VSL

National Metrology Institute

EURAMET
Bilateral comparison

Final Report
11 October 2024

High flow rate water
150 t/h to 1200 t/h

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Introduction and purpose

VSL recently commissioned a new high flow rate water calibration facility (WF2500) within its European Center for Flow Measurement. This facility has a maximum flow rate of 2500 t/h flowing through four Coriolis master meters in parallel. The traceability for this system is based on the direct mass comparison of six individual Coriolis meters to VSL's existing 10t scale up to 500 t/h and a bootstrap calibration process building above 2000 t/h up to 2500 t/h.

The purpose of this Bilateral Comparison (BC) for "High flow rate water" measurement is to support the Calibration and Measurement Capabilities (CMC) of the new water flow facility at VSL as part of the CIPM MRA.

The aim of the comparison should lead to 'a clear and unequivocal' comparison of measurement results between VSL – The Netherlands and PTB - Germany.

This document presents the results of this bilateral comparison. All relevant documents used are referenced in Annex A.

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Revision history

DRAFT 21-07-2024	1) Update Technical Protocol to be the Final Report

1 Project details

The pilot laboratory for this bilateral comparison is VSL. The reference laboratory is PTB. The third-party data collection is IPQ. Details are given below:

Germany [reference lab] (Euramet)	**PTB** Contact: Enrico Frahm (e: Enrico.Frahm@ptb.de, t: 0531 592 1333) **Shipping address:** Physikalisch-Technische Bundesanstalt (PTB) Bundesallee 100 38116 Braunschweig Germany
The Netherlands [pilot] (Euramet)	**VSL B.V.** Contact: Erik Smits Chief Metrologist (e: fsmits@vsl.nl t: +31 15 269 1500) **Shipping address:** VSL B.V. ECFM Walrusweg 5 Port number 7006 3199ME Maasvlakte Rotterdam The Netherlands
Portugal [third party data collection] (Euramet)	**IPQ** Contact: Elsa Batista (e: ipq@ipq.pt t: +351 21 294 8100)

1.1 The reference value and flow rates

In this bilateral comparison project, the error of the travelling standard will be determined from:

"The mass flow rate of water passing through the travelling standard at given flows."

Flow rates: 150, 300, 400, 625, 800, 1200 t/h

The principles of analysis are:

- The before and after results obtained by VSL are used to determine the drift behavior of the travelling standard.
- The results provided by the participants are given under actual conditions.
- A third party (IPQ - Portugal) received the raw results from the participants and reviewed the comparison analysis.
- The results are calculated as measurement errors at the reference flows of each participant.
- The measurement errors are calculated for the travelling standard flow meter making use of the pulse output.
- The travelling standard was set up with a base k-factor (set to 15 pulses per kilogram).
- The results of each participant is corrected for changes in process conditions according to the flow meter manufacturer recommendations.

2 Description of the travelling standard

The travelling standard is an Emerson/Micro Motion CMFHC3 mass flow meter which operates according to the Coriolis principle and a model 5700 transmitter. Inlet and exit spools are provided with the travelling standard. A Rosemount 2051 pressure transmitter is installed on the inlet side and connected to the 5700 transmitter which is used for automatic pressure correction.

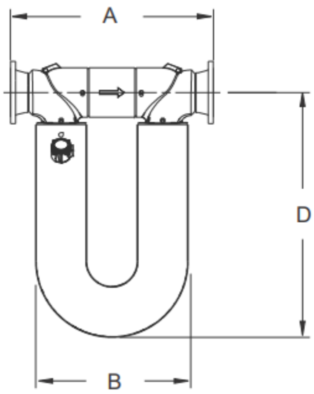
2.1 Description summary of the travelling standard

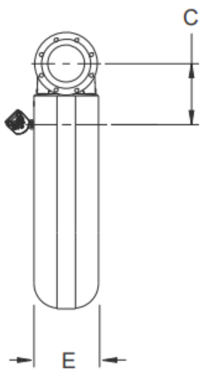
-	**Mass Flow Meter**
Make	: Emerson/Micro Motion
Type	: CMFHC3
Size	: 250mm
Serial number	: 13436784
Process connection	: DN250
Q_{max}	: 2550 t/h
Flow calibration factor	: 6920.74.26
Pressure effect	: -0.015 % per bar

-	**Coriolis Transmitter**
Make	: Emerson/Micro Motion
Type	: 5700
Serial number	: 19013316
Pulse value	: 15 pulses = 1 kg
	: valid for 0 … 10 kHz and flow between 0 t/h … 2,550 t/h

-	**Pressure Transmitter**
Make	: Emerson/Rosemount
Type	: 3051TG2A2B21BB4Q4M4
Serial number	: 22CLPG0029025
Range	: 0 – 10 bar [g]

2.2 Drawings of the travelling standard



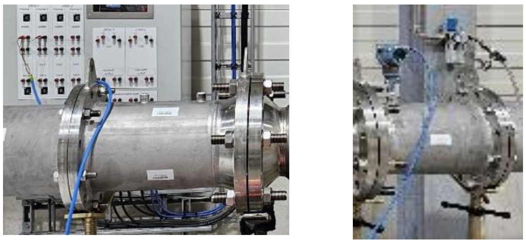


Dim.	mm		Weight	
A	1118		390.7	kg
B	838			
C	335			
D	1349			
E	356			

2.3 Pictures of the travelling standard

Picture 1 travelling standard and model 5700 transmitter.

Picture 2 connecting pipe spools.



3 Transportation

The travelling standard and associated equipment was transported to PTB from VSL and then returned to VSL with no issues or damage during this bilateral comparison.

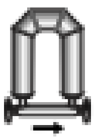
4 Measurement instructions

The measurements for the bilateral comparison were performed according to the test protocol to make sure good results between participants were achieved.

4.1 Measurement methods used by participants

Each participant chose their own method of calibration, but a minimum criterion was met to make sure the travelling standard performed optimally, and no extra measurement uncertainty was introduced.

- Calibration fluid was water at both locations.
- Travelling standard was mounted in the “tubes up” position.



4.2 Connections to the calibration facility

4.2.1 Process connections

VSL provided inlet and outlet spool pieces for the travelling standard. The spool pieces have DN250 PN10 flanges for connecting to each facility. Additional inlet and outlet piping required for connecting to each facility may have been used but was not required for the travelling standard.

4.2.2 Electrical connection

A power supply was not provided. The participants used their own power supply. The electronics accepts AC or DC power according to the table below:

Type	Value
AC power	▪ 85 to 240 VAC, 50/60 Hz ▪ 6 watts typical, 11 watts maximum
DC power	▪ 18 to 100 VDC ▪ 6 watts typical, 11 watts maximum ▪ Size the length and diameter of power conductors to provide 18VDC minimum at the power terminals at a load current of 0.7A
Fuse	1.5A Slow Blow (UL 248-14)

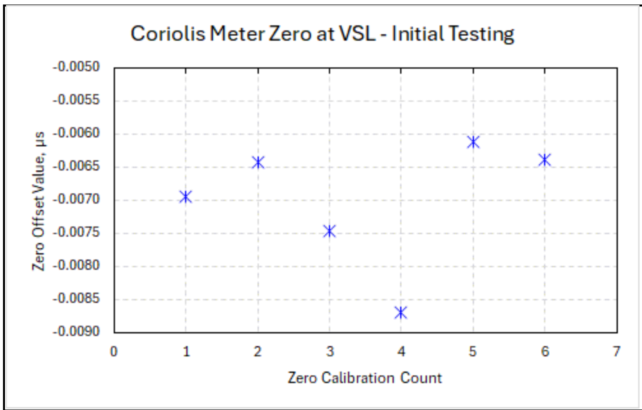
4.3 Measurement procedures

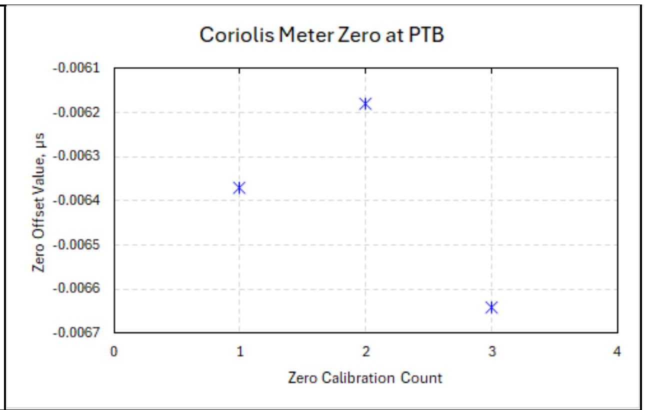
Before any test was performed it was necessary to make sure the travelling standard temperature had been stabilized to match the lab ambient temperature of the calibration facility.

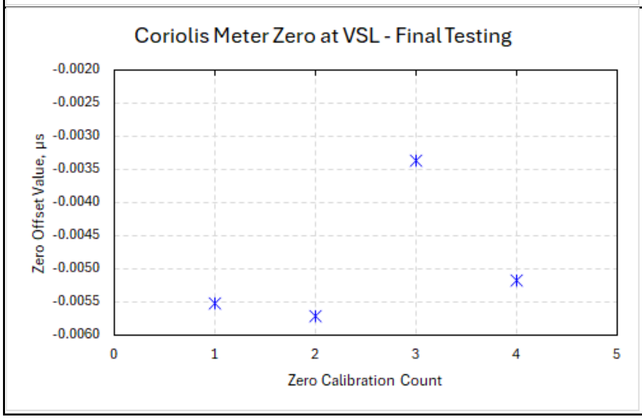
After the travelling standard had been installed, a correct zero was obtained prior to performing the flowing measurements. Below are some general guidelines used to obtain the correct zero.

- The meter should be installed, and electronics powered up for at least 30 minutes.
- The meter should be full of the process fluid.
- There should be no air bubbles or solids moving in the fluid.
- The process fluid pressure and temperature at zeroing conditions should match the process fluid pressure and temperature at working conditions.
- There must be no flow through the sensor when performing a zero calibration.
- A minimum of three zero calibrations must be performed to show there is no trend in the zero calibration results. No trend is defined as the last zero calibration value being between the previous two values.

Zero calibration results are shown below:







Flow rates were set as close as possible to the indicated flows in the test program table below.

Table 1. Flow rates and repeats

Flowrate [t/h]	Repeats [n]	Remarks
150	3*	--
300	5	--
400	10	extra repeats for CMC repeatability
625	5	--
150	3*	--
800	5	--
1200	10	extra repeats for CMC repeatability
150	3*	--

*Data points at 150 t/h are used to determine zero stability uncertainty.

The test data can be found in Annex A.

5 Reporting the measurement results

For reporting the measurement results, a dedicated Excel workbook was provided to the participants.

a) **Calibration data of the laboratory – Annex A: Attachments**

b) **Protocol of calibrations**
The participants have provided a protocol of the calibrations which can be found in Annex A.

c) **Calibration certificate**
Official calibration certificates which include all required measurements of Table 1 are found in Annex A.

6 Data to be provided to the third-party (IPQ)

6.1 Description of test facility and a simplified P&ID

Each participant provided a description and a simplified P&ID drawing, or photo, to show how the travelling standard was connected to the participant's test facilities. The drawing includes the position of all references and instruments used during the comparison. It also includes valves, control valves, pumps, bypasses, and other relevant equipment for the comparison.

6.2 Instruments used for comparison.

A list of instruments is provided with all their specifications like range, read-out etc.

6.3 Calculation equation (Measurement model)

To analyze the result of each participant it was necessary to have the calculation equation used. A description of the parameters and how they were obtained during the measurements.

6.4 The measurement uncertainty

Example data of the measurement uncertainty calculation is reported. Participants have reported type A, type B, the combined uncertainty, and the expanded uncertainty for each data point. The expanded uncertainty is reported as a k=2 value and is performed according to *the Guide to the Expression of uncertainty in measurement* [1].

6.5 Calibration and Measurement Capabilities CMC

Based on the measurement uncertainty calculated in section 7.4 it has been determined that the tests were performed according to the participants CMC claim in the BIPM CMC database.

7 Data analysis

7.1 Post processing of laboratory results

Based on the experience gained from recently finished comparisons, postprocessing of the reported data could be necessary, e.g. [11] and [14]. Particularly if a clear dependency of a meter characteristic was determined during characterization measurements. This procedure would achieve a significant reduction of meter uncertainty. Typical examples are the correction of pressure dependencies [11], or a consideration of the zero effect of the Coriolis flow meter [14]. Pressure and zero effects are used for postprocessing of the reported data. The methods are described in detail in the following sections.

RESULTS

The CMFHC3 Coriolis flow meter used for this comparison has a specified pressure effect on mass flow of (-0.0015 %) per bar[g] deviation from the FCF (Flow Calibration Factor) calibration pressure. The data results from PTB and VSL have been post processed to account for this pressure effect. The uncertainty of the pressure transmitter used during the tests has been added to the estimation of the transfer standard uncertainty (u_{TS}).

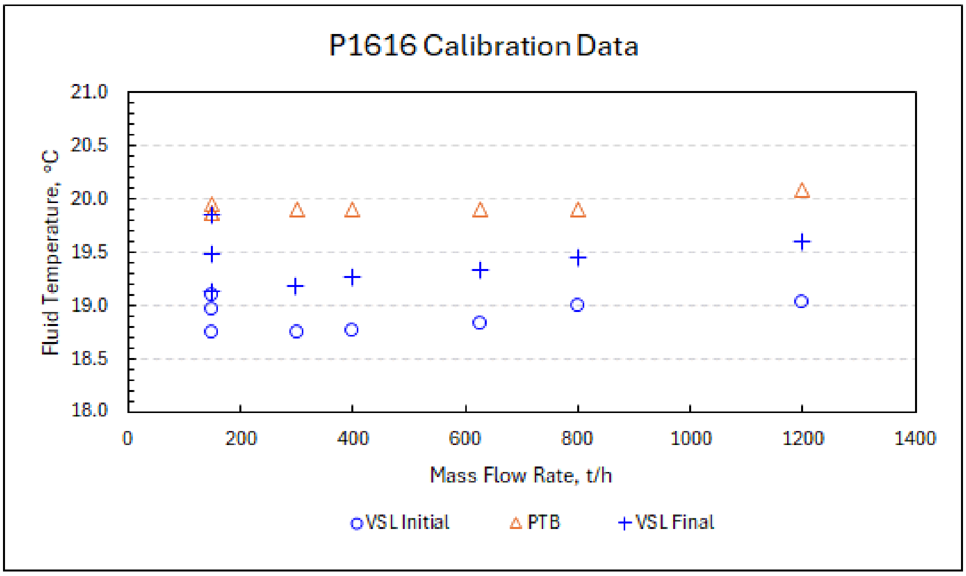
7.2 Estimation of transfer standard uncertainties u_{TS}

In accordance with WGFF recommendations for the evaluation of comparisons [6], the uncertainty u_{TS} should consider all components introduced by the transfer standard and its associated instrumentation which could affect the measurement results when the transfer standard (TS) is used in the participant's lab. Following Equation (1), the uncertainty of the transfer standard will be calculated as the root-sum-of-square (RSS) of all known input parameters. In this case, for the used Coriolis flow meter, the influence of meter drift, zero stability, pressure, and temperature effects will be considered as followed.

Meter drift uncertainty (u_{drift}) is determined by comparing the initial VSL results before sending the meter to PTB, and the final VSL results after receiving the meter back from PTB. Flow rates greater than 150 t/h are used for u_{drift}.

Zero stability uncertainty is determined at each lab by comparing the average mass flow deviations at 150 t/h. This flow rate is reproduced three times throughout the test, (see Section 4.3, Table 1). The average value from the second and third sets of results are compared to the first set of results. Any change in the average mass flow deviations at 150 t/h is assumed to be due to zero stability. The maximum deviation from these results is used as the uncertainty due to zero stability of the transfer standard Coriolis meter and is indicated as reproducibility uncertainty ($u_{reprod\,i}$) in Equation (1). The maximum value used is highlighted in the u_{TS} results table.

Process temperature effects on mass flow are corrected by zeroing at process conditions before each test. Residual uncertainties due to temperature changes during the tests are included in the zero stability uncertainty shown as $u_{reprod\,i}$. The chart below shows the inlet fluid temperature variation throughout the test for each laboratory. The largest temperature deviation during a single test was 0.8 °C.



Process pressure effects on mass flow are corrected by measuring the inlet fluid pressure during each test and applying the factory pressure correction value. A dedicated inlet section with a pressure transducer was supplied for this comparison. The pressure effect uncertainty is determined from the uncertainty of the supplied pressure transducer and the pressure correction value.

The values of u_{TS} will be calculated separately for each flow set point.

$$u_{\mathrm{TS}} = \sqrt{u_{\mathrm{drift}}^2 + u_{\mathrm{reprod}\ i}^2 + u_{\mathrm{p}}^2} \qquad (1)$$

where

where	u_{drift}	Uncertainty due to drift of transfer meter (%)
	$u_{reprod\ i}$	Uncertainty due to zero stability characteristics of transfer meter in each calibration laboratory (%)
	u_p	Uncertainty caused by pressure characteristics of transfer meter (%)

All values of u are expressed as $k = 1$.

RESULTS

PTB DATA							Pressure Corrections			Zero Stability		u_{TS}		
Date (dd/mm/yy)	No.	Rdgs	Flow nominal (t/h)	Flow average (t/h)	Deviation average (%)	Standard deviation (%)	Flow average (t/h)	Deviation average (%)	Standard deviation (%)	Zero drift (% Rdg)	Zero drift % Z. Spec	u_{Reprod} (%)	u_{drift} (%)	u_p (%)
10-04-24	1	3	150	149.85	-0.003	0.012	149.87	0.010	0.012	0.005	11%	0.006	0.004	0.005
12-04-24	2	5	300	299.26	-0.052	0.005	299.30	-0.038	0.005			0.003	0.004	0.005
15-04-24	3	10	400	398.28	-0.048	0.002	398.34	-0.034	0.002			0.002	0.004	0.005
15-04-24	4	5	625	622.56	-0.029	0.002	622.67	-0.013	0.002			0.001	0.004	0.005
18-04-24	5	3	150	149.86	-0.008	0.009	149.87	0.005	0.009	-0.006	-14%	0.006	0.004	0.005
18-04-24	6	5	800	796.70	-0.032	0.004	796.84	-0.013	0.004			0.001	0.004	0.005
18-04-24	7	10	1200	1196.7	-0.023	0.006	1197.0	0.003	0.006			0.001	0.004	0.005
18-04-24	8	3	150	149.75	-0.002	0.019	149.77	0.011	0.019	-0.001	-3%	0.006	0.004	0.005

VSL DATA							Pressure Corrections			Zero Stability		u_{TS}		
Date (dd/mm/yy)	No.	Rdgs	Flow nominal (t/h)	Flow average (t/h)	Deviation average (%)	Standard deviation (%)	Flow average (t/h)	Deviation average (%)	Standard deviation (%)	Zero drift (% Rdg)	Zero drift % Z. Spe	u_{Reprod} (%)	u_{drift} (%)	u_p (%)
19-03-24	1	3	150	149.83	0.006	0.006	149.84	0.014	0.006	-0.009	-22%	0.017	0.004	0.005
19-03-24	2	5	300	299.25	-0.056	0.005	299.28	-0.047	0.005			0.008	0.004	0.005
19-03-24	3	10	400	400.48	-0.048	0.008	400.52	-0.038	0.008			0.006	0.004	0.005
19-03-24	4	5	625	625.48	-0.025	0.004	625.55	-0.014	0.004			0.004	0.004	0.005
19-03-24	5	3	150	151.55	0.014	0.016	151.57	0.024	0.016	0.017	40%	0.017	0.004	0.005
19-03-24	6	5	800	799.47	-0.025	0.004	799.56	-0.014	0.004			0.003	0.004	0.005
19-03-24	7	10	1200	1202.3	0.001	0.005	1202.4	0.011	0.005			0.002	0.004	0.005
19-03-24	8	3	150	152.57	-0.003	0.013	152.59	0.007	0.013	0.008	18%	0.016	0.004	0.005

NOTE: Maximum values of 'Zero Error' (highlighted) are used for u_{Reprod}

7.3 Uncertainty of reported laboratory results

As described in [6], [12] and [13], the uncertainty of the reported value $x_{lab,i}$ includes uncertainties introduced by the participant`s flow reference $u_{lab,i}$, by transfer meter u_{TS} and by repeatability of the reported value. In consequence, the uncertainty of $x_{lab,i}$ will be calculated by applying Equation (2). The input parameters $u_{lab,i}$ do represent the claimed uncertainty values of the laboratories, which are under evaluation during this comparison. The term s/√n represents the repeatability of measurements in the participant`s laboratory and are based on reported calibration results.

$$u_{x,i} = \sqrt{u_{\text{lab},i}^2 + u_{\text{comp}}^2} = \sqrt{u_{\text{lab},i}^2 + u_{\text{TS}}^2 + \left(\frac{s}{\sqrt{n}}\right)^2} \tag{2}$$

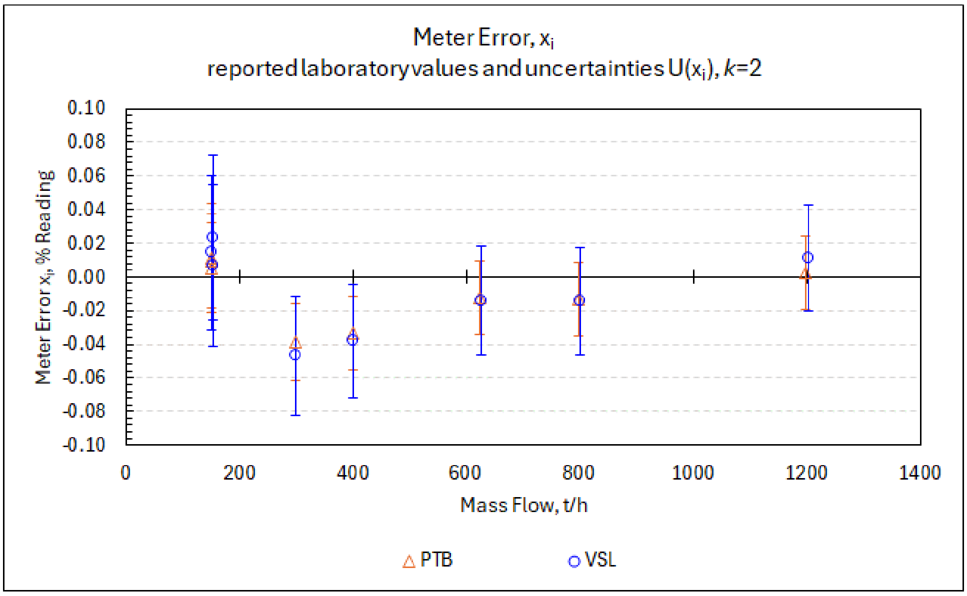
where
$u_{x,i}$ Uncertainty of reported meter error of laboratory i (%)
$u_{lab,i}$ Uncertainty of laboratory reference (%)
u_{comp} Uncertainty of transfer meter measurements (%)
s Standard deviation of the measurements at one flowrate point (%)
n Number of calibrations at one flowrate point (-)

All values of u are valid for $k = 1$.

RESULTS

PTB DATA				Uncertainty of Lab Results			
Date (dd/mm/yy)	No.	Rdgs	Flow nominal (t/h)	u_{TS} $k=1$ (%)	$u_{lab,PTB}$ $k=1$ (%)	Std Dev Mean (%)	$u_{x,PTB}$ k=1 (%)
10-04-24	1	3	150	0.007	0.010	0.007	0.014
12-04-24	2	5	300	0.005	0.010	0.002	0.011
15-04-24	3	10	400	0.004	0.010	0.001	0.011
15-04-24	4	5	625	0.004	0.010	0.001	0.011
18-04-24	5	3	150	0.007	0.010	0.005	0.013
18-04-24	6	5	800	0.004	0.010	0.002	0.011
18-04-24	7	10	1200	0.004	0.010	0.002	0.011
18-04-24	8	3	150	0.007	0.010	0.011	0.016

VSL DATA				Uncertainty of Lab Results			
Date (dd/mm/yy)	No.	Rdgs	Flow nominal (t/h)	u_{TS} $k=1$ (%)	$u_{lab,VSL}$ $k=1$ (%)	Std Dev mean (%)	$u_{x,VSL}$ k=1 (%)
19-03-24	1	3	150	0.017	0.015	0.004	0.023
19-03-24	2	5	300	0.009	0.015	0.002	0.018
19-03-24	3	10	400	0.007	0.015	0.002	0.017
19-03-24	4	5	625	0.006	0.015	0.002	0.016
19-03-24	5	3	150	0.017	0.015	0.009	0.024
19-03-24	6	5	800	0.005	0.015	0.002	0.016
19-03-24	7	10	1200	0.004	0.015	0.002	0.016
19-03-24	8	3	150	0.017	0.015	0.008	0.024



7.4 Determination of reference value and evaluation criterion A (E_{ni} value)

The comparison evaluation is based on the reported measurement results from VSL and PTB. VSL calibrated the meter before and after sending it to PTB. PTB is considered the reference for this bilateral comparison. Bilateral Comparison reference value (BCRV) will be calculated separately for each flowrate using PTB's results, following the procedure A of [6].

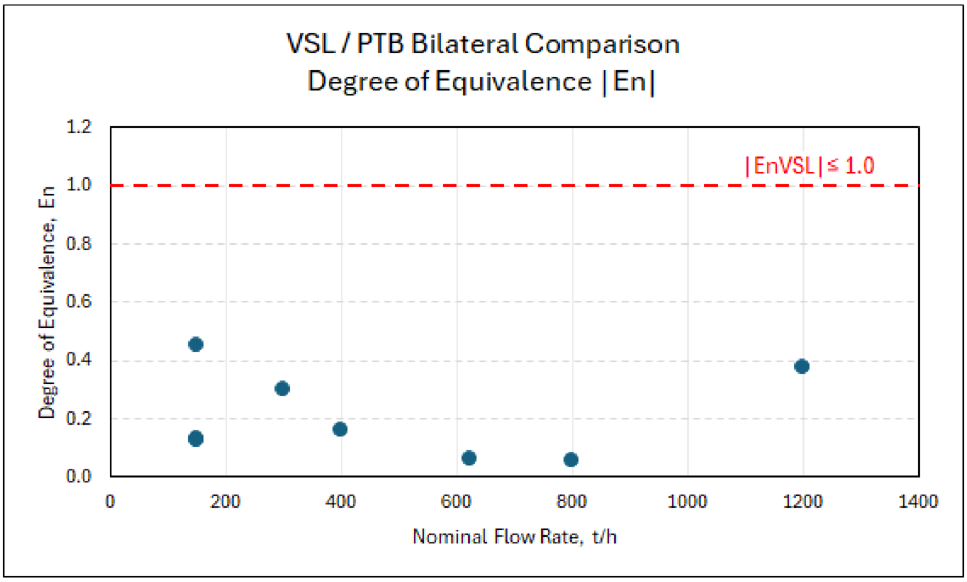
The degree of equivalence (d_i or DoE) will be calculated by the difference between VSL's initial results, before sending the meter to PTB, and PTB's. In combination with the uncertainty of this difference, the normalized Degree of Equivalence $E_{n,i}$ will be calculated, which is called "Criterion A".

Notes:

- Both laboratories act as equal participants on the same metrological level.
- Both laboratories do have their own traceability, there is no dependency between participants.
- For detailed description of BCRV and En_i calculation see 0.

RESULTS

Criterion A					
No.	Rdgs	Flow nominal (t/h)	d_{VSL} (%)	$\|En_{VSL}\|$ -	≤ 1.0
1	3	150	0.004	0.12	PASS
2	5	300	-0.008	0.30	PASS
3	10	400	-0.004	0.16	PASS
4	5	625	-0.001	0.06	PASS
5	3	150	0.018	0.45	PASS
6	5	800	-0.001	0.05	PASS
7	10	1200	0.008	0.37	PASS
8	3	150	-0.004	0.13	PASS



7.5 Determination of calibration conclusiveness - Evaluation criteria B and D

To follow the latest developments in the field of comparison evaluation, an improved method of evaluation comparison results will be applied [4], [7]. The so-called "Criterion B" and "Criterion D" both ensure a conclusiveness check of the comparison results.

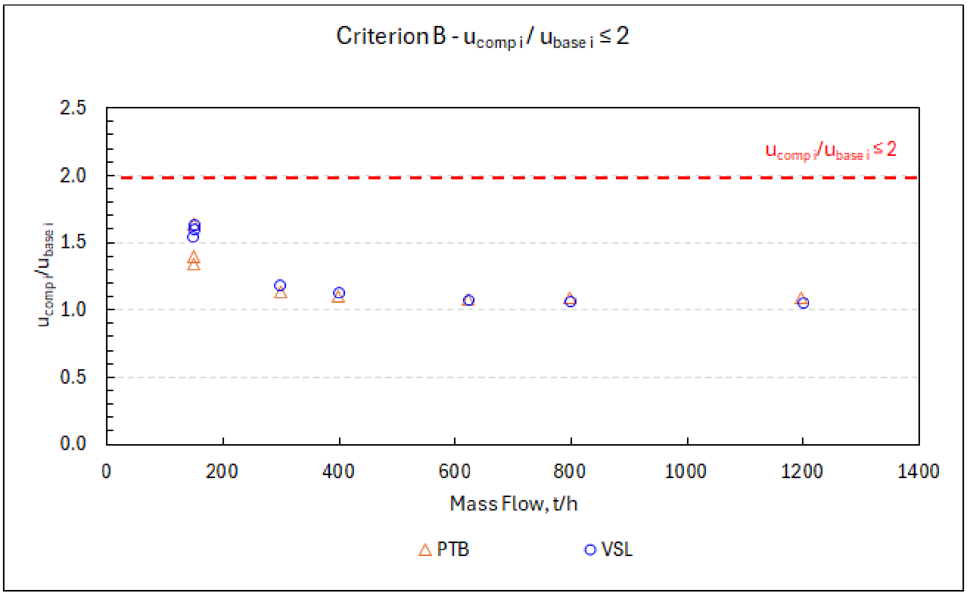
- The ratio of $u_{comp}/u_{lab,i}$, also called evaluation criterion B, is based on recommendations by the WGFF in [6], [12] and [16]. It gives an additional evaluation criterion beside criterion A by considering the ratio of the comparison uncertainty and uncertainty of participant's flow reference. Criterion B underlines a suitability of the transfer standard as well as a sufficiently high quality of the calibrations, expressed as the repeatability $s/\sqrt{n}$. The WGFF proposed that $u_{comp}/u_{lab,i} \leq 2$ for conclusive comparison results and to avoid a participant passing solely because the transfer standard uncertainty and/or repeatability of calibrations are large. Based on an extraction of Equation (2), u_{comp} will be calculated by using Equation (3).

$$u_{\text{comp}} = \sqrt{u_{\text{TS}}^2 + \left(\frac{s}{\sqrt{n}}\right)^2} \qquad (3)$$

RESULTS

Criterion B, PTB				
No.	Rdgs	Flow nominal (t/h)	u_{comp} / u_{base} (-)	≤ 2.0
1	3	150	1.40	PASS
2	5	300	1.14	PASS
3	10	400	1.10	PASS
4	5	625	1.08	PASS
5	3	150	1.34	PASS
6	5	800	1.09	PASS
7	10	1200	1.09	PASS
8	3	150	1.64	PASS

Criterion B, VSL				
No.	Rdgs	Flow nominal (t/h)	u_{comp} / u_{base} (-)	≤ 2.0
1	3	150	1.54	PASS
2	5	300	1.18	PASS
3	10	400	1.13	PASS
4	5	625	1.07	PASS
5	3	150	1.63	PASS
6	5	800	1.06	PASS
7	10	1200	1.05	PASS
8	3	150	1.59	PASS

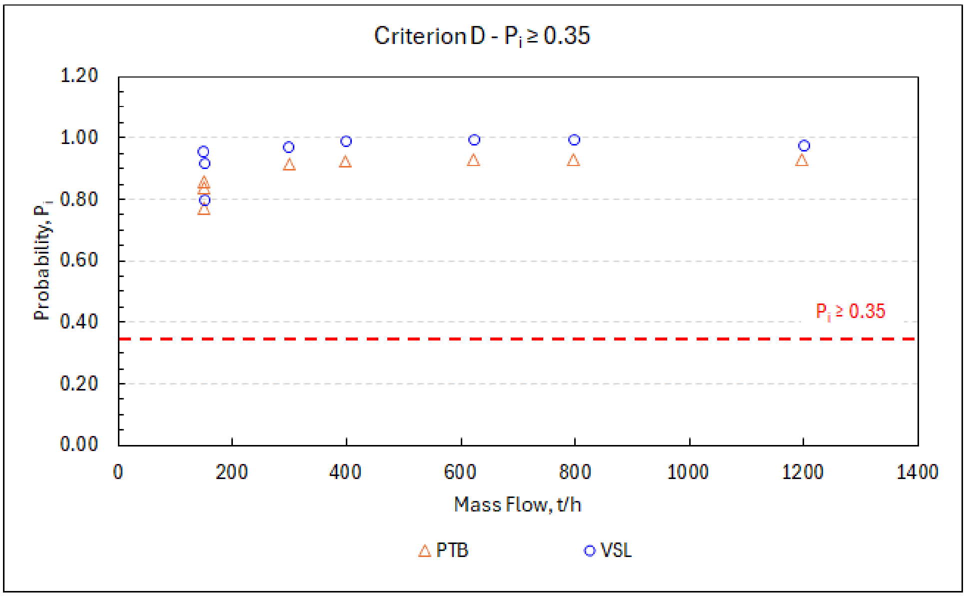


- Criterion D was introduced by [16] as a probability-based measure for conclusiveness. The laboratory results are evaluated by the degree to which two Gaussian probability density functions (PDFs) overlap - comparison reference value N(x_{BCRV}, $u_{x,BCRV}$) and the participant's reported value for the measurand N(x_i, $u_{lab,i}$). The degree of overlap between both PDFs is assessed by a probability content P_i of the KCRV and PDF bound by the participant's 2.5th and 97.5th percentile confidence limits for the uncertainty of the participant's flow reference, which indicates a confidence level of 95 %. The calculation of the probability P_i is given by [16] along with a "threshold" value of P_{th} = 0.35. The value of P_{th} determines the minimum required overlapping area between the PDFs of x_{KCRV} and x_i for conclusive calibration results. The practical use of Criterion D for comparison evaluation was recently evaluated by [13].

RESULTS

Criterion D, PTB						
No.	Rdgs	Flow nominal (t/h)	Probability Distribution (0.975)	(0.025)	Δ	≥ 0.95
1	3	150	0.92	0.08	0.84	PASS
2	5	300	0.96	0.04	0.92	PASS
3	10	400	0.96	0.04	0.93	PASS
4	5	625	0.96	0.04	0.93	PASS
5	3	150	0.93	0.07	0.86	PASS
6	5	800	0.96	0.04	0.93	PASS
7	10	1200	0.96	0.04	0.93	PASS
8	3	150	0.88	0.12	0.77	PASS

Criterion D, VSL						
No.	Rdgs	Flow nominal (t/h)	Probability Distribution (0.975)	(0.025)	Δ	≥ 0.95
1	3	150	0.992	0.038	0.95	PASS
2	5	300	0.969	0.000	0.97	PASS
3	10	400	0.989	0.001	0.99	PASS
4	5	625	0.995	0.002	0.99	PASS
5	3	150	1.000	0.204	0.80	PASS
6	5	800	0.995	0.002	0.99	PASS
7	10	1200	1.000	0.027	0.97	PASS
8	3	150	0.936	0.019	0.92	PASS



7.6 Final evaluation procedure of comparison data for CMC and Decision Table

For final data evaluation and decision table the following criteria were applied - based on [11], [12], [13], [6]:

- VSL **passes the comparison if $E_{ni} \leq 1.0$ and $P_{th} \geq 0.35$.**
  The results of VSL's laboratory agrees within 95 % confidence level uncertainty expectations with PTB (k = 2). The calibrations are conclusive.
- VSL passes the comparison at **"warning level" if $1.0 < E_{ni} \leq 1.2$ and $P_{th} \geq 0.35$.**
- VSL **fails the comparison if $E_{ni} > 1.2$.** The claimed laboratory results cannot be accepted.
- **Inconclusive results if $E_{n,i} \leq 1.2$ is combined with $P_{th} < 0.35$**
  The results are inconclusive, due to the low overlapping area between density functions. This decision involves an evaluation of the transfer meter, which does not show sufficiently low uncertainties to discern VSL to PTB below a certain level. In this case, the transfer standard is not suitable for a confirmation of the declared laboratory uncertainties.

RESULTS

The results of this bilateral comparison indicate that the VSL CMC claim of 0.03% (*k=2*) for mass flow over a range of 150 t/h to 1200 t/h is valid based on En values less than 1.0 when compared to the reference mass flows from PTB. The En comparison results from this bilateral comparison are deemed to be conclusive based on the analysis of criterion B & D.

CMC Decision Table				
No.	Rdgs	Flow nominal (t/h)	PTB	VSL
1	3	150	PASS	PASS
2	5	300	PASS	PASS
3	10	400	PASS	PASS
4	5	625	PASS	PASS
5	3	150	PASS	PASS
6	5	800	PASS	PASS
7	10	1200	PASS	PASS
8	3	150	PASS	PASS

Appendix 1 - Detailed Description of data evaluation

The Bilateral Comparison reference value will be calculated separately for each flowrate, following the procedure A of [6]. The refence value y will be calculated as a weighted mean error of the participating laboratories, including standard uncertainties $u_{x,i}$ of the measurements as the weights:

$$y = \frac{\left(\frac{x_1}{u_{x,1}^2} + \frac{x_2}{u_{x,2}^2} + \dots \frac{x_i}{u_{x,i}^2}\right)}{\left(\frac{1}{u_{x,1}^2} + \frac{1}{u_{x,2}^2} + \dots \frac{1}{u_{x,i}^2}\right)} \quad (4)$$

where y - Reference value of the comparison (%)

The standard uncertainty u_y is given with:

$$\frac{1}{u_y^2} = \frac{1}{u_{x,1}^2} + \frac{1}{u_{x,2}^2} + \dots + \frac{1}{u_{x,i}^2} \quad (5)$$

where u_y - Standard uncertainty of y with $k = 1$ (%)

The expanded uncertainty of y is calculated with:

$$U(y) = 2 \cdot u_y \quad (6)$$

where $U(y)$ - Expanded uncertainty of y with $k = 2$ (%)

The value of y will be accepted as the Comparison Reference Value x_{BCRV} and $U(y)$ is accepted as the expanded uncertainty $U(x_{BCRV})$.

Determination of normalized degree of equivalence En_i - Evaluation criterion A

Differences between laboratory results (x_i) and BCRV (x_{BCRV}) will be calculated in accordance with Equation (7) separately for each flow meter and flow rate. The results give the degree of equivalence (DoE) of each laboratory.

$$d_i = x_i - x_{BCRV} \quad (7)$$

where
d_i - Degree of equivalence (DoE) for each laboratory i in %
x_i - Reported meter error of laboratory i in %
x_{BCRV} - Comparison Reference value in %

Based on differences d_i, the normalized Degree of Equivalence En_i will be calculated for each laboratory and flow rate with:

$$En_i = \left|\frac{d_i}{U(d_i)}\right| \quad (8)$$

where En_i - Normalized Degree of Equivalence

The extended uncertainty of d_i will be calculated by Equation (9) for laboratories with contribution to the BCRV. Participating laboratories, which will be excluded from the BCRV determination, do not have any interference. In that case the value of $U(d_i)$ will be calculated according to Equation (10).

$$U(d_i) = 2 \cdot \sqrt{u_{\mathrm{x},i}^2 + u_{\mathrm{BCRV}}^2 - 2 \cdot u_{\mathrm{BCRV}}^2} = 2 \cdot \sqrt{u_{\mathrm{x},i}^2 - u_{\mathrm{BCRV}}^2} \tag{9}$$

$$U(d_i) = 2 \cdot \sqrt{u_{x,i}^2 + u_{\mathrm{BCRV}}^2} \tag{10}$$

References

[1] VSL: Quality manual including work instructions and procedures.

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[3] BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML and ILAC (2008): Evaluation of measurement data - Guide to the expression of uncertainty in measurement (GUM), GUM 1995 with minor corrections, JGCM 100: 2008.

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[15] Cox M. G., M.G. Cox (2002): Evaluation of key comparison data, Metrologia 39, 589–595, https://doi.org/10.1088/0026-1394/39/6/10.

[16] Wright, J, Toman, B., Mickan, B., Wübbeler, G., Bodnar, O., Elster, C. (2016): Transfer standard uncertainty can cause inconclusive inter-laboratory comparisons, Metrologia 53, 243–1258, https://doi.org/10.1088/0026-1394/53/6/1243.

Abbreviations

BC = Bilateral Comparison
BCKV = Bilateral Comparison reference value
BIPM = Bureau International des Poids et Mesures (the International Bureau of Weights and Measures)
CCM = Consultative Committee for Mass and Related Quantities
CIPM = Comité International des Poids et Mesures (International Committee for Weights and Measures)
CMC = Calibration and Measurement Capabilities
DoE = Degree of Equivalence
GUM = Guide to the Expression of Uncertainty in Measurement
FF = Fluid Flow
FSF = Flying Start Finish method
MRA = Mutual Recognition Arrangement
NMI = National Metrology Institute
PTB = The National Metrology Institute of Germany
RTD = Resistive Temperature Device
SSF = Standing Start Finish method
TS = Transfer Standard
VIM = Vocabulaire International de Metrologie
VSL = The National Metrology Institute of the Netherlands
WGFF = Working Group for Fluid Flow

Annex A: Attachments

Attachments	Description
A	PTB Calibration Protocol
B	PTB Calibration Certificate
C	VSL Calibration Protocol
D	VSL Calibration Certificate

A. PTB Calibration Protocol

EURAMET – Project 1616
Bilateral comparison between VSL and PTB

Protocol of calibrations at PTB, Braunschweig
Hydrodynamisches Prüffeld
10 April – 18 April 2024

High flow rate water
150 t/h to 1200 t/h

Dr. Enrico Frahm

Arbeitsgruppe 1.52 - Darstellung Flüssigkeitsmenge
// Working Group "Realisation of Liquid Flow Measurements"

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Florian Bürsing	- meter installation, flow calibration and protocol
Torsten Jahn	- flow calibration

Table of contents

1 Foto documentation

Delivery to PTB	  (05.04.2024)
Installation (flow meter)	  (10.04.2024)
Transmitter	  (10.04.2024)

Pressure sensor (inlet section)	  (10.04.2024)
Before pickup to VSL	  (26.04.2024)

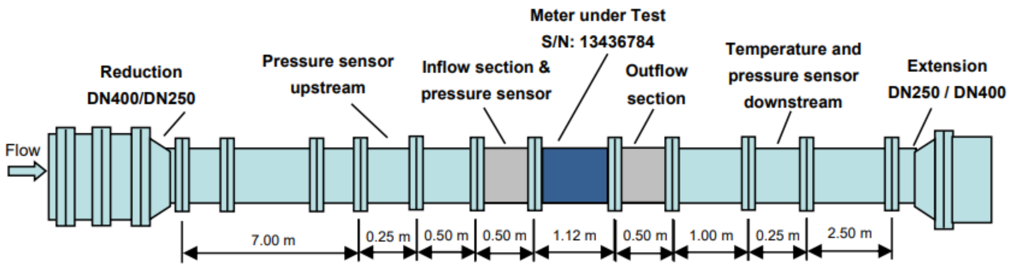
2 Timetable

Table 1. Timetable of calibration actions at PTB

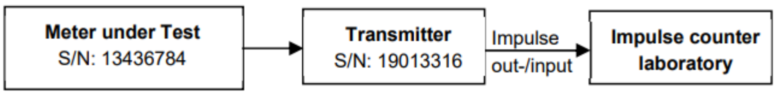
Date	Action	Remarks
05.04.2024	Delivery at PTB	
09.04.2024	1st installation at calibration line	Coriolis mounted in the "tubes down" position
	warm up for 4 hours, with flow up to Qmax	
	zero setting following the procedure explained in TP -0,00575 µs (0,01263 µs) 0,00567 µs (0,01272 µs) **final value:** -0,00649 µs (0,01260 µs)	
	calibration at 150 m³/h	3 repeats
10.04.2024	2nd installation at calibration line	Coriolis mounted in the "tubes **up**" position
	warm up for 4 hours, withflow up to Qmax	
	zero setting following the procedure explained in TP -0,00637 µs (0,01255 µs) -0,00618 µs (0,01231 µs); **final value:** -0,00664 µs (0,01230 µs)	
	calibration at 150 m³/h	n = 3 calibrations
12.04.2024	calibration at 300 m³/h	n = 5 calibrations
15.04.2024	calibration at 400 m³/h	n = 10 calibrations
	calibration at 625 m³/h	n = 5 calibrations
18.04.2024	calibration at 150 m³/h	n = 3 calibrations
	calibration at 800 m³/h	n = 5 calibrations
	calibration at 1.200 m³/h	n = 10 calibrations
	calibration at 150 m³/h	n = 3 calibrations
19.04.2024	removal of MUT from calibration line	
25.04.2024	final packing and preparation for pickup	
02.05.2024	pickup by transportation company to VSL	

3 Installation of the setup and measurement devices

Installation in calibration line:



Electronical connection:



Note: Meter under test, in- and outflow section and transmitter were provided by VSL

Table 2. Used measurements instrumentation

Sensor	Type	QM number	Remarks
Fluid Temperature	E+H - TST41N	A1-5-0074	downstream of MUT used for density calculations
Line pressure	E+H - Cerabar PMC731	A1-5-0073	upstream of MUT
		A1-5-0074	downstream of MUT
3 t Balance	MettlerToledo - electromagnetic force compensation weighing cell	A1-5-0094	
30 t Balance		A1-5-0085	
Density	Anton Paar - DMA5001	A1-5-0300	temperature dependent fluid density (10 °C and 34 °C)
Timer	Frequency Timer/Counter/Analyzer FLUKE PM6681	A1-5-0220	
Impulse counter	Frequency Timer/Counter/Analyzer FLUKE PM6680 B	A1-5-0222	impulses – mass output
	Frequency Timer/Counter/Analyzer FLUKE PM6681	A1-5-0223	impulses – volume output
Diverter 3 t Balance		A1-5-0251	
Diverter 3 t Balance		A1-5-0252	
Ambient conditions (air temperature, air humidity, pressure)	Vaisala - PTU 301	A1-5-0064	calibration hall – top
		A1-5-0065	calibration hall – bottom
		A1-5-0066	balance basement - top
		A1-5-0067	balance basement - bottom

4 Calibration facility

Characteristic information of primary standard used during comparison

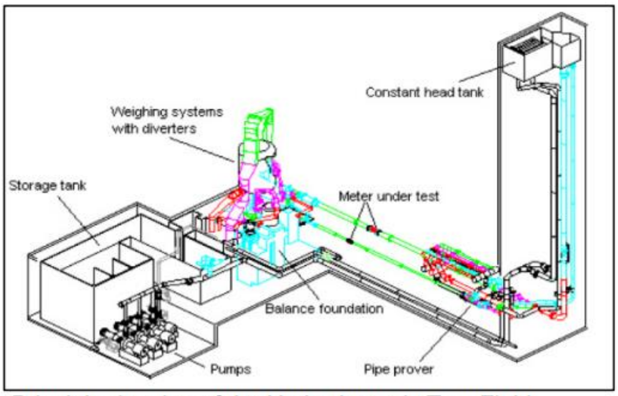
Range of flow	0.3 m³/h ... 2,100 m³/h
Fluid temperature	10 °C ... 35 °C
Line pressure	2 bar ... 6 bar
Uncertainty (k = 2)	0.02 volume, mass
Reference	gravimetric
Operating method	Direct pumping, flying-start-stop
Calibration line diameter	25 mm ... 400 mm
Test fluid	water

Working procedure

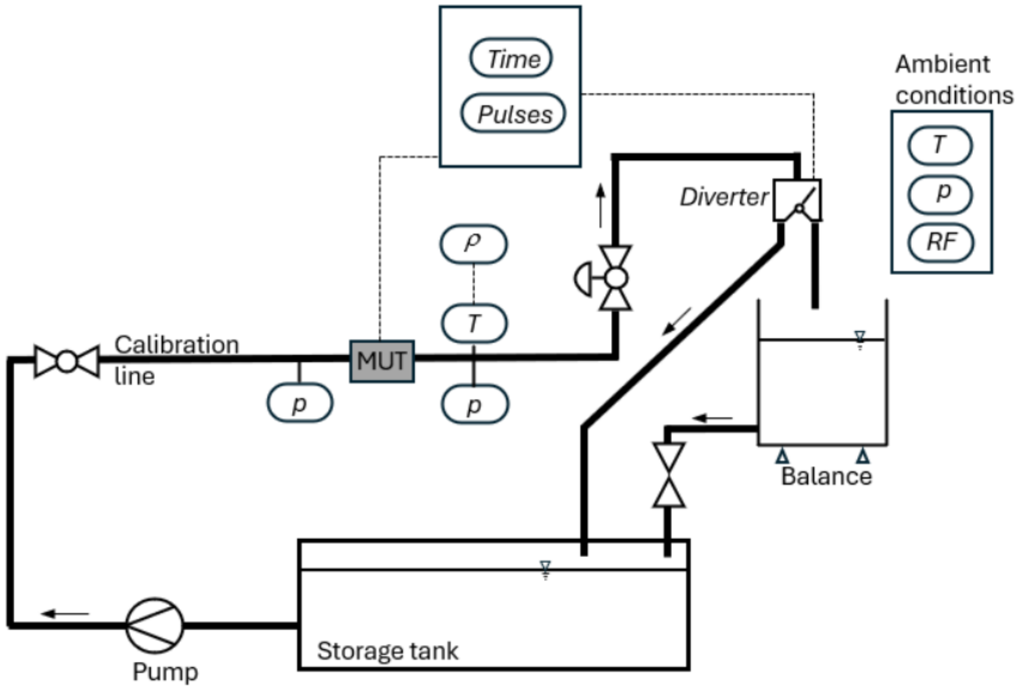
The PTB hydrodynamic test field (HDP) represents the national primary standard of Germany for the realization of the measurands volumetric and mass flow rate as well as the total volume and mass of flowing liquids (water). The gravimetric reference consists of three independent diverter and balance systems with max. loads of 30 t, 3 t and 300 kg. For generating and stabilizing flow rates, the supply system consists of a 400 m³ storage tank, of a frequency controlled pumping system, a constant head tank (30 m³, at a height of 30 m) and two calibration lines. For each diameter an upstream straight pipeline with a length of 50D and downstream of 20D is available. The fluid temperature is adjusted and controlled by two separate heat exchanger systems.

Upstream view to calibration lines

3 t balance and diverter system



Principle drawing of the Hydrodynamic Test Field



Simplified P&ID drawing of the facility

5 Uncertainty

The following uncertainty calculation is an example budget for the flow of 200 m³/h, valid for used calibration facility “Hydrodynamisches Prüffeld”.
Due to several improvements of the facility, the shown budget is currently under review.

CALCULATION OF UNCERTAINTY BUDGET

Test Rig:

	Parameters:				
3.1	***Facility***	Flowrate:	**200,0**	m³/h	
3.2	*- Balance*	Target weight:	**3000,0**	kg	
3.3	*- Cal. weights*	Density	**7845,0**	kg/m³	Carbon steel
3.4		Diversion time:	54,1	s	
3.5		Ref. Volume:	2,7032	m³	
3.6	*- Ambient air*	Air density	1,1800	kg/m³	
3.7	*- Interc. piping*	IP volume:	0,5008	m³	steel, plastics
3.8		"effective" TC	1,7689E-04	1/K	
3.9		delta Temp.:	**0,050**	K	During measm.
3.10	*- Diverter*	Timing error:	**6,0**	ms	Standard dev.
3.11	***Fluid***	Water density:	998,8173	kg/m³	(at 20 °C)
3.12		Water temp.:	**20,000**	°C	
3.13	***Test meter***	Pulse frequency	**368,50**	Hz	Turbine meter
3.14	***Repeatability***		**6,00E-06**		Measurement

Measurement quantity:

- Mass

Symbol	*Source of uncertainty*	*Value ±g*	*Probability distribution*	*Divisor*	c_i	$u_i(W_x)$ ±g	$u_i(W_x)$ ± %
W_S	Calibration of standard weights	2,3	normal	2,0	1,0	1,150	3,83E-05
S_D	Discrimination of balance	0,5	rectangular	1,73	1,0	0,289	9,63E-06
S_R	Repeatability of balance	104	normal	2,0	1,0	52,000	1,73E-03
S_{Drift}	Drift of balance	10	rectangular	1,73	1,0	5,780	1,93E-04
							1,744E-03
$u_c(W_X)$	Combined uncertainty		normal			52,3	**1,744E-03**
$U(W_X)$	Expanded uncertainty		normal(k = 2)			104,7	0,003

- Buoyancy

Symbol	*Source of uncertainty*	*Value ±kg/m³*	*Probability distribution*	*Divisor*	c_i	$u_i(W_x)$ ±kg	$u_i(W_x)$ ± %
D_{Air}	Ambient air density	5,90E-04	normal	2,0	8,758E-04	2,584E-07	2,19E-05
D_{Water}	Water density	3,31E-02	normal	2,0	1,920E-08	3,178E-10	3,18E-11
D_{Cal}	Density of calibration weights	1,0	normal	2,0	1,185E-06	5,927E-07	7,56E-09
							2,189E-05
$u_c(C_B)$	Combined uncertainty		normal			6,466E-07	**5,479E-08**
$U(C_B)$	Expanded uncertainty		normal(k = 2)			0,0	0,000

- Temperature

Symbol	*Source of uncertainty*	*Value ±K*	*Probability distribution*	*Divisor*	c_i	$u_i(T_x)$ ±K	$u_i(T_x)$ ± %
T_D	Discrimination of temp.measuremen	0,025	rectangular	1,73	1,0	0,014	7,23E-02
T_C	Sensor/meter calibration	0,18	rectangular	1,73	1,0	0,104	5,20E-01
T_G	Temp. gradient in water (estimated)	0,5	rectangular	1,73	1,0	0,289	1,45E+00
							1,538E+00
$u_c(T_X)$	Combined uncertainty		normal			**0,308**	1,538E+00
$U(T_X)$	Expanded uncertainty		normal(k = 2)			0,615	3,075

- Density (Aproximation function based on density measurement with densitometer)

Symbol	*Source of uncertainty*	*Value ±*	*Probability distribution*	*Divisor*	c_i	$u_i(D_x)$ ±kg/m³	$u_i(D_x)$ ± %
D_{T_approx}	Temp. Meas. for appr. [K]	0,010	normal	2,0	6,6435E-06	3,3218E-08	3,33E-09
D_{D_approx}	Density meas. for appr. [kg/m³]	0,0085	normal	2,0	1,9995	0,008	8,51E-04
D_P	Temp. downstream of MUT [K]	**0,308**	normal	2,0	2,08E-01	0,032	3,20E-03
D_S	Numeric approx. Error [kg/m³]	0,002	rectangular	1,73	1,0	0,001	1,16E-04
							3,315E-03
$u_c(D_X)$	Combined uncertainty		normal			0,033	**3,315E-03**
$U(D_X)$	Expanded uncertainty		normal(k = 2)			0,066	0,007

- Time (Measurement/Diversion)

Symbol	*Source of uncertainty*	*Value ± ms*	*Probability distribution*	*Divisor*	c_i	$u_i(T_x)$ s	$u_i(T_x)$ ± %
T_C	Calibration of Timer (5x10-9)	5,0E-12	normal	2,0	1,0	2,500E-15	4,62E-15
T_D	Discrimination of Timer display	0,001	rectangular	1,73	1,0	5,780E-07	1,07E-06
T_T	Discrmination of Diverter Time	0,05	rectangular	1,73	1,0	2,890E-05	5,35E-05
							5,347E-05
$u_c(T_X)$	Combined uncertainty		normal			2,891E-05	**5,3469E-05**
$U(T_X)$	Expanded uncertainty		normal(k = 2)			5,782E-05	1,069E-04

- Diverter timing error

Symbol	Source of uncertainty	Value ±	Probability distribution	Divisor	c_i	$u_i(T_{D\_Error})$ m^3	$u_i(T_{D\_Error})$ ± %
T_C	Diverter timing error [ms]	6,00	normal				
F	Flowrate [m³/h]	200,00					
V_{Error}	Diversion error volume [m³]	3,3333E-04	normal	2,0	1,0	1,667E-04	6,1655E-03
$u_c(T_{Error})$	Combined uncertainty		normal			1,667E-04	**6,166E-03**
$U(T_{Error})$	Expanded uncertainty		normal(k = 2)			3,333E-04	1,233E-02

- Interconnecting piping volume error

Symbol	Source of uncertainty	Value ±	Probability distribution	Divisor	c_i	$u_i(V_{IP\_Error})$ m^3	$u_i(V_{IP\_rror})$ ± %
delta T_{IP}	Temp. Variation during calibr. [K]	0,050	rectangular				
V_{IP_TC}	IP volume [m³]	0,501					
TC	effektive TC [1K]	1,7689E-04					
	IP volume error	4,4294E-06	rectangular	1,73	1,0	2,560E-06	9,472E-05
$u_c(T_{Error})$	Combined uncertainty		normal			2,560E-06	**9,472E-05**
$U(T_{Error})$	Expanded uncertainty		normal(k = 2)			5,121E-06	1,894E-04

- Meter under test (MUT)

Symbol	Source of uncertainty	Value ±	Probability distribution	Divisor	c_i	$u_i(f_x)$ Hz	$u_i(f_x)$ ± %
f_D = 1 / Npulses	Discr. of frequency meas.	5,02E-05	rectangular	1,73	1,0	1,0692E-02	2,901E-03
	Non-linearity		rectangular				
$u_c(f_x)$	Combined uncertainty		normal			1,069E-02	**2,901E-03**
$U(f_x)$	Expanded uncertainty		normal(k = 2)			2,138E-02	0,006

Summarized Uncertainty - *"Flowrate measurement"*

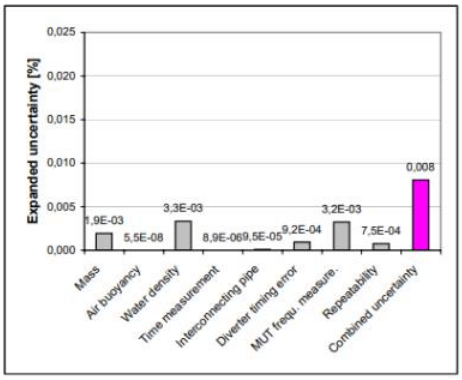
Symbol	Source of uncertainty	Value ± %	Probability distribution	u_i(FLOW) ± %
$u_c(m)$	Combined uncertainty (MASS)	1,744E-03	normal	1,744E-03
$u_c(C_{Buoy})$	Combined uncertainty (BUOYANCY	5,479E-08	normal	5,479E-08
u_c(RHO)	Combined uncertainty (DENSITY)	3,315E-03	normal	3,315E-03
$u_c(T_{MEAS})$	Combined uncertainty (TIME)	5,347E-05	normal	5,347E-05
$u_c(V_{IP})$	Combined uncertainty (IP volume)	9,472E-05	normal	9,472E-05
$u_c(T_{Error})$	Combined uncertainty (Time error)	6,166E-03	normal	6,166E-03
u_c(frequency)	Combined uncertainty (Frequency)	2,901E-03	rectangular	2,901E-03
S(Repeatabil.)	Repeatability uncertainty	6,000E-04	normal	6,000E-04
u_c(FLOW)	Combined uncertainty (FLOW)		normal	0,00724
U(FLOW)	**Expanded uncertainty (FLOW)**		**normal(k = 2)**	**0,014**

Summarized Uncertainty - *"Quantity passed measurement"*

Symbol	Source of uncertainty	Value ± %	Probability distribution	u_i(FLOW) ± %
$u_c(m)$	Combined uncertainty (MASS)	1,744E-03	normal	1,744E-03
$u_c(C_{Buoy})$	Combined uncertainty (BUOYANCY	5,479E-08	normal	5,479E-08
u_c(RHO)	Combined uncertainty (DENSITY)	3,315E-03	normal	3,315E-03
$u_c(T_{MEAS})$	Combined uncertainty (TIME)	5,347E-05	not effective	
$u_c(V_{IP})$	Combined uncertainty (IP volume)	9,472E-05	normal	9,472E-05
$u_c(T_{Error})$	Combined uncertainty (Time error)	6,166E-03	normal	6,166E-03
u_c(frequency)	Combined uncertainty (Frequency)	2,901E-03	rectangular	2,901E-03
S(Repeatabil.)	Repeatability uncertainty	6,000E-04	normal	6,000E-04
u_c(QUANTITY)	Combined uncertainty (QUANTITY)		normal	0,00724
U(Quantity)	**Expanded uncertainty (QUANTITY)**		**normal(k = 2)**	**0,014**

Summarized Uncertainty - *"Meter K-factor determination"*

Symbol	Source of uncertainty	Value ±%	Probability distribution	u_i(K) ± %
$u_c(m)$	Combined uncertainty (MASS)	1,744E-03	normal	1,744E-03
$u_c(C_{Buoy})$	Combined uncertainty (BUOYANCY	5,479E-08	normal	5,479E-08
u_c(RHO)	Combined uncertainty (DENSITY)	3,315E-03	normal	3,315E-03
$u_c(T_{MEAS})$	Combined uncertainty (TIME)	5,347E-05	normal	5,347E-05
$u_c(V_{IP})$	Combined uncertainty (IP volume)	9,472E-05	normal	9,472E-05
$u_c(T_{Error})$	Combined uncertainty (Time error)	6,166E-03	normal	6,166E-03
u_c(Frequence)	Combined uncertainty (Frequency)	2,901E-03	rectangular	2,901E-03
S(Repeatabil.)	Repeatability uncertainty	6,000E-04	normal	6,000E-04
u_c(K-FACTOR)	Combined uncertainty (K-FACTOR)		normal	0,00780
U(K-FACTOR)	**Expanded uncertainty (K-FACTOR)**		**normal(k = 2)**	**0,016**



B. PTB Calibration Certificate

PTB
Physikalisch-Technische Bundesanstalt
Nationales Metrologieinstitut

Kalibrierschein

Calibration Certificate

Gegenstand: *Object:*	Coriolis-Durchflussmessgerät, DN250 *Coriolis flowmeter*
Hersteller: *Manufacturer:*	Emerson - Micro Motion, USA
Typ: *Type:*	MASS FLOW CMFHC3M804N2GND2ZZ (sensor) 5700R1WAGMAZZZ (transmitter)
Kennnummer: *Serial No.:*	S/N: 13436784 (sensor) S/N: 19013316 (transmitter)
Auftraggeber: *Customer:*	VSL - ECFM Walrusweg 5 3199ME Maasvlakte Rotterdam Netherlands
Anzahl der Seiten: *Number of pages:*	6
Geschäftszeichen: *Reference No.:*	
Kalibrierzeichen: *Calibration mark:*	
Ort der Kalibrierung: *Location of calibration:*	PTB Braunschweig, Hydrodynamisches Prüffeld
Datum der Kalibrierung: *Date of calibration:*	10.04.2024 - 18.04.2024

Im Auftrag
On behalf of PTB

Dr. E. Frahm

Braunschweig, 06.05.2024

Siegel
Seal

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT 53

Im Auftrag
On behalf of PTB

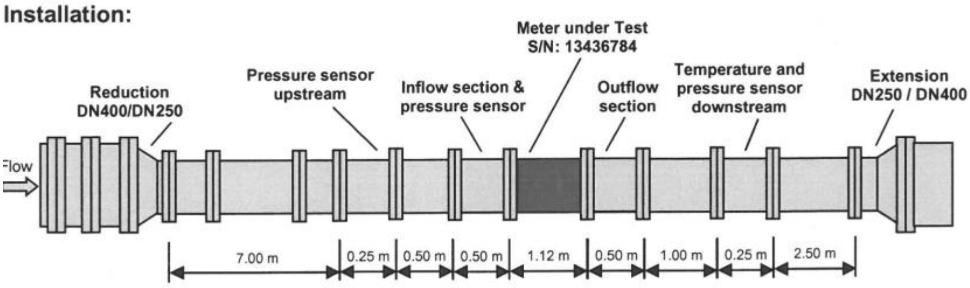
F. Bürsing

Seite 2 zum Kalibrierschein vom 06.05.2024, Kalibrierzeichen:
Page 2 of the Calibration Certificate dated 06.05.2024, calibration mark:

Calibration

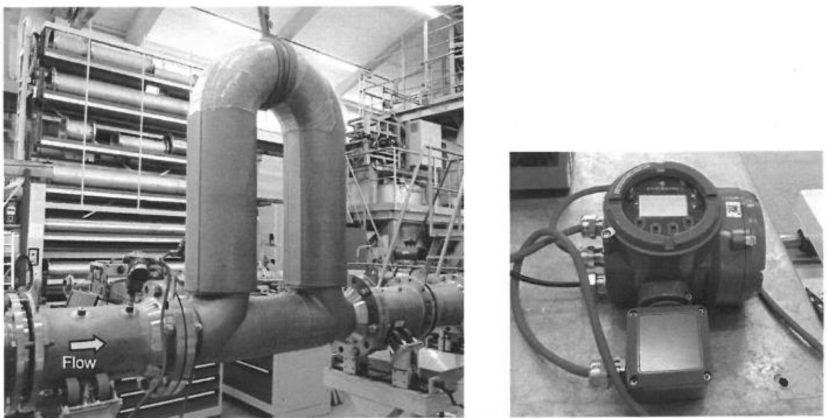
Operation mode: Flying Start-Stop, Direct pumping, Gravimetric reference

Installation:



Electronical connection:

Note: Meter under test, in- and outflow section and transmitter were provided by the applicant.



Installation of meter under test (MUT) in calibration line and transmitter of MUT

Calibration results

Test medium: Water:
- Average density: 998.34 kg/m³
- Average pressure: 2.99 bar
  (downstream of MUT)
  all given pressure values of test fluid are gauge pressure
- Average temperature: 20.11 °C

Conditions:

Air pressure:	1006.49 mbar	Air temperature:	20.41 °C
Air humidity:	58.90 %	Air density:	1.19 kg/m³

Test meter, parameter:
- K_m-factor: 15,00 pulses/kg (nominal K_m-factor)
- K_V-factor: 10,00 pulses/L (nominal K_V-factor)
  (Reference value for rel. measurement deviation)

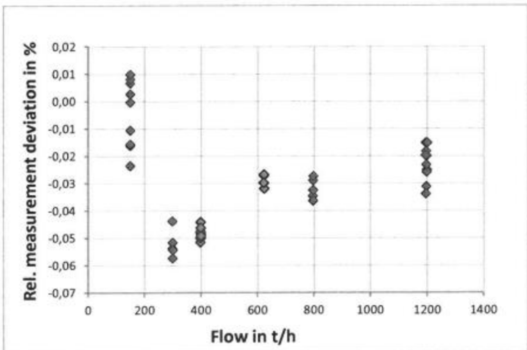
Preparations before calibration:

- installation of the setup
- warm up of MUT at several flowrates (up to 1,200 t/h) for four hours
- stop flow
- 3 x autozero setting
  -0,00637 µs (0,01255 µs); -0,00618 µs (0,01231 µs); **-0,00664 µs (0,01230 µs)**

Calibration results - Mass output

		Gravimetric standard			Test fluid conditions		
Date	No.	Flow	Measurement time	Mass	Pressure upstream	Pressure downstream	Temperature
		mean	mean	mean	mean	mean	mean
		[t/h]	[s]	[kg]	[bar]	[bar]	[°C]
10.04.24	1	149.852	64.900	2701.490	3.02	3.00	20.08
12.04.24	2	299.418	324.848	27018.165	3.05	2.99	20.07
15.04.24	3	398.472	243.818	26987.338	3.10	2.99	20.08
15.04.24	4	622.746	156.365	27048.774	3.25	2.99	20.08
18.04.24	5	149.867	64.895	2701.570	3.02	3.00	20.07
18.04.24	6	796.950	122.329	27080.482	3.41	2.99	20.06
18.04.24	7	1196.930	81.823	27204.572	3.90	2.99	20.26
18.04.24	8	149.757	64.903	2699.897	3.02	3.00	20.02

		Gravimetric standard			Meter under test				Measurement uncertainty
Date	No.	Flow	Measurement time	Mass	Pulses	K_m-factor Measure-ment	Measurement deviation		U_{rel} (k = 2)
		mean	mean	mean	mean	mean	mean	stand. deviation	combined uncertainty
		[t/h]	[s]	[kg]	[pulses]	[pulses/kg]	[%]	[%]	[%]
10.04.24	1	149.852	64.900	2701.490	40521	14.999	-0.003	0.012	0.024
12.04.24	2	299.418	324.848	27018.165	405061	14.992	-0.052	0.005	0.020
15.04.24	3	398.472	243.818	26987.338	404615	14.993	-0.048	0.002	0.020
15.04.24	4	622.746	156.365	27048.774	405613	14.996	-0.029	0.002	0.020
18.04.24	5	149.867	64.895	2701.570	40520	14.999	-0.008	0.009	0.022
18.04.24	6	796.950	122.329	27080.482	406077	14.995	-0.032	0.004	0.020
18.04.24	7	1196.930	81.823	27204.572	407976	14.997	-0.023	0.006	0.020
18.04.24	8	149.757	64.903	2699.897	40498	15.000	-0.002	0.019	0.030

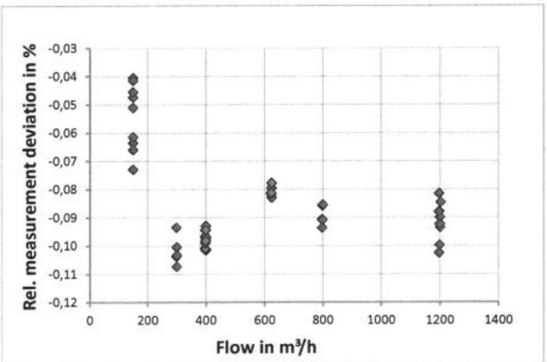


Seite 4 zum Kalibrierschein vom 06.05.2024, Kalibrierzeichen:
Page 4 of the Calibration Certificate dated 06.05.2024, calibration mark:

Calibration results - Volume output

		Gravimetric standard			Test fluid conditions		
Date	No.	Flow	Measurement time	Volume	Pressure upstream	Pressure downstream	Temperature
		mean	mean	mean	mean	mean	mean
		[m³/h]	[s]	[m³]	[bar]	[bar]	[°C]
10.04.24	1	150.101	64.900	2.706	3.02	3.00	20.08
12.04.24	2	299.914	324.848	27.063	3.05	2.99	20.07
15.04.24	3	399.132	243.818	27.032	3.10	2.99	20.08
15.04.24	4	623.778	156.365	27.094	3.25	2.99	20.08
18.04.24	5	150.115	64.895	2.706	3.02	3.00	20.07
18.04.24	6	798.268	122.329	27.125	3.41	2.99	20.06
18.04.24	7	1198.958	81.823	27.251	3.90	2.99	20.26
18.04.24	8	150.004	64.903	2.704	3.02	3.00	20.02

		Gravimetric standard			Meter under test				Measurement uncertainty
Date	No.	Flow	Measurement time	Volume	Pulses	K_V-factor Measure-ment	Measurement deviation		U_{rel} (k = 2)
		mean	mean	mean	mean	mean	mean	stand. deviation	combined uncertainty
		[m³/h]	[s]	[m³]	[pulses]	[pulses/L]	[%]	[%]	[%]
10.04.24	1	150.101	64.900	2.706	27046	9.995	-0.052	0.012	0.024
12.04.24	2	299.914	324.848	27.063	270354	9.990	-0.102	0.005	0.020
15.04.24	3	399.132	243.818	27.032	270058	9.990	-0.097	0.003	0.020
15.04.24	4	623.778	156.365	27.094	270718	9.992	-0.081	0.002	0.020
18.04.24	5	150.115	64.895	2.706	27045	9.994	-0.058	0.010	0.022
18.04.24	6	798.268	122.329	27.125	271010	9.991	-0.089	0.004	0.020
18.04.24	7	1198.958	81.823	27.251	272258	9.991	-0.091	0.006	0.020
18.04.24	8	150.004	64.903	2.704	27029	9.995	-0.053	0.017	0.028



The calibration results (tables) represent average values. Each of these values was calculated from five individual measurements (diagrams).
The combined uncertainty of the measurements represents the expanded measurement uncertainty which is based on a standard uncertainty multiplied by a coverage factor $k = 2$. This provides a level of confidence of 95 %. The estimate of the standard uncertainty has been carried out with the methods recommended in the „Guide to the Expression of Uncertainty in Measurement“ of ISO.
The represented value of U_{rel} was estimated in accordance to ILAC-P14 12/2010: U_{rel} additionally includes the short-term contributions during calibration.

Die Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig und Berlin ist das nationale Metrologieinstitut und die technische Oberbehörde der Bundesrepublik Deutschland für das Messwesen. Die PTB gehört zum Geschäftsbereich des Bundesministeriums für Wirtschaft und Energie. Sie erfüllt die Anforderungen an Kalibrier- und Prüflaboratorien auf der Grundlage der DIN EN ISO/IEC 17025.

Zentrale Aufgabe der PTB ist es, die gesetzlichen Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI) darzustellen, zu bewahren und weiterzugeben. Die PTB steht damit an oberster Stelle der metrologischen Hierarchie in Deutschland. Die Kalibrierscheine der PTB dokumentieren eine auf nationale Normale rückgeführte Kalibrierung.

Dieser Ergebnisbericht ist in Übereinstimmung mit den Kalibrier- und Messmöglichkeiten (CMCs), wie sie im Anhang C des gegenseitigen Abkommens (MRA) des Internationalen Komitees für Maße und Gewichte enthalten sind. Im Rahmen des MRA wird die Gültigkeit der Ergebnisberichte von allen teilnehmenden Instituten für die im Anhang C spezifizierten Messgrößen, Messbereiche und Messunsicherheiten gegenseitig anerkannt (nähere Informationen unter http://www.bipm.org).

Diese Aussage und das CIPM-MRA-Logo beziehen sich nur auf die Messergebnisse in diesem Kalibrierschein.

CIPM MRA

The Physikalisch-Technische Bundesanstalt *(PTB) in Braunschweig and Berlin is the National Metrology Institute and the supreme technical authority of the Federal Republic of Germany for metrology. The PTB comes under the auspices of the Federal Ministry of Economics and Energy. It meets the requirements for calibration and testing laboratories as defined in DIN EN ISO/IEC 17025.*

The central task of PTB is to realize, to maintain and to disseminate the legal units in compliance with the International System of Units (SI). PTB thus is at the top of the metrological hierarchy in Germany. The calibration certificates issued by PTB document a calibration traceable to national measurement standards.

This certificate is consistent with the Calibration and Measurement Capabilities (CMCs) that are included in Appendix C of the Mutual Recognition Arrangement (MRA) drawn up by the International Committee for Weights and Measures (CIPM). Under the MRA, all participating institutes recognize the validity of each other's calibration and measurement certificates for the quantities, ranges and measurement uncertainties specified in Appendix C (for details, see http://www.bipm.org).

The CIPM MRA Logo and this statement attest only to the measurement component of the certificate.

\- end of calibration certificate -

Physikalisch-Technische Bundesanstalt
Bundesallee 100
38116 Braunschweig
DEUTSCHLAND

Abbestraße 2-12
10587 Berlin
DEUTSCHLAND

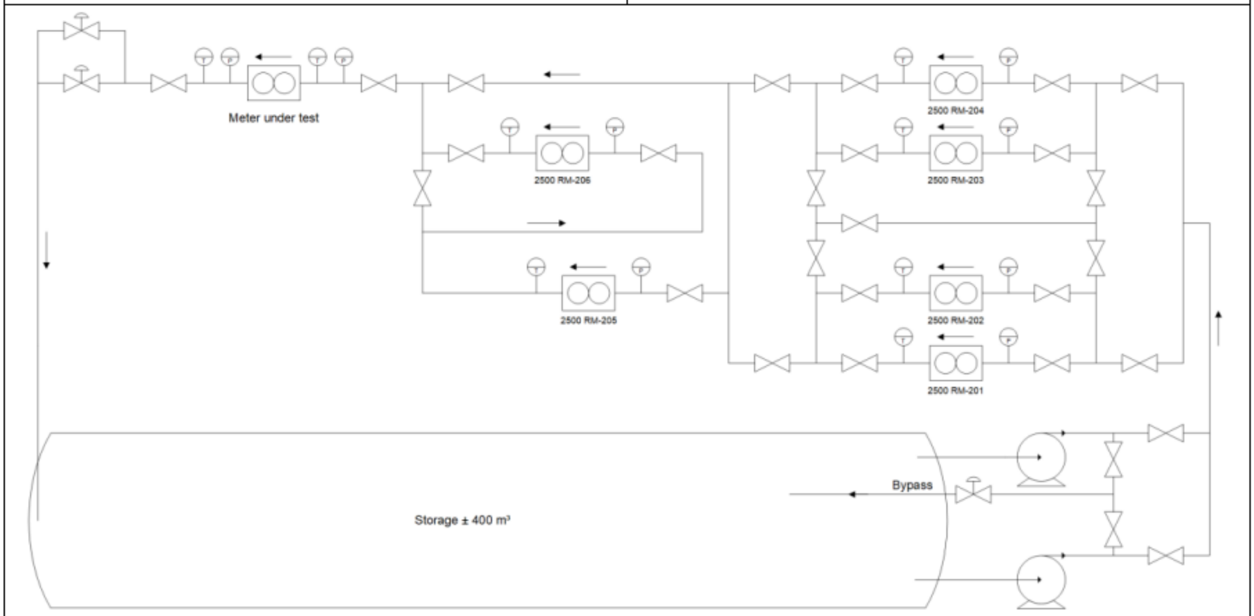
C. VSL Calibration Protocol

Characteristic information liquid flow meter calibration facility WF2500

Range of flow	10 m³/h to 2500 m³/h
Fluid temperature	Ambient depending on use and time of year. 15 °C to 25 °C
Line pressure	2 to 4 bar(g)
Uncertainty (*k*=2)	Claimed CMC 0.04 % Real 0.03 %
Method of calibration	Master Meter
Operating method	Flying start and stop with pulse interpolation
Calibration line	8 m length and diameters ranging from 150 mm to 450 mm. Inlet pipe to meter under test section is 300 mm.
Test fluid	Water

Working procedure

The VSL WF2500 facility for the calibration of liquid flow meters is part of the National Standards of the Netherlands. The facility utilizes water to establish a direct link for a flow meter calibrated to the SI measurement units for mass and volume quantities and mass and volume flow rates. The facility has six reference meters traceable to the gravimetric system of the WF650 facility and uses the so-called master meter method. In the basement there is a storage for 400 m³ water. Depending on the flow rate one or two pumps are used to generate the flow, both with a frequency controlled drive. Two control valves are in use located after the flow meter under test location. With the pumps and the control valve flow rate can be set and maintained at required pressures. Approximately 8 m of build in space is available for a flow meter under test. The temperature is not controlled. The natural cooling from the surrounding soil is used to keep temperature as stable as possible during calibration runs.



D. VSL Calibration Certificate

VSL National Metrology Institute

CERTIFICATE OF CALIBRATION

Number 3930049
Page 1 of 4

Applicant VSL B.V.
Walrusweg 5
3199 ME Maasvlakte Rotterdam
The Netherlands

Submitted A liquid Coriolis mass flow meter.

Manufacturer	:	Emerson (Micro Motion)
Type/model	:	CMFHC3M804N2GND2ZZIC
Serial number	:	13436784

Calibration method The measurement error of the Coriolis mass flow meter, as a function of flow rate has been determined by direct comparison with the National Standard for liquid quantity measurements (master meters).

The Coriolis mass flow meter was zeroed before the calibration (used zero) and was validated before and after the calibration during a static test of six minutes to be within the specification[1] set by the manufacturer.
Tests have been carried out using water with a gauge pressure up to 2.9 × 10^5 Pa and a mean temperature of (18.9 ± 0.4) °C.
The measurements are performed at an ambient air temperature of (20.4 ± 1.0) °C, air pressure of (1017.5 ± 5) hPa and a relative air humidity of (50 ± 5) %.

Date of calibration 19 March 2024

Result The results of the calibration are shown on page 3 of this certificate.
The reported uncertainty of measurement is based on the standard uncertainty multiplied by a coverage factor $k = 2$, which for a normal distribution corresponds to a coverage probability of approximately 95 %. The standard uncertainty has been determined in accordance with the GUM 'Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement'.

Traceability The results of the calibration services are traceable to primary and/or (inter)nationally accepted measurement standards.

Maasvlakte (Rotterdam), 31 July 2024

On behalf of VSL,
The Certificate Committee

VSL National Metrology Institute

VSL B.V.
Thijsseweg 11, 2629 JA Delft (NL)
T +31 15 269 15 00
I www.vsl.nl

This certificate is electronically signed and sealed. This can be verified on www.vsl.nl/en/digital-certificates.

The measurement results presented in this certificate only relate to the standard(s) as described in this certificate.

version 28

VSL National Metrology Institute

CERTIFICATE OF CALIBRATION

Number 3930049
Page 2 of 4

Instrument **Coriolis mass flow meter**

Manufacturer	: Emerson (Micro Motion)
Type/model	: CMFHC3M804N2GND2ZZIC
Serial number	: 13436784
TAG number	: --
Q_{nom}	: 1604.333 t/h [1]
Flow.cal.factor	: 6920.74.26
FT	: 4.26
DT	: 4.33
FD	: 250
D1	: 0
D2	: 1
K1	: 9309.27
K2	: 11396.93
Pressure effect mass	: -0.015 %/(10^5 Pa) [1]
Pressure effect density	: -0.0363 kg/m³/(10^5 Pa) [1]
As found zero	: -0.00695 µs
Used zero	: -0.00639 µs
In- and outlet diameter	: 250 mm

Core processor

Manufacturer	: Emerson (Micro Motion)
Type/model	: 800
Serial number	: 34227350

Transmitter

Manufacturer	: Emerson (Micro Motion)
Type/model	: 5700R1WAGMAZZZ
Serial number	: 19013316
Base k-faktor mass	: 15000 pulses/t
Meter Factor Mass	: 1.0000
Meter Factor Volume	: 1.0000
Meter Factor Density	: 1.0000

The transmitter is provided with a pulse-output.

VSL National Metrology Institute

CERTIFICATE OF CALIBRATION

Number 3930049
Page 3 of 4

Results

Indicated mass flow-rate (t/h)	Mass error (%)	U (%)	n (-)
149.83	+0.006	0.03	3
299.25	- 0.056	0.03	5
400.48	- 0.048	0.03	10
625.48	- 0.025	0.03	5
151.55	+0.014	0.03	3
799.47	- 0.025	0.03	5
1202.3	+0.001	0.03	10
152.57	- 0.003	0.03	3

$$\text{Mass error (\%)} = \frac{\text{Indicated mass} - \text{Reference mass}}{\text{Reference mass}} \times 100\ \%$$

References

1) Micro Motion ELITE Coriolis flow and density meters - Product Data Sheet PS-00374, Rev AN, March 2023

VSL National Metrology Institute

CERTIFICATE OF CALIBRATION

Number 3930049
Page 4 of 4

The reported results are consistent with the national designation of VSL, its international acceptance under the CIPM MRA and international accreditation (ILAC/RvA) as mentioned on this page. If identified, only the noted designation or accreditation is valid.

[1] The reported content in this certificate is traceable to the National (Primary) Standards of The Netherlands, which realize units of measurement according to the International System of Units (SI). Measurement traceability is realized according to ILAC policy on Metrological Traceability of Measurement results (ILAC-P10:07/2020) and Acceptable Traceability (RvA-T018-NL/UK, article 3.1).

Van Swinden Laboratorium (VSL) is designated by law as the National Metrology Institute (NMI) of the Netherlands. As such, it provides direct traceability of measurement results to internationally accepted measurement standards. VSL is a signatory member of the Mutual Recognition Arrangement (MRA) of the International Committee of Weights and Measures (CIPM). The existence of mutual confidence in product specifications and product control is of fundamental importance in order to fulfill international, harmonized legislation on trade, quality, health, safety, and the environment. In this respect, standardized and equivalent measurement units and traceability to internationally accepted standards are essential. More information can be found at https://www.vsl.nl/ .