Whitepaper

Endress+Hauser
People for Process Automation

Transferability of water calibration to gas applications in Promass flowmeters

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Executive summary

This whitepaper describes the validity of the initial water calibration of Coriolis flowmeters intended for use in gas applications. The transferability of calibration using alternative fluids has already been described in important normative documents such as AGA Report No. 11 API MPMS 14.9. Today, with the increase in flow measurement applications involved in the global energy transition strategy, this alternative approach is becoming more relevant. The discussion of the technical aspects supporting this approach, as well as the results obtained in third party gas calibrations of Coriolis flowmeters initially calibrated with water, will help our customers to understand our transferability approach.

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1 Introduction

The global energy-transition strategy, intended to change our energy production/consumption structures from fossil-based to renewable and less environmentally harmful sources, demands a particularly reliable measurement infrastructure. Fluid flow is a relevant quantity involved in this measurement infrastructure. Flowmeters based on the Coriolis principle have expanded their presence to a wide variety of applications other than liquids. International measurement organizations, such as AGA and API MPMS[1], have supported the use of Coriolis mass flowmeters in natural gas custody transfer applications, giving a clear signal of trust from the international measuring and engineering community to the use of this technology in gas applications. Thus, this flow measurement technology continues to be a valid option in the implementation of energy-transition strategies for fluids such as H_2, CO_2, natural gas, and others. Endress+Hauser provides a variety of Coriolis mass flowmeters with proven performance in gas applications. These flowmeters, initially calibrated using water as calibration fluid, have demonstrated good performance in gas applications without any further adjustment of the calibration parameters. This transferability from water calibration to gas applications is analyzed in this technical white paper. In addition, the results from third-party calibrations facilities using gas as calibration fluid are discussed.

2 Coriolis flowmeter principle of operation

The Coriolis flow measurement principle is based on the linear relationship between the mass flowing through the measuring tubes of the device (q_m) and the phase shift ($\Delta\varphi$) or delay (Δt) detected between two points equipped with electrodynamic sensors (A and B in Figure 1). Each read measuring tube oscillates at its resonance frequency, imposed by the excitation driver.

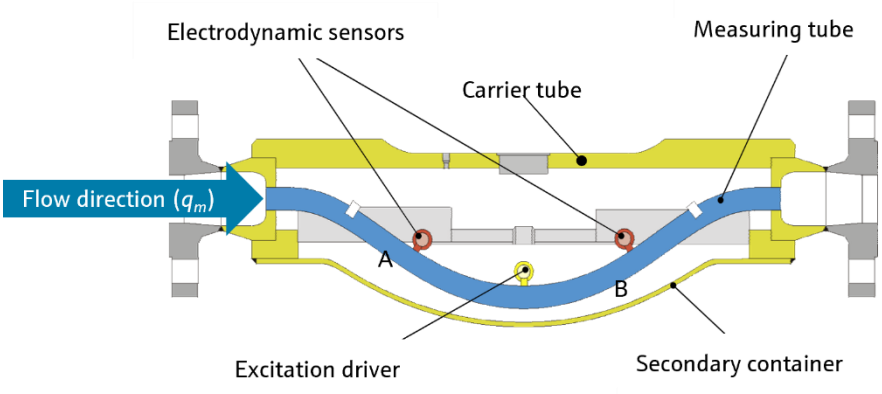

Figure 1: Coriolis sensor (simplified diagram).

[1] AGA: American Gas Association
API MPMS: American Petroleum Institute Manual of Petroleum Measurement Standards

The phase shift (Δφ) is caused by the so-called Coriolis force, which is proportional to the mass flow rate (q_m). The system balance is ensured by the antiphase oscillation of the two measuring tubes (Endress+Hauser Flow, 2022). In addition to the mass flow measurement, Coriolis mass flowmeters also measure other two variable, such as the density and temperature of the fluid.

A change in the total mass of the measuring tube, produced by a variation in a fluid density, will also produce a change in the measuring tube's resonance frequency, which is proportional to the fluid density. This variable is available as an output signal of the flowmeter.

A significant difference of temperature between the process temperature and a defined reference temperature (i.e., calibration fluid temperature) produces an offset effect in the density and mass flow rate measurements. This effect is compensated, using as input the signals supplied by temperature sensors installed in the measuring tube and in the instrument carrier. The process temperature measurement is also available as an output signal of the instrument.

The fluid pressure can also influence the flow and density measurements as a result of the deformation of the measuring tubes due to the internal pressure. By using the fluid pressure, either as a fixed value or the measured pressure supplied by a signal input of the instrument, this effect is also compensated in the instrument. A more detailed description of the effect of the pressure on Endress+Hauser Coriolis mass flowmeters and its compensation can be found in (Rojas Sossa, 2022).

3 Endress+Hauser Coriolis mass flowmeters in gas applications

Endress+Hauser Coriolis mass flowmeters have a significant presence in gas flow measurement applications worldwide. These flowmeters have demonstrated good performance under challenging gas measurement conditions, particularly where accurate and repeatable measurements are required and where direct mass reading is preferred. These flowmeters have been used in CNG (Compressed Natural Gas) dispensers for refueling natural gas vehicles, as well as various H_2 and CO_2 applications, mainly in custody transfer. The flowmeters have been certified for such applications by Notified Bodies and certification organizations such as the German Physikalisch-Technische Bundesanstalt (PTB), as a clear acknowledgement of compliance with the OIML-R137 (OIML-R137, 2012) recommendations established for these applications.

Gas applications are challenging for Coriolis mass flowmeters, mainly due to the low density of the fluid and consequently its operation at the lower end of the flowmeter's mass flow range. In this range, zero-point stability plays an important role. Endress+Hauser Coriolis mass flowmeters are designed with specific features to reduce this effect. Two examples of these features are the high homogeneity of the materials used to build these instruments and the strict symmetry tolerances allowed in their construction. These features help to balance the mechanical behavior of the measuring tube dynamics, thus reducing the effect on zero-point stability.

However, gas flow measurement with Coriolis mass flowmeters also deals with the compressible behavior and the low speed of sound (SoS) of the gas, responsible for introducing changes in the resonance frequency with respect to the driving frequency imposed on the measuring tubes. This gas-related frequency effect is mostly influenced by three elements: the SoS in the gas, the fluid velocity, and the measuring tube geometry. These three elements are taken into consideration when implementing corrections to mitigate their effect (Rieder & Aguilera-Mena, 2018).

4 Water to gas transferability

According to AGA Report No. 11 API MPMS Chapter 14.9, section 7 (API MPMS, 2013): "*Calibration with an alternative calibration fluid (e.g., water) is valid with Coriolis sensor designs where the transferability of the alternative calibration fluid, with an added uncertainty relative to gas measurement, has been demonstrated by the meter manufacturer through tests conducted by an independent flow calibration laboratory*." This statement recognizes the calibration results obtained in gas measurement with Coriolis mass flowmeters originally calibrated with water, whenever the new measurement error and measurement uncertainties values are clearly demonstrated. This alternative becomes a feasible option in avoiding expensive initial gas calibration/ verification, which is also difficult to implement due to the lack of proper gas flow calibration facilities.

4.1 Water calibration as initial metrological confirmation for flowmeters to be used in gas applications

Endress+Hauser Coriolis mass flowmeters are initially calibrated in water calibration facilities, accredited in conformity to ISO/IEC 17025 (ISO/IEC-17025, 2017) by accreditation bodies such as Swiss Accreditation Service (SAS), American Association for Laboratory Accreditation (A2LA), China National Accreditation Service for Conformity Assessment (CNAS), or the Brazilian Instituto Nacional de Metrologia, Qualidade e Tecnologia (INMETRO). These calibration follows the standard ISO 4185 (ISO-4185, 1980), where the calibration factor (CALF) is determined by using the gravimetric approach as described in that standard.

Water calibration is a preferred approach that allows the consistent evaluation of flowmeter performance using a well-known fluid under reference conditions. Under these conditions, deviations can be identified, isolated and effectively corrected. Water calibration is therefore the ideal starting point to explore the flowmeter performance and to determine its flowmeter CALF, a parameter that characterizes the device's dynamic behavior. Consequently, flowmeters intended for gas applications can also be initially calibrated using water as a calibration fluid.

4.2 Proving Promass in gas applications

A sample of Endress+Hauser Coriolis mass flowmeters intended for gas applications has been systematically calibrated in third-party laboratories, such as the Gas Research Institute - Colorado

Engineering Experiment Station Inc. (GRI-CEESI), Southwest Research Institute (SwRI), Pigsar (Germany's national standard for high-pressure natural gas metering, together with PTB), Det Norske Veritas (DNV) and others, using gas in all cases. Figure 2 shows the results of the calibration of a Promass 83F in CEESI facilities, using water, air, and dry and wet natural gas as calibration fluids. The complete report of this calibration round can be found in (GRI-04/0172, 2004).

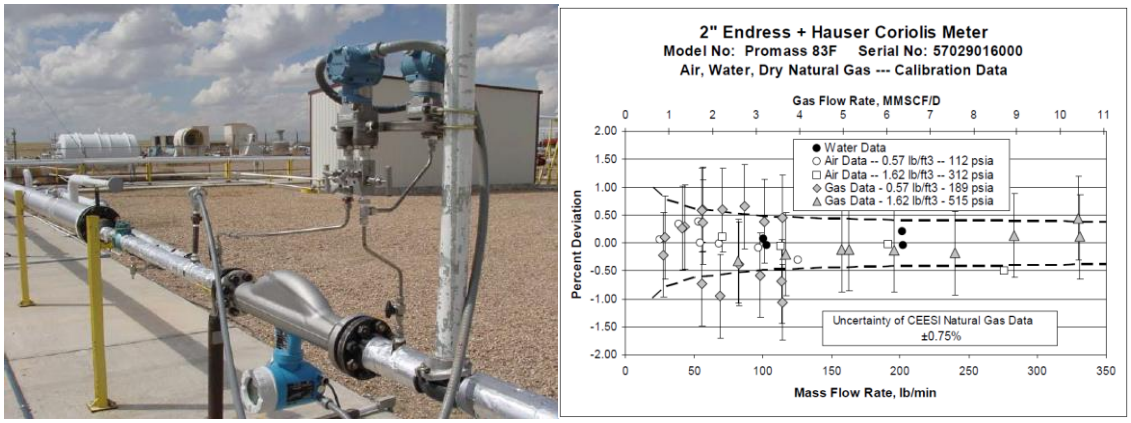

Figure 2: Promass 83F calibrated in CEESI wet test facility (left), result of the calibrations (right) (GRI-04/0172, 2004).

These third-party calibrations, which are part of our quality assurance policies, are intended to prove the performance of the meter in gas flow measurement under real process conditions, without any adjustments (as found) to the CALF obtained in water calibrations. Under new calibration facility conditions, a zero-point verification is a must, and a zero-point adjustment is performed if necessary (DE-19-MI002-PTB001, 2019). The basic setup used in these calibrations follow the manufacturer's installation requirements and the calibration procedure of the facility.

Ultimately, the goal is to prove that the flowmeters fulfill the maximum permissible error or tolerance limit according to the standard document under which the calibration is performed, as well as the maximum measured error specified by the manufacturer for the fluid and for the measured flow rate range.

Recent calibration results obtained in Pigsar facilities (see Figure 3) using natural gas as calibration fluid, are shown in Annexes 1 – 3. All the calibrations were performed using the same initial water CALF. The effect of the pressure on the flow reading was compensated in the instrument by considering the gas pressure as described in (Rojas Sossa, 2022).

The error values over the entire calibration range were always within the range of the maximum measurement error specified for gas flow measurement in the technical information of the instrument (Endress+Hauser Flow, 2022). This value corresponds to ±0.25% o.r. for the linear range of the instrument. Consequently, the errors are also within the OIML-R137 maximum permissible error (MPE) accuracy class 0.5.

The flow weighted mean error (FWME) and the expanded measurement uncertainty, U(k=2) per each flow rate value, can also be seen in each calibration certificate (Annexes 1 – 3).

Figure 3: Proline Promass Q DN200 being calibrated in Pigsar facilities using natural gas as calibration fluid.

The error curve of one the flowmeters calibrated in Pigsar combining natural gas and water calibration is shown in Figure 4 (see Annex 3). Promass Q DN 200 was initially calibrated with water in Endress+Hauser Flow facilities in Reinach. This calibration was made only at two points, 57 698 kg/h and 229 184 kg/h with ±0.1% o.r. of maximum permissible error, and an expanded measurement uncertainty, U(k=2), equal to 0.054%.

The combination of high zero-point stability with high repeatability and linearity at an extended turndown ratio (up to 33:1, see

Table **1**) exhibited by the instruments, allows to achieve this consistency between the calibration results in water and in natural gas throughout the calibrated range. This favorable behavior reinforces, with experimental data, the transferability approach from water to gas addressed in this whitepaper.

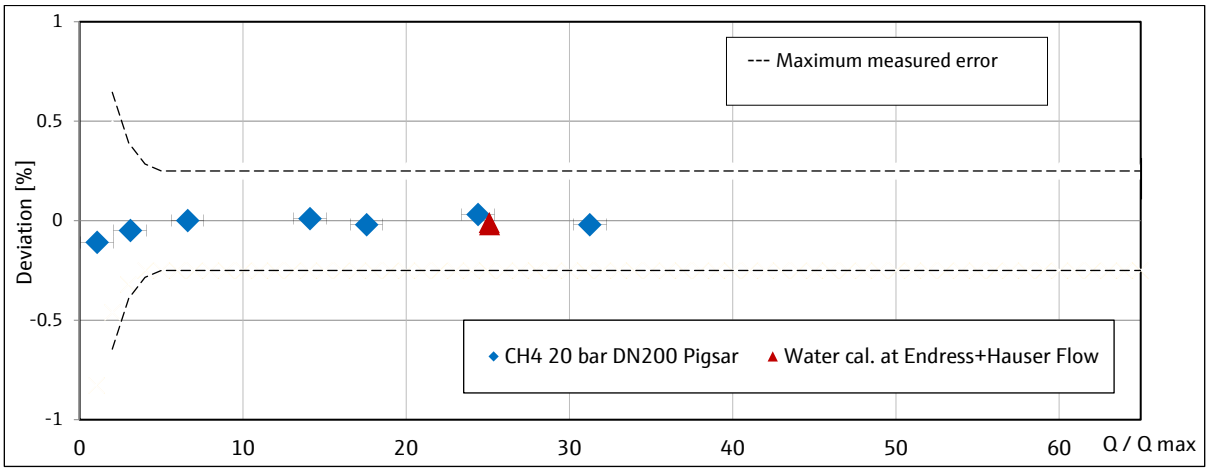

Figure 4: Error curve of a Promass Q DN 200 calibrated using water and natural gas: good measurement performance with natural gas, using the CALF value determined in water calibration.

The certificates for all the calibrations performed in Pigsar are shown in Annexes 1 – 3, according to the Table 1.

Table 1: List of Annexes with the calibration results for each Endress+Hauser flowmeter in third-party facilities.

Annex	Sensor model	DN	Calibration flow range [kg/h]	Turndown ratio	Pressure [bar]	Fluid	FWME [%]	Calibration facility
1	Promass F	25	84 – 2 800	33:1	20	CH_4	−0.1	Pigsar
2	Promass Q	25	84 – 2 800	33:1	20	CH_4	−0.08	Pigsar
3	Promass Q	200	2 400 – 70 000	29:1	20	CH_4	0.0	Pigsar
4	Promass Q	80	455 – 746	1.6:1	30	H_2	0.18	DNV
			493 – 1 091	2.2:1	2.3	N_2	0.08	DNV
			466 – 1 337	2.9:1	40	H_2	0.33	DNV
			7 184 – 36 021	5:1	2.1	H_2O	–	Endress+Hauser Flow

Another group of calibrations was carried out on Promass Q DN 80 in DNV facilities, this time using hydrogen at 30 bar and 40 bar, and nitrogen at 2.3 bar, see Annex 4. This flowmeter was also initially calibrated with water at Endress+Hauser Flow, Reinach, at five points, from 7 184 kg/h to 36 021 kg/h, with ±0.05% o.r. of the maximum permissible error and U(k=2) equal to 0.025%.

The “as found” gas calibrations were performed at mass flow rates, between approximately 1.3% and 4%, relative to the maximum calibrated flowrate in water. For these calibrations the gas density was ranging from 2.3 kg/m^3 to 3.3 kg/m^3, which is a common scenario for H_2 applications.

The error (deviation) during the calibration, the standard deviation (Std. Dev (95%)) of the error, as a measure of the repeatability, and the expanded measurement uncertainty (U_{-tot} (95%)) are shown in Annex 4. The flow weighted mean error values (FWME), as defined in AGA Report No. 11 API MPMS Chapter 14.9) can also be seen in this annex.

As shown in Figure 5, even in this region of the flowmeter range, where the stability at zero-point is relevant, the error values obtained during the calibration were within the band of the maximum measured error for gas fluids at these flow rates (trumpet or non-linear region). It is also remarkable, that most of the error values were also within the maximum measured error value specified in the instrument’s technical information for gas flow measurement in the linear region (±0.25% o.r.).

This performance is possible due to the high zero-point stability and the instrument’s high repeatability and linearity, also shown under gas measurement conditions.

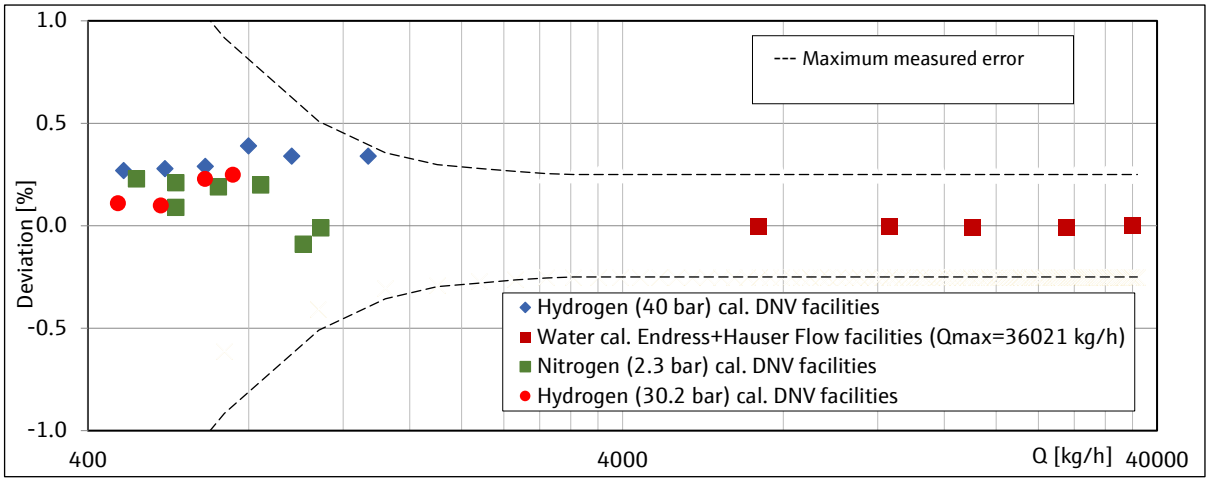

Figure 5: Error curve of Promass Q DN 80 combining H_2, N_2 and water calibration.

5 Conclusion

Endress+Hauser Coriolis mass flowmeters have consistently shown a very good performance in diverse gas applications using the same CALF obtained during their initial water calibration. Beyond the theoretical considerations, there are trustable results obtained in third-party gas calibration facilities using different sensors and nominal diameters, different fluids, pressures, densities, etc., all of them initially calibrated using water and with no further adjustments in CALF. Some of these recent calibrations are shown in this document.

These results are possible thanks to the advanced design of Endress+Hauser Coriolis mass flowmeters, which combines high zero-point stability with high repeatability and linearity at an extended turndown ratio. On the other hand, influencing factors such as the gas speed of sound (SoS) and the pressure effect in the oscillating tubes are also taken into account for their proper correction.

The validation of these results is one of the factors considered by the Notified Bodies when granting custody transfer certificates according to OIML-R137 for Endress+Hauser Coriolis mass flowmeters. To maintain such certifications, periodic testing of the instruments in third-party calibration facilities is also required. The results of these tests also allow us to extend and reinforce the Endress+Hauser transferability approach applied to our family of Coriolis mass flowmeters when used in gas applications. This eliminates the need for new, expensive and time-consuming special calibrations in gas. At the same time, the instruments maintain their performance requirements as stated in the technical information and required by national and international standards.

6 References

API MPMS, C. 1. (2013). Measurement of Natural Gas by Coriolis Meter.

DE-19-MI002-PTB001. (2019). *EU Type-examination Certificate Promass F/O/X 300/500. PTB.*

Endress+Hauser Flow. (2022). TI01222D/06/EN/08.21. *Technical Information Proline Promass F 500 Coriolis flowmeter*.

GRI-04/0172. (2004). Gas Research Institute: Topical Report, Coriolis mass flow meter performance with water, air, dry-gas and wet–gas.

ISO/IEC-17025. (2017). General requirements for the competence of testing and calibration laboratories.

ISO-4185. (1980). Measurement of liquid flow in closed conduits Weighing method.

OIML-R137. (2012). International Organization of Legal Metrology. *Gas Meters, P. 1 Metrological and technical requirements, P. 2 Metrological controls and performance tests (Including Amendment 2014)*.

Rieder, A., & Aguilera-Mena, J. (2018). Coriolis Flow meters. *Japanese Society of Mechanical Engineers Handbook*.

Rojas Sossa, V. (2022). Pressure effect of Coriolis Flowmeters and compensation. *Endress+Hauser Flow, Technical Paper*.

Appendix

Annex 1: Promass F DN 25; 84 kg/h – 2800 kg/h CH_4 @20 bar

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Operator of German National Standards for volume of high-pressure natural gas

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Calibration Certificate
Number 19225/2021
Date 2021-05-06

Applicant	Name:	Endress & Hauser Flowtec AG
	Order no.	275001178
Meter under test	Description:	Coriolis meter
	Manufacturer:	Endress+Hauser
	Type:	Promass F
	Serial number:	S31AE202000
	Nominal size:	1"
	Range of flowrate:	84...2800 kg/h
	Year of manufacture:	2021
	Nominal diameter of meter:	25 mm
	Nominal diameter of flange:	25 mm
	Nominal flange pressure:	ANSI 600 RF
Date of test	2021-05-06	
Results	The results of the calibration are presented on page 3.	
Test procedure	PTB-Prüfregeln Band 30, Messgeräte für Gas, Hochdruckprüfung von Gaszählern Physikalisch-Technische Bundesanstalt, Braunschweig und Berlin, 2003	
Test facility	*pigsar* represents the National Standard of the Federal Republic of Germany for the unit of volume for high pressure natural gas under supervision of PTB. *pigsar* disseminates the harmonised values for the unit of volume for high pressure gas flow measurements of the Federal Republic of Germany, France and The Netherlands. *pigsar* maintains a management system according to EN ISO 17025.	
Traceability	The presented results of the calibration are based on the unified Dutch-French-German reference values for the unit of volume for high-pressure gas flow measurements. On June-02-1999, PTB (Physikalisch-Technische Bundesanstalt) and VSL (formerly NMi-VSL, Netherlands Measurement Institute - Van Swinden Laboratorium) and later on May-04-2004 LNE (The Laboratoire national de métrologie et d'essais) have joined the harmonization (unification) procedure and the use of these reference values, see page 2.	

Dorsten, 2021-05-06

German National Standards for Volume of High Pressure Natural Gas
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Certificate Number: 19225/2021
Date: 2021-05-06

Applicant Endress & Hauser Flowtec AG

Meter under Test

Type	Coriolis meter Promass F
Manufacturer	Endress+Hauser
Serial number	S31AE202000
Nominal Size	1"
Year of manufacture	2021

Test Conditions

Test medium	Natural gas		CO_2	1,57	mole %
Pressure, absolute	21,2	bar	H_2	0,0	mole %
Gas Temperature	17	°C	Calorific value,s	10,35	kWh/m³
Gas density (p, T)	17,0	kg/m³	Density,normal	0,8306	kg/m³
Dyn. viscosity (p, T)	1,15E-5	Pa s	Normal conditions (273,15 K; 101,325 kPa)		

Results (as left)

Qi / Qmax	Qi (kg/h)	Reynoldsnumber	Deviation (%)	n	Umeter (%)	Utot (%)
0,03	**82,77**	0,10 *10⁶	**0,09**	5	0,05	0,28
0,05	**128,17**	0,16 *10⁶	**0,17**	5	0,04	0,25
0,10	**282,89**	0,35 *10⁶	**0,09**	5	0,05	0,24
0,21	**600,77**	0,74 *10⁶	**-0,06**	5	0,03	0,23
0,46	**1296,39**	1,61 *10⁶	**-0,12**	6	0,12	0,26
0,64	**1794,62**	2,22 *10⁶	**-0,18**	5	0,08	0,24
1,02	**2843,55**	3,48 *10⁶	**-0,03**	5	0,12	0,26

Weighted mean error, with continuous and linear decrease of weighing factor between 0,7 Qmax and Qmax: **-0,1 %.**

The *deviation* is defined as: $Deviation = \frac{(Indicated\ Value - Reference\ Value)}{(Reference\ Value)} \cdot 100\,\%$

where the reference volume refers to the conditions at the meter under test. The reported values of this deviation are the arithmetical means of *n* single repeat measurements at each flow-rate.

The reported *total uncertainty* is defined as: $U_{tot} = \sqrt{U^2_{harmonized} + U^2_{meter}}$

where $U_{hamonized}$ is the expanded uncertainty of the harmonized reference value, stated as the standard uncertainty of measurement multiplied by the coverage factor *k*=2, and U_{meter} is the expanded standard uncertainty of the meter under test, determined on the base of n repeats at each flow-rate, multiplied by Student-t-factor (n) / $n^{0,5}$, with a probability of 95%.

Remarks Security marks are applied
At customer´s request the meter had not been adjusted.
The meter had been calibrated at 20 bar and at 40 bar.
The results at 40 bar are presented in certificate no. 19224/2021.

Following parameters have been used during the calibration and have an influence to the test results:
Measuring mode: Gas
Gas type: Methane
Meter factor: 2,0496
Stored zero(pipo): 1,4
Sensor pressure corr. (bar): 20
Zero offset before calibration (g/3 min): 6,121
Zero offset after calibration (g/3 min): 4,338

Tested in Dorsten at *pigsar*, on 2021-05-06 Göbbeler

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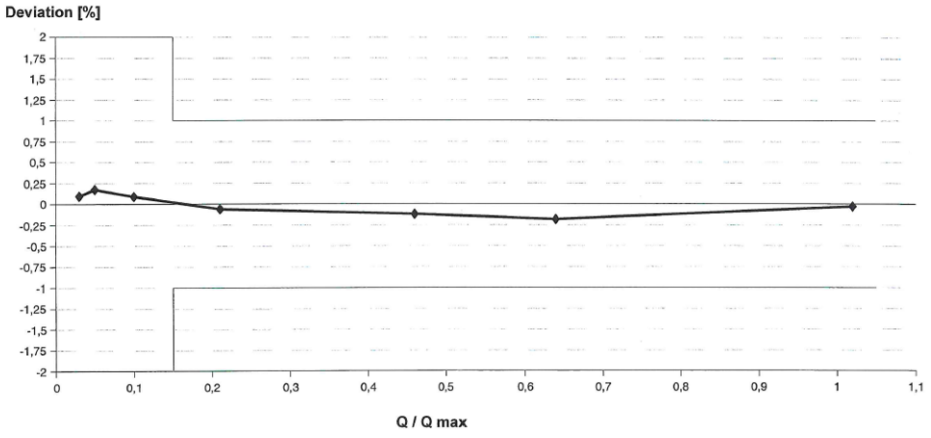
19225/2021

Error Curve

Type of meter:	Coriolis meter	Customer:	Endress & Hauser Flowtec AG	DN:	25 mm	p(abs):	21	bar	HF	1000,00 pulses / kg
Meter no:	S31AE202000	Manufacturer:	Endress+Hauser	Size:	1"	Q max:	2800	kg/h	-	pulses / kg
Date:	2021-05-06	Gear 1:	-			Q min:	84	kg/h	-	pulses / kg
Inspector:	Göbbeler	Gear 2:	-			-		pulses / kg	-	pulses / kg



Annex 2: Promass Q DN 25; 84 kg/h – 2800 kg/h CH_4 @20 bar

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Calibration Certificate

Number 19189/2021
Date 2021-04-23

Applicant	Name:	Endress & Hauser Flowtec AG
	Order no.	275001178
Meter under test	Description:	Coriolis meter
	Manufacturer:	Endress+Hauser
	Type:	Promass Q
	Serial number:	RB0F7202000
	Nominal size:	1"
	Range of flowrate:	84...2800 kg/h
	Year of manufacture:	2020
	Nominal diameter of meter:	25 mm
	Nominal diameter of flange:	25 mm
	Nominal flange pressure:	ANSI 600 RF
Date of test	2021-04-23	
Results	The results of the calibration are presented on page 3.	
Test procedure	PTB-Prüfregeln Band 30, Messgeräte für Gas, Hochdruckprüfung von Gaszählern Physikalisch-Technische Bundesanstalt, Braunschweig und Berlin, 2003	
Test facility	*pigsar* represents the National Standard of the Federal Republic of Germany for the unit of volume for high pressure natural gas under supervision of PTB. *pigsar* disseminates the harmonised values for the unit of volume for high pressure gas flow measurements of the Federal Republic of Germany, France and The Netherlands. *pigsar* maintains a management system according to EN ISO 17025.	
Traceability	The presented results of the calibration are based on the unified Dutch-French-German reference values for the unit of volume for high-pressure gas flow measurements. On June-02-1999, PTB (Physikalisch-Technische Bundesanstalt) and VSL (formerly NMi-VSL, Netherlands Measurement Institute - Van Swinden Laboratorium) and later on May-04-2004 LNE (The Laboratoire national de métrologie et d'essais) have joined the harmonization (unification) procedure and the use of these reference values, see page 2.	

Dorsten, 2021-04-23

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Certificate Number: 19189/2021
Date: 2021-04-23

Applicant Endress & Hauser Flowtec AG

Meter under Test	Type		Coriolis meter Promass Q			
	Manufacturer		Endress+Hauser			
	Serial number		RB0F7202000			
	Nominal Size		1"			
	Year of manufacture		2020			
Test Conditions	Test medium	Natural gas	CO_2	1,53	mole %	
	Pressure, absolute	21,2 bar	H_2	0,0	mole %	
	Gas Temperature	17 °C	Calorific value,s	10,36	kWh/m³	
	Gas density (p, T)	17,0 kg/m³	Density,normal	0,8312	kg/m³	
	Dyn. viscosity (p, T)	1,15E-5 Pa s	Normal conditions (273,15 K; 101,325 kPa)			

Results (as left)

Qi / Qmax	Qi (kg/h)	Reynoldsnumber	Deviation (%)	n	Umeter (%)	Utot (%)
0,03	**85,09**	0,11 *10⁶	**-0,11**	6	0,12	0,30
0,05	**132,83**	0,16 *10⁶	**0,04**	5	0,05	0,25
0,10	**281,18**	0,35 *10⁶	**0,13**	5	0,03	0,24
0,22	**602,46**	0,74 *10⁶	**0,03**	5	0,03	0,23
0,46	**1278,39**	1,58 *10⁶	**-0,17**	5	0,10	0,25
0,64	**1804,60**	2,22 *10⁶	**-0,13**	5	0,19	0,30
0,98	**2735,50**	3,35 *10⁶	**-0,01**	6	0,14	0,27

Weighted mean error, with continuous and linear decrease of weighing factor between 0,7 Qmax and Qmax: **-0,08 %.**

The *deviation* is defined as: $Deviation = \frac{(Indicated\ Value - Reference\ Value)}{(Reference\ Value)} \cdot 100\,\%$

where the reference volume refers to the conditions at the meter under test. The reported values of this deviation are the arithmetical means of *n* single repeat measurements at each flow-rate.

The reported *total uncertainty* is defined as: $U_{tot} = \sqrt{U^2_{harmonized} + U^2_{meter}}$

where $U_{harmonized}$ is the expanded uncertainty of the harmonized reference value, stated as the standard uncertainty of measurement multiplied by the coverage factor *k*=2, and U_{meter} is the expanded standard uncertainty of the meter under test, determined on the base of n repeats at each flow-rate, multiplied by Student-t-factor (n) / $n^{0,5}$, with a probability of 95%.

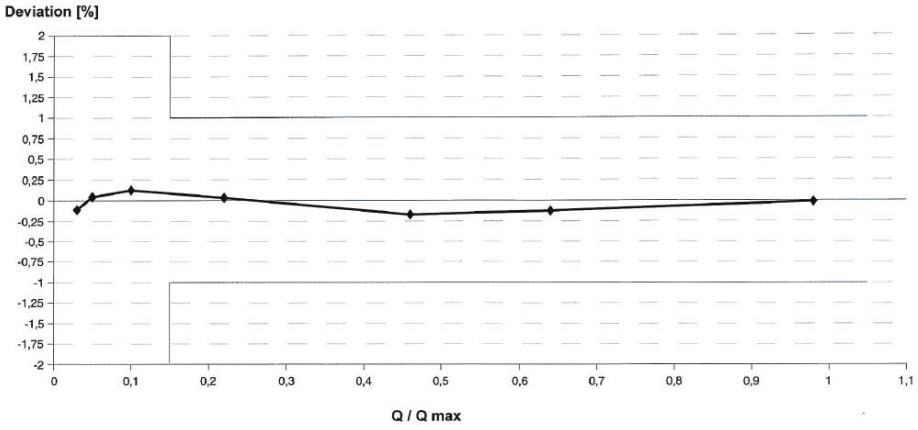
Remarks Security marks are applied
At customer´s request the meter had not been adjusted.
The meter had been calibrated at 20 bar and at 40 bar.
The results at 40 bar are presented in certificate no. 19222/2021.

Following parameters have been used during the calibration and have an influence to the test results:
Measuring mode: Gas
Gas type: Methane
Meter factor: 0,83113
Stored zero(pipo): -43,1
Sensor pressure corr. (bar): 20
Zero offset before calibration (g/3 min): -5,281
Zero offset after calibration (g/3 min): -0,151

Tested in Dorsten at *pigsar*, on 2021-04-23 Görgülü

Error Curve

Type of meter:	Coriolis meter	Customer:	Endress & Hauser Flowtec AG	DN:	25 mm	p(abs):	21	bar	HF	2000,00 pulses / kg
Meter no:	RB0F7202000	Manufacturer:	Endress+Hauser	Size:	1"	Q max:	2800	kg/h	-	pulses / kg
Date:	2021-04-23	Gear 1:	-			Q min:	84	kg/h	-	pulses / kg
Inspector:	Görgülü	Gear 2:	-			-		pulses / kg	-	pulses / kg



Annex 3: Promass Q DN200; 2400 kg/h – 70000 kg/h CH_4 @20 bar

pigsar ™
Operator of German National Standards for volume of high-pressure natural gas

page 1 of 4

Calibration Certificate
Number 19756/2021
Date 2021-12-15

Applicant	Name:	Endress+Hauser Flowtec AG
	Order no.	1005273117
Meter under test	Description:	Coriolis meter
	Manufacturer:	Endress+Hauser
	Type:	Promass Q
	Serial number:	TEST0002145
	Nominal size:	8"
	Range of flowrate:	2400...70000 kg/h
	Year of manufacture:	2021
	Nominal diameter of meter:	200 mm
	Nominal diameter of flange:	200 mm
	Nominal flange pressure:	ANSI 600 # RF
Date of test	2021-12-15	
Results	The results of the calibration are presented on page 3.	
Test procedure	PTB-Prüfregeln Band 30, Messgeräte für Gas, Hochdruckprüfung von Gaszählern Physikalisch-Technische Bundesanstalt, Braunschweig und Berlin, 2003	
Test facility	*pigsar* represents the National Standard of the Federal Republic of Germany for the unit of volume for high pressure natural gas under supervision of PTB. *pigsar* disseminates the harmonised values for the unit of volume for high pressure gas flow measurements of the Federal Republic of Germany, France and The Netherlands. *pigsar* maintains a management system according to EN ISO 17025.	
Traceability	The presented results of the calibration are based on the unified Dutch-French-German reference values for the unit of volume for high-pressure gas flow measurements. On June-02-1999, PTB (Physikalisch-Technische Bundesanstalt) and VSL (formerly NMi-VSL, Netherlands Measurement Institute - Van Swinden Laboratorium) and later on May-04-2004 LNE (The Laboratoire national de métrologie et d'essais) have joined the harmonization (unification) procedure and the use of these reference values, see page 2.	

Dorsten, 2021-12-15

Operator of German National Standards for Volume of High-Pressure Natural Gas
pigsar ™ State Approved Facility Management System according to ISO/IEC 17025

pigsarTM · Vier Gas Services GmbH & Co. KG · Halterner Straße 125 · 46284 DORSTEN · GERMANY · www.pigsar.de · e-mail: info@pigsar.de

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page 3 of 4

Certificate Number: 19756/2021
Date: 2021-12-15

Applicant	Endress+Hauser Flowtec AG					
Meter under Test	Type	Coriolis meter Promass Q				
	Manufacturer	Endress+Hauser				
	Serial number	TEST0002145				
	Nominal Size	8"				
	Year of manufacture	2021				
Test Conditions	Test medium	Natural gas		CO_2	1,41	mole %
	Pressure, absolute	20,6 bar		H_2	0,0	mole %
	Gas Temperature	20 °C		Calorific value,s	10,36	kWh/m³
	Gas density (p, T)	16,3 kg/m³		Density,normal	0,8299	kg/m³
	Dyn. viscosity (p, T)	1,15E-5 Pa s		Normal conditions (273,15 K; 101,325 kPa)		

Results (as left)

Qi / Qmax	Qi (kg/h)	Reynoldsnumber	Deviation (%)	n	Umeter (%)	Utot (%)
0,03	**2426,27**	0,37 *10⁶	**-0,11**	7	0,03	0,23
0,10	**7089,82**	1,09 *10⁶	**-0,05**	6	0,04	0,23
0,22	**15157,84**	2,33 *10⁶	**0,00**	6	0,02	0,23
0,46	**32303,27**	4,96 *10⁶	**0,01**	6	0,04	0,24
0,57	**40249,26**	6,18 *10⁶	**-0,02**	6	0,08	0,25
0,80	**55909,73**	8,59 *10⁶	**0,03**	7	0,14	0,27
1,02	**71591,80**	11,06 *10⁶	**-0,02**	8	0,12	0,26

Weighted mean error, with continuous and linear decrease of weighing factor between 0,7 Qmax and Qmax: **0 %.**

The *deviation* is defined as: $Deviation = \frac{(Indicated\ Value - Reference\ Value)}{(Reference\ Value)} \cdot 100\ \%$

where the reference volume refers to the conditions at the meter under test. The reported values of this deviation are the arithmetical means of *n* single repeat measurements at each flow-rate.

The reported *total uncertainty* is defined as: $U_{tot} = \sqrt{U^2_{harmonized} + U^2_{meter}}$

where $U_{harmonized}$ is the expanded uncertainty of the harmonized reference value, stated as the standard uncertainty of measurement multiplied by the coverage factor *k*=2, and U_{meter} is the expanded standard uncertainty of the meter under test, determined on the base of n repeats at each flow-rate, multiplied by Student-t-factor (n) / $n^{0,5}$, with a probability of 95%.

Remarks Security marks are applied

The meter had been calibrated at 20 bar and at 40 bar.
The results at 20 bar are presented in certificate no. 19756/2021.

Tested in Dorsten at *pigsar*, on 2021-12-15 Görgülü

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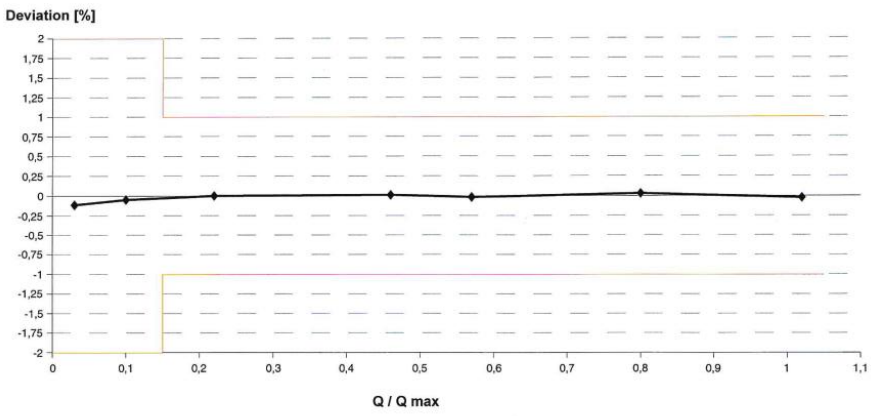
Calibration certificates without signature and seal on the first page are not valid.

Error Curve

Type of meter:	Coriolis meter	Customer:	Endress+Hauser Flowtec AG	DN:	200 mm	p(abs):	21	bar	HF	62,5000 pulses / kg
Meter no:	TEST0002145	Manufacturer:	Endress+Hauser	Size:	8"	Q max:	70000	kg/h	-	pulses / kg
Date:	2021-12-15	Gear 1:	-			Q min:	2400	kg/h	-	pulses / kg
Inspector:	Görgülü	Gear 2:	-			-		pulses / kg	-	pulses / kg



Annex 4: Promass Q DN80; 455 kg/h – 746 kg/h H_2 @30 bar; 493 kg/h – 1091 kg/h N_2 @2.3 bar; 466 kg/h – 1337 kg/h H_2 @40 bar; 7184 kg/h – 36021 kg/h H_2O @2.1 bar

DNV

Test Certificate

Applicant: Endress+Hauser Flowtec AG, Christoph Merian-Ring 4, 4153 Reinach, Switzerland
Certificate No: H003
Page: 1 of 2

Meter: Serial No: T6040202000; Meter type ID: Promass Q 300, DN80; Manufacturer: Endress+Hauser Flowtec AG; Type: Coriolis; Build Year: 2022
G-size: n.a.; Pressure rate: ANSI-300; Diameter [mm]: 100; Q-min [kg/h]: 0; Q-max [kg/h]: 5904; P-max [bar]: -; Density range [kg/m³]: -

Appendix:

Project Description: Flowtest of E+H Coriolis on DNV hydrogen loop — Project No: 10370462

Test method: The deviation of the meter under test is established with the master meter method.

Gascomposition [mol%]: H_2: 99,998, N_2 >0,002%

Test Date: 2022-07-20

Result: The 'As Left' results of the Test are presented on page 2.

Uncertainty: The reported expanded uncertainty is based on the standard uncertainty of the measurement resulting in a coverage probability corresponds to 95% uncertainty. The standard uncertainty has been estimated based on known Test and esimated model uncertainties.

Traceability: The reference turbine meter used was calibrated at 4 pressures in ISO 17025 accredited labs. The behaviour of the turbine reference meter under hydrogen has been predicted using the PTB turbine model, described in DNV document ESNL.220127.FFA.
Precaution is that the reference is not compared with other references under hydrogen flow.

Remark: Reference meter: 4" Elster Instromet SM-RI-X, G250, built 2014, s.n. 10520901

Signatures: For DNV Netherlands B.V. Groningen 2022-12-09
Task responsible: Peter Groeneveld
Principal analist: Bertus Bergsma

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DNV

Meter: Serial No: T6040202000; Meter type ID: Promass Q 300, DN80; Manufacturer: Endress+Hauser Flowtec AG; Type: Coriolis
Certificate No: H003
Page: 2 of 2

Adjustment [%]: no
FWME As Lft [%]: 0,18

Results:

Rev. flow [m³/h]	MUT flow [kg/h]	Deviation [%]	CMC (95%) [%]	Std Dev (95%) [%]	U-tot (95%) [%]	Reynolds [-]
316	746	0,25	0,36	0,23	0,42	301236
280	662	0,23	0,36	0,08	0,37	268579
232	547	0,10	0,36	0,13	0,38	222647
193	455	0,11	0,36	0,12	0,38	185220

Location	Date		Medium	P [bar](abs)	T [°C]	Rho [kg/m³]
Groningen	2022-07-20		Hydrogen	30,2	33,0	2,36

Deviation: Formula = ((IndicatedFlow / ReferenceFlow) - 1) * 100%

CMC: Test and Measurement Capability is the (95%) uncertainty that is normally available for Tests.

U-tot: U-tot is the total (95%) measurement uncertainty.

Ambient conditions: 33 ± 2 °C

Disclaimer: Please note that this report reflects the performance of the calibrated device only at the time of test and in the circumstances prevailing during the Test.

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DNV

Test Certificate

Applicant: Endress+Hauser Flowtec AG, Christoph Merian-Ring 4, 4153 Reinach, Switzerland
Certificate No: H002
Page: 1 of 2

Meter: Serial No: T6040202000; Meter type ID: Promass Q 300, DN80; Manufacturer: Endress+Hauser Flowtec AG; Type: Coriolis; Build Year: 2022
G-size: n.a.; Pressure rate: ANSI-300; Diameter [mm]: 100; Q-min [kg/h]: 0; Q-max [kg/h]: 4842; P-max [bar]: -; Density range [kg/m³]: -

Appendix:

Project Description: Flowtest of E+H Coriolis on DNV hydrogen loop — Project No: 10370462

Test method: The deviation of the meter under test is established with the master meter method.

Gascomposition [mol%]: N2 >99,9%

Test Date: 2022-07-19

Result: The 'As Left' results of the Test are presented on page 2.

Uncertainty: The reported expanded uncertainty is based on the standard uncertainty of the measurement resulting in a coverage probability corresponds to 95% uncertainty. The standard uncertainty has been estimated based on known Test and esimated model uncertainties.

Traceability: The reference turbine meter used was calibrated at 4 pressures in ISO 17025 accredited labs. The behaviour of the turbine reference meter under hydrogen has been predicted using the PTB turbine model, described in DNV document ESNL.220127.FFA.
Precaution is that the reference is not compared with other references under hydrogen flow.

Remark: Reference meter: 4" Elster Instromet SM-RI-X, G250, built 2014, s.n. 10520901

Signatures: For DNV Netherlands B.V. Groningen 2022-12-09
Task responsible: Peter Groeneveld
Principal analist: Bertus Bergsma

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DNV

Meter: Serial No: T6040202000; Meter type ID: Promass Q 300, DN80; Manufacturer: Endress+Hauser Flowtec AG; Type: Coriolis
Certificate No: H002
Page: 2 of 2

Adjustment [%]: no
FWME As Lft [%]: 0,08

Results:

Rev. flow [m³/h]	MUT flow [kg/h]	Deviation [%]	CMC (95%) [%]	Std Dev (95%) [%]	U-tot (95%) [%]	Reynolds [-]
426	1091	-0,01	0,55	0,10	0,56	219011
395	1010	-0,09	0,55	0,08	0,55	202612
330	841	0,20	0,55	0,15	0,57	168421
276	701	0,19	0,55	0,08	0,55	140813
230	584	0,09	0,55	0,16	0,57	117709
194	493	0,23	0,55	0,01	0,55	99388
231	584	0,21	0,55	0,02	0,56	118187

Location	Date		Medium	P [bar](abs)	T [°C]	Rho [kg/m³]
Groningen	2022-07-19		Nitrogen	2,3	33,0	2,56

Deviation: Formula = ((IndicatedFlow / ReferenceFlow) - 1) * 100%

CMC: Test and Measurement Capability is the (95%) uncertainty that is normally available for Tests.

U-tot: U-tot is the total (95%) measurement uncertainty.

Ambient conditions: 33 ± 2 °C

Disclaimer: Please note that this report reflects the performance of the calibrated device only at the time of test and in the circumstances prevailing during the Test.

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DNV

Test Certificate

Applicant:	Endress+Hauser Flowtec AG Christoph Merian-Ring 4 4153 Reinach Switzerland	Certificate No: Page:	**H001** 1 of 2
Meter:	Serial No: T6040202000 Meter type ID: Promass Q 300, DN80 Manufacturer : Endress+Hauser Flowtec AG Type: Coriolis Build Year: 2022	G-size: Pressure rate: Diameter [mm]: Q-min [kg/h]: Q-max [kg/h]: P-max [bar]: Density range [kg/m³]:	n.a. ANSI-300 100 0 7836 - -
Appendix:			
Project Description:	**Flowtest of E+H Coriolis on DNV hydrogen loop**	Project No :	10370462
Test method:	The deviation of the meter under test is established with the master meter method.		
Gascomposition [mol%]: H_2: 99,996 N_2: 0,004			
Test Date:	2022-07-20		
Result:	The 'As Left' results of the Test are presented on page 2.		
Uncertainty:	The reported expanded uncertainty is based on the standard uncertainty of the measurement resulting in a coverage probability corresponds to 95% uncertainty. The standard uncertainty has been estimated based on known Test and esimated model uncertainties.		
Traceabillity:	The reference turbine meter used was calibrated at 4 pressures in ISO 17025 accredited labs. The behaviour of the turbine reference meter under hydrogen has been predicted using the PTB turbine model, described in DNV document ESNL.220127.FFA. Precaution is that the reference is not compared with other references under hydrogen flow.		
Remark:	Reference meter: 4" Elster Instromet SM-RI-X, G250, built 2014, s.n. 10520901		

Signatures: For DNV Netherlands B.V. Groningen 2022-12-09

Task responsible: Peter Groeneveld

Principal analist: Bertus Bergsma

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DNV

Meter:	Serial No: Meter type ID: Manufacturer : Type:	T6040202000 Promass Q 300, DN80 Endress+Hauser Flowtec AG Coriolis	Certificate No: Page: **H001** 2 of 2

Adjustment [%]: no

FWME As Lft [%]: 0,33

Results:

Rev. flow [m³/h]	MUT flow [kg/h]	Deviation [%]	CMC (95%) [%]	Std Dev (95%) [%]	U-tot (95%) [%]	Reynolds [-]
426	1337	0,34	0,36	0,14	0,38	538583
307	962	0,34	0,35	0,03	0,36	387866
255	798	0,39	0,36	0,03	0,36	321464
212	663	0,29	0,36	0,13	0,38	267650
178	557	0,28	0,36	0,10	0,37	225427
149	466	0,27	0,36	0,10	0,37	188677

Location	Date		Medium	P [bar] (abs)	T [°C]	Rho [kg/m³]
Groningen	2022-07-20		Hydrogen	40,0	33,0	3,13

Deviation: Formula = ((IndicatedFlow / ReferenceFlow) - 1) * 100%

CMC: Test and Measurement Capability is the (95%) uncertainty that is normally available for Tests.

U-tot: U-tot is the total (95%) measurement uncertainty.

Ambient conditions: 33 ± 2 °C

Disclaimer: Please note that this report reflects the performance of the calibrated device only at the time of test and in the circumstances prevailing during the Test.

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Endress+Hauser
People for Process Automation

Certificate

Flow Calibration with Adjustment
N° 11054660

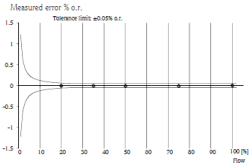
ilac-MRA SCS 0052

3015432979 Purchase order number	FCP-7.1.5 / gravimetric Reference: Calibration rig/Method
N.V. Nederlandse Gasunie Customer	36000 kg/h (≙ 100%) Calibrated full scale
NL-3007032251-10 / Endress+Hauser Flowtec AG Order N°/Manufacturer	Service interface Calibrated output
Promass Q 300 3" Sensor/Transmitter	0.52557 Calibration factor
T6040202000 / T6040202000 Serial N°	-17.2 Zero point
- Tag N°	25.8 °C Water temperature
New Condition	0.025 % Expanded uncertainty of measurement

Flow [%]	Flow [kg/h]	Duration [s]	m target [kg]	m meas. [kg]	Δ o.r.* [%]	Outp.** [mA]
20.0	7184.13	75.1	149.917	149.911	-0.004	7.19
35.0	12608.4	43.0	150.570	150.571	-0.003	9.60
50.1	18030.6	50.1	251.058	251.041	-0.007	12.01
75.0	26994.9	33.5	251.559	251.541	-0.007	16.00
100.1	36021.6	35.2	351.937	351.946	0.003	20.01
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-

*o.r.: of reading
**Calculated value (4 - 20 mA)

Measured error % o.r.



For detailed data concerning output specifications of the unit under test, see Technical Information (TI), chapter Performance characteristics.
This calibration certificate was generated electronically. It documents the traceability to national standards, which realize the physical units of measurements (SI).
The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k=2, which for a normal distribution corresponds to a coverage probability of approx. 95%. The expanded uncertainty of measurement includes uncertainty components of the reference, the calibration method, the environment and of the device under test. A typical value is used for the uncertainty component of the device under test. The reported results of measurement are single measurements.

15.06.2022
Date of calibration

M. Mancuso
Operator

Phuong Le
Head

Endress+Hauser Flowtec AG
Kägenstrasse 7
CH-4153 Reinach

Page 1 / 1