

Protocol for bilateral comparison of water flow measurement standards between the National Metrology Institutes of Bulgaria (BIM) and The Netherlands (NMI VSL)

Euramet project 1072

NMI Van Swinden Laboratorium B.V.

Liquid Flow & Volume
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Micro Motion CMF200



Krohne Altometer Optiflux 5000

Introduction and purpose of the bilateral comparison

The purpose of the bilateral comparison of water flow measurement standards is to support the Calibration and Measurement Capabilities (CMC) of the Bulgarian Institute of Metrology (BIM). This comparison will be performed under the framework of Euramet.

The aim of the comparison is that the deviations at different flow-rates between the two water flow measurement standards found using two flow meters do not exceed the summed measurement uncertainties of the two water flow measurement standards according to the E_n value calculation for bilateral comparisons ($E_n < 1$).

NMI Van Swinden Laboratorium (NMI VSL) is the pilot laboratory for the bilateral comparison due to the fact that NMI VSL has an entry in the International Bureau of Weights and Measures (BIPM) Mutual Recognition Arrangement (known as the CIPM MRA) for water flow measurement.

For this bilateral comparison NMI VSL will use Euramet Guide no. 3 "Euramet Guidelines on Conducting Comparisons". In addition NMI VSL will follow the technical aspects of ILAC guideline G13 "ILAC Guidelines for the Requirements for the Competence of Providers of Proficiency Testing Schemes"

For a bilateral comparison a number of issues need to be addressed to achieve the aim of the comparison. These issues have all been identified and addressed in this document. If other issues appear during the comparison they will be addressed when they appear in accordance with the guiding rules laid down in the above standing documents.

Planning

The planning for the bilateral comparison is as following

Euromet proposal for comparison number	Week 40 (2008)
Protocol of comparison to Euramet	Week 51 (2008)
Tests at NMI VSL	Week 42 and 46 (2008)
Shipment to BIM	Week 51 and 52 (2008)
Test at BIM	Week 2 through week 6 (2009)
Shipment to NMI VSL	Week 7 (2009)
Test at NMI VSL	Week 8 and 9 (2009)
Report finalization	Week 10 through 12 (2008)
Report to Euramet	Latest week 14 (2009)

Inform Pilot laboratory

If any problem arises or the package is damaged immediately contact the coordinator of this bilateral comparison. For contact details see Annex A.

The reference value

To compare the two water flow measurement standards two well known flow meters have been selected. The characteristics of these flow meters are described later in this document. For flow measurement standards it is impossible to have a direct reference value like a volume of a prover tank. Therefore the reference value is the measurement error of the quantity indication(s) (mass and or volume) of the flow meters at given flow-rates.

Reference value for a mass indicator of a flow meter

$$E_M = \frac{M_{IND} - M_{REF}}{M_{REF}} * 100\%$$

- E_M = The mass measurement error of the flow meter (%)
- M_{IND} = Indicated mass of the flow meter (kg)
- M_{REF} = The reference mass passed through the flow meter (kg)

The reference mass and Indicated mass for each observation can be different based upon flow-rate, test time, calibration method etc.

The reference mass could be best described as “The mass of the flowing water passed through the flow meter during an observation”. For example if the gravimetric calibration model is used the mass indication of the balance does not directly correspond with the mass indication of the flow meter. The appropriate calculation model needs to be used to calculate the mass passed through the flow meter. These calculation models correct between a reference instrument (for example the balance) and the flow meter under test for temperature effects, pressure effects, buoyancy forces etc. In the remainder of this document it will be called the reference mass (M_{REF}).

M_{REF} can be calculated using the following formula when a balance is used.

$$M_{REF} = \frac{M_{balance} * \left(1 - \frac{\rho_a}{\rho_M}\right)}{\left(1 - \frac{\rho_a}{\rho_l}\right)}$$

- $M_{balance}$ = Mass difference between start and stop of the measurement on balance (kg)
- ρ_M = Density of used weights for the calibration of the balance (kg/m³)
- ρ_a = Density of air in the laboratory (kg/m³)
- ρ_l = Density of the liquid flowing through the mass flow meter (kg/m³)

The indicated mass can be read from the display of the flow meter or if provided with a software tool on a computer. It could also be the counted pulses divided by a known and programmed k-factor (p/kg). In the remainder of this document it will be called the indicated mass (M_{IND}).

The mass measurement error of the flow meter at a given flow rate between the two water flow measurement standards can be compared. Between two observations on one water flow measurement standards there can be differences at the same flow-rate this is due to the repeatability of both water flow measurement standards and the used flow meter. An average is calculated for the comparison including an uncertainty for the repeatability at each given flow rate. In the remainder of this document it will be called the mass error (E_M).

Reference value for a volume indicator of a flow meter

$$E_V = \frac{V_{IND} - V_{REF}}{V_{REF}} * 100\%$$

- E_V = The volume measurement error of the flow meter (%)
- V_{IND} = Indicated volume of the flow meter (m³)
- V_{REF} = The reference volume passed through the flow meter (m³)

The reference volume and Indicated volume for each observation can be different based upon flow-rate, test time, calibration method etc.

The reference volume could be best described as “The volume of the flowing water passed through the flow meter during an observation”. For example if the gravimetric calibration model is used the mass indication of the balance does not directly correspond with the volume indication of the flow meter. The appropriate calculation model needs to be used to calculate the volume passed through the flow meter. These calculation models correct between a reference instrument (for example the balance) and the flow meter under test for temperature effects, pressure effects, buoyancy forces, density etc. In the remainder of this document it will be called the reference volume (V_{REF}).

V_{REF} can be calculated using the following formula when a balance is used.

$$V_{REF} = \frac{M_{balance} * \left(1 - \frac{\rho_a}{\rho_M}\right)}{(\rho_l - \rho_a) * (1 + \beta * p_l)}$$

- $M_{balance}$ = Mass difference between start and stop of the measurement on balance (kg)
- ρ_M = Density of used weights for the calibration of the balance (kg/m³)
- ρ_a = Density of air in the laboratory (kg/m³)
- ρ_l = Density of the liquid flowing through the mass flow meter (kg/m³)
- β = Compressibility coefficient of the liquid (bar⁻¹ or Pa⁻¹)
- p_l = Pressure of the liquid at flow meter (bar or Pa)

The indicated volume can be read from the display of the flow meter or if provided with a software tool on a computer. It could also be the counted pulses divided by a known and programmed k-factor (p/m³ or p/L). In the remainder of this document it will be called the indicated volume (V_{IND}).

The volume measurement error of the flow meter at a given flow rate between the two water flow measurement standards can be compared. Between two observations on one water flow measurement standards there can be differences at the same flow-rate this is due to the repeatability of both water flow measurement standards and the used flow meter. An average is calculated for the comparison including an uncertainty for the repeatability at each given flow rate. In the remainder of this document it will be called the volume error (E_V).

Bilateral Comparison Evaluation Points (BCEP)

To make this bilateral comparison a success for each flow meter used the most optimized flow rates are chosen to compare the two water flow measurement standards. Per flow meter 2 flow rates are chosen where 10 repeats are taken. At these selected flow rates it is expected that the repeatability of the flow meters are very good (known from previous calibrations and test with the flow meters). The found average measurement errors can then be compared for both water flow measurement standards. These points will be called the Bilateral Comparison Evaluation Points (BCEP).

Specification of water flow measurement standards of BIM

This bilateral comparison has been set up to support the CMC claim of BIM therefore it was needed to select flow meters based upon the specification of the water flow measurement standards of BIM.

The specifications of the water flow facility of BIM are:

Flow range	Stand 1: 0.002 to 6.3 m ³ /h – t/h Stand 2: 6.3 to 40 m ³ /h – t/h
CMC	Stand 1: 0.028 % for volume, volume flow, mass and mass flow Stand 2: 0.056 % for volume, volume flow, mass and mass flow
Volume storage tank	2.75 m ³
Temperature range	Ambient
Pressure range	1×10 ⁵ to 6×10 ⁵ Pa
Unit under test sections	Stand 1: 3 to 25 mm Stand 2: 15 to 50 mm
References	Weighing scales, 150 kg and 600 kg
Liquid	Portable water
Standing start finish method in use	Yes (weighing scale with transfer point)
Flying start finish method in use	No

Based upon these specifications two meter where selected one for each stand.

Specification of water flow measurement standards of NMI VSL

To be sure that the specifications of the BIM water flow measurement standards match with NMI VSL the specifications on the water flow measurement standards of NMI VSL was written down.

The specifications of the water flow facility of NMI VSL are:

Flow range	0.001 to 400 m ³ /h – t/h
CMC	0.02% for volume, volume flow, mass and mass flow
Volume storage tank	190 m ³
Temperature range	Ambient
Pressure range	1 to 5×10 ⁵ Pa
Unit under test sections	2 sections 1 from 25 to 250 mm and 1 from 3 to 25 mm
References	Weighing scales, 10 ton, 3.5 ton, 600 kg, 160 kg and 6.1 kg max. load
	Pipe prover compact type, volume 120 litre and max flow-rate 800 m ³ /h
	Master meters, 3 turbines (50, 100 and 150 mm), 2 PD (25 and 50 mm) and 1 Coriolis mass flow (25 mm)
	Prover tanks 2000, 1000, 100, 50, 20, 10, 5, 2, 1, 0.5 litre
Liquid	Portable water
Standing start finish method in use	Yes (weighing scales, prover tanks both with transfer points)
Flying start finish method in use	Yes (Pipe prover, master meters both using double timing)

It is clear that the specification of the water flow measurement standards of NMI VSL match with the water flow measurement standards of BIM.

Artifacts (two flow meters)

Based upon the specification of the water flow measurement standards mentioned above the bilateral comparison needs to be done using a Standing Start Finish (SSF) method. Knowing this specification two flow meter were selected. The first meter is an Electro Magnetic Flow meter (EMF) size 15 mm. This one was chosen as EMF meters have a good track record during comparison performed in the past. The flow meter is fitted with an inlet and outlet pipe that is fixed to the flow meter. To make sure the pipes are not disconnected during the comparison two seals are put through the bolts with NMI VSL seal number NMI00001 and NMI00002. This meter is owned by NMI VSL and has put in use as a master meter for comparisons of any type. The second meter is a Coriolis mass flow meter size 50 mm. This one was chosen because Coriolis mass flow meters have a good track record during comparisons and BIM also wants to check the CMC for mass and mass flow. This meter is owned by Micro Motion Inc, 7070 Winchester Circle, Boulder, CO 80301, USA. NMI VSL does not own a Coriolis mass flow meter size 50 mm therefore Micro Motion was asked to provide one. NMI VSL has been granted access to the track record including all calibrations performed on this Coriolis mass flow meter. Due to a confidentiality agreement between Micro Motion and NMI VSL these records are kept out of any report or document concerning this bilateral comparison.

Specifications meter 1

Principal	Electro Magnetic Flow
Make	Krohne Altometer
Model	Optiflux 5000
Serial number	A07 05239
Maximum flow-rate	5 m ³ /h
Minimum flow-rate	0.5 m ³ /h
GK value	1.8507
Maximum pressure	8 × 10 ⁵ Pa (due to flanges inlet and outlet pipes)
Temperature range	-40 to +65°C
Electronics model	IFC 300
Serial number	A07 05239
Flanges (inlet and outlet)	DN15 PN16 (DIN 2633)
Build in length package	291 mm

Specifications meter 2

Principal	Coriolis mass flow
Make	Micro Motion (Emerson Process Management)
Model	CMF 200
Serial number	14078674
Core-processor model	800
Core-processor serial number	10036203
Transmitter model	2700
Transmitter serial number	3768101
Maximum flow-rate	87.1 t/h - m ³ /h (*design flow 43.6 t/h - m ³ /h)
Minimum flow-rate	4.36 t/h - m ³ /h
Flow Calibration Factor (FCF)	215.424.45
Maximum pressure	8 × 10 ⁵ Pa
Temperature range	-40 to +65°C
Electronics model	MVD 2700
Serial number	09002241
Flanges	ANSI 2" 300#
Build in length	576 mm

* The design flow is the flow-rate where the pressure drop over the mass flow meter is about 1×10⁵ Pa.

Test protocol Meter 1 (EMF meter)

Installation and preliminary checks

- The EMF meter needs to be installed using correct inlet and outlet pipes.
- The electronics need to plug into 220-230V power supply a minimum of 4 hours before the test can start. Make sure that the measuring tube of the EMF meter is filled with water.
- De-air the installation by flowing at the maximum flow of 5 m³/h for at least 30 minutes.

Test runs and sequence

- 3 runs at 5.0 m³/h = 83.3 l/min
- 10 runs at 4.0 m³/h = 66.7 l/min (BCEP 1)
- 10 runs at 3.0 m³/h = 50.0 l/min (BCEP 2)
- 3 runs at 2.0 m³/h = 33.3 l/min
- 3 runs at 1.0 m³/h = 16.7 l/min
- 3 runs at 0.5 m³/h = 8.33 l/min

Data to be collected during a test run

- EMF meter total at start
- Balance reading at the start
- Flow-rate indicated by EMF meter
- Average inlet temperature
- Average inlet pressure
- Average outlet temperature (if possible)
- Average outlet pressure (if possible)
- EMF meter total at end
- Balance reading at the end
- Air conditions (pressure, temperature and relative humidity)

At the end of the test runs

For the EMF meter there is no specific thing to be checked at the end of the test runs.

Test protocol Meter 2 (Coriolis mass flow meter)

At BIM the Coriolis mass flow meter needs to be tested with the meter-case up due to the meter under test section. To compare the two water flow measurement standards NMI VSL will test also with the meter-case up. To be sure there is no effect between meter-case down and meter-case up NMI VSL perform some extra test to check if the Coriolis mass meter is effected between these two build in methods. See "Extra test at NMI VSL before the start of the bilateral comparison"

Installation and preliminary checks

- The Coriolis mass meter needs to be installed using correct inlet and outlet pipes.
- The electronics need to plug into 220-230V power supply a minimum of 4 hours before the test can start. Make sure that the measuring tube of the Coriolis mass meter is filled with water.
- De-air the installation by flowing at a flow of 40 m³/h – t/h for at least 20 minutes.
- For 15 minutes the flow-rate needs to be set to 10.9 m³/h – t/h. This to stabilize the Coriolis meter before the zero calibration.
- Block in the Coriolis mass flow meters for zero calibration. If possible keep pump running.
- Perform the zero calibration for a minimum of 3 times when the zero has no trend to one side + or – the last zero can be used for the zero check. If there is a trend to one side then keep on zeroing until trend has stopped. If the trend does not stop check pressure and temperature to make sure there is no leak or anything else with the meter under test section otherwise contact the pilot laboratory.
- Set zero cutoff to zero and flow direction to bidirectional. Start totalizing the mass for 6 minutes the total mass in this six minutes should not exceed ± 0.036288 kg/min conform the specification of the Coriolis mass flow meter. If it exceeds the specification restart the procedure from point 4 (For 15 min....).
- When the Coriolis mass flow meter is within the zero specification the zero cut-off can be set back to the initial value and the flow direction to forward.
- Write down all data and provide this to the pilot laboratory

A small video will be provided by the pilot laboratory to show the zero procedure.

Test runs and sequence

- 3 runs at 40.0 m³/h – t/h = 666.7 l/min – kg/min
- 10 runs at 32.7 m³/h – t/h = 545.0 l/min – kg/min (BCEP 3 and 5)
- 10 runs at 21.8 m³/h – t/h = 363.3 l/min – kg/min (BCEP 4 and 6)
- 3 runs at 10.9 m³/h – t/h = 181.7 l/min – kg/min
- 3 runs at 4.36 m³/h – t/h = 72.7 l/min – kg/min

Data to be collected during a test run

- Coriolis mass meter total at start (volume and mass)
- Balance reading at the start
- Flow-rate indicated by Coriolis mass meter (volume flow-rate and mass flow-rate)
- Average inlet temperature
- Average inlet pressure
- Average outlet temperature (if possible)
- Average outlet pressure (if possible)
- Coriolis meter total at end
- Balance reading at the end
- Air conditions (pressure, temperature and relative humidity)

At the end of the test runs

- Repeat the 6 minutes test to check zero flow. If the Coriolis mass flow meter has exceeded its specification ask advice from the pilot laboratory.
- Write down all data and provide this to the pilot laboratory

Extra test at NMI VSL before the start of the bilateral comparison

At BIM the Coriolis mass flow meter needs to be tested with the meter-case up due to the meter under test section. To compare the two water flow measurement standards NMI VSL will test also with the meter-case up. To be sure there is no effect between meter-case down and meter-case up NMI VSL perform some extra test to check if the Coriolis mass meter is affected between these two build in methods. NMI VSL will also perform a test with the meter-case under an angle of 90°. To prevent too much testing time these test will be done using the pipe prover only at the BCEP points on mass flow. The zero procedures are performed after every meter-case setting. These tests will not be reported in the final report for this bilateral comparison. No uncertainty calculation will be performed for this as this is not part of the direct comparison between BIM and NMI VSL.

Reporting the measurement results

Both Metrology Institutes need to report:

- 1 Traceability of the used instruments
- 2 Their calculation model
- 3 Figures for the conductivity and density off set of the used water
- 4 The data as described of the zero calibration of the mass meter
- 5 The test data of both meters in a spreadsheet
- 6 The calculations of Errors, Reference Mass and/or Volume and repeatability in the same spreadsheet
- 7 Extra test if performed
- 8 Pictures of the Meter Under Test section including the flow meters

A spreadsheet will be made by the pilot laboratory to report the results.

Reporting the measurement uncertainty

The measurement should be based upon the CMC claim of the Metrology Institute. The extra uncertainty introduced by the flow meters is minimal as the repeatability is good and the readout has enough digits to allow small uncertainty budgets. The calculation should be done according ISO Guide to the expression of uncertainty in measurement and EA 4/02 Expression of the Uncertainty of Measurement in Calibration. In the spreadsheet a table is made for filling in all the sources, contributions etc. This table is based upon example table 4.2 in document EA 4/02.

The following sources should be addressed minimal

- 1 Calibration uncertainties of used instruments (calibration certificates)
- 2 Long term stability of instruments used (based upon repeatable calibration over the years)
- 3 Reaction time of instrument (example temperature probe is always a little bit slow)
- 4 Averaging measurements (example temperature starts at 19.2°C and ends at 19.8°C during an observation)
- 5 Variants in measurements (example pressure varies between 1.5 and 1.6 bar)
- 6 Transfer point(s)
- 7 Dead volumes between reference and flow meter

Sources should be described simple and how they are quantified this for the pilot laboratory to evaluate.

Calculation of the E_n value

To make this bilateral comparison a success the so called E_n value for comparison should be smaller than 1. For each BCEP point this calculation is made.

The formula for the E_n is:

$$E_n = \frac{X_{lab} - X_{pilot}}{\sqrt{u_{lab}^2 + u_{pilot}^2}}$$

For u the expanded uncertainty is filled in with a coverage factor of $k=2$.

If one BCEP's exceed 1 than an investigation is start up to review all data to see if a mistake is made in calculation or calibration. This investigation is done by NMI VSL. Information will be asked from BIM but without telling where this information is needed for. If this can't be found then this number will be put in the report. If more than one BCEP exceed 1 than a more detailed investigation is start up by NMI VSL and Euramet is contacted to make sure that this done according all rules for bilateral comparison under the framework of Euramet.

The report

The report will be made by NMI VSL according correct formats. Previous report published at the Euramet website will be the basis for the format.

Reference documents

- 1 Euramet Guide no. 3 "Euramet Guidelines on Conducting Comparisons".
- 2 ILAC guideline G13 "ILAC Guidelines for the Requirements for the Competence of Providers of Proficiency Testing Schemes"
- 3 ISO Guide to the expression of uncertainty in measurement
- 4 EA 4/02 Expression of the Uncertainty of Measurement in Calibration

Annex A Contact details

Contact detail for people involved in the bilateral comparison and their role.

Coordinator Bileteral comparison and contact person NMI VSL	Erik Smits Hugo de Grootplein 1 3314 EG DORDRECHT The Netherlands T +31 78 6332201 (direct) E FMSmits@NMI.nl	Responsible for organizing the bilateral comparison and execution of the test at NMI VSL. Person in contact with and contact person for Euramet.
Project leader	Jos Verbeek Thijsseweg 11 2629 JA DELFT The Netherlands T +31 15 2691644 E JVerbeek@NMI.nl	Contact if there are any problems with any communications with coordinator.
Contact person BIM	Eugene Mitev Directorate of Measures and Measuring Instruments Bulgarian Institute of Metrology 52B, G.M.Dimitrov Blvd Sofia, 1125 Bulgaria e.mitev@mail.bg	Responsible for execution of the test at BIM.
Contact person Euramet	Richard Paton TUV NEL Scottish Enterprise Technology Park East Kilbride Glasgow G75 0QU Scotland E rpaton@tuvnel.com	Chairman Euramet technical committee Flow.



Annex B the package

The package contains the following items

Micro Motion Mass flow meter	Sensor and core processor (meter) Transmitter Prolink software (CD-ROM) Computer connection tool (RS485)
Krohne Altometer Volume flow meter	Sensor (meter) Converter including display
NMi VSL	Book with manuals and other relevant information CD-ROM with instruction about zeroing etc