

API CORIOLIS STANDARD FOR MASS MEASUREMENT OF CRUDE OIL

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In the last decade, meter manufacturers have developed technology utilizing the Coriolis force: an apparent force that results from earth's rotation, deflecting moving objects or flowing streams to the right in the northern hemisphere and to the left in the southern hemisphere. The Coriolis force allows a meter to directly measure mass, dynamically.

Mass measurement has the advantage of being unaffected by temperature and pressure; therefore, the total mass that has passed through a meter is much simpler to determine than volume. To state it another way, 1000 pounds of crude oil at 500 psi and 100 degrees is still 1000 pounds at atmospheric pressure and 60 degrees. No corrections have to be made for pressure and temperature. Before Coriolis meters, the only way to directly measure mass was with a scale. A scale cannot measure fluids dynamically (without stopping). Other methods used to dynamically measure mass are inferred mass methods. These calculate inferred mass by measuring the volume with one meter and the density with another. The results are then multiplied to determine the mass of the product ($\text{Volume} \times \text{Density} = \text{Mass}$).

The ability to measure mass dynamically has been of great interest to the hydrocarbon industry. As a result, the American Petroleum Institute has developed two measurement standards. The purpose of these documents is to standardize installation, proving, calibration, and operation methods for hydrocarbon measurement in an evolving technology. The API documents, "Measurement of Single-phase, Intermediate and Finished Hydrocarbon Fluids by Coriolis Meters" and "Measurement of Crude Oil by Coriolis Meters," address issues related to custody transfer as they apply to this technology. Both documents address the measurement of single-phase, merchantable liquids. However, they do not cover two-phase fluids, oil-to-water ratios, or contaminants. The intent of this presentation is to emphasize operational issues that are unique to Coriolis meters as compared to traditional volume meters used in the industry.

The Coriolis meter is unique in several ways:

- It can directly measure the mass (weight) of a flowing stream.
- It can measure the flowing density of the stream.
- It can determine the volume of the stream.
- It does not have rotating mechanical parts that are driven by fluid velocity.
- It is comprised of two elements: a sensor and a transmitter.

As previously stated, a Coriolis meter has two main parts: a sensor and a transmitter. The sensor is made up of one or two tubes through which the fluid passes. An electromagnetic driving mechanism vibrates the tube(s). The flow through the tube(s) exerts a Coriolis force proportional to the mass flow rate. The magnitude of the force is detected by the transmitter and converted to a mass flow rate. The transmitter powers the sensor, processes the signals from the sensor, generates output signals, and totalizes the flowing units.

The transmitter for each sensor is typically programmed with two unique numerical values: the manufacturer's flow and density calibration factors. While manufacturers may address these values in different ways, they all have numerical inputs to the transmitter that convert the sensor outputs to common units. This enables the meter to perform to stated specifications. These factors make the sensor accurate and unique from others. They should not be confused with other terms commonly used in the industry: meter factor and K-factor. These are completely different and will be addressed later in the paper. After programming the transmitter with the calibration factors, the output signals must be programmed.

The frequency output to accessory equipment (flow computer, pulse counter for proving, or totalizer) is expressed as a **pulse scaling factor (PSF)**. This coefficient (or coefficients) defines the relationship between the flow rate and the frequency output. It is usually expressed as Hertz (Hz), a number representing pulses per second, for a given flow rate. These values should represent the maximum value for your operation, but not exceed the sensor's range.

Examples include: 5000 Hz = 5000 pounds per minute, 3000 Hz = 3000 grams per second, and 1000 Hz = 1000 barrels per hour. Most transmitters have all the common units of flow preprogrammed as selectable items. The program not only includes mass units but also units for volume flow.

The K-factor, a coefficient commonly used in this industry, defines each pulse as a value equal to a unit of measure (volume or mass). It is used to determine the total units measured over a period of time. For example, expressed as 1000 pulses per barrel or 1000 pulses per pound, each pulse would represent 0.001 of a unit of measure (barrel or pound). A K-factor can be determined from the PSF by converting flow rate units into units per second. The Hertz value should then be divided by the flow rate units per second. Consider the example below:

- If 5000 Hz = 5000 lbs/minute
- 5000 lbs/ min = 83.333 lbs/ second
- 5000 Hz divided by 83.333 lbs/second = 60 pulses per pound

Because some Coriolis meters allow for a specific K-factor to be programmed, the transmitter will calculate the PSF. In others, the PSF has to be programmed and the transmitter may or may not calculate the K-factor. If it is not calculated and displayed, the K-factor can be determined for accessory equipment from the example above.

Zeroing is a term often used in conjunction with Coriolis meters. Understanding its importance is critical to good measurement. These meters have the ability to detect and indicate small amounts of flow, even in the absence of true flow. A false reading can be caused by such influences as mechanical noise, pipe stress, or trapped gas. Zeroing a meter establishes a no-flow reference point (*zero value*) for the meter and can eliminate or minimize outside influences on the sensor. To properly zero a meter, begin by establishing flow and typical operating conditions (pressure, temperature, and normal product specifications). Before proceeding, stop the flow, close the upstream and downstream valves, and verify that there is no flow or trapped gas in the meter. Having met these criteria, follow the manufacturer's zeroing procedures. Keep in mind that the resulting zero value can change under the following circumstances:

- Poor installation practices that allow mounting conditions to change.

- Stress on the measuring tubes from temperature or piping changes.
- Significant changes in operating conditions (pressure and temperature).
- Density changes.
- Replacement of the sensor or transmitter.

Since the zero value can change, it should be checked periodically. The interval necessary will depend upon the installation, changes in operating conditions, and the model of the meter chosen. A shift in the zero value is called *zero offset*. Any zero offset results in a constant error in measurement and has a direct effect on the meter factor obtained during proving. Therefore, once the zero offset exceeds an acceptable error for the application, the meter must be rezeroed. Improper zeroing is probably the single largest source of error with Coriolis meters. Good practices for zeroing and tracking the zero (*zero management*) should be developed. Poor zeroing practices, or the lack of zeroing, can result in random changes in meter factors and measurement error.

If the zero value is questionable or appears to be unstable, it is recommended that the zero be checked to verify it is not outside of specification. The zero reading will not remain constant. Small variations are expected and will fluctuate between positive and negative values. If the zero value is small, it should have minimal effect on the meter's accuracy at a normal operating flow rate. The lower the flow rate, the more significant the zero offset becomes. Spot or single readings of the zero value cannot be used for evaluation. The zero value should be averaged for ten to twenty seconds. Some transmitters can display the mean zero value based on a configurable or predefined time period. The average value will provide a better measure of the variability of the zero. The real need for rezeroing will depend on the operating flow rate of the system. The error associated with the zero offset can be determined from the following equation:

$$Err_o = \frac{q_o}{q_f} \times 100$$

Where:

Err_o = Zero Error (%)

q_o = Observed Coriolis meter flow rate with no flow (zero value)

q_f = Flow rate during operation

Proving of Coriolis meters seems to be another area of confusion. Understanding that the meter's

accuracy is defined by the calibration factors and not the PSF or K-factor is primary to obtaining good results. The PSF and K-factor only define how the outputs are to be interpreted. As with any other meter, Coriolis meters should be proved as required by contract or normal system operating procedures. Proving is necessary under the following conditions:

- Whenever the meter is rezeroed.
- Sensor installation or mounting conditions change.
- The density is calibrated and the meter is configured to indicate a volume output.
- The sensor, transmitter, or transmitter components are replaced.

The meter should be proved in the same units (mass or volume) as its output signals are configured. Proving in different units leads to confusion and additional errors. The three main proving methods are volumetric, direct mass, and inferred mass. The standards cover these methods and calculations in detail. Refer to them for example reports and equations before performing a prove.

Volumetric proving is basically the same as with other meters. In order for the meter to have a volumetric output, it must be able to measure density. Since the mass measurement is divided by the density measurement to calculate volume, a volumetric proving corrects for the total error in both measurements. If the density is calibrated after a proving, the meter factor will be incorrect by the amount of correction made during the density calibration. Therefore, another proving is required to correct or shift the meter factor.

Direct mass proving is seldom performed in our industry because it is not dynamic and resolution (accuracy) is difficult to achieve. To date, the main type of direct mass prover has been a scale—a static device. A Coriolis master meter is also a direct mass prover and shows promise for a number of applications.

Inferred mass proving uses a volumetric prover and fluid density to calculate mass. The average density of the fluid during the prove is multiplied by the volume to determine inferred mass. The inferred mass is then compared to the meter's mass to generate a mass

meter factor. The accuracy of this method is dependent upon the accuracy of both the prover volume and density measurements. Spot sampling has considerable potential for error. This error is caused by a nonrepresentative value for the flowing density or unstable density during the prove. The use of a density meter to measure and average the density between the prover switches is the preferred method for inferred mass proving.

Since the Coriolis meter is capable of **measuring density**, it can be used as a stand-alone densitometer. The current standards do not address its use in this manner. To use it as a stand-alone densitometer or to calibrate the density, consult API MPMS Chapter 14 Section 6, "Continuous Density Measurement."

In using the different proving methods and equipment discussed in the standards, the most **common source of error** is failure to use the correct significant digits for each variable in the calculation. These are mathematical and systematic errors and are easily corrected. The standards offer specific recommendations on the discrimination levels needed to obtain accurate proving.

Most Coriolis meters have the ability to totalize mass and gross volume. A **flow computer** or similar totalizing device is recommended for volume or mass measurement in order to comply with API MPMS Chapter 21.2, "Electronic Liquid Measurement." An *audit trail*, a requirement of Chapter 21.2, includes quantity transaction records, configuration logs, event logs, alarm logs, corrected quantity transaction records, and field test records. Manufacturer density and calibration factors, pulse scaling factors, zero values, and the date and time of any changes in the aforementioned should be included in configuration and event logs for Coriolis meters.

Mass measurement of crude oil, utilizing Coriolis technology, has shown significant promise in a relatively short period of time. It is a viable alternative to volumetric methods with distinct advantages in both the mass and volume modes. **In conclusion**, it is reasonable to expect that adherence to the American Petroleum Institute standards will facilitate a greater understanding and acceptance of this evolving technology.