EURAMET project No. 1233

Intercomparison of Water Meter Reference Standard

Final Report

Coordinator:

Başak AKSELLİ

(basak.akselli@tubitak.gov.tr)

TUBITAK UME

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Contents

1 Introduction

The aim of this comparison is to compare the results of the calibration of mass flowmeters obtained by different NMIs water flow laboratories that participated in this exercise. A DN 40 ABB coriolis mass flowmeter was used as a transfer standard in the flow range from 3 m^3/h to 28 m^3/h.

2 Participants

The participants and the time schedule are shown in table 1. The comparison measurements started in October 2012 and finished in March 2013.

The transfer standard was calibrated in 5 laboratories listed in the table 1. Each laboratory had several weeks for performing the measurements and for sending the transfer standard to the following laboratory. Due to some problems with customs documents the transfer standard was delayed several times. The transfer standard was measured 2 times during the comparison by pilot laboratory, in the beginning and at the end of the comparison in order to access the stability of the transfer standard.

Table 1 - Participants and the time schedule

Institute /Country	**Delivery Address**	**Contact**	**Date of calibration**
TUBITAK UME /TURKEY	TUBITAK UME Fluid Mechanics Laboratory, Barış mah., TUBITAK-GEBZE Yerleskesi, 41470 Gebze-Kocaeli, TURKEY	**Başak Akselli** basak.akselli@tubitak.gov.tr tel; ++90 262 679 50 00/5103 fax: ++90 262 679 5001	**Calibration:** **17.09.2012-28.09.2012** **Delivery:** **11.10.2012**
Lithuanian Energy Institute/ Lithuanian	Lithuanian Energy Institute Breslaujos str. 3, LT-44403 Kaunas Lithuania	**Gediminas Zygmantas** zygmanta@mail.lei.lt tel. +370 (37) 401861 fax.: +370 (37) 351271	**Calibration:** **16.10.2012-30.10.2012** **Delivery:** **31.10.2012**
Central Office of Measurement / Poland	Główny Urząd Miar ul. Elektoralna 2 00-139 Warszawa Polska/Poland	**Piotr Traczykowski** p.traczykowski@gum.gov.pl tel. +48 22 5819323	**Calibration:** **05.11.2012-16.11.2012** **Delivery:** **19.11.2012**
INRIM / Italy	Istituto Nazionale di Ricerca Metrologica	**Carlo Marinari**	**Calibration:**

	National Institute of Metrological Reseach Divisione Meccanica Mechanical Division Strada delle cacce, 73 10135 Torino- Italy	c.marinari@inrim.it Tel. +011 39 19 377	**26.11.2012-07.12.2012** **Delivery:** **10.12.2012**
National Centre of Metrology Bulgarian Institute of Metrology/ Bulgarian	National Centre of Metrology Bulgarian Institute of Metrology 52B “G. M. Dimitrov” Blvd. 1040 Sofia Bulgaria	**Mariana Miteva** **m.miteva@bim.government.bg** **fax: +3592 9702735** **tel.: +3592 9702752**	**Calibration:** **17.12.2012-31.12.2012** **Delivery:** **02.01.2013**
TUBITAK UME /TURKEY	TUBITAK UME Fluid Mechanics Laboratory, Barış mah., TUBITAK-GEBZE Yerleskesi, 41470 Gebze-Kocaeli, TURKEY	**Başak Akselli** basak.akselli@tubitak.gov.tr tel; ++90 262 679 50 00/5103 fax: ++90 262 679 5001	**Calibration:** **07.01.2013-18.01.2013** **First Draft Report:** **05.02.2013**

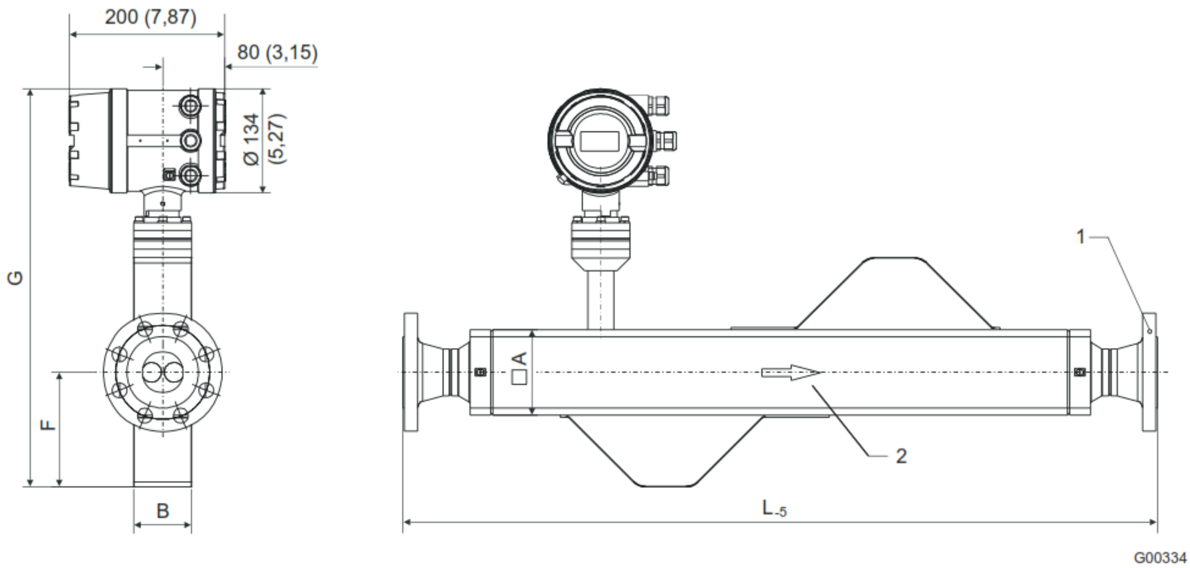
3 The transfer standard

The coriolis mass flowmeter was the instrument to be tested. A description and a picture of the transfer meter are given in Table 2 and in Figure 1 and Figure 2.

Table 2. Technical specification of the transfer meter

Manufacturer: ABB	
Serial number: 000419556/X001	Model: FCM2000 MC23
Model size: DN40	Pulse number: 500 pulse/kg
Process connection: DN50	Pressure class: PN40
Flowrate range: 0-475 kg/min	Weight: approximately 24 kg

Figure 1. The coriolis mass flowmeter



Meter size DN	A	F	B	G	L-5
40	90	129	64	486	940

Figure 2. Dimensions of the Coriolis mass flowmeter

Electrical connections of display unit:

- Operating voltage is 220 V

Pulse output connection:

- Pulse counter can connect to the transfer meter as seen on Figure 3.

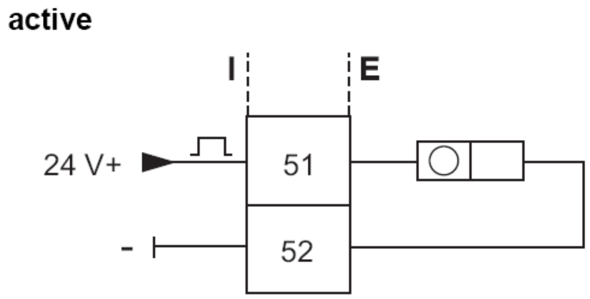


Figure 3. Pulse output connection of the transfer meter

4 The measurement procedure

4.1 Method of measurement

The participating laboratories was requested to use the normal calibration procedure that is also used for customers service. Only the instructions given below must be fulfilled.

- The transfer meter should be installed and tested in horizontal position.
- The transfer meter has to be tested at 5 flow rates: 3 m^3/h, 6 m^3/h, 14 m^3/h, 20 m^3/h and 28 m^3/h. The test in one flow rate should be repeated at least 5 times and the flow rate has to be within the interval ± 3 % of the required value.
- During the test, laboratory air temperature must be close to 20°C. Water temperature should be about 20°C.
- The test meter should be kept in laboratory conditions for at least 24 hours before testing begins.
- Before the beginning of the test, the test meter has to work 20 minutes at Q=10 m^3/h flow rate.
- The duration of a single test at one flow rate must be more than 1 minute. Prior to the test, the flow rate has to be accurately stabilized.
- Start the test and report results in the format presented in Table 3.
- The calibration duration can be added to Table 3 as a column.

Error of the meter is value which shows the relationship in percentage terms of the difference between the flow rate indicated by the meter and the flow rate which has actually flowed through the meter, to the later value.

$$E = \frac{Q_t - Q_r}{Q_r}.100 \quad (\%) \qquad (1a)$$

$$E = \frac{V_t - V_r}{V_r}.100 \quad (\%) \qquad (1b)$$

where, E is the error of the meter,

Q_t is the volume flow rate measured by the transfer meter (m^3/h)

Q_r is the volume flow rate measured by the reference meter (m^3/h)

V_t is the total volume rate measured by the transfer meter (m^3)
V_r is the total volume rate measured by the reference meter (m^3)

4.2 Equipment

Each laboratory described the equipment used in the calibration and the respective traceability.

A summary of used equipment, range of flow rate and traceability can be found in the table 3.

Table 3 – Method of measurement

Country NMI	NMI standard	Flow range of comparison	Traceability
TURKEY TUBITAK UME	Gravimetric Liquid Flow Measurement System	(3 - 28) m^3/h	Independent laboratory
Lithuanian Lithuanian Energy Institute (LEI)	Gravimetric Liquid Flow Measurement System	(3 - 28) m^3/h	Independent laboratory
Poland Central Office of Measurement (GUM)	Gravimetric Liquid Flow Measurement System	(3 - 20) m^3/h	Independent laboratory
Italy INRIM	Gravimetric Liquid Flow Measurement System	(3 - 28) m^3/h	Independent laboratory
Bulgarian Bulgarian Institute of Metrology (BIM)	Gravimetric Liquid Flow Measurement System	(3 - 20) m^3/h	Independent laboratory

5 Measurements results

5.1 Stability of the transfer standard

The stability of the transfer standard was checked before and after the comparison by TUBITAK-UME (Table 4, Figure 4). For calculating of the uncertainty caused by the stability (reproducibility) of the transfer standard (Table 7), 5 measurements was done, because two measurement was not enough.

Table 4- Relative errors (%) of the transfer standard obtained at TUBITAK-UME

Flow rate(m³/h)	**1st measurement**	**2nd measurement**	**3rd measurement**	**4th measurement**	**5th measurement**
3	-1,020	-0,611	-0,539	-0,739	-0,956
6	-0,266	-0,325	-0,199	-0,288	-0,321
14	-0,226	-0,171	-0,234	-0,172	-0,308
20	-0,129	-0,164	-0,162	-0,110	-0,224
28	-0,041	-0,058	-0,045	-0,068	-0,024

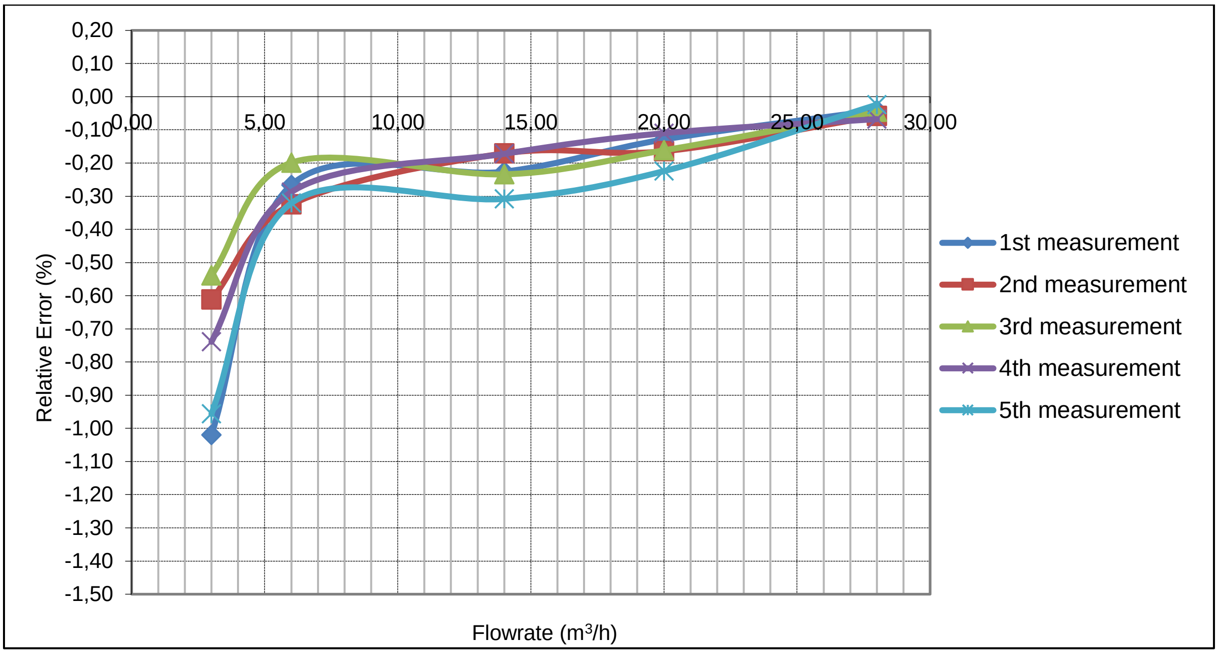


Figure 4. Stability of the transfer standard

5.2 Laboratory results

All data collected from the participating laboratories are summarized in following tables and pictures. Third measurement of TUBITAK-UME was used in the evaluation.

Table 5- Relative errors (%) of the transfer standard obtained at laboratories

Flow rate(m^3/h) \ NMI	TURKEY	LITHUANIA	POLAND	BULGARIA	ITALY
3	-0,539	-0,157	-0,315	1,041	-0,345
6	-0,199	-0,181	-0,142	0,927	-0,223
14	-0,234	-0,171	-0,049	0,727	-0,155
20	-0,162	-0,229	-0,053	0,570	-0,107
28	-0,045	-0,054	-	-	-0,074

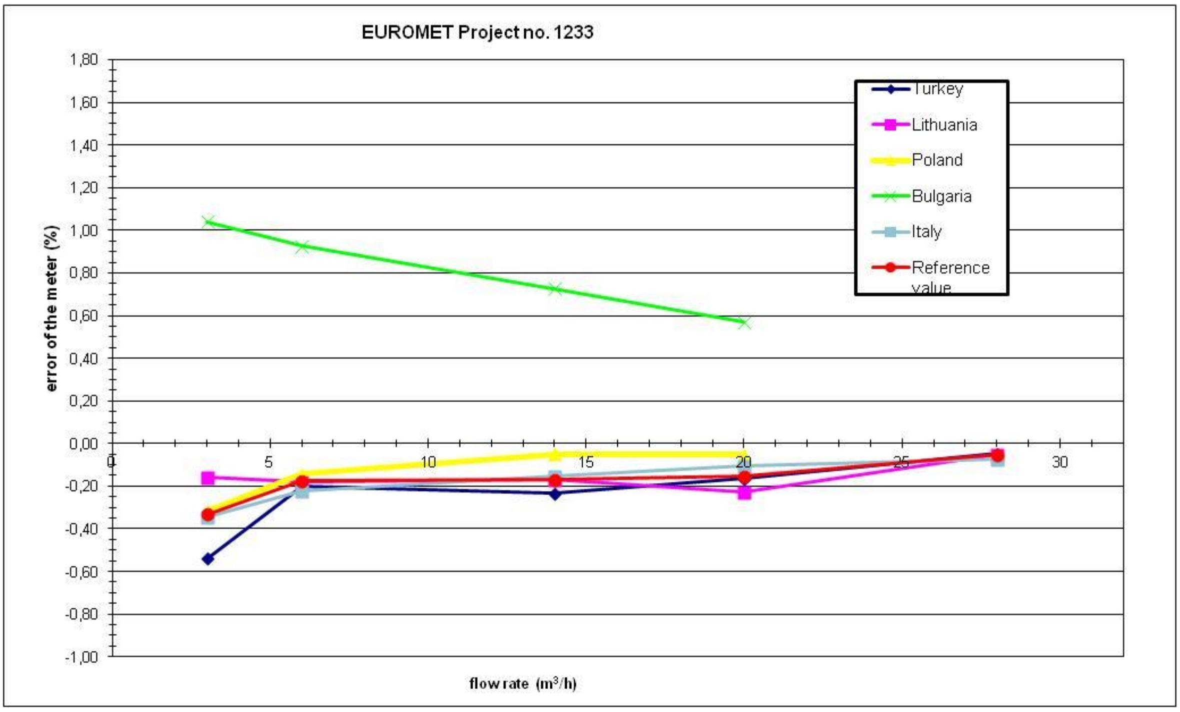


Figure 5. Relative errors of the participating laboratories

5.3 Laboratory uncertainty

The uncertainties are calculated according to the following formulas (see *Guide to Expression of Uncertainty in Measurement* (ISO, Geneva, 1995))

Type A uncertainty based on statistical methods of measurement results is calculated using the following equation:

$$u_A^2 = \frac{1}{n(n-1)} \sum_{i=1}^{n} (e_i - \bar{e})^2 \qquad (2)$$

Type B uncertainty is determined on the basis of non-statistical methods. It consists of square totals relevant sources of uncertainties from the mathematical model:

$$u_B = \frac{1}{V_{Em}} \cdot \sqrt{\sum_{i=1}^{k} \left(\frac{\partial V_{Em}}{\partial x_i} \right)^2 . u^2(x_i)} \tag{3}$$

Combined uncertainty is calculated according to the following formulas:

$$u_c = \sqrt{\left(u_A^2 + u_B^2\right)} \tag{4}$$

The expanded uncertainty *U* is obtained by multiplying the combined standard uncertainty u_c by expansion coefficient according to the formula:

$$U = k \cdot u_c . \tag{5}$$

The expansion coefficient used for flow rate area is *k*=2.

Uncertainty values of the participating laboratories are stated in following table 6.

Table 6- Expanded uncertainties (%) of measurements reported by laboratories

Flow rate(m^3/h) \ NMI	TURKEY	LITHUANIA	POLAND	BULGARIA	ITALY
3	0,134	0,061	0,100	0,053	0,110
6	0,081	0,066	0,100	0,015	0,114
14	0,042	0,062	0,100	0,013	0,105
20	0,040	0,061	0,100	0,027	0,101
28	0,040	0,064	-	-	0,101

5.4 Uncertainty of the corrections and stability of the transfer standard

The standard uncertainties (not expanded) of the error in different laboratories u_{x1}, u_{x2},.....u_{xn} (equation (6)) included the stability of the meter. These uncertainties were calculated by

$$u_{xi} = \sqrt{\left(\frac{U(x_i)}{2}\right)^2 + u_{st}^{\ 2}} \tag{6}$$

where $U(x_i)$ is the expanded uncertainty (*k*=2) determined by laboratory *i* and presented in results of laboratory *i*

u_{st} is estimated expanded uncertainty caused by the stability (reproducibility) of the transfer standard.

The transfer standard was tested five times in the pilot laboratory (based on the time schedule) and from these results u_{st} was determined. A maximum difference for each flowrate was found during the experiments (E_{exp}) and given table 7.

$$u_{st} = \sqrt{\left(\frac{E_{exp}}{2\sqrt{3}}\right)^2} \qquad (7)$$

Table 7- The stability (reproducibility) of the transfer standard

Flow rate(m^3/h)	E_{exp}	u_{st}
3	0,481	0,142
6	0,126	0,037
14	0,137	0,040
20	0,114	0,034
28	0,043	0,013

Corrected uncertainty values of each laboratory are stated in annex B. This values were used in the evaluation.

Note:
The value of flow stability from (7) was determined from the measurements at pilot laboratory during the whole period of comparison.

6 Evaluation

The reference value was determined in each flow rate separately. The method of determination of the reference value in each flow rate was correspond to the procedure A presented by M.G.Cox [1]. Only results from independent laboratories was taken into account for the determination of the EURAMET reference value (ECRV) and of the uncertainty of the EURAMET reference value. Then the results from dependent laboratories was compared with the EURAMET reference value and with the uncertainty of the EURAMET reference value.

The determination of the ECRV based on the independent laboratories will include a consistency check according to [1]. All *Independent laboratories* were succeed in the consistency check.

6.1 Determination of the Comparison Reference Value (ECRV) and its uncertainty

The reference value *y* will be calculated as weighted mean error (WME):

$$y = \frac{\frac{x_1}{u_{x1}^2} + \frac{x_2}{u_{x2}^2} + \dots\dots\dots \frac{x_n}{u_{xn}^2}}{\frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + \dots\dots\dots \frac{1}{u_{xn}^2}} \qquad (8)$$

where x_1, x_2, ... x_n are errors of the meter in one flow rate in different independent laboratories *1,2, ...n*

u_{x1}, u_{x2},.....u_{xn} are standard uncertainties (not expanded) of the error in different independent laboratories *1,2, ...n* including the uncertainty caused by stability of the meter.

The standard uncertainty of the reference value u_y is given by

$$\frac{1}{u_y^2} = \frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + \ldots\ldots\ldots \frac{1}{u_{xn}^2} \tag{9}$$

The expanded uncertainty of the reference value *U(y)* is

$$U(y) = 2.u_y \tag{10}$$

The chi-squared test for consistency check was performed using values of errors of the meter in each flow rate. At first the chi-squared value χ_{obs}^2 was calculated by

$$\chi_{obs}^2 = \frac{(x_1 - y)^2}{u_{x1}^2} + \frac{(x_2 - y)^2}{u_{x2}^2} + \ldots\ldots\ldots\ldots \frac{(x_n - y)^2}{u_{xn}^2} \tag{11}$$

The degrees of freedom ν was assigned

$$\nu = n - 1 \tag{12}$$

where n is a number of evaluated laboratories.

The consistency check was failing if

$$Pr\{\chi_\nu^2 > \chi_{obs}^2\} < 0{,}05 \tag{13}$$

(The function *CHIINV(0,05;ν)* in MS Excel was used. The consistency check was failing if *CHIINV(0,05; ν)*< χ_{obs}^2)

If the consistency check does not fail then *y* was accepted as the EURAMET comparison reference value x_{ref} and *U(y)* was accepted as the expanded uncertainty of the EURAMET comparison reference value $U(x_{ref})$.

If the consistency check fails then the laboratory with the highest value of $\frac{(x_i - y)^2}{u_{xi}^2}$ was excluded for the next round of evaluation and the new reference value *y* (WME), the new standard uncertainty of the reference value u_y and the chi-squared value χ_{obs}^2 was calculated again without the values of excluded laboratory. The consistency check was calculated again, too. This procedure was repeated ones till the consistency check has passed.

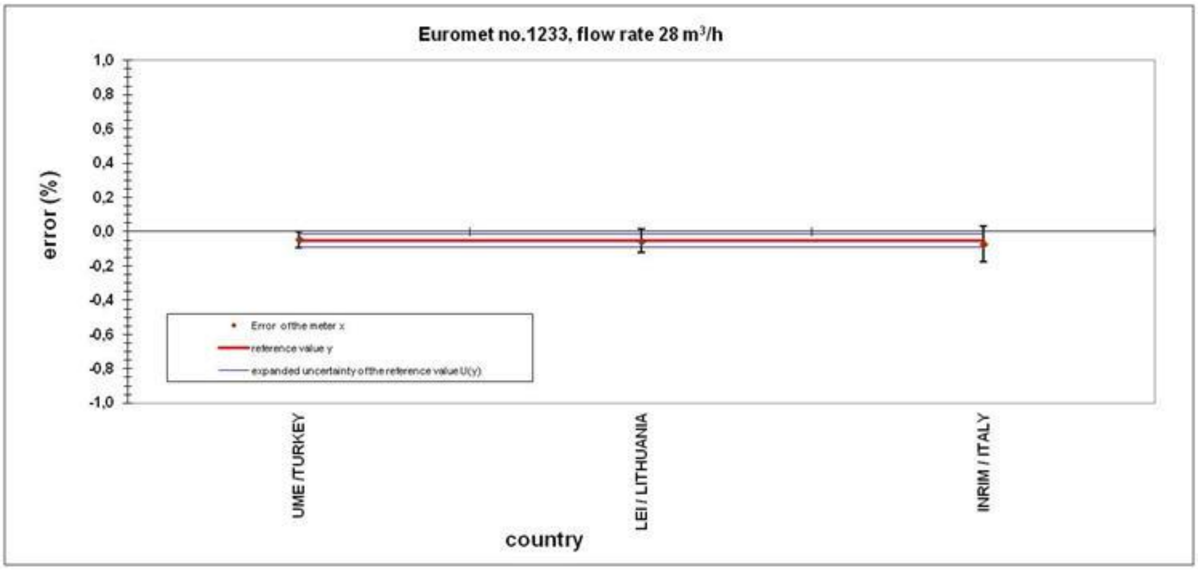


Figure 6. Flowrate evaluation at 28 m^3/h

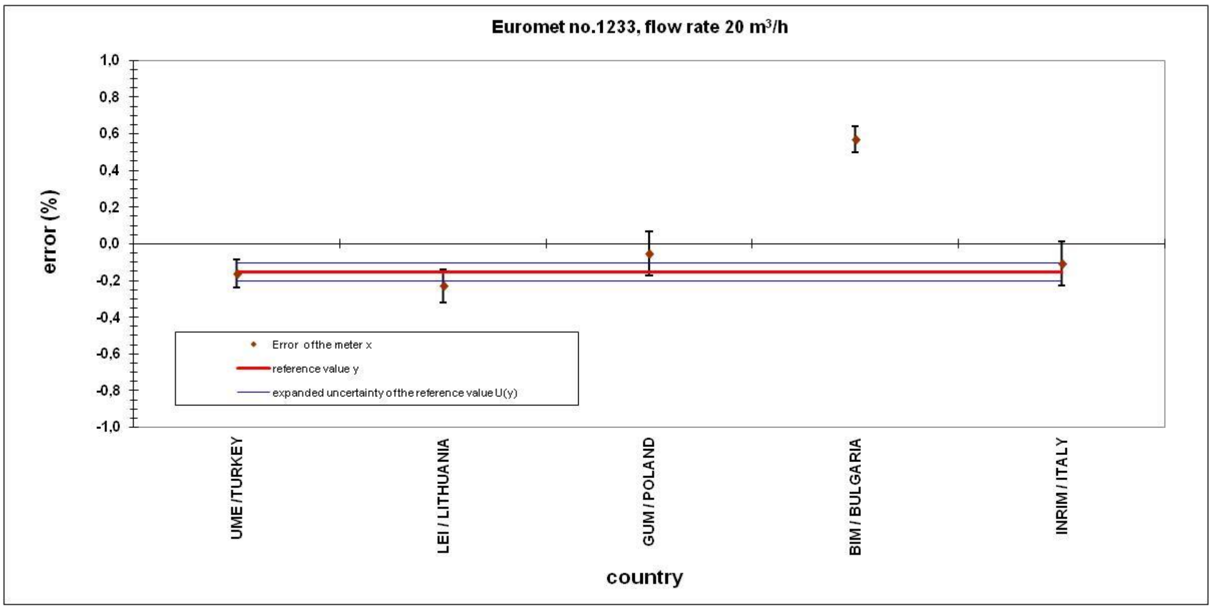


Figure 7. Flowrate evaluation at 20 m^3/h

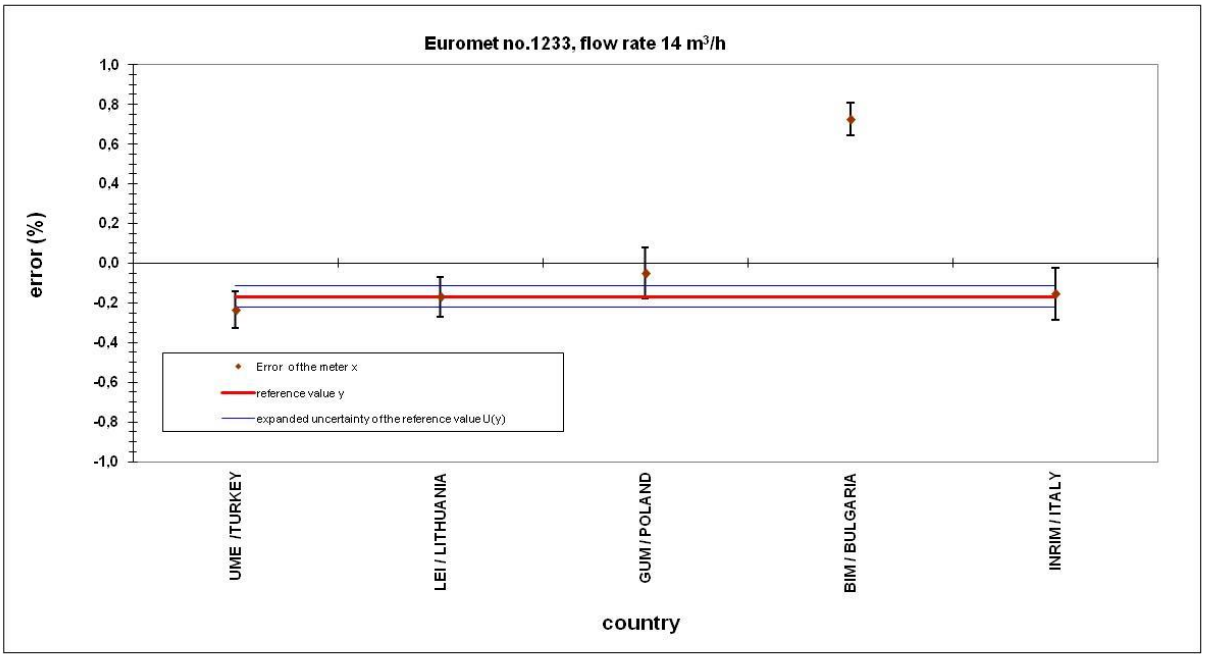


Figure 8. Flowrate evaluation at 14 m^3/h

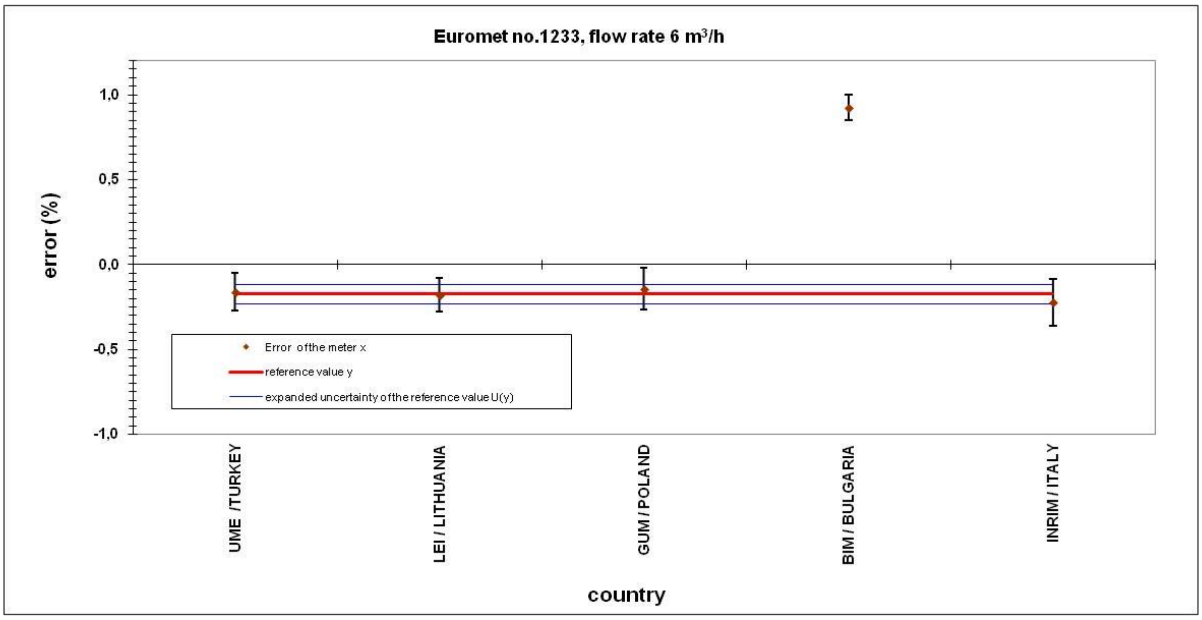


Figure 9. Flowrate evaluation at 6 m^3/h

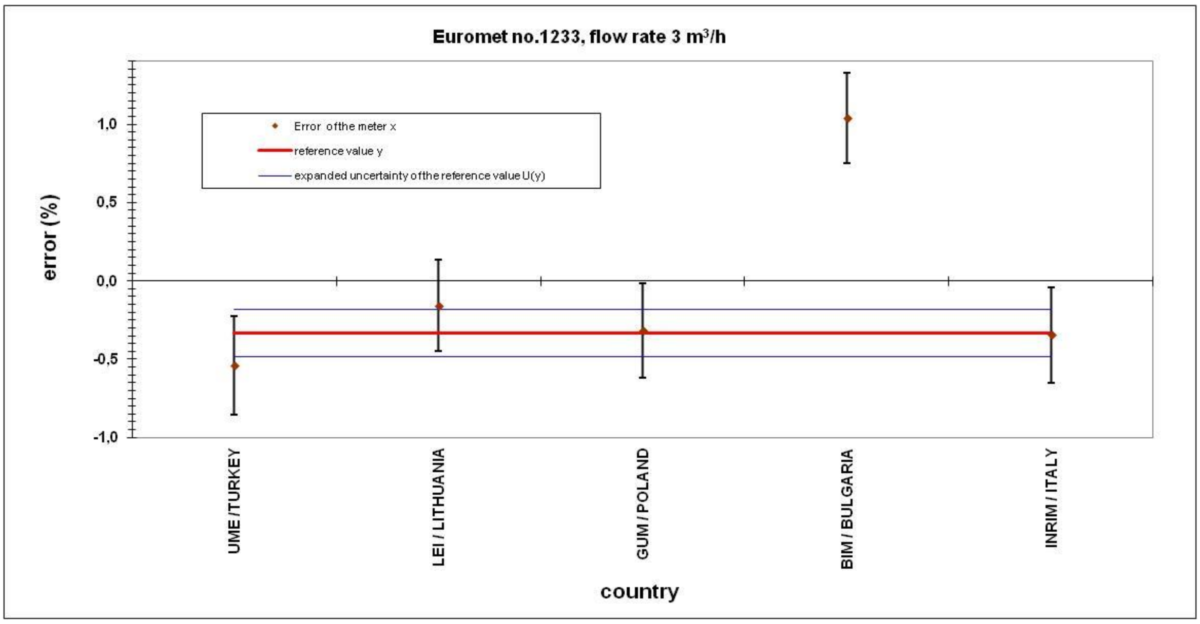


Figure 10. Flowrate evaluation at 3 m^3/h

6.2 The determination of the differences "Lab to ECRV" and "Lab to Lab"

When the ECRV was determined, the differences between the participating laboratories and the ECRV was calculated according to

$$di = x_i - x_{ref} \tag{14}$$

$$dij = x_i - x_j \tag{15}$$

Based on these differences, the Degree of Equivalence (*DoE*) was calculated according to:

$$Ei = \left| \frac{di}{U(di)} \right| \tag{16}$$

and $$Eij = \left| \frac{dij}{U(dij)} \right|$$ respectively. (17)

The *DoE* is a measure for the equivalence of the results of any laboratory with the ECRV or with any other laboratory, respectively:

- the results of a laboratory was *equivalent (**passed**) if Ei or Eij ≤ 1.*
- the laboratory was determined as *not equivalent (**failed**) if Ei or Eij >1.2*.
- for values of *DoE* in the range *1 < Ei or Eij ≤ 1.2* the "**warning level**" is defined. In this case some actions to check are recommended to the laboratory.

The calculation of the *DoE* needs the information about the uncertainty of the differences *di* and *dij* (equations (14) and (15)). To make statements about this, it is necessary to consider first the general problem of the difference of two values x_1 and x_2. If we look to the pure propagation of (standard) uncertainty we find:

$$u_{x_1-x_2}^2 = \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} & \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} \begin{pmatrix} u_1^2 & \mathrm{cov} \\ \mathrm{cov} & u_2^2 \end{pmatrix} \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} \\ \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} = u_1^2 + u_2^2 - 2.\mathrm{cov} \qquad (18)$$

The (standard) uncertainty of the difference is the quadratic sum of the uncertainties of the inputs (u_1 and u_2) subtracting twice the covariance (cov) between the two input values.

Therefore it is possible find the different cases in this comparison.

6.3 Differences to the ECRV

a) *Independent laboratories with contribution to the ECRV*

The covariance between the result of a laboratory (with contribution to the ECRV) and the ECRV is the variance of the ECRV itself. 1)

=> $u(di) = \sqrt{u_{xi}^2 + u_{xref}^2 - 2.u_{xref}^2} = \sqrt{u_{xi}^2 - u_{xref}^2}$ (19)

b) *Independent laboratories without contribution to the ECRV*

There is no covariance between the result of a laboratory without contribution and the ECRV.

=> $u(di) = \sqrt{u_{xi}^2 + u_{xref}^2}$ (20)

c) *Laboratories with traceability to a laboratory contributing to the ECRV*

In this case we have covariance between the laboratory and the ECRV because the laboratory is linked to the ECRV via the source of traceability. Although we have no detailed information about it, we can determine a conservative estimation of an upper limit of this covariance. The upper limit is determined for the theoretical case if we have no additional stochastic influence in the traceability of the lab from its source (which is the lab contributing to the ECRV). Then the results of the lab considered here would be strongly correlated with the results of the laboratory contributing to the ECRV (correlation coefficient = 1) and there would be the same covariance to the ECRV as in case A1. In any case of additional uncertainty caused stochastically the correlation and consequently the covariance is smaller.

$$=> u(di) = \sqrt{u_{xi}^2 + u_{xref}^2 - 2u_{xref}^2} = \sqrt{u_{xi}^2 - u_{xref}^2} \quad (21)$$

The χ_{obs}^2 value was determined and the outlier, lab 4, was removed from the ECRV determined. The results are in following Table 8.

Table 8- EURAMET reference value (ECRV)

Q (m³/h)	3	6	14	20	28
ECRV (%)	-0,331	-0,175	-0,170	-0,154	-0,051
U (x_{ref}) (%)	0,151	0,057	0,054	0,049	0,037
χ_{obs}^2	3,21	0,85	5,67	6,12	0,26

7 Summary

The degree of equivalence to ECRV is a measure for the equivalence of the results of any laboratory with the ECRV or with any other laboratory, respectively. *Ei* ≤ 1 means that *i*-th laboratory is in good agreement with ECRV and *Eij* >1.2 means that *i*-th and *j*-th laboratory are not in good agreement. For values of *DoE* in the range *1 < Ei or Eij* ≤ 1.2 the "warning level" is defined. In this case some actions to check are recommended to the laboratory. From table 9 one can verify that only one laboratory has values that are not in agreement with the reference value.

Table 9- Degree of Equivalence to ECRV

Flow rate(m³/h) \ NMI	TURKEY	LITHUANIA	POLAND	BULGARIA	ITALY
28	0,20	-0,05	-	-	-0,23
20	-0,12	-0,97	0,92	8,23	0,43
14	-0,83	-0,02	1,01	9,18	0,12
6	0,13	-0,07	0,29	11,61	-0,38
3	-0,73	0,68	0,06	19,90	-0,05

8 Conclusions

From the analysis of table 9 it can be verified that Laboratory of Bulgaria has inconsistent results in all measurement ranges.

Related CMC tables of the participants are as follows:

TUBITAK-UME, Turkey

Quantity	Instrument of Artifact	Instrument Type or Method	Minimum Value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of confidence	Is the expanded uncertainty a relative one?	Comments	NMI service identifier
Volume water flow rate	Liquid flow rate (volume)	Visual, pulse or electrical outputs (rotameter, magnetic, ultrasonic, rotary type	0.030	103	m³/h	Fluid	Water	0.20	%	2	95%	Yes	Approve d on 15 October 2013	TR6

		flowmeters)												
						Temperature	19.5 C to 20.5							
						Pressure	Absolute 0.1 MPa							

INRIM - Italy

Quantity	Instrument of Artifact	Instrument Type or Method	Minimum Value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of confidence	Is the expanded uncertainty a relative one?	Comments	NMI service identifier
Mass water flow rate	Liquid flow rate	Gravimetric system with fly start and stop	0.036	25.2	m^3/h	Fluid	Water	0.1	%	2	95%	Yes	Approved on 03 January 2007	IT1
						Temperature	18° C to 30 °C							
						Pressure	Absolute 0.6 MPa							

GUM-Poland

Quantity	Instrument of Artifact	Instrument Type or Method	Minimum Value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of confidence	Is the expanded uncertainty a relative one?	Comments	NMI service identifier
Volume, mass, volume flow rate, mass flow rate	Water meter Flow meter	Visual reading Pulse output	0.5	150	m^3/h	Liquid	Water	0.10	%	2	95%	Yes	Approved on 15 October 2013	PL3
						Temperature	15° C to 25 °C							
						Pressure	0.2 MPa							

9 References

[1] Cox M.G., *Evaluation of key comparison data*, Metrologia, 2002, 39, 589-595

[2] Cox M.G., *The evaluation of key comparison data: determining the largest consistent subset*, Metrologia, 2007, 44, 187-200

[3] Rousseeuw P.J., Leroy A.M., Robust Regression and outlier detection, John Wiley & Sons, New York, 1987

[4] Elster C., Link A., Wöger W., Proposal for linking the results of CIPM and RMO key comparisons, Metrologia, 2003, 40, 189-194

[5] Kharitonov I.A., Chunovkina A.G., Evaluation of regional key comparison data: two approaches for data processing, Metrologia, 2006, 43, 470-476

[6] Decker J.E., Steele A.G., Douglas R.J., Measurement science and the linking of CIPM and regional key comparisons, Metrologia, 2008, 45, 223-232

[7] Engel R., Mickan B., Aspects of traceability and comparisons in flow measurement, 7th ISFFM, Anchorage/Alaska, August 12-14, 2009

[8] JCGM 100:2008 (GUM 1995 with minor corrections) Evaluation of measurement data — Guide to the expression of uncertainty in measurement.

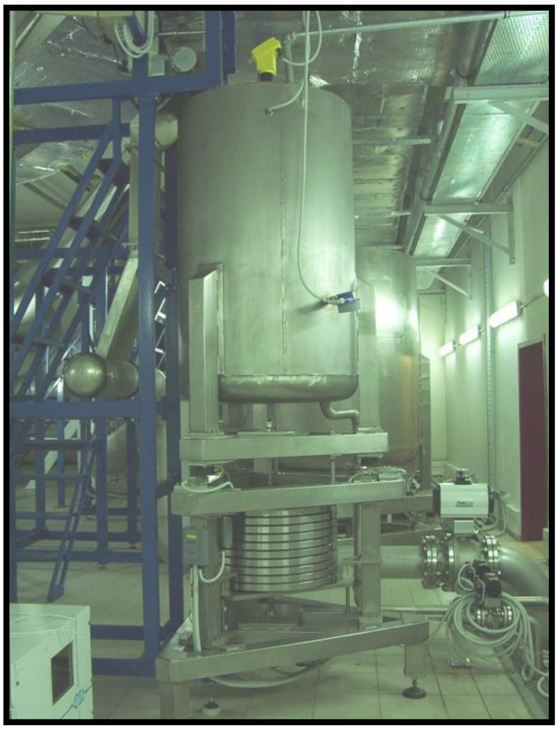
[9] Delahaye F., Witt T. J., Linking the Results of Key Comparison CCEM-K4 with 10 pF Results of EUROMET Project 345, Metrologia 39 (2002), Technical Supplement 01005.

Appendix A – NMI reports

Characteristic information \ picture of the primary standard used by measurements	Working procedure

TUBITAK-UME

Range of flow rate:	(1-100) m^3/h
Uncertainty (k=2):	0,04%



The method in which the mass of liquid collected is deduced from tare and gross weighing made respectively before and after the liquid has been diverted for a measured time interval into the weighing tank.
At least five measurements are carried out for each of series of flow-rate measurement and analysis of random uncertainties are carried out.
The mean mass flow-rate during the filling time is obtained by dividing the real mass m of the liquid collected by the filling time t:

$$q_v = \frac{\Delta m}{\rho \times t} = \frac{m_1 - m_0}{\rho \times t} \times \frac{1-\frac{\rho_a}{\rho_p}}{1-\frac{\rho_a}{\rho}}$$

Bulgarian Institute of Metrology (BIM), Bulgarian

Range of flow rate:	0.4 to 40 m^3/h
Uncertainty(k=2) :	0.056 % for volume and mass

The tests of the meter indication are performed after connecting the meter to the test rig and ensuring that no leakage takes place. The measurement is performed at a constant flow-rate at pressure up to 6000 hPa. The water passed through the meter is received in an open collecting tank at ambient pressure. The volume collected in the tank is the volume passed. The volume is determined by measuring of the mass by means of an electronic weighing platform. The collecting tank is placed on the weighing platform without any physical contacts with other parts of the test rig. At the beginning of each measurement, the collecting tank is empty but wet, with mass M_0. The mass of the water at the end of the test is the difference between the mass of the full tank (M) and the mass of the empty tank

($\Delta M = M - M_0$).

An adjustment of the zero of the meter is performed after its installation at the test rig.

The measurement is performed at different flow-rates, which are determined by six rotameters.

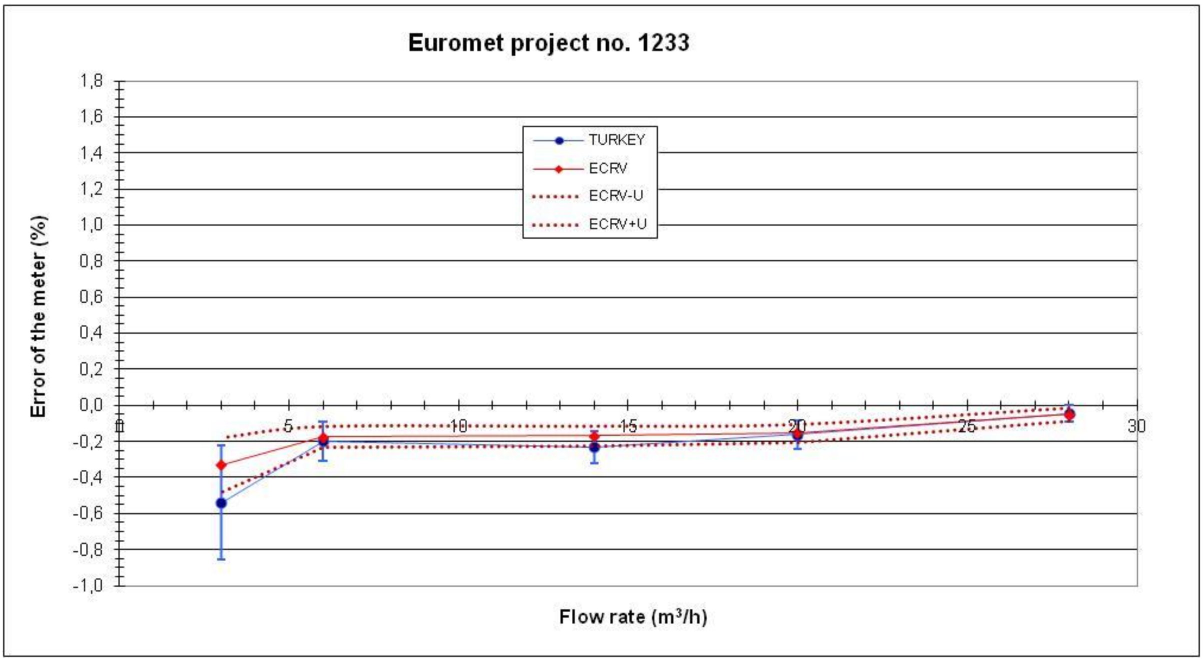
Characteristic information \ picture of the primary standard used by measurements	Working procedure
	Five measurements are carried out for each flow-rate. The actual volume of the water passed V_{act} is determined by the mass of the water in the collecting tank according to expression $V_{act} = \frac{M - M_0}{\rho_w - \rho_a}\frac{1}{k_w}$, where: M is the mass at the end of the measurement, and M_0 is the mass of the tank; ρ_w is the density of the water in the thank at ambient temperature and pressure; ρ_a is the density of the air at ambient temperature and pressure; k_w is a correction of the volume, taking into account water compressibility. Reduces the volume of the water in the tank to its volume at the meter inlet.
INRIM, Italy 	The INRIM water flow rate primary standard is a flow calibration rig based on the static weighing gravimetric system with flying start-and-stop, as established by standard EN-ISO 24185. Its flow rate capacity ranges from 0.036m^3/h to 36m^3/h. The rig is equipped with different measurement lines (pipe bore up to 50 mm), a 150 kg balance and a high speed flow diverter(commutation time less than 4 ms). The temperature of tests can vary from 18 °C up to 80 °C. At least three measurements are carried out for each of series of flow-rate measurement and analysis of random uncertainties are carried out. The mean mass flow-rate during the filling time is: where: P = mass of fluid indicated by the balance τ = time of the diverter k = correction factor for the buoyancy exerted on the fluid, and losses due to evaporation during filling of the weighing reservoir C = correction to be applied to readings following calibration of the balance and thermal effects on the measurement.

<table>
<tr><th>Characteristic information \ picture of the primary standard used by measurements</th><th>Working procedure</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Lithuanian Energy Institute (LEI), Lithuanian</td><td></td></tr>
<tr><td>Central Office of Measurement (GUM), Poland
</td><td>The test rig composes of:
1) Water storage tank
2) Gravity tank
3) Pump section (3 pumps with different flow rate)
4) Control weigh (Mettler Toledo KG 6000, max load 6000 kg)
5) Tank mounted on control weigh (max volume approx. 5 m^3)
6) Flow diverter (hydraulically controlled, automated or manual)
7) Pressure gauge
8) Control valves
9) Electronic control system (manufactured by Plum Białystok)
10) Piping
The water is pumped continuously from storage tank to gravity tank (certain level of water is always kept) and then flows through piping to DUT mounting section. When the water is passed through DUT it enters either control weigh or goes back to storage tank (depends on diverter position). The water temperature is checked just after the DUT output (end of straight pipe section) by temperature sensor (displayed and logged when in automatic mode). Straight pipe section is more than 5m long. The rig is controlled either manually or automatically – depends on operator choice and DUT (for automatic mode there is need</td></tr>
</table>

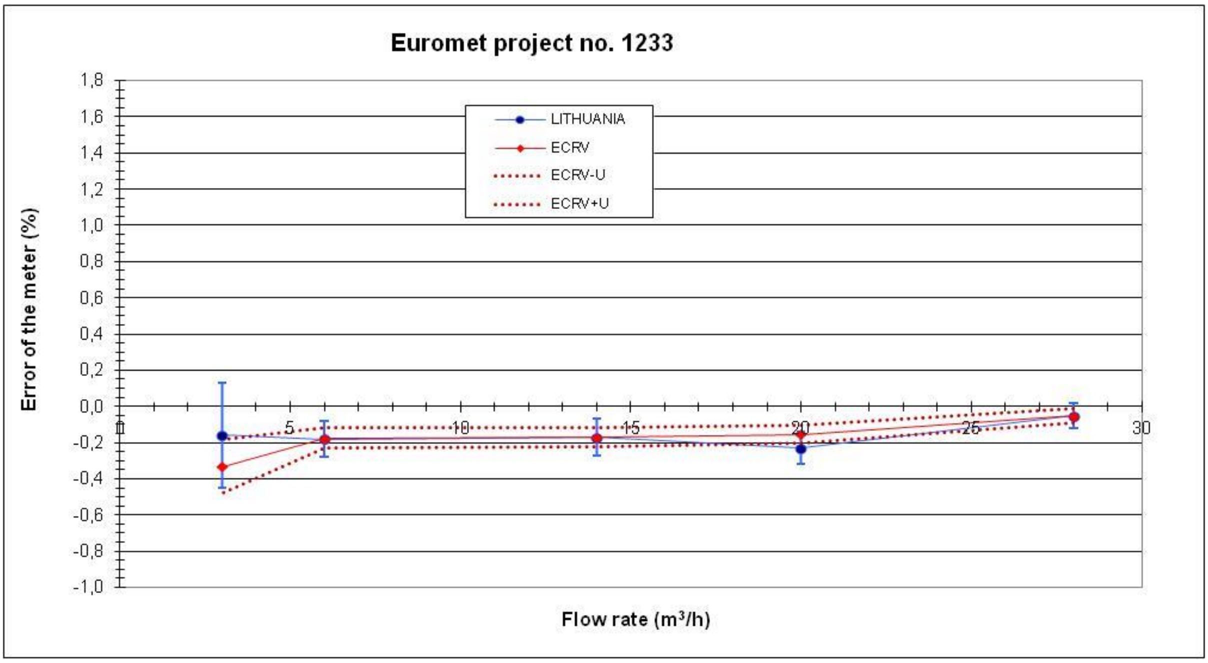
Characteristic information \ picture of the primary standard used by measurements	Working procedure
	to have pulse output or possibility to attach pulsed output optical sensor to DUT i.e. water meter rotating “star” is sufficient). Typical pressure on DUT entry is 0,2 MPa and drops when flow is set above 120 m^3/h. The DUT diameter can vary from DN50 to DN100. There is no thermal control of water in storage tank. Environmental conditions are monitored. The calibration interval of all control devices (weigh, pressure gauge, clock timer, temperature sensors) is set to 48 months.

Appendix B – graphical representation of relative error and expanded uncertainty

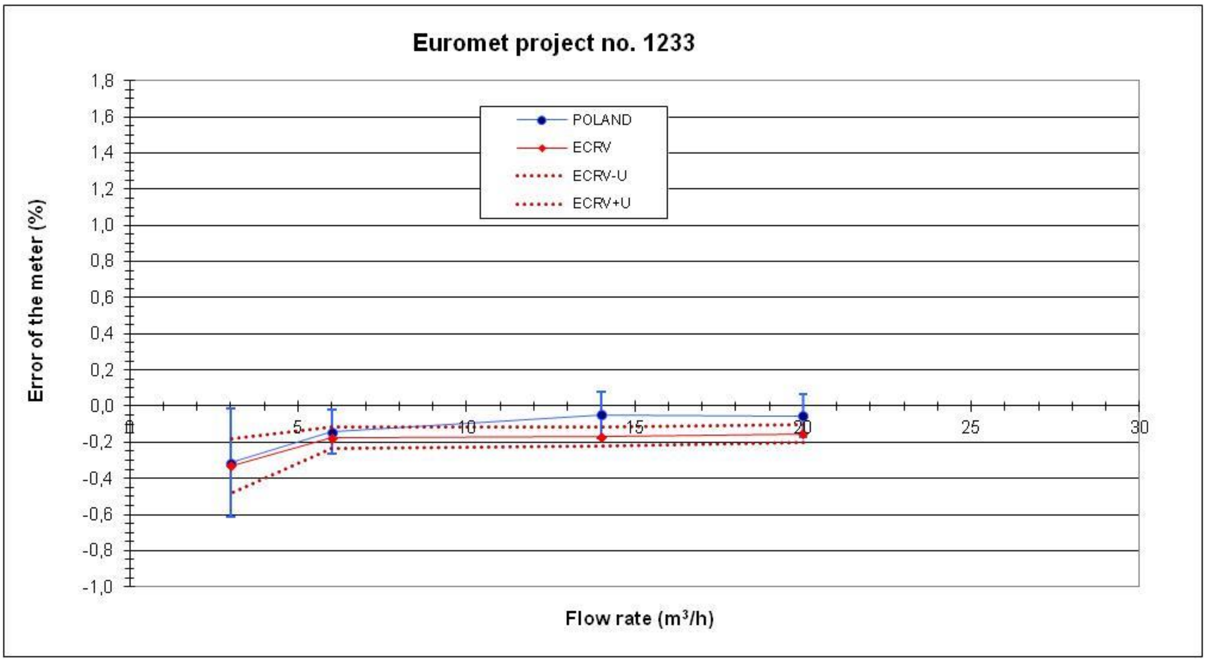
TURKEY					
Flow rate of the transfer standard	Relative error of the transfer standard	Expanded uncertainty of measurement declared by laboratory U_{xi} (%)	Expanded uncertainty of measurement extended by stability U_{st} (%)	d_i	$\lvert E_i \rvert$
28	-0,051	0,040	0,048	0,0061	0,20
20	-0,154	0,040	0,079	-0,0075	0,12
14	-0,170	0,042	0,090	-0,0644	0,83
6	-0,175	0,081	0,110	0,0130	0,13
3	-0,331	0,134	0,314	-0,2075	0,73



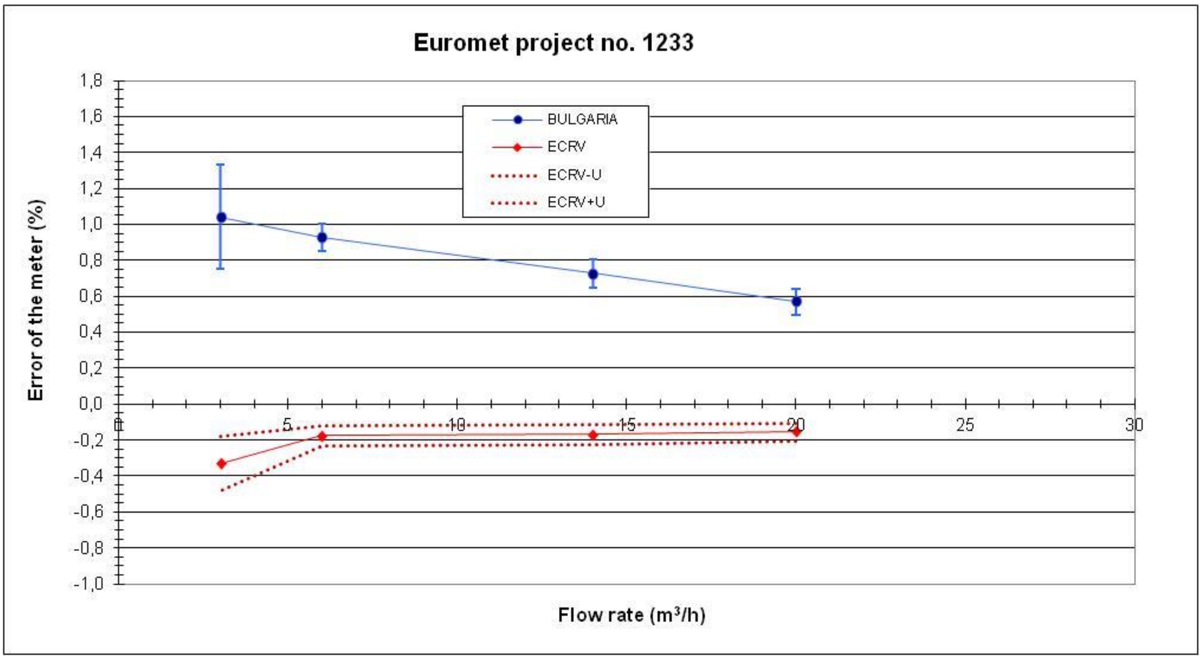
LITHUANIA					
Flow rate of the transfer standard	Relative error of the transfer standard	Expanded uncertainty of measurement declared by laboratory U_{xi} (%)	Expanded uncertainty of measurement extended by stability U_{st} (%)	d_i	$\lvert E_i \rvert$
28	-0,051	0,064	0,069	-0,0029	0,05
20	-0,154	0,061	0,091	-0,0745	0,97
14	-0,170	0,062	0,101	-0,0014	0,02
6	-0,175	0,066	0,099	-0,0060	0,07
3	-0,331	0,061	0,290	-0,1745	0,68



POLAND					
Flow rate of the transfer standard	Relative error of the transfer standard	Expanded uncertainty of measurement declared by laboratory U_{xi} (%)	Expanded uncertainty of measurement extended by stability U_{st} (%)	d_i	$\lvert E_i \rvert$
20	-0,154	0,10	0,121	0,1015	0,92
14	-0,170	0,10	0,128	0,1206	1,01
6	-0,175	0,10	0,124	0,0330	0,29
3	-0,331	0,10	0,301	0,0165	0,06



BULGARIA					
Flow rate of the transfer standard	Relative error of the transfer standard	Expanded uncertainty of measurement declared by laboratory U_{xi} (%)	Expanded uncertainty of measurement extended by stability U_{st} (%)	***d***d_i	$\vert E_i \vert$
20	-0,154	0,027	0,073	0,724	8,23
14	-0,170	0,013	0,081	0,897	9,18
6	-0,175	0,015	0,076	1,102	11,61
3	-0,331	0,053	0,289	1,372	19,90



ITALY					
Flow rate of the transfer standard	Relative error of the transfer standard	Expanded uncertainty of measurement declared by laboratory U_{xi} (%)	Expanded uncertainty of measurement extended by stability U_{st} (%)	***d****i*	│***E***i│
28	-0,051	0,101	0,104	-0,0229	0,23
20	-0,154	0,101	0,122	0,0475	0,43
14	-0,170	0,105	0,132	0,0146	0,12
6	-0,175	0,114	0,136	-0,0480	0,38
3	-0,331	0,110	0,305	-0,0135	0,05