MEASUREMENT UNCERTAINTY

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Introduction

Many different words are used to define (or advertise) how well a meter will perform measurement. These include: accuracy, uncertainty, error (systematic and bias), repeatability, hysteris and reproducibility. Without getting into a detailed lesson in statistics, the term uncertainty is defined as the statement of test data to a limit of which 95% of the data taken will fall. This is also defined as two standard deviations of the data. This definition of performance has become popular to use in the Oil and Gas business.

There are several problems with this definition. First, there has been no specified procedure by an industry or governmental agency that defines the test. Second, the tests are normally run in a laboratory environment under controlled conditions, but the meter is then used in the field under poor operating conditions and the applicability of the data can be questioned. Third, there is no industry or governmental agency that controls what a manufacturer or user can say the Aaccuracy of this meter≅ is.

Definition of Accuracy - Relationship to Uncertainty

The accepted definition of the term accuracy in measurement of any kind is based on the ratio of the Aindicated measurement≅ to the Atrue measurement.≅ For flow measurement the ratio is Aindicated flow≅ to Atrue flow.≅ This seems to be a rather simple problem until an attempt is made to define and demonstrate Atrue flow.≅ Some definitions of true flow have included:

1) AWhat the orifice with a recording chart says≅;
2) AWhat the tank gauge says≅;
3) AWhat the government agency says≅;
4) AWhat the manufacturer says≅;
5) AWhat the lab test says≅; or
6) AWhat I know is right.≅

All of these, or variations of them, have been used to define true flow, and hence accuracy. The obvious weakness in each is how it allows a wide variety of answers to be obtained. Recently, considerably more Atesting to determine various accuracies≅ has been done by individuals and standards groups. But, even now, not all of results are in agreement.

The flow measurement industry does not have an acceptable statement of how these comparisons of indicated and true measurements should be made. It is becoming more common to use a statement of twice the standard deviation of a statistically valid test-sample population as the uncertainty reported. This in itself is not an absolute statement of what a given meter will do; it simply states how it will do in some 95% f the cases compared to Athe most probable value≅ as determined by test. The test procedure is not specified. The investigator - whether in industry, a manufacturer, or a governmental agency - sets the test conditions. Results may appear Acorrelated≅ when fluid is measured once. In industry, however, fluid is normally measured twice: once in and once out; differences then become apparent.

The second area of caution relates to accuracy or uncertainty of a meter system compared to a primary measuring device. The use is interest in overall *system* accuracy (i.e., how good is the number from the system readout), not statements about individual parts of a system. Without this understanding of the background of the Aaccuracy numbers game,≅ it is difficult to evaluate statements about a meter=s accuracy made by users and manufacturers.

Most of the numbers that come up in a discussion of flow accuracies are supplied by sources other than the one with the most critical data: the user. The user, then, should be aware of all pertinent factors involved so that a meaningful estimate of likely measurement accuracy can be made. Properly used flow meters of all types are capable of accuracies that fit in certain categories of proper application. It is the responsibility of those using such meters properly to fit the meters to the actual user needs.

AGA-3 Uncertainty

Because of these problems the AGA-3 Part 1, September 1990 specified a procedure to be used with the orifice meter. This is what is used as the basis for the discussion in this paper.

Flow measurement with an orifice meter is made up of a number of individual measurements that are then combined in the following equation:

$$Q\ 7709.61\, C_d\, (FT)\, E_v\, Y_1\, d^2 \sqrt{\frac{Pf_1\, Zs\, hw}{Gr\, Z_f 1 T_f}}$$

Each term is not defined, but the measurements needed to determine the term are listed.

7909.61 based on a base temperature of 60EF and a base pressure of 14.73 psia for cubic feet per hour at these base conditions.

C_d(FT)	orifice taps at 1 inch upstream and 1 inch, downstream and beta (diameter orifice/diameter of meter at flowing temperature), Reynolds number (density x diameter x velocity/viscosity all in consistent units. Since multiple labs were used to determine these values, no bias is assumed in the data.
E_v	beta(see above)
Y_1	differential, absolute static pressure, beta, isentropic exponent.
d	orifice diameter
Pf_1	static pressure psia
Zs	pressure, temperature, specific gravity at base conditions
hw	differential in inches of meter at 60EF
Gr	specific gravity or composition to calculate SG
Z_{f1}	static pressure, temperature, composition
T_f	flowing temperature

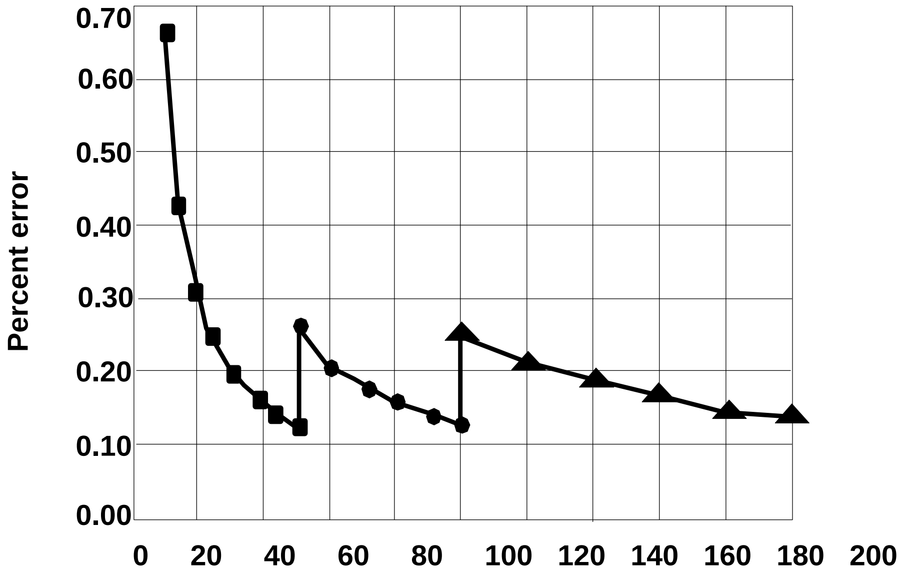
You can see in examining this that several of the variables occur more than once which makes their influence on the calculated uncertainty more complex. The calculation requires an estimation of the uncertainty of each of these independent values. At times, arriving at the proper numbers for these calculations is the hardest part of the calculation of uncertainty. There are three general categories of orifice installation uncertainties:

1) The mass (volume at base conditions has a related value to mass) flow equation;

2) Physical properties of the fluid;

3) Imprecision of installation parameters such as: orifice diameter and beta ratio.

On an orifice, the uncertainty calculated varies within the flow range. Hence, the uncertainty at 1 inch differential is ten times more than the uncertainty at 100 inch differential. To minimize these problems, multiple differential pressure devices or multiple meters (tubes or other meters) are used. See Figure 1 for effect of multiple differentials.



Differential pressure reading (inches H_20_{60})

Π **Differential Pressure 1** ! **Differential Pressure 2** **Differential Pressure 3**

Note: The precision of the differential pressure device used in this example is ∀0.25 percent of full scale.

Contribution to Flow Error due to
Differential Pressure Instrumentation

Minimizing Uncertainty

It should be remembered that if minimum uncertainty is desired the meters must be applied in the most acceptable portion of their range. On the orifice meter, the intermediate betas and higher differentials are the best. On turbine meters, the upper end of their range is the best. The use of multiple differential devices as shown in Figure 1 is an example of this principle. The use of multiple orifice runs for best uncertainty is shown on calculations 1-3. In these calculations you can also see the effect of differential pressure.

The calculations in 1-3 determine the uncertainty in the standard flow rate for orifice meters. A similar calculation can be made for other type meters. The calculation requires the previous variables such as pressure, temperature, the primary element, differential pressure, etc., and the percentage relative uncertainty of these parameters. This calculation follows the guidelines in AGA-3 Part 1, 1980

There is a tendency to under estimate the uncertainties involved in measurement based on uncertainties that were developed in laboratory conditions. Usually, this does not reflect the field operating condition effects for such items as temperature coefficient, static pressure, atmospheric pressure, etc. The use of smart transducers can minimize some of these effects.

Another assumption in the calculation is that every instrument is working according to its specification. Proper maintenance has kept them properly calibrated and applied for the operating range and ambient conditions, so that their performance complies with its initial uncertainty specification.

With these considerations followed, the uncertainty levels are calculated at a 95% confidence level. This requires the input data to be specified at the 95% confidence level. Even with all of the conditions controlled, the calculated numbers are theoretical, but are more realistic if the conditions above are met.

In the calculations 1-3 that follow, there are several items of importance that become obvious.

1. A single statement of an orifice uncertainty is meaningless.
2. Quality parameter measurement - especially the differential devices - are of prime importance to the uncertainty.
3. The coefficient of discharge is the largest contributor to the uncertainty with density the next largest.
4. Beta ratio has an effect on the calculated uncertainty.
5. Low differential pressures have more uncertainty than high differentials.
6. The beta ratios above .2 and below .6 are less uncertain than the very high and low betas.
7. The use of multiple tubes improve the uncertainty obtained - the more tubes, the less uncertainty. (Note: not shown by these calculations is the fact that above 4 tubes, there is little gained by adding more tubes).

Summary

The use of accuracy terms are misleading unless they follow a structured calculation procedure such as AGA-3 Part 1. The calculated values are not absolute, but give the operator a procedure to study what aspects of their metering system can be worked on to improve the metering. As an example, the differential pressure device. Likewise, in a large delivery station a case can be made for the use of two chromatographs to improve the measurement. To fully realize the value, each chromatograph should be calibrated by standardized samples from two different reputable sources.

The uncertainty calculation is used to point out the important considerations that effect the operation of your meter station. It should not be misused to A guarantee accuracy because it is still a theoretical calculation with a number of rather ideal assumptions made.