



Technical Protocol

Comparisons of standards for liquid flow rates between 6 kg/h to 20000 kg/h

EURAMET identifier: 1805

EURAMET Supplementary comparison

BIPM KCDB identifier: EURAMET.M.FFxxx

Co-ordinator / pilot

INRIM/Italy

Co-pilot

RISE/Sweden

June 2026

Comparisons of standards for liquid flow rates

Contents

1	Introduction.....	3
2	Participants and planning.....	3
3	Transfer standards.....	7
3.1	Output Configuration.....	7
3.2	Pictures of the transfer standards and flight case.....	8
3.3	Electrical connections.....	10
4	Measurement procedure and calibration protocol.....	10
4.1	Measured quantity.....	10
4.2	Calibration protocol and measurement conditions.....	12
4.3	Zeroing procedure.....	13
4.4	Zero instability.....	14
4.5	Transfer standard CMFS015M.....	14
4.6	Transfer standard CMFS050M.....	15
4.7	Transfer standard CMFS100M.....	16
4.8	Reporting the results.....	17
5	Measurement results.....	17
5.1	Uncertainty $u(\varepsilon_{lab, i})$ of laboratory reported value $\varepsilon_{lab, i}$	18
5.2	Determination of Comparison Reference Value (CRV) and its uncertainty.....	18
5.3	Determination of normalized degree of equivalence $E_{N, i}$ - Evaluation criterion A.....	19
5.4	Determination of calibration condusiveness - Evaluation criteria B and D.....	20
5.5	Final evaluation procedure of comparison data for decision table.....	21
6	References.....	21
7	Appendix.....	23

Comparisons of standards for liquid flow rates

1 Introduction

The CIPM Mutual Recognition Arrangement (CIPM MRA) is the framework through which National Metrology Institutes demonstrate the international equivalence of measurement standards. In this context, the BIPM publishes a list of Calibration and Measurement Capabilities (CMC-lists) of the institutes which have signed the MRA. However, calibration services can only be included if a quality management system according to ISO standard 17025 is established. However, quality assurance and confidence in the capabilities of other laboratories can be ensured by successful participation in a comparison in which the degree of equivalence with other national metrology institutes or calibration laboratories is determined.

A comparison is organized to determine the degree of equivalence of standards for liquid flow rates under static load changes in the range of 6 kg/h to 20 000 kg/h.

Three Coriolis Mass Flow Meters will be used as Transfer Standards (TS):

- TS1: Coriolis Mass Flow Meter, Emerson CMFS015M, for flow rates in range from 6 kg/h to 300 kg/h, at 20 °C
- TS2: Coriolis Mass Flow Meter, Emerson CMFS050M, for flow rates in range from to 600 kg/h to 5000 kg/h, at 20 °C and 50 °C; and in range from to 600 L/h to 5000 L/h, at 20 °C and 50 °C
- TS3: Coriolis Mass Flow Meter, Emerson CMFS10M, for flow rates in range from to 5000 kg/h to 20000 kg/h, at 20 °C

2 Participants and planning

The participants and planning are shown in Table 1. Each laboratory is requested to arrange transportation to the next institute.

Each laboratory is allocated a total of one month: three weeks to perform the measurements and one week to ship the TS to the next laboratory.

After the transfer standards arrive, the participating institute shall inform the pilot institutes by e-mail (a.malengo@inrim.it; r.romeo@inrim.it, oliver.buker@ri.se). Immediately after receipt, a visual inspection should be performed. The participating institute will check the instruments for any damage.

Each participating laboratory, as soon as calibrated, will send the TS to the next laboratory according to the circulation scheme (Table 1), informing the receiving laboratory and the pilot laboratory.

The travelling standards are placed in appropriate containers provided by the pilot laboratory.

The package will be transported by courier or directly by the laboratory staff.

The package will be equipped with a warning: To be opened only by laboratory staff.

After the arrival of the package, the laboratory will inform the pilot laboratory without delay, indicating the date of arrival, the status of the package, and its contents.

Comparisons of standards for liquid flow rates

Each participating laboratory bears its own costs for the transportation of the travelling standards to the next laboratory and any customs charges. The participants are responsible for completing local customs formalities. It is advised to include in each shipment order an insurance covering the hardware cost of 15 000 €.

ATA Carnet will be provided to laboratories that request it, please ensure that the carnet is presented to the customs authorities and stamped correctly.

Each laboratory must complete all customs formalities as soon as possible to avoid delays in circulation.

Comparisons of standards for liquid flow rates

Table 1: Participants and times schedule.

Institute	Country	Shipping address	Contact/mail/phone	Remarks	Date
INRIM	Italy	INRIM Strada delle Cacce, 91 10135 Torino Italy	Andrea Malengo Raffaella Romeo a.malengo@inrm.it r.romeo@inrm.it	Only CMFS015M	2026 From 01 June to 28 June
LNEC-UHM	Portugal	Laboratório Nacional de Engenharia Civil, Av. do Brasil 101, 1700-066 Lisboa Portugal	Álvaro Ribeiro asribeiro@lnec.pt		2026 From 29 June to 31 July
DTI	Denmark	Danish Technological Institute Kongsvang Allé 29, Building 14, Port A 8000 Aarhus C Denmark	Mikkel Nørgaard Bollesen mikb@teknologisk.dk		2026 From 03 August to 30 August
VTT MIKES	Finland	National Metrology Institute VTT MIKES Tehdaskatu 15, Puristamo 9P19 FI-87100 Kajaani Finland	Huovinen Mika Mika.Huovinen@vtt.fi		2026 From 01 September to 30 September
BEV	Austria	BEV - Bundesamt für Eich- und Vermessungswesen, Arltgasse 35, 1160 Vienna, Austria	Berkmann Claudia Claudia.Berkmann@bev.gv.at		2026 From 01 October to 31 October
CMI	Czechia	Czech Metrology Institute Okružní 31, 63800 Brno Czechia	Miroslava Benkova miroslava.benkova@cmi.gov.cz		2026 From 01 November to 30 November
NEL	United Kingdom	James Young Building TÜV SÜD National Engineering Lab Scottish Enterprise Technology Park, Reynolds Ave G75 0AF, United Kingdom.	Chris Mills Chris.Mills@tuvsud.com	No CMFS015M	2026 From 01 December to 8 January
METAS	Switzerland	Federal Institute of Metrology Hugo Bissig Lindenweg 50 CH-3003 Bem-Wabern Switzerland	Hugo Bissig Hugo.Bissig@metas.ch	Only CMFS015M	2026 From 01 December to 8 January
INRIM	Italy	INRIM Strada delle Cacce, 91 10135 Torino Italy	Andrea Malengo Raffaella Romeo a.malengo@inrm.it r.romeo@inrm.it		2027 From 11 January to 07 February
JV	Norway	Justervesenet Fetveien 99 2007 Kjeller Norway	Maxime Mussard mmu@justervesenet.no		2027 From 08 February to 8 March
RISE	Sweden	RISE AB Oliver Bükér / 105104 Brinellgatan 4 SE - 504 62 Borås SWEDEN	Oliver Bükér oliver.buker@ri.se		2027 From 09 March to 31 March
PTB	Germany	Physikalisch-Technische Bundesanstalt Fachbereich 1.5 Flüssigkeiten Bundesallee 100 38116 Braunschweig Germany	Corinna Kroner corinna.kroner@ptb.de		2027 From 05 April to 30 April

Comparisons of standards for liquid flow rates

CETIAT	France	CETIAT Laboratoire Débitmétrie Liquide Domaine Scientifique de la Doua 54 boulevard Niels Bohr 69100 Villeurbanne France	Kevin Romieu kevin.romieu@cetiat.fr		2027 From 03 May I to 30 May
MIRS	Slovenija	Urad RS za meroslovje Tkalska ulica 15 3000 Celje Slovenija	Matjaž Gaber Matjaz.Gaber@gov.si	No CMFS100M	2027 From 01 June to 27 June
INRIM	Italy	INRIM Strada delle Cacce, 91 10135 Torino Italy	Andrea Malengo Raffaella Romeo a.malengo@inrm.it r.romeo@inrm.it		2027 From 01 July to 31 July
VSL	The Netherlands	VSL Walrusweg 5 Rotterdam, 3199ME The Netherlands	Erik Smits fsmits@vsl.nl		2027 From 02 August to 29 August
SMU	Slovakia	Slovenský metrologický ústav (SMÚ), Karloveská 63, 841 04 Bratislava, Slovakia	Sammarah George sammarah@smu.gov.sk		2027 From 01 September to 30 September
LEI	Lithuania	Lithuanian Energy Institute, Breslaujos str. 3, LT-44403 Kaunas, Lithuania	Andrius Bončkus andrius.bonckus@lei.lt		2027 From 04 October to 30 October
INM	Moldavia	Institutul Național de Metrologie Strada Eugen Coca 28, Chișinău, Moldavia	Victor Grușcă victor.grusca@inm.gov.md		2027 From 01 November to 28 November
UKRMETRTEST STANDART	Ukraine	SE UKRMETRTESTSTANDART 4 Metrologichna str. 4, Kyiv, 03143, Ukraine	Yaroslava Volynska yvolynska@ucsm.com.ua		2027 From 01 December to 31 December
INRIM	Italy	INRIM Strada delle Cacce, 91 10135 Torino Italy	Andrea Malengo Raffaella Romeo a.malengo@inrm.it r.romeo@inrm.it		2028 From 03 January to 31 January

Comparisons of standards for liquid flow rates

3 Transfer standards

For the comparison INRIM provides three transfer standards, details are shown in the following table.

Table 2: The transfer standards used for the comparison.

Manufacturer	EMERSON		EMERSON		EMERSON	
Model	CMFS015M		CMFS050M		CMFS100M	
Serial number	12176384		15060646		15061260	
Fitting	1/4" threaded fitting		DN25 flanged pipe		DN50 flanged pipe	
	with flanges supplied EN 1092 01 DN25		EN 1092-01/11/ DN25/15/ PN40		EN 1092-01/11D/ DN50/ PN40	
Dimensions						
Face-to-face flanges	38	cm	48	cm	59	cm
Dimension from centreline to bottom	11	cm	18	cm	22	cm
Dimension from centreline to top	21	cm	22	cm	25	cm

The **CMFS015M** meter is equipped with small-diameter inlet and outlet process connections. **This meter cannot be installed** in calibration rigs that rely on a flange clamping system to achieve a seal. For these rigs, the meter must be mounted off-line. It can be connected using threaded fittings or with the supplied flanges.

3.1 Output Configuration

The output configuration is shown in the following table.

Table 3: Output configuration.

Model	CMFS015M	CMFS050M	CMFS100M
Calibration	Mass totalized	Mass and Volume totalized	Mass totalized
Output A	4–20 mA for zero verification 4 mA: -0.1 kg/h 20 mA: +0.1 kg/h	4–20 mA for zero verification 4 mA: -1 kg/h 20 mA: +1 kg/h	4–20 mA for zero verification 4 mA: -2 kg/h 20 mA: +2 kg/h
Output B	-	Digital pulse 0.5 mL/pulse	-
Output C	Digital pulse 0.2 g/pulse	Digital pulse 0.5 g/pulse	Digital pulse 3 g/pulse
Measurand	Totalized mass error	Totalized mass error	Totalized mass error
		Totalized volume error	

Comparisons of standards for liquid flow rates

For all meters, the mass flow cutoff threshold is set to zero. The volume flow cutoff is also set to zero for the CMFS050M.

For the **CMFS015M** only, the **meter factor** is set to 1.005; for the other two, it is 1.

3.2 Pictures of the transfer standards and flight case

The transfer standards CMFS015M and CMFS050M (Figure 1) are transported in a common flight case (Figure 2).

Dimension: (40x 50 x 80) cm

Weight: 40 kg

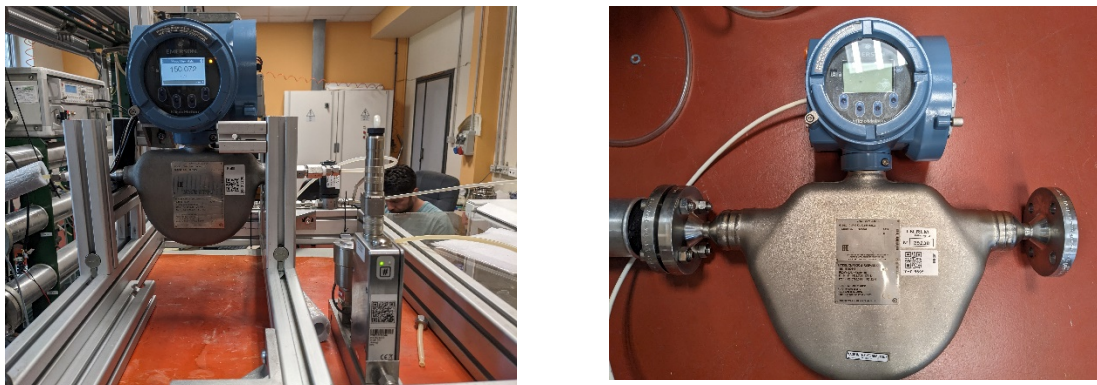


Figure 1: Pictures of CMFS015M (left) and CMFS050M (right).



Figure 2: Picture of the flight case.

Comparisons of standards for liquid flow rates

The transfer standard CMFS100M (Figure 3) is transported in a special package in a cardboard box (Figure 4). **Please use the pallet provided.**

Dimension: (60x 65 x 30) cm

Weight: 25 kg



Figure 3: Picture of the CMFS100M.



Figure 4: Picture of the cardboard box.

3.3 Electrical connections

Power Supply

Micro Motion transmitters are equipped with an auto-switching AC/DC input that automatically detects voltage. Connect the power supply to the terminals located under the protective cover.

Digital and analog outputs

Table 4: Connector terminal block description.

Channel	Terminals	Output Type	Function
A	1 (+) 2 (-)	Analog 4-20 mA	Mass flow rate
B	3 (+) 4 (-)	Digital	Volume Pulse Output, only for CMFS050M
C	5 (+) 6 (-)	Digital	Mass Pulse Output

The outputs can be configured as active or passive. The configuration was checked before connecting the outputs; details are provided in the Appendix.

4 Measurement procedure and calibration protocol

4.1 Measured quantity

The comparison is based on the measurement of the relative error in the totalized mass and volume (only for the CMFS050M) of the transfer standards.

The mass relative error ε_m (%) is defined as:

$$\varepsilon_m = \frac{m_{\text{DUT}} - m_{\text{ref}}}{m_{\text{ref}}} \cdot 100\% \quad (1)$$

where m_{DUT} is the totalized mass by the meter and m_{ref} is the reference totalized mass.

For meter CMFS050M, the relative error for the volume is also determined

The volume relative error ε_V (%) is defined as:

$$\varepsilon_V = \frac{V_{\text{DUT}} - V_{\text{ref}}}{V_{\text{ref}}} \cdot 100\% \quad (2)$$

where V_{DUT} is the totalized volume by the meter and V_{ref} is the reference totalized volume.

Comparisons of standards for liquid flow rates

The errors have to be determined at the flow rate points defined in Sections 4.5, 4.6 and 4.7, at a temperature of approximately 20 °C. Calibration at 50 °C is required only for the CMFS050M meter.

Since the flow meters under test are affected by changes in fluid temperature and pressure, corrections must be made to account for errors under specified conditions.

The conditions under which measured errors must be expressed are as follows:

- The reference pressure p_{ref} at which errors must be calculated is 3 bar (absolute)
- The reference temperature t_{ref} at which errors must be calculated are 20 °C and 50 °C for the calibration of the CMFS050M meters at 50 °C.

The coefficients of variation with respect to temperature dependence are shown in Table 5. The values were specified by the manufacturer. The corrections for temperature are negligible if the temperatures are (20 ± 5) °C and (50 ± 5) °C, and considering that a zero-flow calibration is performed before conducting the measurements.

With regard to pressure dependence, the coefficients of variation for mass flow rate C_m and density measurement C_ρ are shown in the Table 5. The effect of pressure on density is only relevant for the CMFS050M meter, where the volume error is determined. These values were determined experimentally and confirmed the manufacturers' specifications.

Since the pressure measurement affects the corrections applied to the measurements, it is recommended that the pressure measurement be performed with an expanded uncertainty of less than 0.1 bar.

Table 5. Coefficients of variation for the temperature and pressure.

	CMFS015M	CMFS050M	CMFS100M
coefficients of variation for mass flow	No effect	$C_m = 0.014$ % per bar $u(C_m) = 0.001$ %	$C_m = 0.026$ % per bar $u(C_m) = 0.002$ %
coefficients of variation for density	Not required	$C_\rho = 0.36$ kg/m ³ per bar $u(C_\rho) = 0.01$ kg/m ³	Not required
coefficients of variation for temperature	± 0.0002 % per °C	± 0.0001 per °C	± 0.0001 per °C

Correction for pressure effects for the mass

The correction of the totalized mass reading m_{read} on the meter, obtained by counting the pulses in each test, must be performed as follows

Comparisons of standards for liquid flow rates

$$m_{DUT} = m_{read}[1 + C_m(p - p_{ref})] \quad (3)$$

Where p is the upstream pressure of the meter (absolute in bar)

This value is to be used to calculate the mass error in Equation 1.

Correction for pressure effects for volume (only DN15)

Since the volume recorded by the meter depends on the density measurement, which is influenced by pressure, the following procedure is used:

For each test, simultaneously record the pulse counts for both mass and volume, from which the totalized mass reading m_{read} and the totalized volume reading V_{read} are determined

The average density measured by the meter ρ_{read} during the test is therefore:

$$\rho_{read} = \frac{m_{read}}{V_{read}} \quad (4)$$

then convert this measurement to the reference pressure p_{ref} to obtain ρ_{DUT} , according to the equation

$$\rho_{DUT} = \rho_{read} + C_p(p - p_{ref}) \quad (5)$$

As in the case of mass measurements, correct the reading m_{read} for pressure according to the equation 3, to obtain m_{DUT} .

The volume measurement corrected for the reference pressure V_{DUT} is therefore obtained as

$$V_{DUT} = \frac{m_{DUT}}{\rho_{DUT}} \quad (6)$$

This value is to be used to calculate the mass error using Equation 2.

For the exclusive purpose of analyzing the results, it is required to report the error observed on the density

$$\varepsilon_\rho = \frac{\rho_{DUT} - \rho_{ref}}{\rho_{ref}} \cdot 100\% \quad (7)$$

4.2 Calibration protocol and measurement conditions

In this section, the calibration protocol is described, and the range of measurement conditions is provided.

The participating laboratories ensured the following conditions during the measurements:

- working fluid temperature: $(20 \pm 5)^\circ\text{C}$ and $(50 \pm 5)^\circ\text{C}$ only for the meter CMFS050M
- ambient temperature: $(20 \pm 5)^\circ\text{C}$
- ambient humidity: from 30 % to 80 %

Comparisons of standards for liquid flow rates

- absence of free air in the measuring line of the standard.

After installing the meters on the test bench, it was necessary to stabilise the bench temperature and allow it to flow for at least one hour before beginning the calibration.

Please read the information in the Appendix regarding the use of the transmitter

4.3 Zeroing procedure

Coriolis flowmeters must be regularly zeroed with zero flow. The procedure for performing zeroing is shown in the Appendix.

Although the meter also allows for a zero check, the meter zeroing procedure should be performed. The time set for zeroing the meters is 180 s.

An approximate check of the zero setting can be performed by reading the mass flow rate on the instrument display.

The 4-20 mA output allows for the accurate verification of the flow rate measurement when no flow is present. It is recommended to perform the test for at least 120 s.

The measurement range of the analog output has been set to a narrow range to ensure accurate measurement.

The zero-point measurement can be used to correct the reading; however, tests have shown that if the zero-adjustment procedure is performed regularly, corrections are unnecessary.

As described in Section 4.4, zero stability may affect the measurements at low flow rates on the CMFS015M meter. For this meter, at flow rates of 6 kg/h and 20 kg/h, it is recommended to adjust or verify the zero every 5 tests. For other meters, it is usually sufficient to perform a zero adjustment every 2 h.

Comparisons of standards for liquid flow rates

4.4 Zero instability

Zero-point instability tests were performed at zero flow rate by recording the measured flow rate via the 4–20 mA analog output.

The tests conducted showed that the zero instability of the meters is as follows:

Table 6: Zero-point instability test results.

Model	Standard deviation in kg/h	Standard deviation of the mean of 5 repetitions in kg/h	Maximum difference between the means of 5 repetitions in kg/h	Uncertainty of instability in kg/h ($u_{k=1}$)
CMFS015M	0.02	0.0015	0.0025	0.007
CMFS050M	0.20	0.033	0.05	0.014
CMFS100M	0.30	0.044	0.07	0.02

At low flow rates, zero instability affects the measurement repeatability.

There are no significant effects for CMFS050M and CMFS100M, for example for the CMFS050M at the minimum flow rate of 600 kg/h the standard deviation increase of about $0.033/600 = 0.005\%$ and for the CMFS100M at 5000 kg/h $0.044/5000 = 0.0009\%$.

For the CMFS015M meter, zero stability does not normally affect the measurements unless the flow rate is below 50 kg/h.

For the meter CMFS015M the increase could be significant, at 20 kg/h is about $0.0015/20 = 0.0075\%$ and at 6 kg/h is about $0.0015/6 = 0.025\%$

Therefore, for flow rates of 6 kg/h and 20 kg/h, it is suggested to perform the test for a duration of at least 120 s, and 180 s is recommended.

The averages obtained from the 5 repetitions may differ slightly from each other. The maximum variations observed are shown in Table 6. Because of this effect, an uncertainty due to zero instability is assigned, which is considered in the uncertainty u_{TS} (Section 6), the values are shown in Table 6.

4.5 Transfer standard CMFS015M

Please note that this meter cannot be installed on benches where sealing is achieved by applying pressure to the flanges.

The calibration process should be performed in accordance with your internal calibration procedure. However, for flow rates of 6 kg/h and 20 kg/h, it is recommended to use times longer than 120 s; if the laboratory uses shorter times, it must indicate this in the report.

The following requirements must be fulfilled:

- Install, purge, and warm-up the transfer standard using your internal procedures.

Comparisons of standards for liquid flow rates

- Close the valves upstream and downstream of the transfer standard and perform the zero adjustment. Record the flow rate indicated by the analog output of the flow meter recorded for a period long enough to check its stability (at least 120 s).
- Perform static calibration (constant flow rate) with water at a temperature of $(20 \pm 5) ^\circ\text{C}$. Each point must be measured 5 times.
 - o 6 kg/h
 - o 20 kg/h
 - o 50 kg/h
 - o 150 kg/h
 - o 300 kg/h

Record the upstream pressure p and temperature during the tests.

From the pulse count and the pressure p , calculate m_{DUT} using the equation 3.

- After taking the measurements, close the valves upstream and downstream of the transfer standard. Then record the indication of the flow meter with no flow to check for deviation.

At flow rates of 6 kg/h and 20 kg/h, it is recommended to adjust or record the zero after every five tests. For the other flow rates, the zero drift is less significant, and the zero check can be performed after approximately 2 h of testing.

The expected changes in zero are listed in Table 6.

If necessary, the recorded zero values can be used to correct the measurements.

4.6 Transfer standard CMFS050M

Perform the calibration in accordance with your internal calibration procedure. The following requirements must be fulfilled:

- Install, purge, and warm-up the transfer standard using your internal procedures.
- Close the valves upstream and downstream of the transfer standard and perform the zero adjustment. Record the flow rate indicated by the analog output of the flow meter recorded for a period long enough to check its stability (at least 120 s).
- Perform static calibration (constant flow rate) with water at a temperature of $(20 \pm 5) ^\circ\text{C}$. Each point must be measured 5 times.
 - o 600 kg/h
 - o 1000 kg/h
 - o 2000 kg/h
 - o 3000 kg/h
 - o 5000 kg/h

Record the upstream pressure p and temperature during the tests.

From the pulse count and the pressure p , calculate m_{DUT} using the equation 3.

Comparisons of standards for liquid flow rates

- After taking the measurements, close the valves upstream and downstream of the transfer standard. Then record the indication of the flow meter with no flow to check for deviation.

For this meter, the zero check can be performed after approximately 2 h of testing.

The expected changes in zero are listed in Table 6.

If necessary, the recorded zero values can be used to correct the measurement.

Volume tests must be performed at the same flow rates as those specified for the mass tests.

For the volume test, it is necessary to simultaneously record both the totalized volume and mass pulses. From these two measurements, the average density value is obtained, which must be used to calculate the volume, as described in Section 4.1. For the volume tests, it is also necessary to record the average reference density of the water used in the test.

Therefore, it is recommended to perform both mass and volume calibrations simultaneously.

For this meter, the measurement error should also be determined at a water temperature of 50 °C, at the same flow rates as those measured at 20 °C, and using the same procedure as described above.

4.7 Transfer standard CMFS100M

Perform the calibration in accordance with your internal calibration procedure. The following requirements must be fulfilled:

- Install, purge, and warm-up the transfer standard using your internal procedures.
- Close the valves upstream and downstream of the transfer standard and perform the zero adjustment. Record the flow rate indicated by the analog output of the flow meter recorded for a period long enough to check its stability (at least 120 s).
- Perform static calibration (constant flow rate) with water at a temperature of (20 ± 5) °C. Each point must be measured 5 times.
 - o 5000 kg/h
 - o 7000 kg/h
 - o 10000 kg/h
 - o 15000 kg/h
 - o 20000 kg/h

Record the upstream pressure p and temperature during the tests.

From the pulse count and the pressure p , calculate m_{DUT} using the equations 3.

For this meter, the zero check can be performed after approximately 2 h of testing.

The expected changes in zero are listed in Table 6.

If necessary, the recorded zero values can be used to correct the measurement.

Comparisons of standards for liquid flow rates

4.8 Reporting the results

The parameters to be reported are listed in Table 7.

The clear indication of the determination of the uncertainty of the reference flow is a prerequisite. In addition, the results should be sent to the pilot laboratories within one month of the tests being carried out. Furthermore, the participants are requested to use the table in the Excel sheet to report the individual measurement results. The table has the following layout:

Table 7: Measurement results – for each TS and flow rate.

Test number	1	2	3	4	5
Reference flow / kg h ⁻¹					
Test duration / s					
Mean upstream pressure / bar					
Uncertainty upstream pressure (k=2) / bar					
Mean water temperature / °C					
Flow rate at zero flow / kg h ⁻¹ (if necessary)					
Correction of m_{read} due to zero flow / g (if necessary)					
TS Totalized mass m_{read} / g					
TS Totalized mass m_{DUT} / kg					
Reference Totalized mass m_{ref} / kg					
Correction for V_{read} due to zero flow / L (if necessary)					
TS Totalized Volume V_{read} / L					
TS mean density ρ_{read} / kg m ⁻³					
TS mean density ρ_{DUT} / kg m ⁻³					
Reference mean density ρ_{ref} / kg m ⁻³					
Mean density relative error / %					
TS Totalized Volume V_{DUT} / L					
Reference Totalized mass V_{ref} / L					
Mass relative error / %					
Mean mass relative error / %					
Standard deviation of the mean error / %					
Lab expanded uncertainty mean mass relative error / %					
Volume relative error / %					
Mean volume relative error / %					
Standard deviation of the mean error / %					
Lab expanded uncertainty mean volume relative error / %					

5 Measurement results

The comparison reference value (CRV) will be determined for all individual flow points and will be determined based on the weighted average from all individual laboratories. All results will be compared with this reference value. The chi-squared test will be used to identify outliers. The procedure described in [1] will be used.

The pilots and co-pilots will provide the uncertainty u_{TS} of the transfer standards, which includes the long-term instability of the standards themselves, their pressure sensitivity, their temperature sensitivity, and zero instability.

Comparisons of standards for liquid flow rates

5.1 Uncertainty $u(\varepsilon_{lab,i})$ of laboratory reported value $\varepsilon_{lab,i}$

As described in [1], [2] and [3], the uncertainty of the reported value $\varepsilon_{lab,i}$ includes uncertainties introduced by the participant's flow reference $u_{lab,i}$ by the transfer meter u_{TS} and by the repeatability of the reported value (Equation (8)). The used input parameters of $u_{lab,i}$ do represent the claimed uncertainty values of the laboratories, which were under evaluation during this comparison. As values for $u_{lab,i}$ the expanded laboratory uncertainty are used. Uncertainty calculations of u_{TS} are based on the discussions in Chapter 5, final values of u_{TS} . The term $s/\sqrt{n}$ represents the repeatability of measurements in the participants laboratory and are based on reported calibration results.

$$u(\varepsilon_{lab,i}) = \sqrt{u_{lab,i}^2 + u_{comp}^2} = \sqrt{u_{lab,i}^2 + u_{TS}^2 + \left(\frac{s}{\sqrt{n}}\right)^2} \quad (8)$$

where:

- $u(\varepsilon_{lab,i})$ 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 mean of measurements at one flowrate point (%)
- n Number of calibrations at one flowrate point (-)

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

5.2 Determination of Comparison Reference Value (CRV) and its uncertainty

The CRV is calculated separately for each flow rate, following Procedure A in [4]. The determination of CRV includes a consistency check according to [5]. The reference value y is calculated as the weighted mean error of the participating laboratories, including the standard uncertainties $u(\varepsilon_{lab,i})$ of the measurements as the weights:

$$y = \frac{\left(\frac{\varepsilon_{lab1}}{u_{\varepsilon,lab1}^2} + \frac{\varepsilon_{lab2}}{u_{\varepsilon,lab2}^2} + \dots + \frac{\varepsilon_{lab i}}{u_{\varepsilon,lab i}^2}\right)}{\left(\frac{1}{u_{\varepsilon,lab1}^2} + \frac{1}{u_{\varepsilon,lab2}^2} + \dots + \frac{1}{u_{\varepsilon,lab i}^2}\right)} \quad (9)$$

where y is the reference value of the comparison (%).

The standard uncertainty u_y is given with:

$$\frac{1}{u_y^2} = \frac{1}{u_{\varepsilon,lab1}^2} + \frac{1}{u_{\varepsilon,lab2}^2} + \dots + \frac{1}{u_{\varepsilon,lab i}^2} \quad (10)$$

where u_y is the standard uncertainty of y with $k=1$ (%).

The expanded uncertainty of y for $k = 2$ (95% coverage probability) is calculated with:

Comparisons of standards for liquid flow rates

$$U(y) = 2 \cdot u_y \quad (11)$$

Finally, the chi-squared test is applied to determine whether the determined errors and accompanying uncertainties can be expected based on a Gaussian distribution. If so, y is accepted. The chi-squared test is defined as follows:

$$\chi_{obs}^2 = \sum_{i=1}^n \left(\frac{\varepsilon_{lab\ i} - \varepsilon_{RV}}{u(\varepsilon_{lab\ i})} \right)^2 \quad (12)$$

where χ_{obs}^2 is the observed chi-squared value.

The degrees of freedom ν are estimated with:

$$\nu = n_i - 1 \quad (13)$$

where n_i is the number of evaluated laboratories.

For data evaluation, the CHINVT(0.05; ν) function of MS Excel is used. The consistency check fails if CHINVT(0.05; ν) gives values < than χ_{obs}^2 . Note, here $u(\varepsilon_{lab\ i})$ is the standard uncertainty ($k = 1$). The set of measurement results for a certain flow point is accepted only when:

$$Pr\{\chi_{\nu}^2 > \chi_{obs}^2\} < 0.05 \quad (14)$$

where χ_{ν}^2 is the chi-squared test value.

If consistency check of Equation (14) passes, y is accepted as the Comparison Reference Value ε_{CRV} and $U(y)$ is accepted as the expanded uncertainty $U(\varepsilon_{CRV})$. If the test of Equation (14) fails, the laboratory with the highest value of $(\varepsilon_i - y)^2 / u_{\varepsilon_i}^2$ is excluded for the next evaluation round. New values of y , $U(y)$ and χ_{obs}^2 are calculated and the consistency check of Equation (14) is repeated.

5.3 Determination of normalized degree of equivalence $E_{N,i}$ - Evaluation criterion A

Differences between laboratory results ($\varepsilon_{lab,i}$) and CRV (ε_{CRV}) are calculated in accordance with equation (15) separately for each flow meter and flow rate. The results provide the degree of equivalence (DoE) for each laboratory.

$$d_i = \varepsilon_{lab,i} - \varepsilon_{CRV} \quad (15)$$

where:

d_i Degree of equivalence (DoE) for each laboratory i in %

$\varepsilon_{lab,i}$ Reported meter error of laboratory i in %

Comparisons of standards for liquid flow rates

ε_{CRV} Comparison Reference value in %

Based on the differences d_i , the normalized Degree of Equivalence $E_{N,i}$ is calculated for each laboratory and flow rate as follows:

$$E_{N,i} = \left| \frac{d_i}{U(d_i)} \right| \quad (16)$$

where $E_{N,i}$ is the normalized Degree of Equivalence.

The expanded uncertainty of d_i is calculated with equation (17) for laboratories with contribution to the CRV. Participating laboratories which are excluded from the CRV determination do not have any interference. In this case, the value of $U(d_i)$ is calculated using Equation (18).

$$U(d_i) = 2 \cdot \sqrt{u_{\varepsilon,lab\ i}^2 + u_{\text{CRV}}^2 - 2 \cdot u_{\text{CRV}}^2} = 2 \cdot \sqrt{u_{\varepsilon,lab\ i}^2 - u_{\text{CRV}}^2} \quad (17)$$

$$U(d_i) = 2 \cdot \sqrt{u_{\varepsilon,lab\ i}^2 + u_{\text{CRV}}^2} \quad (18)$$

5.4 Determination of calibration conclusiveness - Evaluation criteria B and D

To follow the latest developments in the field of comparison evaluation, an improved method for evaluating the comparison results is used. This method was discussed for a long time within the CCM Working Group for Fluid Flow (WGFF) and the results were presented at Flomeko 2022 [6]. Criteria B and D, both apply a quality check of the comparison uncertainty to see if a result is conclusive before applying the $|E_n| \leq 1.00$, respectively, $|E_n| \leq 1.20$ criterion.

In detail, the conclusiveness of the calibration results is verified by the following two criteria, where Criterion B is a recommendation and Criterion D is the final decision value [3]:

- The ratio of $u_{\text{comp}}/u_{\text{lab } i}$, also called evaluation criterion B, underlines the suitability of the transfer standard as well as a sufficiently high quality of the calibrations, expressed as the repeatability. The WGFF proposed that $u_{\text{comp}}/u_{\text{lab } i} \leq 2$ for conclusive comparison results and to avoid a participant passing solely because the transfer standard uncertainty and repeatability are large [2, 3, 6]. Following Equation (8), u_{comp} was calculated using:

$$u_{\text{comp}} = \sqrt{u_{\text{TS}}^2 + \left(\frac{s}{\sqrt{n}}\right)^2} \quad (19)$$

- The second additional evaluation criterion D was introduced by [2] as a probability-based measure for evaluating whether a comparison result is conclusive. Here, laboratory results are evaluated by the degree to which two Gaussian probability density functions (PDFs) overlap, one representing the comparison reference value $N(\varepsilon_{\text{CRV}}, u_{\varepsilon\text{CRV}})$ and the other representing the participant's reported value for the measurand $N(\varepsilon_i, u_{\text{lab } i})$. The degree of overlap between

Comparisons of standards for liquid flow rates

both PDFs is assessed by the probability content P_i of the CRV PDF bound by the participant's 2.5% and 97.5% percentile confidence limits for the uncertainty of the participant's flow reference. The calculation of probability P_i is given in [2] 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 ε_{CRV} and ε_i for the calibration results to be conclusive.

5.5 Final evaluation procedure of comparison data for decision table

For the final data evaluation and decision table, the following criteria were used, based on [2], [3], [4], [5], and [7]:

- **Chi-squared test** - Data evaluation and consistency check,
- The participant passes the comparison if $E_{N,i} \leq 1.0$ and $P_{th} \geq 0.35$

The results of the participating laboratory i agree within 95 % confidence level uncertainty expectations with the CRV ($k = 2$). The calibrations are conclusive.

- The participant passes the comparison at "warning level" if $1.0 < E_{N,i} \leq 1.2$ and $P_{th} \geq 0.35$
- The participant **fails the comparison** if $E_{N,i} > 1.2$. 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 overlap between the density functions. This decision involves an evaluation of the transfer meter, which did not show sufficiently low uncertainties to discern lab to CRV below a certain level. In this case, the transfer standard was not suitable for confirming the declared laboratory uncertainties.

6 References

- [1] WGFF (2013): WGFF Guidelines for CMC Uncertainty and Calibration Report Uncertainty. 21.10.2013. <https://www.bipm.org/en/committees/cc/ccm/wg/ccm-wgff>.
- [2] Wright, J., Toman, B., Mickan, B., Wübbeler, G., Bodnar, O., Mickan, B., and Elster, C. (2016): Transfer standard uncertainty can cause inconclusive inter-laboratory comparisons, Metrologia 53, 1243 – 1258. DOI 10.1088/0026-1394/53/6/1243
- [3] Frahm, E. and Wright, J. D. (2023): Evaluation of Inter-Laboratory Comparison Results: Representative Examples, Measurement, Volume 223, 2023, 113723, ISSN 0263-2241, <https://doi.org/10.1016/j.measurement.2023.113723>.
- [4] Cox M. G. (2002): Evaluation of key comparison data, Metrologia 39 589 – 595.
- [5] Cox M. G. (2007): the evaluation of key comparison data: determining the largest consistent subset, Metrologia, 44, 187 – 200
- [6] Frahm, E. and Wright, J. D., Evaluating Inter-laboratory Comparison Data, FLOMEKO, Chongqing, China, November 1 to 4, 2022.

Comparisons of standards for liquid flow rates

[7] Wright, J., Mikan, B., Benkova, M., Chun-Lin Ch. (2022): Laboratory Comparison Calculations Spreadsheet Template Following Cox 2002 Method, BIPM WGFF, unpublished working paper.
<https://www.bipm.org/en/committees/cc/ccm/wg/ccm-wgff>

Comparisons of standards for liquid flow rates

7 Appendix

The following describes some functions for using the Micro Motion 5700 transmitter, which is controlled via the display and the four optical buttons (right, left, up, down)

The right button is used to select a function. It is also used to save changes; in this case, it needs to be held down. Another function is to select the digits that need to be changed.

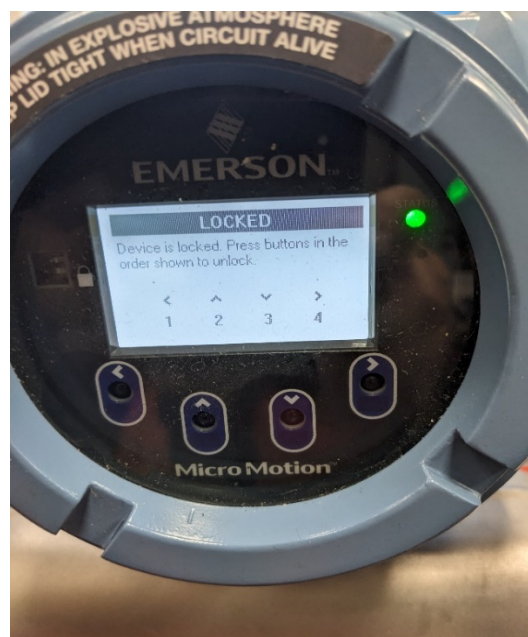
The up and down buttons are used to navigate through menus, or to increase or decrease the entered numbers.

They are also used to scroll through the displayed measurements, such as the mass flow rate, volume flow rate, temperature, and density.

The left button is used to exit the menus or select the digits of the numbers to be edited.

To return to the measurement display, press the left button several times.

Some functions are password-protected; in that case, the following screen appears



To activate, press the buttons in sequence from left to right: 1, 2, 3, and 4

“Output saturated” message

Since the analog output has a limited measurement range, to improve the accuracy of the flow measurement at zero, the message “Output saturated” will appear during normal operation; simply acknowledge the alarm using the left button.

Comparisons of standards for liquid flow rates



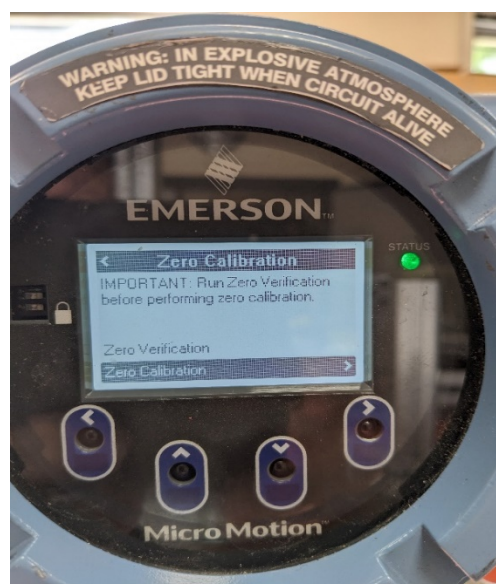
Zero the meter

Prepare the meter:

- After applying power, allow the meter to warm up for at least 20 min.
- Allow the process medium to flow through the sensor until the sensor temperature reaches the normal process operating temperature.
- Stop the flow through the sensor by first shutting the downstream valve and then, if present, the upstream valve.

Use the buttons to select the zero-point adjustment function:

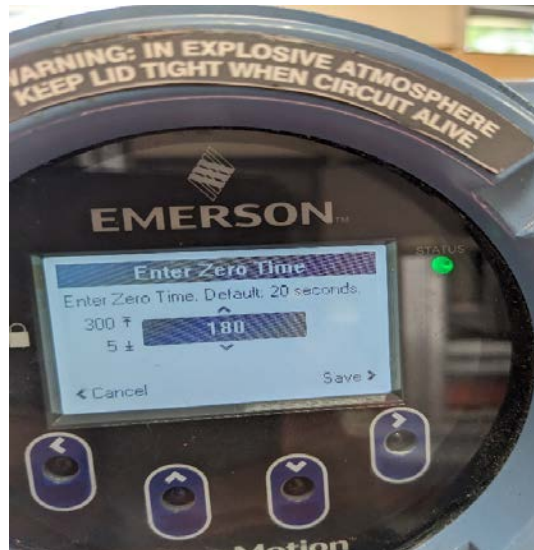
Menu → Service Tools → Verification & Calibration → Meter Zero → Zero Calibration



Comparisons of standards for liquid flow rates

d) Check Zero Time

Zero Time controls the amount of time the transmitter takes to determine its zero-flow reference point. The default zero time is 180 s.

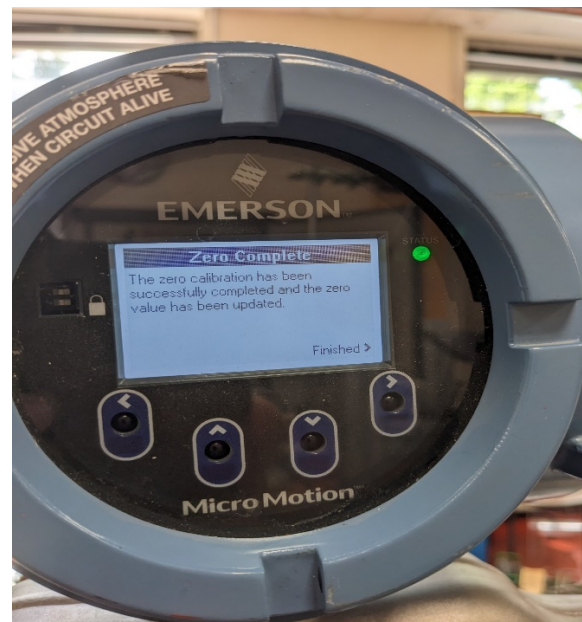


3. Start the zeroing procedure and wait until it has finished.

When the calibration is complete:

- If the zero procedure was successful, a Calibration Success message and a new zero value are displayed.

Press the button to Continue and after Finished



- If the zero procedure failed, a Calibration Failed message is displayed, in this case, repeat the procedure

Comparisons of standards for liquid flow rates

Configure the Outputs (Set Power internal or external)

Use the buttons to select the pulse output Channel

Channel A for the current output

Channel B for pulses for the volume

Channel C for pulses for mass

Menu → Configuration → Inputs/Outputs → Channel A, B or C.

For example Channel C



Select Power to change internal or external

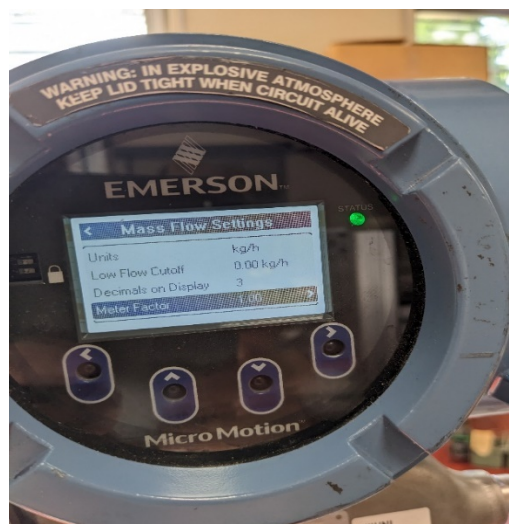


To save your changes, hold down the right button (Save)

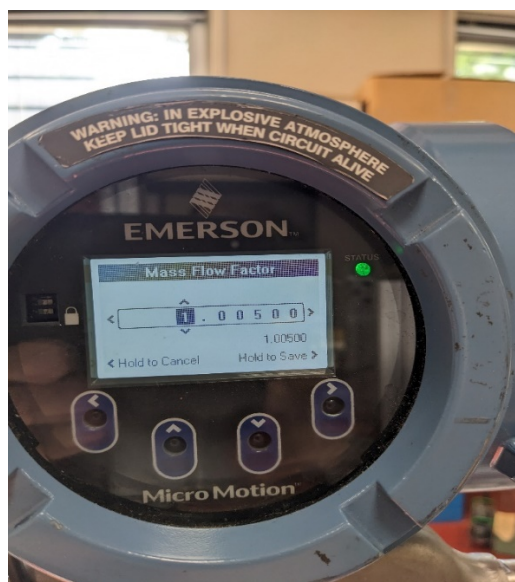
Check the Factor Meter

Menu → Configuration → Process Measurement → Flow Variables → Mass Flow Settings → MeterFactor

Comparisons of standards for liquid flow rates



Select Meter Factor



Check the Output configuration

Menu → Configuration → Inputs/Outputs → Channel A, B or C

For example for the Channel C

Select I/O Setting

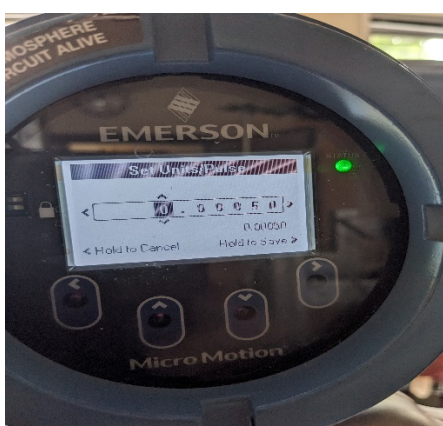
Comparisons of standards for liquid flow rates



Select Units/Pulse



Read the value



Press and hold the left button to exit.