sizes smaller than an orifice while having similar pressure drops at flowing pressures in the 300 ANSI class and above. Therefore it is typical to see a 150mm (6") Coriolis meters installed in up to 200mm (8") line sizes and above.



A 4" meter installed in 8" piping system

Coriolis meters are very cost competitive with other metering technologies on an installed cost basis, where installed cost includes:

- Instrument purchase price
- Instrument laboratory gas calibration
- Temperature and pressure compensation
- Flow conditioning and meter flow tube requirements
- Engineering and Procurement of these instruments
- Labor to install metering equipment

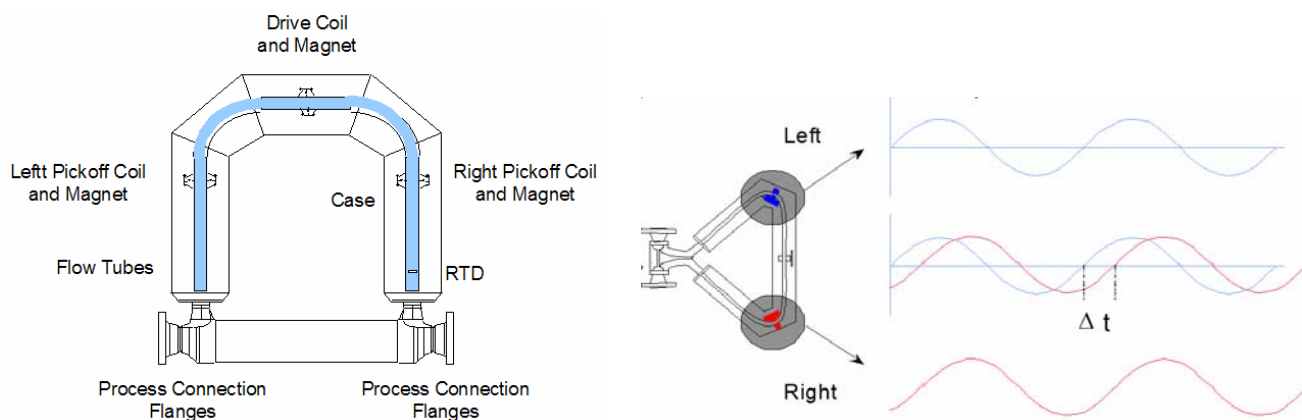
When operating costs are included into the evaluation of Coriolis compared to traditional high turndown technologies, Coriolis is the undisputed fiscally responsible meter choice in the 300 to 900 ANSI class in line sizes of 200 mm (8") and below.

### **Application "Sweet Spots"**

- Gas delivery locations/Pressure cut locations
- Measurement locations where high regulator or flow controller noise is a concern
- Measurement locations where flow surge (rate of change) and pulsations from compression or regulation will damage rotating elements (i.e. Turbine and Rotary)
- Locations where sporadic peak flows could exceed normal flow range design causing damage (i.e. Rotary and Turbine) or loss of measurement (i.e. Orifice and Ultrasonic)
- Line sizes 150mm and smaller
- High turndown requirements (20:1 up to 50:1 is common), eliminating parallel metering runs of differential head meters or having to change orifice plates.
- Dirty or wet gas where maintenance is an issue and the "wet" is liquid hydrocarbons of considerable value.
- No room for adequate straight-runs (i.e. Turbine, Orifice, and Ultrasonic)
- Changing gas composition and flowing density (i.e. Turbine)
- Critical phase fluids such as Ethylene ( $C_2H_4$ ) or Carbon Dioxide ( $CO_2$ ), where fluid density is nearly impossible to determine accurately on-line.
- Custody transfer, process control, or system balances where mass based measurement provides a lower uncertainty.

## Theory of Operation

A Coriolis meter is comprised of two main components, a sensor (primary element) and a transmitter (secondary). Coriolis meters infer the gas mass flow rate by sensing the Coriolis force on a vibrating tube or tubes. The conduit consists of one or more tubes which are vibrated at their resonant frequency. Sensing coils located on the inlet and outlet sections of the tube(s) oscillate in proportion to the sinusoidal vibration. During flow the vibrating tube(s) and gas mass flow couple together due to the Coriolis force causing a phase shift in the signals produced by the sensing coils. The phase shift, which is measured by the Coriolis meter transmitter, is directly proportional to the mass flow rate.



Note that the vibration frequency is proportional to the flowing density of the fluid. For gas applications, the flowing or “live” density is not used for gas measurement, but can be used as an indicator to change in a Coriolis meter’s flow factor.

For a more complete discussion of the Coriolis theory of operation, please contact the author or refer to AGA Report Number 11.

## Standards work, approvals, and research

Coriolis meters have long been used for process control, and a number of worldwide approvals and reports or recommended practices exist for fiscal (custody) transfer. These include:

- AGA Report Number 11
- API MPMS 14.9
- API MPMS Ch. 5.6
- NIST (USA) C.O.C.
- German PTB
- Dutch NMI
- Measurement Canada
- Brazil INMETRO

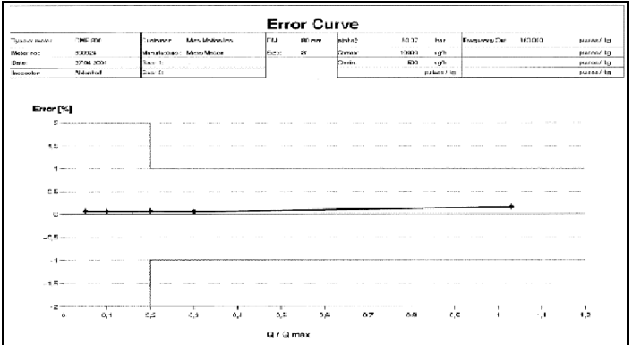
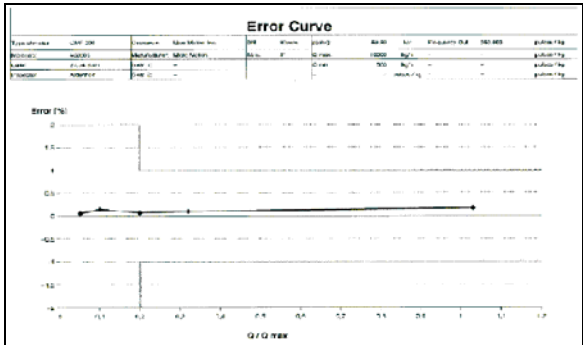
Numerous other countries, including Canada, China, Brazil, Switzerland, Belgium, Austria, and Russia

Dutch weights and measures (NMI) has performed testing and published a statement that the flow calibration factor established on water transfers without field calibration to gas phase applications,

within a tolerance determined in their testing relative to the transferability of a water calibration to a gas calibration.

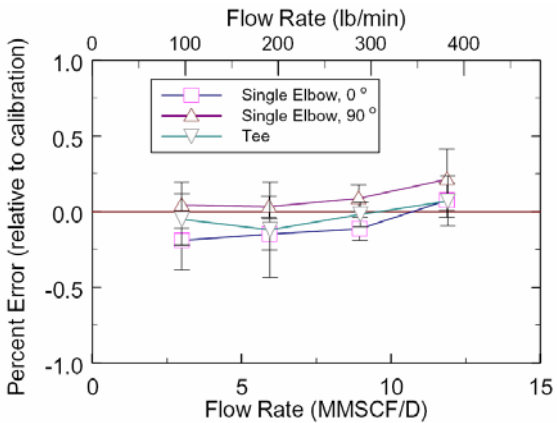
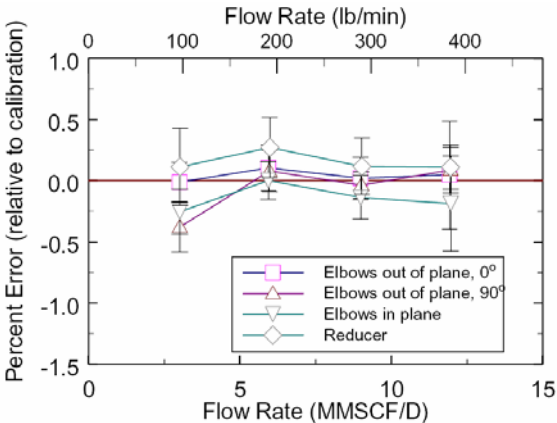
In spring of 2001, Measurement Canada granted type approval to Micro Motion Coriolis meters for use in fiscal transfer of natural gas.

Shown below figures 1 are two recent calibration curves on 3” custody transfer meters. These are being used in “Industry Gate” applications in Australia and the U.S.A.

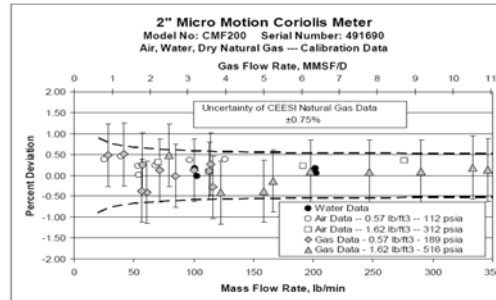


Laboratory is Pigsar-Dorsten, with natural gas at 725 psi. Flow rates ranged from 21 to 438 MSCFH (0.5 to 10.5 MMSCFD). Accuracies were better than +/-0.2% over the 20:1 test range.

Installation effects testing performed by Southwest Research Institute (SwRI) and sponsored by the Gas Research Institute (GRI) in 2002 confirmed bent tube Coriolis meters to be immune, within the uncertainty of the SwRI flow lab, to upstream installation effects. The test results can be found in GRI Topical Report GRI-01/0222. Some of the installation effects test data is shown below.

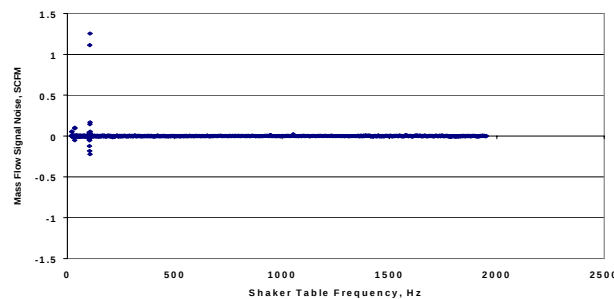


In 2004 the Colorado Engineering Experiment Station Inc. (CEESI) performed testing on the transferability of water calibration data to the measurement of gases under the sponsorship of the Gas Research Institute (GRI). Their findings shown below lead CEESI to conclude that “The single fluid calibration tests show that a water calibration of a Coriolis mass flow meter can be used for natural gas applications without loss of accuracy.”

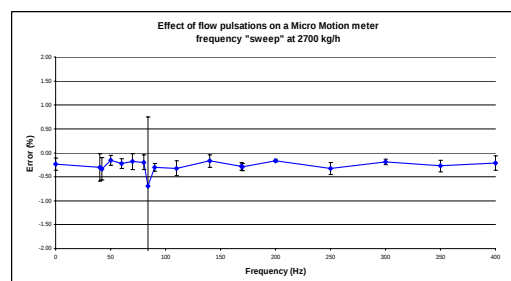


## Vibration and fluid pulsation

During product development, extensive analysis and testing have resulted in meter designs that are inherently stable under a wide range of mechanical vibration and fluid pulsation conditions. Although Coriolis meters are for the most part immune to mechanical vibration and fluid pulsations, they are sensitive to vibrations or pulsations at the resonant frequency of the flow tubes. The resonant frequency of the flow tubes is meter design and fluid density dependent. Testing of a Coriolis meter subjected to mechanical vibrations is show in the graph below. Note that the area of sensitivity is only at the resonant frequency of the meter’s flow tubes.



Testing of a Coriolis meter subjected to fluid pulsations is shown in the following graph. Note that the area of sensitivity is only at the resonant frequency of the meter’s flow tubes.



In applications where mechanical vibration or fluid pulsations are present it is recommended that the manufacturer be consulted to determine the resonant frequency of the flow tubes at operating conditions.

## Sizing and Selection

Selection of a Coriolis meter for gas application is quite straight forward, but different than traditional technologies. The flow range of a Coriolis meter is determined on the low end by how much error is in its weight measurement and on the high end by the maximum allowable pressure drop across the meter up to a maximum velocity limit called out by the manufacturer where measurement becomes unstable, but remains accurate and does not damage the meter. This is quite different from traditional flow technologies where the specified minimum and maximum flow is highly dependent on natural gas pressure and the maximum flow velocity where measurement is lost and/or flow damage occurs to the flow element. The two major considerations when sizing a Coriolis meter are:

- Pressure Drop @ Maximum Flow
- Accuracy @ Minimum Flow

A Coriolis meter's minimum flow is dictated by the meter's zero specification and the minimum acceptable accuracy for a particular application. The following equation is the most utilized method for determining the minimum flow rate of a Coriolis meter.

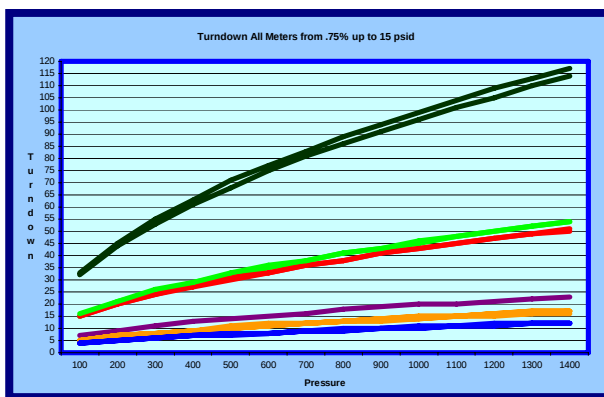
$$MinFlow = \frac{ZeroStability}{Accuracy\%/100}$$

The maximum flow through a Coriolis meter is dictated by allowable pressure drop across the meter, fluid density, and a set of reference test conditions often found in the manufacturers specifications. The equation for calculating the maximum allowable flow rate relative to allowable pressure drop is as follows.

$$\frac{\left[ \sqrt{\frac{\Delta P_{AppGas} \rho_{f_{Re fGas}}}{\Delta P_{Re fGas} \rho_{f_{AppGas}}}} \right] Q_{vf_{Re fGas}} \rho_{f_{AppGas}}}{\rho_{b_{AppGas}}} = Q_{vb_{AppGas}}$$

|        |                      |   |                                                                                                                          |
|--------|----------------------|---|--------------------------------------------------------------------------------------------------------------------------|
| Where: | $\Delta P_{AppGas}$  | = | Differential pressure across Coriolis meter with application gas at $\rho_{f_{AppGas}}$ and $V_{AppGas}$ in <u>psid</u>  |
|        | $\rho_{f_{Re fGas}}$ | = | Density of reference gas at flowing conditions in <u>lb/cf</u>                                                           |
|        | $\Delta P_{Re fGas}$ | = | Differential pressure across Coriolis meter with reference gas at $\rho_{f_{Re fGas}}$ and $V_{Re fGas}$ in <u>psid</u>  |
|        | $\rho_{f_{AppGas}}$  | = | Density of application gas at flowing conditions in <u>lb/cf</u>                                                         |
|        | $Q_{vf_{Re fGas}}$   | = | Volume flow rate of reference gas at flowing conditions of $\rho_{f_{Re fGas}}$ and $\Delta P_{Re fGas}$ in <u>cf/hr</u> |
|        | $\rho_{b_{AppGas}}$  | = | Density of application gas at base conditions in <u>lb/cf</u>                                                            |
|        | $Q_{vb_{AppGas}}$    | = | Volume flow rate of application gas at base conditions in <u>cf/hr</u> or <u>scf/hr</u>                                  |

Coriolis meters can be installed upstream of a pressure regulator, resulting in a smaller and less expensive primary (sensor) and increased turndown. A good example of the relationship of line pressure to turndown is shown in the chart below, where the change in turndown with pressure for multiple meters is graphed.



## Velocity in the Coriolis Meter

Some Coriolis meters have performance limitations at high gas velocities due to noise imposed on the meter signal. Such signal noise can affect meter accuracy and repeatability. The gas velocity at which signal noise becomes a problem is design (vendor) specific. Seldom is signal noise a concern when the gas velocity in the meter is below approximately 200 ft/sec. Some manufacturer's can achieve much higher gas velocities (up to choke point or sonic velocity) with the use of advanced signal processing techniques. To define the maximum recommended velocity a Mach limit is usually provided by the meter manufacturer.

From the standpoint of a high velocity gas eroding the metal of the flow tubes, high gas velocities are not an issue. The reason for this is that Coriolis meters are made of nickel alloy metals. For gas to erode metals, the metal must oxidize from moisture in the gas and the high velocity gas then erodes the oxide layer. This is why erosion on carbon steel pipe is of concern for many piping engineers. Carbon steel is susceptible to oxidation from the moisture in the gas and therefore is susceptible to erosion from high velocity gas. A Coriolis meter's immunity to high velocity gas erosion is similar to that of an orifice plate or sonic nozzle, in that they are made of stainless steel or other nickel alloys.

If abrasive contaminants are present in the gas flow stream, erosion of the wetted meter components may be a concern when the meter is exposed to high gas velocities. This concern is application specific and when present filtration is recommended.

## Zero Stability

The zero stability value defines the limits within which the meter zero may drift during operation and is constant over the operating range. It may be given as a value in flow rate units, or a percentage of a stated nominal mass flow rate. The zero stability value is the limiting factor when establishing meter turndown ratio. The stated zero stability value is achievable when the Coriolis flow meter is installed, and re-zeroed at operating conditions.

Because process temperature will affect the meter zero stability, the estimated value of the zero stability is usually limited to meters at thermal equilibrium. The manufacturer typically states the effect of changes in this value. In most gas applications changes in process temperature are negligible, but to minimize the effect it is recommended that a Coriolis meter be zeroed at normal process temperature conditions.

## **Temperature and Pressure Compensation**

Both pressure and temperature affect the meter vibration characteristics, hence the magnitude of the sensed Coriolis force. In comparison to zero stability, these effects are small, but should be compensated for to achieve optimum meter performance.

Most meter designs compensate for temperature effect automatically by monitoring the temperature of the flow tube(s).

The pressure effect can be continuously monitored and corrected for using an external pressure transmitter, or by entering a fixed adjustment for the known average pressure.

Some Coriolis meter designs periodically check meter sensitivity by applying a waveform reference force to the tube(s), during field operation, and compare the system response to that achieved under reference flowing conditions. This system will compensate for both pressure and temperature effects.

Errors and compensation methods for pressure and temperature effects should be stated in the manufacturer's meter performance specifications and included, if necessary, when establishing meter performance.

## **Installation (Mounting)**

Proper mounting of the sensor is required. Consideration should be given to the support of the sensor and the alignment of the inlet and outlet piping flanges with the sensor. A spool piece should be used in place of the meter to align pipe-work prior to welding the Coriolis sensor mating flanges if piping is constructed in the field.

Piping should follow typical industry piping codes. Meter performance, specifically zero stability, can be affected by axial, bending, and torsion stresses. When these stresses exist they can be amplified by pressure, weight, and thermal expansion effects. Although Coriolis meters are designed to be relatively immune to these effects, utilizing properly aligned pipe-work and properly designed piping supports insures these effects remain minimal when present.

It is recommended that users of Coriolis meters perform a mounting inspection test before approval of a Coriolis metering installation. The inspection test consists of unbolting one set of Coriolis meter flanges along with the piping support fasteners on either side of the Coriolis meter. If a shift is seen in the alignment between the unbolted Coriolis meter's flange and piping flange, the installation should not be approved and the piping fabricator should be directed to take corrective action.

## Installation (Orientation)

As a rule the Coriolis sensor should be oriented in such a way as to minimize the possibility of “settling” heavier components in the sensor flow tube(s), such as condensate, in the vibrating portion of the sensor. Solids, sediment, plugging, coatings or trapped liquids can affect the meter performance, especially when present during zeroing of the meter. Allowable sensor orientations will depend on the application and the geometry of the vibrating flow tube(s). In gas service the ideal orientation of the sensor is with the flow tubes in the upright position.

## Standard or Normal Volume

Coriolis technology measures the mass of fluids (gas, liquid, or slurries) flowing through the primary element. The Coriolis meter also has the ability to measure fluid densities comparable to the accuracy of a liquid densitometer. Mass flow and density are separate measurements for a Coriolis meter and their accuracies are not inter-related. For liquid applications, the on-line density from the Coriolis meter is used to output flowing or actual volume. This is useful for fiscal transfers of liquid petroleum, and is often corrected to base conditions, such as barrels of oil at 60 deg F using API volume correction methods.

For gas applications, the meter output can be configured for standard or normal volumetric flow units, such as MMscfd or NM<sup>3</sup>/hr. Since the measurement accuracy of fluid density by a Coriolis meter is relative to a liquid densitometer’s accuracy, this measurement does not meet the accuracies required for gas measurement. Therefore the on-line density from the meter is not used for flow measurement with gas; rather the relative gravity or base density of the gas is entered into a flow computer as determined from either sampling methods or on-line gas analysis. It should be noted that the gas physical property information (AGA8 Gross Method 1, Gross Method 2, or Detail Method) and procedural methods required by a Coriolis meter are identical to that which is required by volumetric meters; i.e. Turbine, Orifice, Rotary, and Ultrasonic.

Coriolis technology uses the following calculations to output a highly accurate standard or normal volumetric output.

$$NCM_{(gas)} = \frac{Mass_{(gas)}}{\rho_{b(Gas)}}$$

$$NCM_{(gas)} = \frac{Mass_{(gas)}}{Gr_{(Gas)} \times \rho_{b(Air)}}$$

$$\rho_b = \frac{P_b \times M_r(Gas)}{Z_b \times R \times T_b}$$

Where :

$NCM$  = Volume at  $T_b$  and  $P_b$   
 $Mass$  = Weight of gas (Coriolis Output)  
 $\rho_b$  = Density at  $T_b$  and  $P_b$   
 $T_b$  = Temperature at Base (Standard) Conditions  
 $P_b$  = Pressure at Base (Standard) Conditions  
 $Z_b$  = Compressibility Factor at  $T_b$  and  $P_b$   
 $Gr(Gas)$  = Gravity Real at  $T_b$  and  $P_b$   
 $R$  = Universal Gas Constant  
 $M_r = \sum_{i=1}^N x_i M_{r_i}$

In the accounting of flow volumes with a Coriolis meter, flow computers should log flow weighted specific gravity or base density. The purpose for doing so allows for simple gas compositional recalculation of logged volumes using the following equations.

$$NCM_{Gr(New)} = NCM_{Gr(Old)} * \frac{G_{r(Old)}}{G_{r(New)}}$$

Relative Density Recalculation Method

$$NCM_{\rho_b(New)} = NCM_{\rho_b(Old)} * \frac{\rho_{b(Old)}}{\rho_{b(New)}}$$

Base Density Recalculation Method

|        |                 |   |                                                                                                                                                                            |
|--------|-----------------|---|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Where: | $NCM_{Gr(New)}$ | = | Recalculated base or standard volume of gas accumulated over time interval at the average $G_{r(New)}$ determined from a sample cylinder or chromatograph data.            |
|        | $NCM_{Gr(Old)}$ | = | Base or standard volume of gas accumulated over time interval at the original $G_{r(Old)}$ or $G_{r(FW)}$                                                                  |
|        | $G_{r(Old)}$    | = | Flow weighted average Specific Gravity over time interval                                                                                                                  |
|        | $G_{r(New)}$    | = | Flow weighted average relative density or specific gravity over time interval, determined from a sample cylinder or chromatograph data and used for recalculation purposes |
|        | $\rho_{b(Old)}$ | = | Flow weighted average base density over time interval                                                                                                                      |
|        | $\rho_{b(New)}$ | = | Flow weighted average base density over time interval, determined from a sample cylinder or chromatograph data and used for recalculation purposes                         |

## Operation and Maintenance Considerations

Other than the vibrating sensor flow tube(s), Coriolis meters have no moving parts, requiring minimal maintenance.

There are three common types of field verification checks, which include meter zero verification, sensor diagnostic checks, and transmitter diagnostic checks. Performing these verification procedures will confirm accurate performance of the Coriolis meter and when an out of tolerance condition exists where re-calibration of the sensor maybe required.

### Meter Zero Verification

Meter zero stability should be checked periodically and reset if it does not meet the manufacturer's specifications. Drift in Zero Reading is an indication of product buildup, erosion, or corrosion and will affect the meter performance. Product buildup (coating) may bias the meter zero. It should be noted that a zero shift will affect a Coriolis meter's accuracy more at low flows than at high flows. This is dictated by the "MinFlow" equation called out in the previous "Sizing and Selection" section of this document. If the buildup is causing a zero drift, cleaning and re-zeroing the meter should bring performance back to its original performance specification. If coating of the sensor continues, the zero will continue to drift. Although rare, erosion or corrosion will permanently affect meter calibration and will compromise sensor integrity. When used within the specified fluid and ambient condition limits, fatigue of the sensing tubes of a Coriolis meter due to vibration during the stated meter lifetime is not of concern, and

does not need to be considered when inspecting a meter. However, operating the meter in more extreme corrosive or erosive applications will shorten the meter's expected lifetime.

Improper zeroing will result in measurement error. In order to adjust the zero of the meter there must be no flow through the flow sensor and the sensor must be filled with gas at process conditions. The meter zero must be established at process conditions of temperature, pressure and density. Even though the stream is not flowing, the flow meter may indicate a small amount of flow, either positive or negative. Causes for the zero error are usually related to the differences between the calibration conditions and the actual installation, which include the following:

- Differences between the calibration media density and the gas density
- Differences in temperature
- Differing mounting conditions

The meter should read a mass flow rate that is less than the manufacturer's zero stability specification under the no-flow condition.

The zeroing of the meter must be performed at nominal operating condition with no flow through the meter. Once it has been confirmed that there is no flow through the meter, the zeroing procedure specified by the meter manufacturer should be followed.

### Sensor and Transmitter Diagnostics

On the transmitter a diagnostic LED(s) and display may be provided to indicate operating status of the sensor and transmitter. See the manufacturer's documentation for detailed description of the transmitter diagnostic and trouble shooting procedures.

As of this writing, operating density measured by the meter should not be used to convert mass flow rate to volume flow rate when measuring gases. However, it is useful as a diagnostic tool to monitor changes in meter performance, corrosion, erosion, or change in operating conditions.

Of particular note is recent advances in sensor diagnostics offered by a leading manufacturer of Coriolis and specifically their in-line resonant structural analysis of the Coriolis flow tube(s). By comparing the resonant structural analysis performed during operation against a stored factory or previous calibration resonant structural analysis, quick and reliable verification of a meter's flow calibration factor is performed. This technique is fairly exciting in that Coriolis is the first flow measurement technology to achieve this technological feat; where in the use of other flow technologies, flow test and/or visual inspection at considerable cost is required to accomplish flow factor verification.

### **Application Examples**

Coriolis meters have been used in a wide variety of applications, from the "wellhead to the burner tip". Coriolis meters are primarily a smaller line size meter, ideally suited to these "sweet spots":

- Line sizes 200mm (8") and smaller

- 300 ANSI through 900 ANSI
- High turndown requirements
- Dirty, wet, or sour gas where maintenance can be an issue with other technologies
- There is no room for long straight-runs
- Changing gas composition and density
- Sudden changes in gas flow velocity (fuel gas applications at startup)
- Pulsating gas flows (fuel gas to reciprocating compressors and flow measurement near regulation)
- Applications where abnormally high flow rates can occur periodically.

Coriolis meters can be sized for very low-pressure drop (100" H<sub>2</sub>O), but can also be installed upstream of the pressure regulator with high pressure drop for increased useable turndown without concern of damage or malfunction. For instance, in one application for custody transfer of nitrogen, a 50-psid drop (1390" H<sub>2</sub>O) was allowed across the Coriolis meter and the pressure regulator adjusted accordingly. This allowed the use of a 1" Coriolis meter instead of a 3" meter downstream of the regulator and a 40:1 useable turndown (Better than 1% accuracy at minimum flow and an average 0.45% base volume accuracy over 95% of the upper flow range).

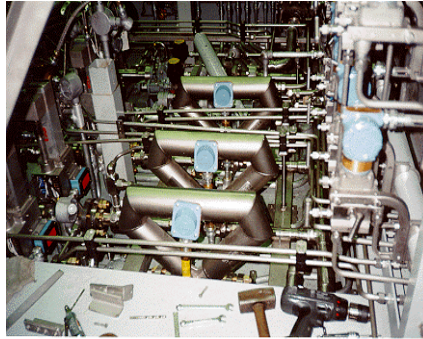
### *Separator Gas*

Saudi Aramco uses a number of Coriolis meters on both the liquid and gas side of separators. This application is of particular note because the gas stream is wet (entrained hydrocarbon condensates). Measurement of this stream is within a few percent over a wide range of conditions, greatly enhancing separator operation and accurately quantifying the value of the entrained hydrocarbon liquids hydrocarbon stream.



## *Fuel Control*

A major US vendor of gas power turbines designs a high-efficiency, low emissions offering. This design utilizes a trio of Coriolis meters to measure the natural gas burned in each of three combustion zones (fuel “rails”). The combination of high turndown, high accuracy, immunity to vibration in a very high vibration environment, along with ease of installation due to no straight pipe run requirements makes Coriolis technology a perfect fit.



## *Natural Gas Fiscal Transfer*

One specific example of gas measurement capability is at a natural gas utility in Western Australia. Two 3” meters are used in parallel with a third used as a “hot spare”.

The justification for using the Coriolis meters was based on installed and calibration/maintenance cost improvements over the more traditional turbine metering systems. Since Coriolis meters require no straight runs or flow conditioning the installed costs were reduced by five times, even with the parallel meters required to handle the highest flows.

Additionally, periodic maintenance costs were much reduced due to the intrinsic reliability of Coriolis meters (i.e. no moving parts). Similarly, reliability improvements had a very positive effect on calibration and proving costs.

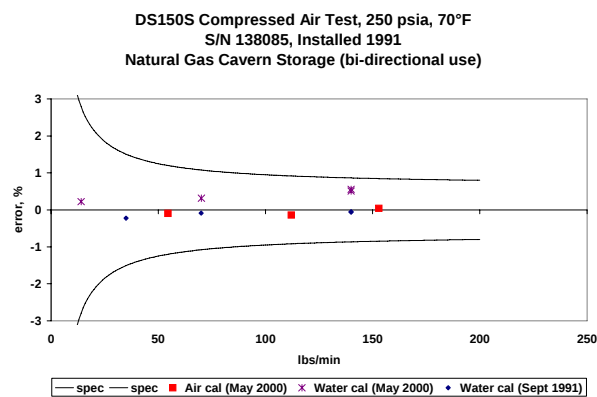
Internal checks by the customer have shown agreement to better than 0.1% on all gas transfers at this location over a 6 year period.

## *Natural Gas Storage*

A storage field in Hungary utilizes 27 Coriolis meters for the injection and withdrawal measurement of natural gas. The storage reservoir consists of a multilayer sandstone formation with an aquifer flowing through it. Due to the complexity of managing the water level in a sandstone formation on the injection and withdrawal of natural gas, multiple small diameter wells are required. The withdrawal gas is also fully saturated, contains H<sub>2</sub>S, and during high flows the wells produce sand. In this difficult application only Coriolis meters can provide bidirectional measurement, long-term accuracy, and achieve the wide turndowns required for reservoir management.



The graph below shows performance testing on a Coriolis meter from an identical metering application in Redfield, Iowa; where the meter tested was subjected to saturated gas laden with H<sub>2</sub>S, sand, and iron sulfide over a 9 year period. The post 9 year data shows the meter is maintaining an accuracy of 0.5% or better and still performing within the manufacturers specifications.



### *Proving*

Based on an extensive database of water vs. gas calibration data, there is no change in calibration between water and gas. In addition, a history of over 400,000 installed meters on liquid and gas indicates no change in meter factor over time (barring corrosion or erosion issues).

Since proving any gas meter in-situ is difficult, the stability of Coriolis meters makes them ideal for use on gas. By utilizing the transferability of water calibration to gas and the meter stability over time, an extremely accurate and stable metering system can be established. The following methodology was proposed by the Australian utility in the previous example to establish traceability for high-value gas transfers:

- Establish the meter factor on water
- Validate the meter factor on gas (i.e. natural gas at Pigsar)
- Periodically remove the meter from service and verify the meter factor on water

Although this methodology requires that the meter be removed from service, it defines very accurately the in-situ performance of the meter. Since steps 1 & 2 establish the meter traceability between water and gas, verifying water performance in step 3 automatically validates the meter in-situ (gas) performance and eliminates the high cost of gas validations. After some experience, it is likely that the period to repeat step 3 would be lengthened from every year to every two or three years.

A variation of this proving methodology is to use a Coriolis meter as a master meter. By establishing the traceability between water and gas measurement on the master meter, it can be used to prove other meters (of any type).

### *Energy Metering*

Coriolis meters can be an excellent reality check on energy consumption. Energy per SCF can vary as much as 10 times to that of energy per a unit weight for natural gas mixtures. If composition varies and an average relative density and heating value is utilized for energy measurement Coriolis can achieve total energy accuracies unparalleled by volumetric meters utilizing the same average values. A Coriolis meter by itself offers a very affordable method of inferring energy flow rates.

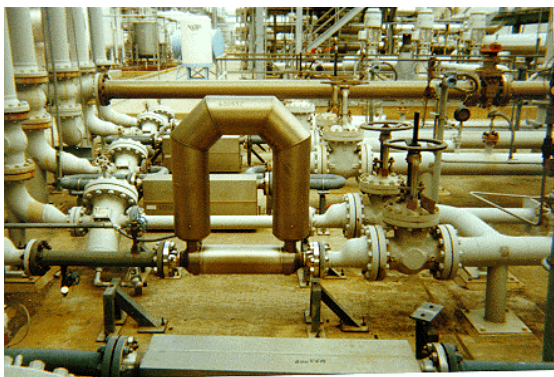
| Natural Gas Component                   | Ideal Heating Value Btu/lbm | Ideal Heating Value Btu/scf | Mix A     | Mix B     |
|-----------------------------------------|-----------------------------|-----------------------------|-----------|-----------|
| N2                                      | 0                           | 0.0                         | 0.9000    | 1.0000    |
| CO2                                     | 0                           | 0.0                         | 0.8000    | 1.2000    |
| Methane                                 | 23.891                      | 1,012.3                     | 98.3000   | 85.0000   |
| Ethane                                  | 22.333                      | 1,773.7                     | 0.0000    | 4.5000    |
| Propane                                 | 21.653                      | 2,521.9                     | 0.0000    | 3.5000    |
| I-Butane                                | 21.232                      | 3,259.4                     | 0.0000    | 2.5000    |
| N-Butane                                | 21.300                      | 3,269.8                     | 0.0000    | 1.5000    |
| I-Pentane                               | 21.043                      | 4,010.2                     | 0.0000    | 0.8000    |
| N-Pentane                               | 21.085                      | 4,018.2                     | 0.0000    | 0.0000    |
| N-Hexane                                | 20.943                      | 4,766.9                     | 0.0000    | 0.0000    |
| N-Heptane                               | 20.839                      | 5,515.2                     | 0.0000    | 0.0000    |
| N-Octane                                | 20.759                      | 6,263.4                     | 0.0000    | 0.0000    |
| N-Nonane                                | 20.701                      | 7,012.7                     | 0.0000    | 0.0000    |
| Variation Hydrocarbons from Average Btu | 7.15%                       | 74.77%                      |           |           |
| Heating value Btu/lbm                   |                             |                             | 23,009.45 | 22,278.70 |
| Heating value Btu/scf                   |                             |                             | 996.90    | 1,195.04  |
| Average on Btu/lb basis                 |                             |                             | 22,644.07 |           |
| Variation % from average Btu/lb         |                             |                             | 1.61%     |           |
| Average on Btu/scf basis                |                             |                             | 1095.98   |           |
| Variation % from average Btu/scf        |                             |                             | 9.04%     |           |

### *Combustion Control to Boilers*

In this application, a Pulp mill in Quebec sought a more reliable way to meet EPA emissions requirements. Combustion control was easier, based on the mass ratio between the natural gas and combustion air, over wider turndowns with no flow conditioning.

## *Ethylene Gas Transfer*

Ethylene is commonly viewed as a difficult to measure gas, due to its highly non-ideal nature. In this application, Coriolis meters are used for intra-plant transfers attaining accuracies unattainable by volumetric meters, helping to meet both unit mass-balance goals, as well as reactor feed rate requirements. Ethylene is fed continuously to a polymerization reactor, where various grades of polyethylene (LDPE, etc) are made.



## **Conclusions**

Although a relatively new technology for natural gas applications outside of compressed natural gas (CNG), Coriolis meters have gained worldwide acceptance for other fluids and in other industries. With a worldwide installed base of over 500,000 units, Coriolis technology is seeing expanded use for both liquid petroleum and natural gas. A number of countries and groups have published standards or are in the process of studying the technology. Most notably is AGA and API who have jointly published AGA Report No. 11 / API MPMS Chapter 14.9, Measurement of Natural Gas by Coriolis Meter.

Technology limitations of earlier designs have been largely overcome, with high accuracy high turndown measurement now possible at low-pressure drop, typically 150" wc. Coriolis "sweet spots" are mainly in lines of 8" and smaller, 300 ANSI and above, where high turndown is needed, flow conditioning with other technologies to meet new AGA requirements is costly, pulsating, surging, and/or the gas is of dirty, sour, or of changing composition. Also, good potential exists for "simple" energy metering, using the Coriolis meter output directly, scaled for energy units.

Coriolis technology merits serious consideration as a bona fide contender to complement Ultrasonic in low cost of ownership metering for natural gas applications. These two technologies overlap in the 4" to 8" line size range.



A ½” Coriolis and 12” ultrasonic in a fuel gas metering installation.

Third-party data from CEESI, Pigsar, SwRI, and others show little if any effect of flow profile, and transferability of a factory water calibration to gas measurement applications.

Common Coriolis gas applications range from wellhead separator, medium to high pressure distribution metering, and fuel gas to power turbines, reciprocating engines, and boilers for combustion control. As users of gas meters investigate Coriolis they are finding it to be a fiscally responsible choice for gas measurement in today’s competitive business environment.

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