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Comparison of different approaches to calculate a final meter factor for rotary-type natural gas displacement meters

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ABSTRACT

The meter factor is the ratio between the reference volume and the indicated test meter volume for a particular flow rate. In some applications, a final and a single meter factor that covers all the flow meter rates is required, and there are several approaches to calculate it. However, none of them are specific to rotary-type natural gas displacement meters. In this paper, certain established approaches, such as AGA 7, AGA 9, non-weighted and weighted regression lines were applied to calibration data of this type of meter and their results were compared. An Excel spreadsheet was developed to calculate the final meter factors using all these approaches and to indicate users the one with the lowest uncertainty, based on input data in order to configure the flow computer. In the specific case studies shown, the approaches using linear regression were found to be more suitable.

1. Introduction

The use of natural gas, an attractive fossil fuel is increasing. Gas pipeline transportation companies are demanding credibility and excellence in meter calibration as the principal parameter in ensuring accountability for the gas invoiced [1].

When a meter is a mechanical device, such as a displacement or turbine meter [2], it can be affected by slippage, drag, and wear. Since there is little literature concerning rotary-type displacement meters, and turbine meters have similar mechanical characteristics, concepts and references of these were broadened to comprise the MF (meter factor) applied to rotary-type meters. A turbine meter is a type of velocity flow meter comprising a turbine, a bearing and a preamplifier [3] that generates frequencies proportional to volumetric flow rates [4]. In the right situations, they offer a useful combination of simplicity, accuracy, and economy [5]. Since it is mechanical equipment, through years of use its MF can gradually change, which means that regular recalibration is needed to provide an updated MF and consequently an accuracy control [6]. Usually, an optimum meter factor and zero bias are chosen so that the meter error at any given flow rate lies within the manufacturer's specified error band for a flow-calibrated meter [7].

A meter factor corrects the indicated volume to the reference or actual metered throughput. It can be defined as a number by which the result of a measurement is multiplied to compensate for systematic error. It is a non-dimensional value determined for each flow rate at which the meter is calibrated, and is calculated by dividing the value from the reference meter by the indicated value of the meter under test (MUT). Though, in some cases it is not feasible to apply multiple meter factors, each one to an individual flow rate, given that many flow computer models require an average single factor (final meter factor – FMF). FMF is the number developed either by averaging the individual meter factors over the range of the meter or by weighting more heavily the meter factors over flow rates at which the meter is more likely to be used. In addition, multi-point linearization or polynomial curve fitting techniques may be used [8].

The simplest way to express the meter factor or to describe the flow rate difference between the working standard (reference meter) and the meter under test (MUT) is given by the Eqs. (1) [9,10]:

$$MF = \frac{q_{Standard}}{q_{MUT}} \tag{1}$$

Alternatively, meter factors can be calculated from the percentage error values provided at each calibration flow rate, by the Eq. (2) [8]:

$$Meter\,factor = \frac{100}{100 + percent\ error} \tag{2}$$

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Thus, the meter factor example of 1.005 would be the same as −0.5 percentage error. The error adjustments can be calculated offline manually or online in an electronic accessory device, and can be applied to each specific flow rate, using individual meter factor, or across the range of flow rates, using a single FMF [11]. The calibration facility may provide meter factors in addition to or in place of percentage error values for each test flow rate of a meter [8].

The FMF may be the arithmetic average of the meter factors or calculated by a non-weighted ordinary least square regression over the range of flow rates at which the meter is to be used. The FMF may also be weighted more heavily toward the individual meter factors at the higher flow rates at which the meter is to be used or by a weighted ordinary least square regression.

Rotary-type natural gas displacement meters are commonly used in custody transfer applications, and reference [12] represents a basic standard for safe operation, substantial and durable construction, and acceptable performance for this type of meter. However, this reference does not mention how to establish a single meter factor.

The flow rate literature principally mentions two approaches to calculate a final (single) meter factor, based on turbine and ultrasonic meter technologies, although they can be applied to other similar measurement systems. Alternatively, statistical techniques can also be used to provide a solution to this issue.

The aim of this paper is to compare the results of FMF calculations using different approaches, applied to rotary-type natural gas displacement meters.

2. Methodology

The methodology comprises two topics. The first one is the uncertainty evaluation which is the criterion used to choose the final meter factor. The second one details the different approaches used to calculate the FMF.

2.1. Uncertainty evaluation

To metrologists, measurement results cannot be appropriately expressed and evaluated without knowing their uncertainty [13]. The uncertainty has a probabilistic basis, while the error is deterministic, and reflects incomplete knowledge of the quantity. All measurements are subject to uncertainty and it can be used to evaluate the quality of a result.

It is not always possible to correct significant systematic effects from a calibration curve [14]. In these situations, the total uncertainty becomes increased by this source of uncertainty called here as *Error*. In this paper, the total uncertainty is evaluated as the algebraic sum of the expanded uncertainty U (k=2; 95.45%), considering that there is no bias, and also the maximum absolute value of the *Error*, over the calibration range.

The rotary-type displacement meter performance is usually expressed by giving the relative meter error as a function of flow rate. The flow rate relative meter error and the FMF error are defined by Eqs. (3) and (4), respectively [15]:

$$Error(\%)_{q_i} = \frac{q_{MUT_i} - q_{Standard_i}}{q_{Standard_i}} \times 100 \tag{3}$$

$$Error(\%)_{FMF} = \frac{FMF - MF_i}{MF_i} \times 100 \tag{4}$$

where Standard is the reference or actual flow meter, and MUT is the meter under test.

2.2. Different approaches to calculate the final meter factor

2.2.1. AGA 7 approach

This approach calculates each meter factor based on Eq. (1). Afterwards, an arithmetic average of meter factors is taken, and then the error between each meter factor and the average one is calculated. The final meter factor is the one which has the least bias among all meter factors. Here, the standard uncertainty is simply considered as the standard deviation of the meter factor.

2.2.2. AGA 9 approach

In this approach, it is necessary to have available both the meter under test (MUT) results and actual or reference meter results, the nominal test rate, or desired flow rate.

The percentage error of each flow rate is calculated by Eq. (3).

The next step is to calculate weighting factor values, wf_i, using the relationship between each actual flow rate and the maximum desired flow rate, q_{max}, Eq. (5), [7,16].

$$wf_i = \frac{q_{Actual_i}}{q_{\max}} \tag{5}$$

The flow mean error (FME) is then found by Eq. (6), [7,16].

$$FME = \frac{\sum_i^n wf_i \times Error(\%)_{q_i}}{\sum_i^n wf_i} \tag{6}$$

Considering the uncorrelated quantities in Eq. (6), the combined standard uncertainties are shown in Eqs. (7) and (8):

$$u_c^2(FME) = \left(\frac{\partial FME}{\partial wf_i} u(wf_i)\right)^2 + \left(\frac{\partial FME}{\partial Error(\%)_{q_i}} u(Error(\%)_{q_i})\right)^2 \tag{7}$$

$$u_c^2(FME) = \sum_i^n \left(\frac{Error(\%)_{q_i} \sum_i^n wf_i - \sum_i^n wf_i Error(\%)_{q_i}}{\left(\sum_i^n wf_i\right)^2}\right)^2 u^2(wf_i) + \sum_i^n \left(\frac{wf_i}{\sum_i^n wf_i}\right)^2 u^2(Error(\%)_{q_i}) \tag{8}$$

Finally, the final meter factor is calculated by Eq. (9) and its uncertainty by Eq. (10).

$$FMF = \frac{100}{100 + FME} \tag{9}$$

$$u_c^2(FMF) = \left(\frac{-100}{(100 + FME)}\right)^2 u_c^2(FME) \tag{10}$$

2.2.3. Non-weighted ordinary least squares (OLS)

In the classical univariate calibration, considering η calibration points, the calibration curve is defined by y=$f(x)$, and the unknown quantity (x_0) is determined by the solution to the Eq. y_0=$f(x_0)$, where y_0 is the result for the unknown variable. The most simple and widely used case is the following linear model:(y=b_0+b_1x) [17]. The unweighted linear regression is used to obtain estimates of the calibration parameters b_0 and b_1, derived from x_0=(y_0−b_0)/b_1. In this paper, this latter equation becomes $MUT_0 = (Standard_0 - b_0)/FMF$. So, it is assumed that there is a linear relationship between the reference meter and the meter under test (MUT) and the error in the y-values is constant, having homoscedastic behavior. It can be shown that the least squares straight line is given by Eq. (11):

$$\text{Slope of least squares line}: FMF = \frac{\sum_i^n \{(q_{MUT_i} - \overline{q}_{MUT})(q_{Standard_i} - \overline{q}_{Standard})\}}{\sum_i^n (q_{MUT_i} - \overline{q}_{MUT})^2} \tag{11}$$

The random error in value for the slope is thus significant and it must be now considered. Firstly, the value of $s_{y/x}$ is calculated.