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Design and Implementation of a Real-Time Measurement Uncertainty Monitoring System for Orifice Gas Meters System Using a Human–Machine Interface

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ABSTRAK

Sistem Meter Gas Orifice (MGO) banyak digunakan dalam industri migas untuk aplikasi *custody transfer* karena memiliki tingkat akurasi pengukuran yang tinggi. Namun, hasil pengukuran secara inheren dipengaruhi oleh ketidakpastian yang berasal dari berbagai besaran masukan (*input quantities*), seperti tekanan, temperatur, tekanan diferensial, densitas fluida, serta karakteristik instrumen pengukuran. Oleh karena itu, pemantauan ketidakpastian pengukuran secara kontinu sangat diperlukan untuk menjamin keandalan hasil pengukuran dan mendukung pengambilan keputusan operasional. Penelitian ini menyajikan perancangan dan implementasi sistem monitoring ketidakpastian pengukuran pada Meter Gas Orifice secara *real-time* berbasis *Human–Machine Interface* (HMI). Sistem yang dikembangkan mengakuisisi data proses secara *real-time* dari *flow computer* dan menghitung ketidakpastian pengukuran dengan menerapkan hukum propagasi ketidakpastian berdasarkan *American Gas Association* (AGA) *report no. 3* dan Keputusan Direktur Jenderal Perlindungan Konsumen Dan Tertib Niaga No. 17 Tahun 2025. Nilai ketidakpastian yang dihitung, beserta kontribusi masing-masing komponen ketidakpastian, ditampilkan melalui HMI untuk mendukung pemantauan secara *real-time* dan evaluasi kinerja sistem pengukuran. Hasil validasi menunjukkan bahwa sistem yang dikembangkan mampu melakukan perhitungan ketidakpastian pengukuran secara *real-time* dengan tingkat kesesuaian yang tinggi terhadap hasil perhitungan referensi Direktorat Metrologi. Sistem memperoleh *Average Relative Error* (ARE) sebesar 0,0001% dan *Mean Absolute Error* (MAE) sebesar 0,0001%, yang menunjukkan konsistensi yang sangat baik terhadap hasil perhitungan *excel-based* standar Direktorat Metrologi. Selain itu, HMI mampu memvisualisasikan kontribusi masing-masing komponen ketidakpastian sehingga operator dapat mengidentifikasi sumber ketidakpastian yang dominan dan melakukan evaluasi kinerja sistem pengukuran secara lebih efektif.

Kata Kunci: *American Gas Association report no. 3, Flow Computer, Human-Machine Interface,* Ketidakpastian Pengukuran, Sistem Meter Gas Orifice

ABSTRACT

Orifice Gas Meter (OGM) systems are widely used in the oil and gas industry for custody transfer applications due to their high measurement accuracy. However, measurement results are inherently affected by uncertainties arising from multiple input quantities, including pressure, temperature, differential pressure, fluid density, and the characteristics of the measuring instruments. Therefore, continuous monitoring of measurement uncertainty is essential to ensure measurement reliability and support informed operational decision-making. This study presents the design and implementation of a real-time measurement uncertainty monitoring system for an Orifice Gas

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Meter (OGM) based on a Human–Machine Interface (HMI). The proposed system acquires real-time process data from a flow computer and calculates measurement uncertainty by applying the law of propagation of uncertainty in accordance with American Gas Association (AGA) Report No. 3 and Director General Decision of Customer Protection And Trade Compliance No. 17 : 2025 about Technical Requirement of Orifice Gas Meter. The calculated uncertainty values, together with the contribution of each uncertainty component, are continuously displayed through the HMI to facilitate real-time monitoring and comprehensive evaluation of measurement system performance. Validation results demonstrate that the proposed system accurately performs real-time measurement uncertainty calculations with excellent agreement with the reference calculations provided by the Directorate of Metrology. The system achieved an Average Relative Error (ARE) of 0.0001% and a Mean Absolute Error (MAE) of 0.0001%, indicating excellent consistency with the Directorate of Metrology's standard Excel-based calculation. Furthermore, the HMI visualizes the contribution of individual uncertainty components, enabling operators to identify the dominant sources of measurement uncertainty and evaluate measurement system performance more effectively.

Keywords: *American Gas Association report no. 3, Flow Computer, Human Machine Interface, Measurement Uncertainty, Orifice Gas Meter*

1. INTRODUCTION

Natural gas is one of the world's primary energy resources and is widely used in industrial processes and power generation. In custody transfer applications, accurate gas flow measurement is essential because it directly affects commercial transactions, operational efficiency, and regulatory compliance. Among various flow measurement technologies, the Orifice Gas Meter (OGM) is widely adopted due to its simplicity, reliability, international acceptance, and high measurement accuracy. The reliability of OGM measurements depends not only on instrument accuracy but also on the associated measurement uncertainty.

According to regulations issued by the Directorate of Metrology, the maximum permissible measurement uncertainty (MPU) for orifice gas metering systems is 1% at a 95% confidence level. Therefore, it is essential to implement an uncertainty evaluation method that is both accurate and compliant with applicable standards. Despite its importance, real-time monitoring of measurement uncertainty integrated with operator interfaces remains limited, especially systems aligned with national metrology regulations. This research presents the design and implementation of a real-time uncertainty monitoring system using a Human–Machine Interface (HMI). The system utilizes real-time process data obtained from a flow computer and computes measurement uncertainty dynamically, enabling operators to monitor system performance continuously.

2. RESEARCH METHODOLOGY

The research conducted in this study was carried out in several stages. In the first stage, a literature review was performed, followed by the determination of parameters for each instrument to be installed in the OGM system, including the measurement ranges of transmitters for pressure, temperature, and differential pressure. These parameters were subsequently configured into the flow computer [7], and the data analysis method was established. In the second stage, the HMI interface was designed, and the mathematical models required for calculating measurement uncertainty in the OGM system were implemented based on applicable regulatory documents [1], [2], [8]. In the third stage, flow rate simulations were conducted, and the measurement uncertainty values displayed on the HMI were compared with calculation results obtained from the standard application of the Directorate of Metrology. In the final stage, conclusions were drawn based on the results of the study.

2.1 System Components

1. Flow Computer

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The flow computer serves as the primary computational unit of the OGM system. This study employs the FloBoss S600+ manufactured by Emerson. The device was selected because it incorporates built-in AGA Report No. 3 (AGA3) flow calculation algorithms, supports Modbus TCP/IP communication for seamless integration with the HMI, and is widely deployed in custody transfer gas metering systems. The key configuration parameters are summarized as follows:

TABLE I. SYSTEM PARAMETERS

Description	Range	Unit
Pressure base	14,73	psia
Temperature base	60	degF
Pipe diameter	7,981	inch
Orifice diameter	1,6254 & 2,5487	inch
Pipe calibration temp.	68	degF
Orifice calibration temp.	68	degF
Pressure	0 – 500	psig
Differential pressure	0 – 200	inH2O
Temperature	0 – 200	degF

2. Human-Machine Interface (HMI)

The system employs AVEVA™ InTouch HMI as the user interface platform for real-time visualization and operator interaction. It was selected for this study due to its high reliability, user-friendly interface, and widespread deployment in industrial automation systems.

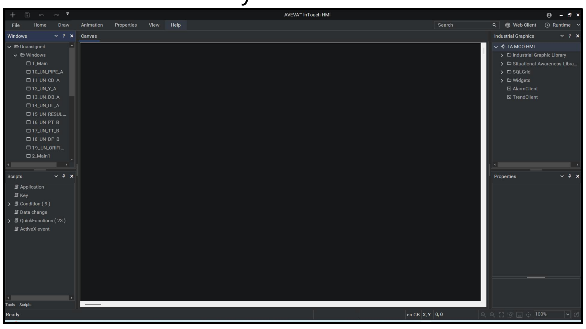

Figure 1. AVEVA™ InTouch HMI

3. Modbus Server

A Modbus server is implemented to facilitate communication between the flow computer and the HMI.

4. Network Infrastructure

An Ethernet switch hub is used to interconnect all system components within a local area network.

2.2 System Architecture

The proposed system consists of an Orifice Gas Meter (OGM), a flow computer, a Modbus TCP/IP communication network, and a HMI, as shown in Fig. 2. The flow computer continuously acquires process variables, including pressure, differential pressure, temperature, density, base density, discharge coefficient, expansion factor, orifice diameter, meter tube diameter, and flow rate. These variables are transmitted to the HMI through the Modbus TCP/IP protocol for real-time processing.

The HMI receives the process variables from the Modbus server and executes the measurement uncertainty algorithm. The calculated uncertainty values and the contribution of each uncertainty component are displayed continuously to support real-time monitoring of the OGM measurement system.

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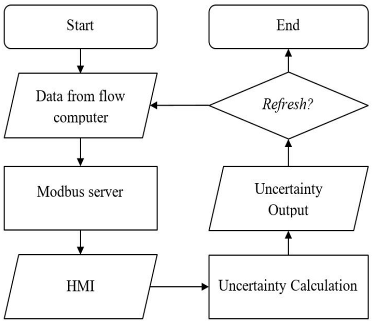

Figure 2. System Architecture

2.3 Real-Time Data Processing

Fig. 3 illustrates the real-time data processing sequence implemented in the proposed system. The process begins with the acquisition of measurement data from the flow computer. The acquired variables are transmitted to the HMI through the Modbus TCP/IP communication protocol.

The HMI automatically processes the received data using the implemented uncertainty calculation algorithm. The algorithm evaluates the uncertainty contribution of each input quantity and calculates the combined standard uncertainty, expanded uncertainty, and relative expanded uncertainty. The calculated results are then displayed on the HMI together with the contribution of each uncertainty component.

After each calculation cycle, the system automatically refreshes the communication by requesting the latest process variables from the flow computer. This continuous acquisition–calculation–display cycle enables real-time monitoring of measurement uncertainty throughout system operation.

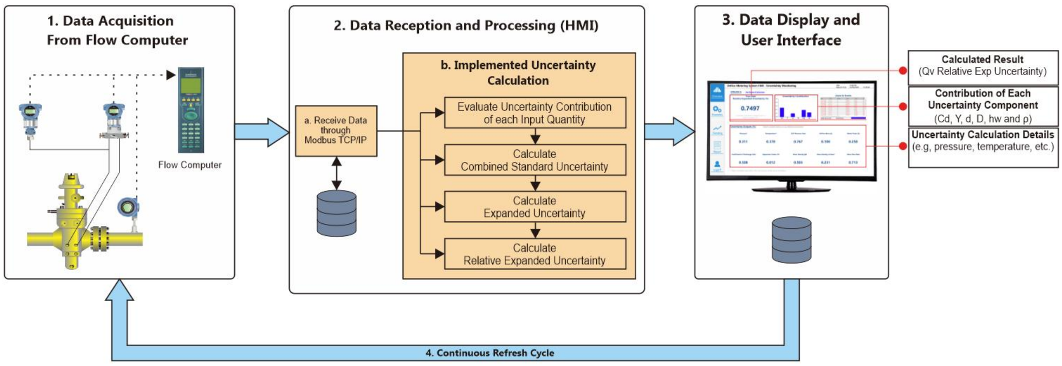

Figure 3. Real-Time Data Processing Sequence

2.4 Measurement Uncertainty Evaluation

Measurement uncertainty was evaluated using the law of propagation of uncertainty in accordance with AGA Report No. 3 and Director General Decision of Customer Protection And Trade Compliance No. 17 : 2025 about Technical Requirement of Orifice Gas Meter [1], [2]. The uncertainty calculation considers all input quantities that significantly influence the measurement result.

1. Temperature, Pressure and Differential Pressure

Table II summarizes the temperature, pressure and differential pressure measurement uncertainty sources and their assigned uncertainty values as specified in the Directorate of Metrology regulation [1].

TABLE II. Assignment of Temperature, Pressure and Diff. Pressure Measurement Uncertainty Values

Input Quantity	Source of Uncertainty	Assigned Value
Temperature	Max. Permissible Error (MPE) at calibration point	0,25% of Full Scale (FS)
	Readability	Transmitter specification

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	Stability	0,1% of reading
	Effect of ambient temperature	0,01% of FS
	Effect of power supply	0,005% of FS
	Effect of RFI	0,018 degC
Pressure & Differential Pressure	MPE at calibration point	0,25% of FS
	Readability	Transmitter specification
	Stability	0,1% of reading
	Effect of ambient temperature	0,1% of reading
	Effect of ambient pressure	0,1% of reading
	Effect of power supply	0,005% of FS
	Effect of RFI	0,00007 Mpa

2. Discharge Coefficient

The expanded uncertainty of the Discharge Coefficient at a 95% confidence level is expressed as follows [1], [2]:

A. For diameter ratios (β) > 0,175:

$$\frac{u(C_d)}{C_d} = 0{,}5600 - 0{,}2550\beta + 1{,}9316\beta^8 \quad (1)$$

B. For diameter ratios (β) $\leq$ 0,175:

$$\frac{u(C_d)}{C_d} = 0{,}700 - 1{,}0550\beta \quad (2)$$

3. Expansion Factor

The expanded uncertainty of the Expansion Factor, expressed as a percentage (%) at a 95% confidence level, is given by [1], [2]:

$$U_Y = 2{,}6\left[\frac{\Delta P}{N_3 Pf}\right] \quad (3)$$

Where:

N_3 : constant whose value depends on the units of differential pressure (ΔP) and upstream gas pressure (Pf)

P_f : upstream gas pressure

ΔP : differential pressure

4. Orifice Bore Diameter

The standard uncertainty of the Orifice Bore Diameter at the flowing temperature is calculated as follows [1], [2]:

$$u(d) = \sqrt{\left(c(d_r)\right)^2\left(u(d_r)\right)^2 + \left(c(a_1)\right)^2\left(u(a_1)\right)^2 + \left(c(T)\right)^2\left(u(T)\right)^2} \quad (4)$$

Where:

TABLE III. Orifice Plate Sensitivity Coefficient

Sensitivity Coefficient	Standard Uncertainty		
$c(d_r) = \frac{d}{dr}$	$u(d_r)$	:	The bore diameter uncertainty obtained from the orifice plate calibration certificate.
$c(T) = d_r a_1$	$u(T)$	:	Temperature uncertainty
$c(a_1) = d_r(T - T_r)$	$u(a_1)$	:	The uncertainty of the linear thermal expansion coefficient of the orifice plate is assigned a value of

0.00000018/ degC

5. Pipe Bore Diameter

The standard uncertainty of the Pipe Bore Diameter at the flowing temperature is calculated as follows [1], [2]:

$$u(D) = \sqrt{\left(c(D_r)\right)^2\left(u(D_r)\right)^2 + \left(c(a_2)\right)^2\left(u(a_2)\right)^2 + \left(c(T)\right)^2\left(u(T)\right)^2} \quad (5)$$

Where:

TABLE IV. Pipe Sensitivity Coefficient

Sensitivity Coefficient	Standard Uncertainty		
$c(D_r) = \frac{D}{Dr}$	$u(D_r)$	:	The uncertainty of the pipe bore diameter is assigned a value of 0.25D_r
$c(T) = D_r a_2$	$u(T)$	:	Temperature uncertainty
$c(a_2) = D_r(T - T_r)$	$u(a_2)$	:	The uncertainty of the linear thermal expansion coefficient of the pipe is assigned a value of 0.00000018/ degC

6. Mass Density and Base Density

The uncertainty values assigned to the base compressibility factor, flowing compressibility factor, and real gas relative density are summarized in Table V [1].

TABLE V. Assignment of Mass Density and Base Density Uncertainty Values

Input Quantity	Source of Uncertainty	Assigned Value
Mass Density	Base compressibility factor (Z_b)	0,1%
	Flowing compressibility factor (Z_f)	0,1%
Mass Density & Base Density	Real gas relative density factor (G_r)	0,1%

7. Mass Flow Rate

The mass flow rate uncertainty is influenced by six primary input quantities: the Discharge Coefficient (C_d), Expansion Factor (Y), Orifice Bore Diameter (d), Meter Tube Internal Diameter (D), Gas Density (ρ), and Differential Pressure (ΔP). The contribution of each input quantity to the overall mass flow rate uncertainty is represented by its corresponding sensitivity coefficient (c_i), which is expressed as follows [1], [2]:

TABLE VI. Assigned Sensitivity Coefficient

Variables	Sensitivity Coefficient
Discharge Coefficient ($\mathbf{C_d}$)	1
Expansion Factor (Y)	1
Orifice plate bore diameter (d)	$\left(\frac{2}{1-\beta^4}\right)$
Pipe bore diameter (D)	$\left(\frac{-2\beta^4}{(1-\beta^4)}\right)$
Gas density (ρ)	0,5
Differential pressure (ΔP)	0,5

The relative expanded uncertainty of the mass flow rate is obtained by combining the uncertainty contributions of the input quantities according to the following equation:

$$u_r(Q_m) = \frac{u(Q_m)}{Q_m} = 2\sqrt{1\left(\frac{u(C_d)}{C_d}\right)^2 + 1\left(\frac{u(Y)}{Y}\right)^2 + \left(\frac{2}{1-\beta^4}\right)^2\left(\frac{u(d)}{d}\right)^2 + \left(\frac{-2\beta^4}{(1-\beta^4)}\right)^2\left(\frac{u(D)}{D}\right)^2 + (0{,}5)^2\left(\frac{u(\rho_{t,p})}{\rho_{t,p}}\right)^2 + (0{,}5)^2\left(\frac{u(h_w)}{h_w}\right)^2} \quad (6)$$

Where:

Q_m = Mass flow rate
C_d = Coefficient of discharge
Y = Expansion factor
d = Orifice plate bore diameter
D = Pipe bore diameter
$\rho_{t,p}$ = Flowing gas density
h_w = Differential pressure

8. Volume Flow Rate

The uncertainty of the volume flow rate is determined by the uncertainties associated with the mass flow rate and the base density. Accordingly, the relative expanded uncertainty of the volume flow rate is calculated using the following equation [1]:

$$u_r(Q_v) = \frac{u(Q_v)}{Q_v} = 2\sqrt{\left(\frac{u(Q_m)}{Q_m}\right)^2 + \left(\frac{u(\rho_b)}{\rho_b}\right)^2} \quad (7)$$

Where:
Q_v : Volume Flow Rate
Q_m : Mass Flow Rate
ρ : Density at base condition

Each uncertainty source is converted into a standard uncertainty before being propagated using the law of propagation of uncertainty.

The variance contribution of each uncertainty component is calculated by:

$$Var_i = (c_i u_i)^2 \quad (8)$$

The combined standard uncertainty is obtained from:

$$u_c = \sqrt{\sum_{i=1}^{n} (c_i u_i)^2} \quad (9)$$

The expanded uncertainty is determined by:

$$U = k\, u_c \quad (10)$$

Finally, the relative expanded uncertainty is calculated as:

$$U_r = \frac{U}{Y} \times 100\% \quad (11)$$

Where:
c_i : Sensitivity coefficient
u_i : Standard uncertainty of the i^{th} input quantity
k : Coverage factor
Y : Measured quantity

The uncertainty calculation algorithm was implemented using the scripting functions available in the AVEVA InTouch HMI [8]. The implementation consists of several calculation modules corresponding to the uncertainty evaluation procedure, including data acquisition, standard uncertainty calculation, uncertainty propagation, combined uncertainty calculation, expanded uncertainty calculation, and real-time visualization. Fig. 4 illustrates an example of the implementation of the temperature uncertainty calculation in the HMI system.

```
{=UNCERTAINTY FOR TEMPERATURE STR A=}

V1_TTA_UN = ( 0.25 * STR1_TT_HIRANGE ) / 100; {Given uncertainty of BKD multiplied by total range of the transmitter}
V2_TTA_UN = STR1_TT_READABILITY; {Given uncertainty of the readability of the transmitter}
V3_TTA_UN = (0.1 * TT_A_INUSE) / 100; {Given uncertainty of stability multiplied by actual value of the transmitter}
V4_TTA_UN = ( 0.01 * STR1_TT_HIRANGE ) / 100; {Given uncertainty of amb temperature multiplied by total range of the transmitter}
V5_TTA_UN = ( 0.005 * STR1_TT_HIRANGE ) / 100; {Given uncertainty of power supply effect multiplied by total range of the transmitter}
V6_TTA_UN = 0.01; {Given uncertainty of the RFI effect of the transmitter}


V1_TTA_DIV = 3;
V2_TTA_DIV = Sqrt(3);
V3_TTA_DIV = Sqrt(3);
V4_TTA_DIV = Sqrt(3);
V5_TTA_DIV = Sqrt(3);
V6_TTA_DIV = Sqrt(3);

V1_TTA_UI = V1_TTA_UN / V1_TTA_DIV;
V2_TTA_UI = V2_TTA_UN / V2_TTA_DIV;
V3_TTA_UI = V3_TTA_UN / V3_TTA_DIV;
V4_TTA_UI = V4_TTA_UN / V4_TTA_DIV;
V5_TTA_UI = V5_TTA_UN / V5_TTA_DIV;
V6_TTA_UI = V6_TTA_UN / V6_TTA_DIV;

V1_TTA_CI = 1;
V2_TTA_CI = 1;
V3_TTA_CI = 1;
V4_TTA_CI = 1;
V5_TTA_CI = 1;
V6_TTA_CI = 1;

V1_TTA_VAR = V1_TTA_CI * V1_TTA_UI;
V2_TTA_VAR = V2_TTA_CI * V2_TTA_UI;
V3_TTA_VAR = V3_TTA_CI * V3_TTA_UI;
V4_TTA_VAR = V4_TTA_CI * V4_TTA_UI;
V5_TTA_VAR = V5_TTA_CI * V5_TTA_UI;
V6_TTA_VAR = V6_TTA_CI * V6_TTA_UI;

TTA_ROOT = Sqrt((V1_TTA_VAR*V1_TTA_VAR) + (V2_TTA_VAR*V2_TTA_VAR) + (V3_TTA_VAR*V3_TTA_VAR) + (V4_TTA_VAR*V4_TTA_VAR) + (V5_TTA_VAR*V5_TTA_VAR) + (V6_TTA_VAR*V6_TTA_VAR));

TTA_EXP_UN = 2 * TTA_ROOT;

TTA_REL_EXP_UN = 100 * (TTA_EXP_UN / TT_A_INUSE);
```

Figure 4. Temperature Uncertainty Calculation Script

Where:

V_i_TT_i_UN	: Source of uncertainty
V_i_TT_i_DIV	: Divisor
V_i_TT_i_UI	: Standard uncertainty
V_i_TT_i_CI	: Sensitivity coefficient
V_i_TT_i_VAR	: Variance
TT_i_ROOT	: Square root of sum of squared variances
TT_i_EXP_UN	: Expanded uncertainty
TT_i_REL_EXP_UN	: Relative expanded uncertainty

2.5 System Validation

The proposed system was validated by comparing the uncertainty values calculated by the HMI with the reference calculations from the Directorate of Metrology standard application. System performance was evaluated using the Average Relative Error (ARE) and Mean Absolute Error (MAE).

The ARE is defined as:

$$ARE \;= \frac{1}{n}\sum \frac{u(Q_v)\,HMI - u(Q_v)\,REF}{u(Q_v)\,REF} \tag{12}$$

The MAE is calculated as:

$$MAE \;= \frac{1}{n}\sum u(Q_v)\,HMI - \; u(Q_v)\,REF \tag{13}$$

Where:

$u(Q_v)\,HMI$: Uncertainty calculation by HMI

$u(Q_v)\,REF$: Uncertainty calculation by reference standard application

3. RESULTS AND DISCUSSION

3.1 HMI Interface

1. Start-Login Screen

This section shows the initial HMI interface, where the operator is required to log in before accessing the system menu. The HMI can be accessed by two categories of users, each with different access privileges and operational responsibilities.

TABLE VII. USER LEVELS

User Level	Access Allowed			
	Edit Meter Devices Info & Parameters	Trending	HMI Report	Exit or Minimize Application
Operator	•	✓	✓	•
Engineer	✓	✓	✓	✓

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2. Overview

This section represents the main display, presenting measurement uncertainty data along with the associated influencing variables. Fig. 5 illustrates the overview screen.

Figure 5. Overview

3. Parameters

This section displays the operator input data corresponding to the flow computer parameters. Fig. 6 illustrates the parameters screen.

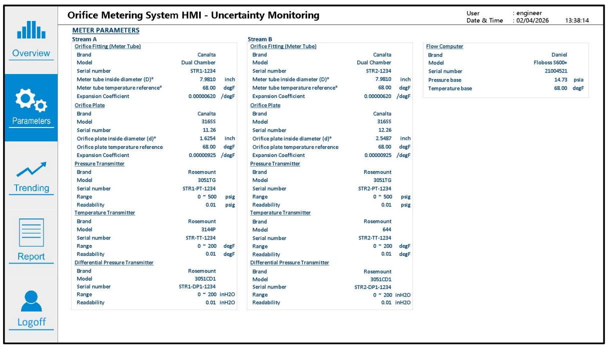

Figure 6. Parameters

4. Trending

This section displays trends of measurement uncertainty and its influencing variables, which can be used for future OGM performance analysis. Fig. 7 illustrates the trending screen.

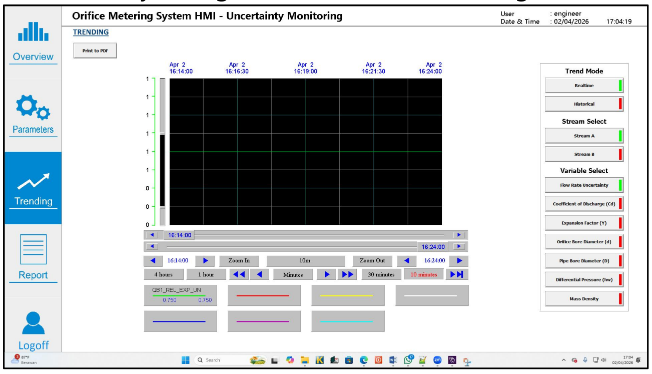

Figure 7. Trending

5. Report

This section displays the current HMI report, including real-time data from the flow computer and the corresponding measurement uncertainty results. Fig. 8 illustrates the HMI report screen.

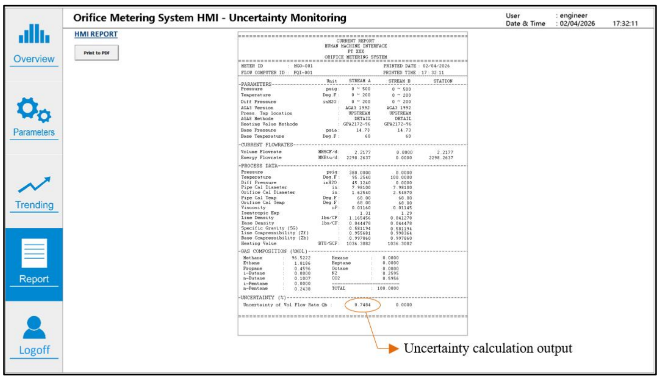

Figure 8. HMI Report

3.2 Experimental Data Collection

Flow simulations were performed using varying pressure, differential pressure, and temperature inputs. The results were compared with standard application calculations as a reference.

To facilitate the evaluation and comparison of the proposed method, uncertainty values in this study are presented to four decimal places. In practical applications, however, the reported uncertainty should be expressed using two significant digits, in accordance with metrology standards and the recommendations of the Guide to the Expression of Uncertainty in Measurement (GUM) [3], [4].

3.3 Calculation Test Result

Table VIII and Fig. 9 shows the results of twenty test samples from the HMI compared with the standard application.

TABLE VIII. CALCULATION TEST RESULT

SAMPLE NO.	PRESSURE (PSIG)	TEMPERATURE (°F)	DIFFERENTIAL PRESSURE (INH_2O)	FLOW RATE (MMSCFD)	HMI UNCERTAINTY (%)	REFERENCE UNCERTAINTY (%)	ABSOLUTE ERROR (PERCENTAGE POINTS)
1	48.84	86.93	20.11	0.5867	1.2078	1.2075	0.0002
2	48.84	86.93	50.22	0.9216	0.9407	0.9406	0.0001
3	49.28	86.85	100.18	1.2243	0.9013	0.9012	0.0001
4	49.34	86.71	150.11	1.5706	0.9071	0.9071	0.0000
5	48.58	86.15	199.85	1.7849	0.9312	0.9312	0.0000
6	250.16	86.15	20.51	1.2279	1.0143	1.0139	0.0004
7	250.24	86.05	50.21	1.9186	0.6908	0.6907	0.0001
8	250.22	85.88	100.09	2.7029	0.6288	0.6288	0.0000
9	250.42	85.78	150.42	3.3076	0.6176	0.6176	0.0000
10	250.34	85.44	200.01	3.8064	0.6151	0.6151	0.0000
11	375.16	85.65	21.05	1.5219	0.9911	0.9907	0.0004
12	375.21	85.62	40.26	2.1033	0.7249	0.7247	0.0003
13	374.95	85.22	60.85	2.5839	0.6549	0.6548	0.0002
14	374.89	85.11	100.25	3.3125	0.6178	0.6178	0.0000
15	374.49	85.06	120.43	3.6267	0.6111	0.6111	0.0000
16	499.52	86.56	18.25	1.6382	1.0890	1.0885	0.0005
17	498.85	86.56	24.15	1.8830	0.9092	0.9088	0.0004
18	498.59	86.47	98.25	3.7900	0.6147	0.6147	0.0000
19	497.90	86.15	149.52	4.6680	0.6016	0.6016	0.0000

Sample No.	Pressure (psig)	Temperature (°F)	Differential Pressure (inH_2O)	Flow Rate (MMSCFD)	HMI Uncertainty (%)	Reference Uncertainty (%)	Absolute Error (percentage points)
20	497.78	86.13	199.21	5.3814	0.5975	0.5975	0.0000
			Mean Absolute Error				**0.0001**
			Maximum Absolute Error				**0.0005**

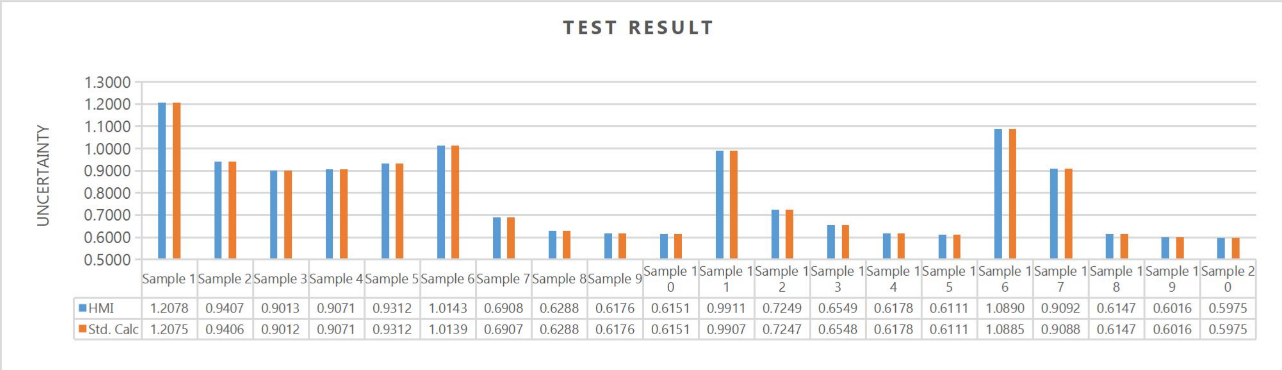

Figure 9. Comparison of HMI Test Results and Standard Calculations

3.4 Discussion

The contribution analysis indicates that six uncertainty components dominate the overall measurement uncertainty, namely the Discharge Coefficient, Expansion Factor, Orifice Plate Bore Diameter, Meter Tube Diameter, Differential Pressure, and Line Density, as shown in Fig. 10. Visualizing these contributions enables operators to identify dominant uncertainty sources and prioritize corrective actions that have the greatest impact on measurement performance.

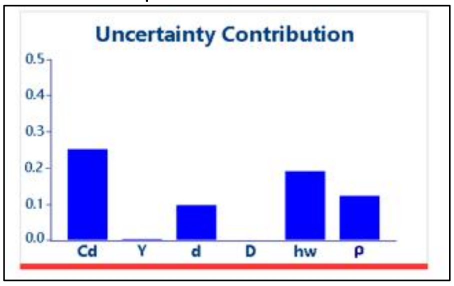

Figure 10. Contribution Distribution of Measurement Uncertainty Components for the OGM System

Among these components, the Discharge Coefficient exhibits the largest contribution. Since this parameter is highly sensitive to the beta ratio and the dimensional characteristics of the orifice plate, an excessive contribution may indicate that the installed orifice plate no longer satisfies the required operating conditions or dimensional tolerances. In such cases, operators should verify the beta ratio and inspect or replace the orifice plate to restore measurement performance.

The Differential Pressure component also contributes significantly to the combined uncertainty. A high contribution generally indicates that the differential pressure transmitter has an excessively wide measurement range or insufficient resolution for the operating conditions. Selecting a transmitter with an appropriate measurement range or performing recalibration can reduce this uncertainty component and improve measurement accuracy.

Similarly, increased contributions from the Orifice Plate Bore Diameter and Meter Tube Diameter may indicate dimensional deviations caused by wear, installation errors, calibration drift, or beta ratio. These conditions require dimensional verification or recalibration to maintain compliance with custody transfer measurement requirements. Meanwhile, a significant Line Density contribution may indicate inaccuracies in the measured gas properties or process conditions, requiring verification of density-related inputs and associated instrumentation.

These results demonstrate that the proposed system provides more than real-time uncertainty monitoring. By continuously displaying the contribution of each uncertainty component, the HMI supports maintenance planning and operational decision-making. Operators can prioritize calibration, transmitter replacement, orifice plate inspection, or verification of gas property measurements based on the dominant uncertainty contributors rather than relying solely on the overall uncertainty value.

3.5 Conclusion and Recommendation

This study presented the design and implementation of a real-time measurement uncertainty monitoring system for an OGM system using a HMI. The proposed system successfully acquired real-time process data from the flow computer and implemented the uncertainty propagation algorithm based on AGA Report No. 3 and the applicable Directorate of Metrology regulation. The calculated uncertainty values and the contribution of each uncertainty component were continuously displayed through the HMI, enabling operators to monitor measurement performance in real time. Experimental validation showed excellent agreement between the uncertainty values calculated by the proposed HMI and the Directorate of Metrology reference calculations. The system achieved an Average Relative Error (ARE) of 0.0001% and a Mean Absolute Error (MAE) of 0.0001%, indicating that the implemented algorithm accurately reproduces the reference calculation for the tested operating conditions.

The developed system demonstrates the feasibility of integrating real-time uncertainty evaluation into an HMI-based monitoring platform for OGM applications. In addition to providing continuous uncertainty information, the visualization of individual uncertainty contributions assists operators in identifying dominant uncertainty sources and supports maintenance and calibration planning. However, the proposed system was validated using a single OGM configuration and one flow computer platform. Therefore, the reported performance should be interpreted within the scope of the tested system. Future work should evaluate the proposed approach using different OGM configurations, additional flow computer platforms, and wider operating conditions to further assess its applicability in broader industrial environments.

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