Flomeko 2000 - IMEKO TC9 Conference
**Salvador, Bahia, BRAZIL**
4-8 June, 2000

# AN OPERATIONAL VIEW ON GAS MEASUREMENT USING ORIFICE PLATE DEVICE WITH LOW UNCERTAINTY

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*The new scenario for the Brazilian energetic policy points out to a steep growth on natural gas demand for diverse applications, such as electric energy generation and industrial, domestic or vehicular use. Therefore, the necessity of an intensified effort toward the improvement of the volume gas balance is increasing.*

*Recently there was a great technological advance in this area, covering equipments and procedures, which has contributed to the reduction of measurement errors. The modern flow meters present very low uncertainty. Although new equipments have appeared on the market, the orifice place maintains its preponderant status. Recent standards and procedures have reinforced the idea of painstaking work in order to minimize measurement errors.*

*As an attempt to standardize gas flow rate calculation with orifice plates and to assess the uncertainty of a defined meter run, two softwares were developed in Excel. All the calculations meet the newest standards for gas measurement and uncertainty.*

*The first software calculates the flow rates, generates tables for instantaneous flow rates and sizes an orifice plate for a given set of process data, using the criterion of minimum uncertainty. This software is useful for operational and design purposes.*

*The second software was developed in Excel with the objective of calculating the total uncertainty of the meter run, including the equipment and the metering installation. It executes a thorough diagnosis of the installation, identifying points out of the standard. This software is useful for operational and design purposes.*

*With the use of these tools, some modifications and improvements of gas measurement networks were carried out, based on the results obtained from the softwares. They are able to simulate several application ranges.*

*The advantages of these softwares are application easiness, standardization of gas calculation, easy process simulation, possibility of printing formatted reports, diagnosis, and personnel training. The softwares and the manuals permit a training update, covering measurement theory, application, errors, calibration, installation, etc.*

## 1 INTRODUCTION

The necessity of an intensified effort toward the improvement of volume gas balance is increasing in the new Brazilian scenario, due to the increasing demand on natural gas for diverse applications. New equipments and standards have contributed to the reduction of measurement errors.

Modern flow meters present very low uncertainty. However, a good calculation depends also upon good procedures. It's important to determine not only the results, but also to assess the uncertainty of the measurements.

As orifice plate maintains its preponderant status as a primary element for measuring gas, despite new equipments on the market, a new software was developed in Excel with the objective of calculating flow rates, using the newest standards for gas measurement and uncertainty.

Considering the possible partership of new petroleum operators for developing Brazilian fields and the possibility of a shared measurement, the search for a more advanced technology becomes necessary in order to minimize the uncertainty and to meet the world's metrological requirements.

## 2 APPLICATIONS ACCORDING TO AGA 3 STANDARD

Differential pressure flowmeters are the most used in industrial applications. The orifice plate is the most used restriction-type primary element. It is applied for measuring clean liquids, most gases and low speed steam. Its manufacture is simple, but (must be) of high quality, so that the flow measurement is legally accepted for custody transfer, according to AGA 3 Standard.

There are several editions of AGA 3 Standard. The most recent ones are:

- The second edition (1985) [1]: defines the measurement of a concentric circular orifice plate, with pressure taps upstream and downstream the plate. Flange taps or pipe taps may be used.
- The third edition (1992) [2]: developed only for flange taps.

In order to minimize the errors of the calculations, the last AGA 3 report (1992) highlights the following points:

- Pulsating flow must be avoided;
- The fluid should not undergo a phase change passing through the orifice;
- No by-pass around the orifice should occur anytime during measurement;
- The fluid should have a totally developed velocity profile, free of swirls or vortices. The velocity profile is probably the most important influence parameter for flow rate.

## 3 FLOW RATE CALCULATION ACCORDING TO AGA 3 AND AGA 8

The last edition of AGA Standard is based on the discharge coefficient ($C_d$), defined as the ratio of the real flow rate (with the flowmeter) to the theoretical flow rate (without the flowmeter). It's a function of various parameters, including Reynolds number, which is a function of flow rate. Thus, the flow rate is determined iteratively.

The general equation of flow may be written in several ways:

$$q_m = C_d \; E_v \, Y \, (\pi \, d^2 / 4) \, (2 \, \rho_t \; hw)^{0,5} \tag{1}$$

$$q_m = N_1 \, C_d \, E_v \, Y \, d^2 \, (2 \, \rho_t \, hw)^{0,5} \tag{2}$$

$$Q = q_m / \rho_b \tag{3}$$

$$Q = N_1 \, C_d \, E_v \, Y \, d^2 \, F_{pv} \, [(P_{f1} \, hw) / (Gr \, T_f)]^{0,5} \tag{4}$$

The volume flow rate (Q) is calculated as a function of various variables, such as $R_{eD}$ (Reynolds number), $C_d$ (which is a function of $R_{eD}$ , orifice diameter d, internal pipe diameter D, b), $E_v$ (a function of beta, which is the diameter ratio d/D), Y (a function of $P_f$, beta, differential pressure hw, isentropic exponent k), Fpv (a function of the compressibility factor $Z_f$).

The calculation of Z should be done using the AGA 8 Standard [3]. It's an iterative calculation. There are two methods for calculating Z:

- The "gross" method (considering only $CO_2$, $N_2$ and the relative density);
- The detailed method (considers the complete composition of the gas).

Depending on the desired uncertainty, flow rate determination may require only a simple visual observation of differential pressure on a square-root chart, or it may involve the use of a dedicated microprocessor that receives several measurement signals and calculates the flow rate. The flow rate calculation can be viewed as the product of 3 terms: an unmeasured-variable term, a measured-variable term, and differential pressure. The last one is always measured. The unmeasured-variables term includes a unit conversion factor and all factors assumed to be constant; the measured variables are quantities that must be measured for the desired accuracy. They are usually density related (such as pressure and temperature) or are derived from other measurements (such as Reynolds-number correction, and the gas expansion factor) [4].

Many manufacturers supply analog computers that receive 2 or 3 standardized input signals proportional to measured variables (e.g., differential pressure, temperature, and absolute pressure). In the natural gas industry, the need for improved calculation accuracy led to the development of dedicated digital computers. Receiving inputs from transmitters, these computers can be programmed to correct for Reynolds number, gas expansion factor, temperature, pressure, and gas compressibility, and to display either flow rate or total volume.

Many of the process variables previously grouped as unmeasured are now being continuously corrected by computers, via stored calibration data. Transmitter zeroing and changes of differential pressure transmitters for wide-range meters are now also computer controlled.

## 4 INSTALLATION SPECIFICATION AND REQUIREMENTS

AGA Standard presents some limitations for its use. The equations are valid for:

- Beta between 0.1 and 0.75 (3rd. Edition); beta between 0.15 and 0.70 (2nd. Edition);
- D bigger than or equal to 2 in;
- $R_{eD}$ bigger than 4000;
- Ratio hw / ( 27.7 Pf ) less than or equal to 0.2;
- Pipe roughness less than or equal to 50 microinches (or 1.27 micrometer).

There are other limitations, such as flatness, plate width and orifice width, eccentricity, bevel, etc. As to straight-pipe length upstream and downstream the orifice plate, AGA Report shows several arrangements as a function of beta and the accidents (1 elbow, 2 elbows, 1 reducer, 1 expander, 1 valve, etc.). AGA Standard also determines the pressure tap locations (for differential pressure and line pressure) and the locations of thermal wells.

The readings of differential pressure, generated by the orifice plate, and of the static pressure may be obtained using either a mechanical device (FR), or an electronic device, typically a flow transmitter with a pressure transmitter. The flow rate calculation using a mechanical device is obtained through a software that generates a table with instantaneous flow rate.

## 5 EQUIPMENT PERFORMANCE

In order to determine the equipment performance, it's important to define some quality parameters:

- Accuracy: degree of conformity of an indicated value to a standard or ideal value; it's a qualitative concept (no number may be associated to it);
- True value: it may never be found; it's not known. Actually, it's replaced by the conventional true value, given by an instrument with a lower uncertainty (3 to 10 times lower), considered as a standard and traceable to certified standards;
- Traceability: all measurement, test or reference instruments should be periodically calibrated with another instrument of a superior accuracy class, reaching the traceability pyramid (or chain) up to the primary standard. Calibrations must be certified, in order to be validated.
- Uncertainty: it's a measure of the degree of freedom of the random errors of the instrument. It's a value obtained through a standardized procedure. Numerically, it's the interval where the true value has a high probability (e.g., 95%) to be found. The instrument uncertainty is related to its manufacturing process, its quality and its maintenance program.
- Repeatability: it's the closeness among several consecutive output measurements for the same input value, under the same operational conditions.
- Reproducibility: it's an expression of the a group of measurements of the same value of the same variable, under different conditions. A good reproducibility means that the instrument does not deviate as time passes. It includes repeatability, hysteresis, drift, etc.
- Dead zone: it's the effect that appears when measures move to the scale endings;
- Time of reply: it's the interval the instrument demands to reply a step signal, applied in its input.

Besides all these parameters, it's important to determine or to assess the rangeability (or turndown) of the instrument, which is the ratio of the maximum to the minimum measure of a variable within the same uncertainty.

## 6 MEASUREMENT ERRORS

Due to the own physical nature of measurements, it is impossible to measure a physical quantity with no error. Thus one seeks to maintain for measurement an uncertainty within tolerable limits and to assess its value in a reliable way. The measurement errors may never be thoroughly eliminated, since the true value of any variable is unknown. The true value is given by the equation:

$$A = a \pm e_j \qquad (5)$$

where: a = measured value;
$e_j$ = uncertainty (interval where the true value has a high probability to be found).

As to the origin, the errors may be:

- Systematic: a bias error, which may be static or variable; it is associated to accuracy;
- Random: it is a probability error, related to the dispersion (scattering) of data; it is associated to uncertainty;
- Spurious: it is an accidental error.

For random errors, the equation that estimates the uncertainty of the measuring point is obtained through the partial derivative of the flow rate equation, considering the terms independent of each other. It may be written as follows:

$$E_j = \delta Q / Q = (\sum S_j^2 \; E_j^2)^{0,5} \qquad (6)$$

where: $S_j$ = sensibility coefficient ($S_{Cd}$, $S_Y$, $S_D$, $S_d$, $S_{hw}$, $S_\rho$)
$E_j$ = partial uncertainties ($E_{Cd}$, $E_Y$, $E_D$, $E_d$, $E_{hw}$, $E_\rho$)

When the standard deviation is used to determine the uncertainty calculation, it is necessary to correct it using Student's t equation, which is a function of the desired confidence level. For a 95 % probability, the following equation may be used:

$$t_{95\%} = 1,96 + 2,36/(n-1) + 3,2/(n-1)^2 + 5,2/(n-1)^{3,84} \qquad (7)$$

where: n = number of samples

There are some systematic errors, due to probable installation imperfections, that are difficult to quantify. To compensate for that, it is added, to the result above, an incremental uncertainty, as a function of beta.

Table 1. Uncertainty due to installation

| Beta | Installation uncertainty (%) |
|---|---|
| $0,10 < \beta < 0,60$ | 0,50 |
| 0,65 | 0,75 |
| 0,70 | 1,00 |
| 0,73 | 1,40 |
| 0,75 | 1,90 |

## 7 CALIBRATION

The main quality of a measurement instrument is its metrological reliability. In this context, calibration of the instruments at a preset interval is extremely important. Calibration is a set of operations that establishes a relation between the measured values and the values established by traced standards. If necessary, some adjustment operations are done on the instrument, in order to minimize the systematic errors and make it adequate to its application.

Calibration is reliable and meaninful only when it's done:

- Based upon replicated measures, and using the measurements as a decision basis;
- According to clear and objective procedures, written by the executor;
- In an ambient with known (and, if necessary, controlled) temperature, pressure and humidity;
- By expert personnel with ability and experience with the procedure;
- Establishing a validity period, after which it should be redone;
- Documenting the records.

The calibration of the network, when possible, should be done "in situ", rather than on the lab bench. The "in situ" wet calibration takes less time, is more reliable, is more accurate and supplies the measured value for uncertainty, obtained as a function of the standard.

Although the orifice plate may be considered a primary standard, the measurement point should be calibrated, for checking the differential pressure, the installation, the pipe (meter run) and the plate conditions, etc.

## 8 MEASUREMENT WITH AN OPERATIONAL FOCUS

One should always work on measurement in order to get the procedures in accordance to the standard specifications, so that the least uncertainty is obtained to a given condition.

Considering a gas network, in a daily measurement, one may often find different measured values among flow meters. These differences are directly proportional to the combination of the meter uncertainties. The bigger the uncertainty, the bigger the value difference.

In order to have a reliable measurement it's necessary to:

- ♦ Maintain a periodic calibration program for each measuring point, including the orifice plate and the measuring runs, with the objective of preventing or correcting systematic errors;
- ♦ Actuate on the network to reduce systematic errors and minimize uncertainties;
- ♦ Actuate on the measurement (production) rates on a mathematics basis;
- ♦ Create a process for following up the trends of measurement differences.

To say some examples, dirt accumulation, sharp edge wear, non flatness of the plate are often found in any measurement audit, and they generally lead to a smaller value.

A simulation was carried out comparing measured values and true values in a gas network, and also between the inlet and out values. It could be seen that, in both cases, the differences show a trend. This trend means that actually there is a gain or loss concerning the true value. The biggest differences are associated to the biggest uncertainties. Practically, it's impossible to compare the measure with the true value, since it's unknown. Therefore, one can never known what the meter trend is, either loss or gain. What is possible to do is regularly compare the results with other flow meters for monitoring the process. A trend shift, indicating out of control, will sign the need to actuate on the flow meters with problems. The control may be done using the network uncertainty, which is composed of the input and out measurement uncertainties:

$$E_{malha} = \{\Sigma[E_j^2(Q_j/\Sigma Q_j)^2]_{input} + \Sigma[E_j^2(Q_j/\Sigma Q_j)^2]_{output}\}^{0,5} \qquad (8)$$

where: $Q_j$ = flow rate of each measuring point
$E_j$ = uncertainty of each measuring point

A sensibility analysis of the total uncertainty may be done as a function of beta, hw and D.

The graph curve showing the total uncertainty of a measuring point using orifice plate is similar to an upward concave parable, with slight changes regarding the diameter of the meter run. Two examples are shown below, considering all the installation according to the standard.

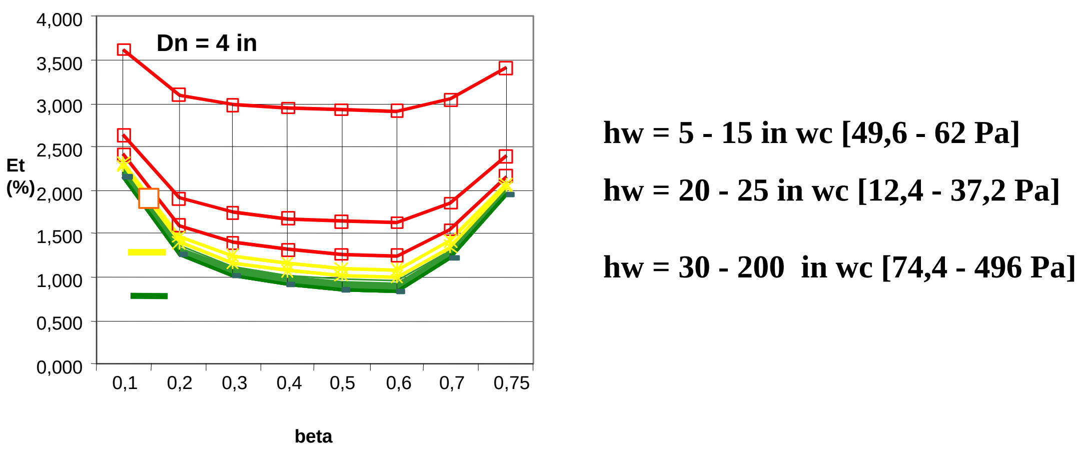


**Figure 1**. Sensibility analysis for total uncertainty (D = 4 in)

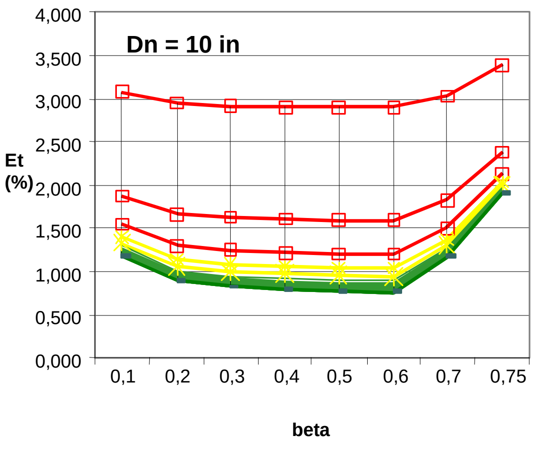


**Figure 2.** Sensibility analysis for total uncertainty (D = 10 in)

Generally, one can say that measurements with hw < 5% will have an uncertainty e > 3,0%. For measurements with hw < 10 in wc, uncertainty e > 1,5%, which is not acceptable for fiscal measurement. In order to obtain an uncertainty < 1,0%, one should try to work with hw > 30 in wc [74 Pa] and a beta between 0.4 and 0.62. In specific cases, a more detailed analysis should be done.

In order to perform these calculations, two softwares were developed in Excel. The first software was developed with the objective of doing flow rate calculations, generating instantaneous flow rate tables and sizing the orifice plate with the minimum uncertainty criterion. The second software was developed with the objective of calculating the total uncertainty of a measurement point using orifice plate. It shows the complete diagnosis of the installation, identifying points that are out of the standard. These softwares are very useful in operational applications, and in designs as well.

## 9 CONCLUSION

Although new technology has appeared recently, the orifice plate maintains its predominant status in industry, for several applications. Recent standards and procedures have reinforced the idea of calculating the flow rate with the least possible error. To achieve that, some requirements are necessary, such as correct installation, adequate ranges, awareness to the quality parameters for a good measurement, in order to obtain the least possible uncertainty, and computation according to the newest approved standards. The softwares that were developed try to meet all these standards and recommend the best range to work with.

REFERENCES

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