ACCURATE MEASUREMENT

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ORIFICE METERS FOR LIQUID MEASUREMENT

Class 2330.1

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INTRODUCTION

Orifice meters have been in common use for many decades, but in the energy industry their use has been primarily in gas metering systems. This is interesting, in that much of the research to develop orifice meter factors (discharge coefficients) has been performed using oil, water, steam and air - as well as natural gas.

Orifice meters used in liquid measurement systems provide good accuracy without the requirement for meter proving as long as they are properly designed, installed, calibrated and maintained. If higher levels of accuracy are wanted, they can be proven using appropriate software and hardware and traditional meter proving systems.

MEASUREMENT ACCURACY OVERVIEW

Orifice metering systems equipped with flow computers and electronic transducers that meet the requirements of API Chapters 14.3 and 21.2 and are not proven in the field, have a total measurement uncertainty of approximately +/-1%. They often perform better than that, and are often capable of system imbalances less than 0.50%. This level of performance requires that the instruments be properly calibrated and maintained; that no significant pulsation be present in the system; that the fluid being measured is a single-phase, Newtonian fluid; and that the flow regime be turbulent, not laminar (Reynolds Numbers greater than 4000). The largest single contributor to this uncertainty is the discharge coefficient itself, with an uncertainty of +/-1/2%. By comparison, a turbine meter based system, which is proven in the field, often demonstrates an accuracy of better than 0.25% and an overall uncertainty of approximately +/- 0.50%.

API Chapter 21.2 recommends that the flow computer itself be capable of performing within +/- ¼% accuracy. Under all but the most severe flow regimes, this essentially requires that the flow computing system sample the flow parameters at least once every 5 seconds. Input accuracies should be within +/- 0.5 °F, within +/- ¼% for the differential, within +/- 3 psi for the static and within +/- 0.5 API gravity for the density.

API Chapter 21 also requires that the calibration equipment used to calibrate the transducers in flow computer systems be at least twice as accurate as the transducers they calibrate, but never need to be better than +/- 0.05%. Accuracies better than 0.05% are typically reserved for laboratory devices that are not portable and do not lend themselves well to field calibrations. API standards also recommend that field calibration equipment be recertified at least every two years. Most companies recertify their test equipment annually.

Now, it is important to point out that orifice metering systems used to measure liquids can be proven in the field, but it's not a common practice. As an example, if the flow computing system were configured to produce a pulse output proportional to the flow rate thru the system, proving with typical ball or piston provers commonly used with turbine meters could be readily adapted to orifice metering systems.

If provings are to be performed, it is critical that they be performed at typical flowing conditions, suitable for both the metering system and the prover. Operating conditions should not be adjusted to fit a prover or meter that is undersized or oversized. For example, it is not uncommon for provers or meters to be oversized and facilities are asked to increase their flow rates during provings to be in the recommended flow range of the meter and/or the prover. Even though the meter factor determined at those temporary, adjusted conditions is accurate at those conditions, the conditions during the proving are not typical and the meter factor is <u>not</u> accurate at typical flowing conditions. The metering and proving systems must be properly sized for the operation if the meter factors are to be accurate under typical operating conditions.

SUPERCRITICAL FLUIDS MEASURMENT

Orifice meters have found a niche in metering supercritical fluids such as ethylene, CO2 and purity ethane. These fluids are very difficult to measure with turbine meters, since sudden changes in the pressure may cause flowing velocities that will damage the turbine. These excursions usually occur during process upsets or during maintenance when the system is being pressurized or depressurized too rapidly. Orifice meters are much more rugged than turbine meters and are much more likely to withstand these surges in velocity. In addition, these fluids are generally lousy lubricants and prove to be hard on turbine meter bearings. Orifice meters have no moving parts, so they are not susceptible to lubrication problems. Ethylene and purity Ethane are typically relatively pure products and their physical properties are well known. If you handle Ethane and Ethylene at relatively warm temperatures and at relatively low pressures, they will act like a gas. If you maintain them at very high pressures and cool temperatures (over 1900 psig and below 70F, for example), they essentially act like a liquid. CO2 is similar in this regard, and if you try to measure CO2 at intermediate pressures (1200 psig for example), small temperature and pressure changes make such large density changes that measurement accuracy is dramatically compromised. It pays to evaluate the phase diagrams for these fluids very carefully when developing project design and operating procedures. Otherwise, measurement performance will suffer dramatically.

OPERATING ENVIRONMENT CONSIDERATIONS

The design of liquid orifice metering systems is little different from gas systems, with an exception being the elevation of the flow computer or chart recorder. In natural gas metering systems, it is recommended to install the meter above the meter run so any condensed liquids will be free to drain back into the orifice taps and out of the meter tubing or manifold. This prevents unequal accumulations of liquid in the lines or manifold from producing errors in the indicated differential. In liquid systems, the meter should be below the run to promote any vapors in the stream rising and clearing the meter lines or manifold, thereby avoiding errors in the differential indication.

In order to inspect an orifice metering system, start by reviewing the entire operating environment of the system. For example, in the case of a liquid metering system, look for product pumps that may be producing pulsation (with pulsation being defined generally as pressure and flow rate variations faster than once per second). Note that pulsation will cause chart recorders to read too high and flow computers to just be wrong. Errors due to pulsation effects can be very large, even greater than 20%, depending on the severity of the pulsation.

Another example of operating problems could be highly variable flows resulting from unstable pressure, level or flow rate control systems. Variation may be defined as pressure or flow rate changes slower than once per second. Highly variable flows cause chart recorders to be integrated far too high typically. Fortunately, flow computers meeting the requirements of API Chapter 21 can usually handle variable flows with only a slight loss of accuracy (tenths of a percent).

Mechanical vibration can produce the same problems as pulsation. The movement of the metering system produces changes in flow rate and apparent pressure that will produce errors in measurement similar to pulsation from other sources.

Another external factor to watch for is a significant change in the composition of the stream during metering periods (particularly if you are depending on spot or composite samples to determine stream composition). Knowing the correct composition of the stream is essential to calculating accurate discharge coefficients.

Piping leading to the metering system can directly affect the accuracy of measurement, particularly if flow conditioning/straightening systems do not meet the requirements in API Chapter 14.3. As an example, two close-coupled elbows, out of plane, will produce strong swirl in the flowing stream (swirl angles greater than 2 degrees relative to the general flow direction). Swirl causes orifice meters to under-indicate flow rates thru the system.

If the flow profile of the stream entering an orifice meter is not well developed, such as a system following a control valve that is partially open, the system may indicate more volume than actually passed.

For volatile liquids, it is critical that the stream be maintained as a single phase fluid. Backpressure control must be provided that will insure no flashing is occurring anywhere in the metering system. The industry standard recommends backpressure equal to at least 1.25 times the vapor pressure of the product at flowing conditions plus twice the differential pressure thru the meter. Some companies are more conservative and simply require backpressure to be maintained at least 1.5 times the vapor pressure of the product at flowing conditions.

SYSTEM DESIGN BASICS

Once external conditions (to the actual meter run) are understood, a close examination of the meter run itself is critical. The meter run should be long enough in the upstream and downstream sections according to the version of API Chapter 14.3 that was in place when the system was installed or the version specified by contract or regulation. The run should be equipped with a tube bundle or flow conditioner meeting API recommendations. Meter runs without flow straighteners or conditioners are not recommended. If an existing run is found to be too short, consideration should be given to using flow conditioners that require shorter run lengths. For example, if a run installed before 2000 has tube bundle straighteners and is too short by current standards, there are several flow conditioners that require much less upstream length and have been tested to meet API Chapter 14.3 test protocol requirements for acceptable flow conditioners.

The upstream section of the meter run should not have fittings or disturbances in the engineered portion of the run – not even taps for pressure indicators or other instrumentation. The downstream section usually incorporates multiple taps for sample probes, pressure indications and other purposes. The sample probe should be in the first fitting downstream of the orifice plate, at least 5 nominal pipe diameters downstream of the plate (5D), followed by any other necessary fittings.

The interior of the run must be clean and relatively free of rust, scale, heavy contaminants and debris. The interior of the run typically should have a surface roughness between 34 and 300 microinches, however for large diameter runs (14 inch and larger), the roughness may be allowed to reach 600 microinches.

The orifice plate itself must be flat, concentric in the fitting and to the interior of the meter run, round within tight tolerances and free of scratches, nicks, pitting and heavy contaminants. Damaged or dirty plates tend to cause metered quantities to be too low.

Care must be taken to insure that beveled orifice plates are not installed backwards, producing very low indicated volumes. The bevel should always be on the downstream side of the plate.

Seal rings around orifice plates must be undamaged and provide positive protection from any fluid bypassing the plate.

The distance between the centerline of the orifice taps must be 1 inch from the adjacent face of the orifice plate, so make sure the type of gaskets designed for are also the type actually used in the field.

The orifice flange taps may be oriented vertically or horizontally, with horizontally being preferred in most applications. Should the taps be oriented vertically, the bottom tap is likely to collect debris and heavy contaminants (lube oil, grease, amine, solids, etc.), and should not be used for measurement.

Remember that the orifice plate bore should be selected so that the beta ratio (ratio of the measured orifice bore diameter to the measured internal diameter of the meter run one inch upstream of the orifice plate) is between 0.2 and 0.6. Uncertainty increases dramatically outside this range, particularly above 0.63.

Select the orifice plate and the range of the meter so that the indicated static and differential are in the upper third of their respective ranges. By maintaining typical readings in the upper range of the meter, any calibration error effects are minimized. Note that if a meter has a calibration error of 1 inch of water and the differential is running 5 inches of water, the metering error is 10.6%. If the same system were typically operating at 80 inches of water with a 1 inch of water calibration error, the metering error is only 0.6%.

Regular internal inspections should be considered for the systems. Debris on the flow conditioners, upstream meter run walls or the orifice plate will definitely bias measurement. Rust and heavy contaminants on the pipe walls or orifice plate will tend to cause the system to meter too low.

Dual chamber orifice fittings are generally preferred, since they allow the plate to be inspected without depressurizing the run or interrupting flow, but single chamber fittings have the same measurement uncertainty as dual chamber fittings, assuming all are properly designed, installed and operated. The extra cost of the dual chamber fitting is usually worthwhile for custody transfer measurement, since it allows frequent inspection without interrupting processes and without releasing large amounts of product to the atmosphere.

Direct mount manifolds are recommended for orifice metering systems, but if lines are used for sensing the static and differential pressure, they should be as short as practical and have similar geometry. Long and/or complex lines are more likely to leak, more likely to exaggerate pulsation and more likely to allow distortion of the differential signal. Remember to keep the meter below the run and meter lines below the run for liquid orifice metering systems. This allows any vapors in the lines or meter assembly to rise to the meter run taps, enter the flowing stream and flow out of the metering system.

It is unlikely that anyone will use chart recorders on a custody transfer liquid orifice metering system, but realize that if they do, measurement accuracy will suffer. Chart integration introduces additional error into the measurement process, increasing uncertainty. The chart recorders themselves are rather primitive mechanical devices and even under the best of conditions (stable flow rates, stable composition and stable flow parameters) they are only good for +/- 2% accuracy by the time the chart is integrated. If, for example, the flow rate is highly variable, the chart will show wide-bands of markings on the differential recording. These wide bands cannot be integrated accurately and usually result in gross over-integration. Using chart recorders does not compare well to orifice flow computer systems meeting API Chapter 21 requirements (even without meter provings). They are good to +/- 1% of flow; even if the flow rate or flow parameters are highly variable. With provings, the system with flow computers will be even better than +/- 1%.

Neither flow computers nor chart recorders can handle significant levels of pulsation and maintain their accuracy, but flow computers can handle highly variable flow rates and/or flow parameters (temperature, pressure, differential) with excellent accuracy. Chart recorders tend to greatly exaggerate flow rates in the presence of highly variable flow. Errors greater than 10% are common for chart recorders when flow rates are highly variable. Flow computers under the same circumstances may increase their uncertainty by only 0.1% or so. When significant pulsation is present, chart recorders tend to over-indicate flow rates. In the presence of significant pulsation, flow computers tend to produce errors that are more random, but significant.

MASS OR VOLUMETRIC MEASUREMENT?

Orifice meters may be used to perform mass measurement or volumetric measurement. In the case of liquid measurement with orifice meters, it is more common to perform mass measurement.

Note that density may be a calculated value, based on the composition of the stream and the temperature and pressure at flowing conditions, or it may be a measured value from an online density meter. Measurement accuracy is typically enhanced when online density meters are used, since calculated densities have a higher uncertainty, particularly with some fluids, such as raw mix LPG streams (Y Grade).

API Chapter 14.3 Part 1, equation 1-2, shows the basic mass measurement equation for orifice meters. It is:

$$\mathbf{q_m = N_1 C_d E_v Y d^2 (\rho_{t,p}\,\Delta P)^{1/2}}$$

Where:

q_m is the mass flow rate in lbs/sec
N_1 is the unit conversion factor
C_d is the orifice plate coefficient of discharge
E_v is the velocity of approach factor
Y is the expansion factor
d is the orifice plate bore diameter at Tf
$\rho_{t,p}$ is the density at flowing conditions
ΔP is the orifice differential pressure (in. h2o)

For volumetric measurement, the equation is $\mathbf{Q_v = q_m / \rho_b}$

Where:

$\mathbf{Q_v}$ is the volume flow rate at standard conditions
$\mathbf{q_m}$ is the mass flow rate in lbs/sec
$\boldsymbol{\rho_b}$ is the density at base conditions

Note that calculating the density at base conditions will have a high uncertainty for some fluids, especially when the molecular sizes of the components in the stream are highly variable (such at Y Grade natural gas liquid mixtures). Mass measurement using an online density meter is much more accurate for these streams.

When performing mass measurement, once the mass is determined, an analysis on a weight percent basis will allow you to determine the amount of each component in units of volume. For example, if a system metered 100,000 pounds of mass flow and the weight percent of propane were equal to 10% (weight fraction of 0.10), then the stream consists of 10,000 pounds of propane in a total stream of 100,000 pounds. By referring to GPA 2145, latest revision, you will find that the density of propane at standard conditions is 4.2285 pounds per gallon, so 10,000 pounds of propane is equal to 2365 gallons at standard conditions (on a mass basis). Similar calculations would be performed for each component to determine the volumes of each component at standard conditions (on a mass basis).

LIQUID SAMPLING

Since accurate measurement requires accurate metering, representative samples and accurate analyses, a brief discussion of sampling is in order. Samples should be collected from a single phase, dynamic region of the flowing stream. Spot samples are not recommended for custody transfer applications for significant amounts of product, since spot samples are only representative of a flowing stream over time if the stream composition is very stable or if you get lucky. If the sample system is a composite sampling system, the sample increments should be collected on a flow proportional basis to insure the final composite sample is representative of the stream composition over time. If a time proportional composite sampling system is used, at least make sure it is equipped with a flow switch so the sampling will stop if flow stops.

A sample probe should always be used, to insure heavy contaminants migrating down the walls of the run are not collected in the sample. The probe should extend well beyond the walls of the run into the flowing stream. A general rule of thumb recommends the probe extend to the center 1/3 of the flowing stream, but practically, it never needs to extend further than 10 inches into the stream, even in very large diameter lines. Very long probes have to be very sturdy to withstand high flow rates and longer probes are simply more prone to damage and resonant vibration and do not provide better samples than a probe extending 10 inches into the stream.

In sample systems providing sample to onstream analyzers, it is important to keep the systems short, leak free and constructed of non-reactive materials. Stainless steel is usually the material of choice. Be sure the stainless steel is cleaned internally if it is new, because it will have machine oil left over from the manufacturing process that could contaminate your first samples.

Sample cylinders must maintain the sample in a single liquid phase. Sample cylinders must be carried in well designed sample transport systems that are rugged and properly labeled, and protect the cylinder valves from damage or inadvertent opening.

ANALYSIS BASICS

Analyzers, regardless of whether they are lab instruments or online devices, must be properly calibrated using gravimetrically prepared calibration standards suitable for custody transfer quality work.

The calibration standards should contain all the peaks likely to be found in the actual flowing stream and in proportions similar to the actual stream.

The repeatability and reproducibility criteria shown in the Lab Review Inspection Checklist in Appendix E of API Chapter 14.1 is a good guide to whether or not a gas chromatograph is performing well.