EURAMET project No. 1333
EURAMET Regional Comparison

Comparison of standards for low-pressure gas flow

Final Report

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October, 2016

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1 Introduction

A comparison is organized in order to determine the degree of equivalence of standards for low-pressure gas flow measurement in the range 1000 m^3/h to 10000 m^3/h at ambient pressure. Two Elster Instromet turbine flow meters have been used as transfer standards. Two transfer standards have been used to determine whether there is any difference between calibration results of meters with different diameters.

If laboratories were not able to cover the whole range, they were allowed to calibrate the transfer standards over a part of the range.

2 Participants and planning

Apart from France all laboratories also participated in the Euramet comparison 1296 [2]. The participants and planning are shown in Table 1. Each laboratory had roughly 1 month to perform the measurements (including receiving and preparation for transport). The schedule is chosen in such a way that travelling costs are minimized. The transport costs are equally shared over the participants. Further, VSL as the pilot laboratory organized the transport between all laboratories. Hence, there was one shipping company with predefined and fixed dates for delivery and pick-up.

After the start of the comparison CMI, Czech Republic, retreated from the comparison due to the relocation of their laboratory. Although capable of performing calibrations at all flow rates, Force only submitted data regarding the G2500. After the tests with the G6500 were performed and the meters were sent to the next participant Force discovered that the results of the G6500 were based on invalid data and that it was not possible to recover the proper data.

Table 1 Participants and time schedule of the measurements

Country	NMI	Contact	remarks	delivery date	pickup date
Netherlands (PILOT)	VSL Dutch Metrology Institute	Peter Lucas, Gerard Blom plucas@vsl.nl gblom@vsl.nl	whole range, no limitations independent laboratory		April 28
Denmark	FORCE	Jesper Busk jrb@force.dk	whole range, no limitations traceable to VSL	May 1	May 26
Lithuania	LEI Lithuanian Energy Institute	Arūnas Stankevičius +370 37 401862 aras@lei.lt	200 – 9700 m^3/h traceable to PTB	June 3	June 26
Hungary	MKEH Hungarian Trade Licensing Office. Section of Flow Measurement	Csaba Czibulka czibulkacs@mkeh.hu	up to 5600 m^3/h traceable to VSL	July 6	July 27
Switzerland	METAS Federal Institute of Metrology	Marc de Huu Marc.deHuu@metas.ch	up to DN300 and 4500 m^3/h Independent laboratory	Aug 3	Sept 25

France	CESAME EXADEBIT S.A	Christophe Windenberger c.windenberger@cesame-exadebit.fr	For DN400 only Independent laboratory	Oct 1	Oct 26
Spain	CEM Centro Español de Metrología Enagas S.A.	Nieves Medina mnmedina@cem.minetur.es	whole range, no limitations traceable to PTB	Oct 29	Nov 24
Turkey	TÜBİTAK UME	Hakan Kaykisizli hakan.kaykisizli@tubitak.gov.tr	whole range, no limitations Independent laboratory	Jan 1	Jan 26
Germany	PTB Physikalisch-Technische Bundesanstalt	Bodo Mickan Bodo.Mickan@ptb.de	whole range, no limitations Independent laboratory	Feb 1	Feb 28
Netherlands (PILOT)	VSL Dutch Metrology Institute	Peter Lucas, Gerard Blom	whole range, no limitations	March	

3 Transfer standards

Two turbine flow meters were used as transfer standards. The specifications as well as a few photos are given below. For extensive information about the transfer packages and the handling thereof reference is made to the protocol of Euramet project no. 1333.

3.1 G2500

Type:	SM-RI-D Turbine meter
Manufacturer:	Instromet
G-value:	G2500
Q_{min}	200 m^3/h
Q_{max}	4000 m^3/h
Serial number:	23927
P_{max} :	20 bar
Inside diameter:	DN 300
Flange type and pressure schedule:	ANSI 125/150

Figure 1 Instromet turbine meter G2500

3.2 G6500

Type:	SM-RI-X-L Turbine meter
Manufacturer:	Instromet
G-value:	G6500
Q_{min}	500 m^3/h
Q_{max}	10000 m^3/h
Serial number:	65515
P_{max} :	10 bar
Inside diameter:	DN 400
Flange type and pressure schedule:	DIN 2632 PN10
Remarks:	The flange is relatively thin and therefore vulnerable. Please use the dedicated gaskets and torque wrench to tighten the bolts.

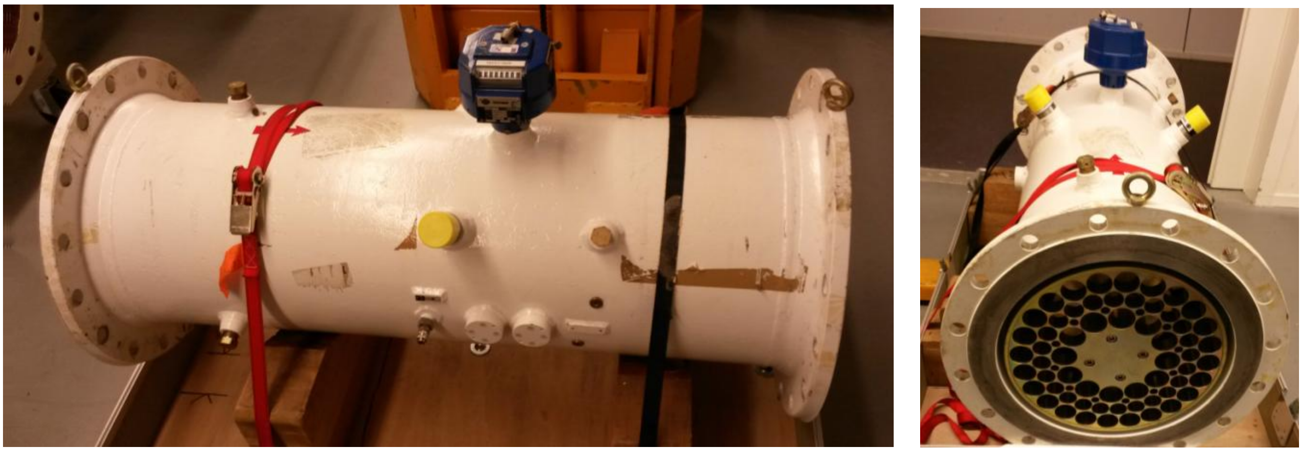


Figure 2 Instromet turbine meter G6500

During the transport from Switzerland to France the package was slightly damaged. After inspection by Cesame the damage appeared to be only on the transport cases and the meters had no damage so the comparison could go on. At some point during the comparison it was noted that pulse output nr. 1 was not always working properly. The remaining participants were advised to use pulse output nr. 2.

4 The measurement procedure

4.1 Calibration protocol

The participating NMIs used their usual calibration protocol. However, the following recommendations were given:

- The transfer standard is tested in the horizontal position.
- The minimum straight upstream pipe length should by 5 times the diameter, whereas the minimum downstream distance should be 3 times the diameter.
- The pressure at the transfer standard is measured at the output "P_r" (pressure tap located on the meter body close to the turbine wheel). Both meters have various pressure tappings, however the one to use is accordingly labeled.
- The temperature at the transfer standard is taken as the upstream temperature. If that is not possible, use the downstream one, however clearly indicate so.
- It is necessary to use a HF pulse connection. There may be various HF connections; however the one to use is accordingly labeled.
- The flow points should be measured from the highest flow rate to lowest. Hence, one has to start with the highest flow rate. Furthermore, prior to the calibrations the meter has to run for at least 5 minutes.
- The test at each flow rate should be repeated at least 3 times. The flow rate has to be set within the interval ± 3% of the required value.
- For each flow point it is required to have stabilized flow. Depending on the facility this may take up to a few minutes.

4.2 Measurement conditions and flow points

The measured range is 1000 m^3/h to 10000 m^3/h. If the laboratory could not cover the whole range, they performed measurements at the flow rates they were able to realise.

The measurement conditions should be around atmospheric pressure and between a minimum and maximum temperature of 19.5°C and 23.5°C, respectively. The flow points are given in the table below.

Table 2 suggested flow rates for the comparison

Transfer standard	Diameter	flow points (m^3/h)
G2500	DN300	1000, 2000, 3000, 4000
G6500	DN400	1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000

4.3 Reporting the results

For each meter that has been calibrated the following measured parameters were reported: absolute pressure and temperature at the meter location, differential pressure over the meter, relative error of the meter and the uncertainty in the reference flow (k=1) (the evaluation will be for k=2, however the data template has been set up for *k*=1). For the uncertainty in the reference flow one can use the CMC of the facility. Following the WG-FF guidelines [1] , the uncertainty of the CMC is determined as:

$$U_{CMC} = 2\sqrt{u_{\mathrm{base}}^2 + \left(\frac{t_{95}}{2}\frac{s_{\mathrm{repeat,\,BED}}}{\sqrt{n}}\right)^2} \tag{1}$$

where s the sample standard deviation
n number of repeated measurements
BED Best Existing Device
t_{95} 95% confidence level student *t*-value for *n*-1 degrees of freedom.

The relative error of the transfer standard ε in (%) is the quantity that has been used to compare the results. It is defined as the difference between the volume flow rate indicated by the transfer standard and the volume flow rate according to the reference:

$$\varepsilon = \frac{Q_{TS} - Q_{ref}}{Q_{ref}} * 100\% \tag{2}$$

where ε the relative error of the transfer standard (%),
Q_{TS} the volume flow rate indicated by the transfer standard (m^3/h)
Q_{ref} the volume flow rate measured by the reference (m^3/h)

Based on the reported results the following values are computed:

- the average reference flow rate (m^3/h)
- the average indicated flow rate (m^3/h)
- the standard deviation of the error (%)
- the expanded uncertainty of the calibration (*k*=2) (%).

5 Measurement results

The Euramet Comparison Reference Value (ECRV) will be determined for each flow rate separately. The method of determination of the reference value at each flow rate will correspond to procedure *A* as suggested by Cox M.G., "Evaluation of key comparison data. Metrologia, 2002, 39, 589-595" [3].

The determination of the ECRV based on the measurement results of the independent laboratories includes a consistency check (chi square test) according to Cox M. G., "The evaluation of key comparison data: determining the largest consistent subset, Metrologia, 2007, 44, 187-200", [4]. If the set of results is inconsistent, then the concept of Largest Consistent Subset (LCS) as suggested by Cox [4] has been applied and a new ECRV is calculated. In the present comparison all results were consistent according to the chi square test.

All laboratories performed tests with the G2500 at all flow points. Five laboratories have an independent traceability chain and thus contribute to the ECRV.

- VSL (independent)
- FORCE
- LEI
- MKEH
- METAS (independent)
- CESAME (independent)
- CEM
- UME (independent)
- PTB (independent)

Seven laboratories performed tests with the G6500. Four laboratories have an independent traceability chain and thus contribute to the ECRV.

- LEI
- CESAME (independent)
- UME (independent)
- VSL (independent)
- MKEH
- CEM
- PTB (independent)

One laboratory performed tests from 1000 m^3/h to 5000 m^3/h. PTB performed measurements with the G6500 on a second installation but only at 1000 m^3/h and 2000 m^3/h.

The CMCs of the participating laboratories as registered on the BIPM website related to the flow rates used in this comparison are listed in the table below.

Table 3 CMCs of the participating laboratories for 1000 - 10000 m^3/h or part of the range

Flow rate (m^3/h)	Laboratory	CMC (%)
1000 – 10000	VSL	0.15
1000 – 4000	FORCE	0.24
1000 – 9500	LEI	0.30

1000 – 5000	MKEH	0.30
1000	METAS	0.15
1000 – 10000	LNE CESAME	0.26
1000 – 5000	UME	0.45
1000 – 10000	UME	0.80
1000 – 10000	PTB	0.12

5.1 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 analyzing measurement results is calculated using the following equation:

$$u_A^2 = \frac{1}{n(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2 \quad (3)$$

Type B uncertainty is determined on the basis of non-statistical methods. It consists the root-sum-of squares of the relevant sources of uncertainty from the mathematical model:

$$u_B = \frac{1}{V_{Em}} \cdot \sqrt{\sum_{i=1}^{k} \left(\frac{\partial V_{Em}}{\partial x_i} \right)^2 . u^2(x_i)} \quad (4)$$

Combined uncertainty is calculated according to the following formula:

$$u_c = \sqrt{u_A^2 + u_B^2} \quad (5)$$

The expanded uncertainty U is obtained by multiplying the combined standard uncertainty u_c by coverage factor according to the formula:

$$U = k \cdot u_c \quad (6)$$

where the coverage factor *k*=2 is usually used in the flow community.

5.2 The determination of Degree of Equivalence and the differences "Lab to ECRV"

For each participating laboratory the degree of equivalence (DoE: (d_i, U_i)) was determined using a following equations:

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

where x_{ECRV} relative error from the present comparison

The expanded uncertainty was obtained using following equations

$$U(d_i) = 2u(d_i) \quad (8)$$

$$u^2(d_i) = u^2(x_i) - u^2(x_{ECRV}) \quad (9)$$

where u_{xi} the standard uncertainties of the relative error in the laboratories $i=1, 2, ...n$ including the uncertainty caused by the stability of the transfer standard

u_{xECRV} the standard uncertainty (not expanded) of the ECRV

Based on these differences the normalized error was calculated according to:

$$E_n = \left| \frac{d_i}{U(d_i)} \right| \qquad (10)$$

The normalized error is a measure for the equivalence of the results of any laboratory with the ECRV, respectively:

- the results of a laboratory were *equivalent (**passed**)* if $E_n \leq 1.0$
- the laboratory were determined as *not equivalent (**failed**)* if $E_n > 1.2$
- for values of E_n in the range $1 < E_n \leq 1.2$ the “**warning level**” was defined. In this case some actions to check are recommended for the laboratory.

The calculation of the E_n-value includes the information about the uncertainty of the differences d_i. First consider the general problem of the difference of two values x_1 and x_2. If we look to the propagation of (standard) uncertainty we find:

$$u_{x_1-x_2}^2 = \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} & \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} \begin{pmatrix} u_1^2 & \mathrm{cov} \\ \mathrm{cov} & u_2^2 \end{pmatrix} \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} \\ \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} = u_1^2 + u_2^2 - 2.\mathrm{cov} \qquad (11)$$

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. Now it is possible to define the different cases in a comparison and the related uncertainties:

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]:

$$u(d_i) = \sqrt{u_{xi}^2 + u_{ECRV}^2 - 2.u_{ECRV}^2} = \sqrt{u_{xi}^2 - u_{ECRV}^2} \qquad (12)$$

b) *Independent laboratories without contribution to the ECRV*

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

$$u(d_i) = \sqrt{u_{xi}^2 + u_{ECRV}^2} \qquad (13)$$

c) *Laboratories with traceability to a laboratory that contributes 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 estimate of an upper limit of this covariance. The upper limit is determined for the theoretical case that we have no additional stochastic influence in the traceability of the laboratory from its source (which is the laboratory contributing to the ECRV). Then the results of the laboratory 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 a).

$$u(d_i) = \sqrt{u_{xi}^2 + u_{ECRV}^2 - 2u_{ECRV}^2} = \sqrt{u_{xi}^2 - u_{ECRV}^2} \quad (14)$$

The expanded uncertainty $U(d_i)$ is determined by

$$U(d_i) = 2.u(d_i) \quad (15)$$

In case of additional uncertainty caused stochastically the correlation and consequently the covariance is smaller.

5.3 Uncertainty and stability of the transfer standard

For the comparison the standard uncertainty of the error in different laboratories u_{x1}. u_{x2}......u_{xn} include the uncertainty contribution from the transfer standard. The uncertainty of the error for the comparison for each laboratory was calculated according to the following formula:

$$u_{xi} = \sqrt{\left(\frac{U_{(xi)}}{2}\right)^2 + u_{TS}^2} \quad (16)$$

where $U_{(xi)}$ = the expanded uncertainty determined by laboratory i and presented in the results of laboratory i,

u_{TS} standard uncertainty based on the reproducebility of the transfer standard.

The transfer standard was tested 2 times in the pilot laboratory and the calibration stability of the transfer standards was determined based on these results. For the flow rates with the G2500 an average uncertainty due to drift u_{drift} of 0.006 % was found during the experiments.

For the flow rates with the G6500 an average uncertainty due to drift u_{drift} of 0.011 % was found during the experiments.

The estimated transfer standard uncertainty component was combined by root-sum-of-squares with the standard uncertainty provided by each participating laboratory. The ratio of the transfer standard uncertainty to any participant´s flow standard uncertainty is ≤ 1.

Before and after the comparison the meters were tested at the pilot's laboratory. The uncertainty due to reproducibility of the transfer standard was calculated according to:

$$u_{TS} = \frac{(\varepsilon_{start} - \varepsilon_{end})}{2\sqrt{3}} \quad (17)$$

The average of u_{TS} from the different flow rates has been used in the calculations. The results for the G2500 are shown in table 4.

Table 4 results of the measurements of the G2500 at the pilot laboratory at the start of the comparison

AVERAGE DATA 2015

Nominal flow rate (m3/h)	Reference flow rate (m3/h)	indicated flow rate (m3/h)	error (%)	Standard deviation error (%)	Uncertainty of the calibration (k=2) (%)
1000	1002.510	998.503	-0.400	0.005	0.150
2000	1998.042	1999.840	0.090	0.001	0.150
3000	2988.525	2999.038	0.352	0.004	0.150
4000	3983.138	3999.574	0.413	0.001	0.150

AVERAGE DATA 2016

Nominal flow rate (m3/h)	Reference flow rate (m3/h)	indicated flow rate (m3/h)	error (%)	Standard deviation error (%)	Uncertainty of the calibration (k=2) (%)	u(drift)
1000	1004.124	1000.355	-0.375	0.007	0.151	0.007
2000	1995.986	1997.691	0.085	0.003	0.150	0.001
3000	2989.948	2998.937	0.301	0.004	0.150	0.015
4000	3985.389	4001.789	0.411	0.005	0.150	0.000
					average	0.006

The results for the G6500 are presented in Table 5.

Table 5 results of the measurements of the G6500 at the pilot laboratory at the start of the comparison

AVERAGE DATA 2015

Nominal flow rate (m3/h)	Reference flow rate (m3/h)	indicated flow rate (m3/h)	error (%)	Standard deviation error (%)	Uncertainty of the calibration (k=2) (%)
1000	1004.504	1004.855	-0.060	0.002	0.150
2000	2009.119	2011.784	0.133	0.002	0.150
3000	2992.864	2999.460	0.220	0.005	0.150
4000	3995.816	4004.724	0.223	0.001	0.150
5000	4983.370	4993.721	0.208	0.002	0.150
6000	6010.535	6020.439	0.165	0.007	0.151
7000	7020.387	7027.432	0.100	0.004	0.150
8000	8012.934	8016.887	0.049	0.008	0.151
9000	9026.379	9029.410	0.034	0.014	0.153
10000	10102.627	10098.944	-0.036	0.008	0.151

AVERAGE DATA 2016

Nominal flow rate (m3/h)	Reference flow rate (m3/h)	indicated flow rate (m3/h)	error (%)	Standard deviation error (%)	Uncertainty of the calibration (k=2) (%)	u(drift)
1000	1003.406	1004.011	0.060	0.031	0.162	0.035
2000	1993.452	1996.434	0.150	0.001	0.150	0.005
3000	2994.035	3000.714	0.223	0.003	0.150	0.001
4000	3986.286	3993.858	0.190	0.007	0.151	0.010
5000	4989.318	4996.379	0.142	0.005	0.150	0.019
6000	5996.033	6002.476	0.107	0.008	0.151	0.017
7000	6996.316	7001.879	0.080	0.003	0.150	0.006
8000	7997.165	8002.029	0.061	0.003	0.150	0.003
9000	9002.254	9005.070	0.031	0.005	0.150	0.001
10000	9997.229	9997.250	0.000	0.008	0.151	0.011
					average	0.011

6 Laboratory results

6.1 G2500

All results of the independent laboratories passed the ChiSquare-test.

6.1.1 Flow rate 4000 m^3/h

Results of the independent laboratories:

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.62	0.26	1.5612
UME	0.15	0.45	1.8817
VSL	0.41	0.15	0.4227
PTB	0.47	0.08	0.0115
METAS	0.48	0.16	0.0401

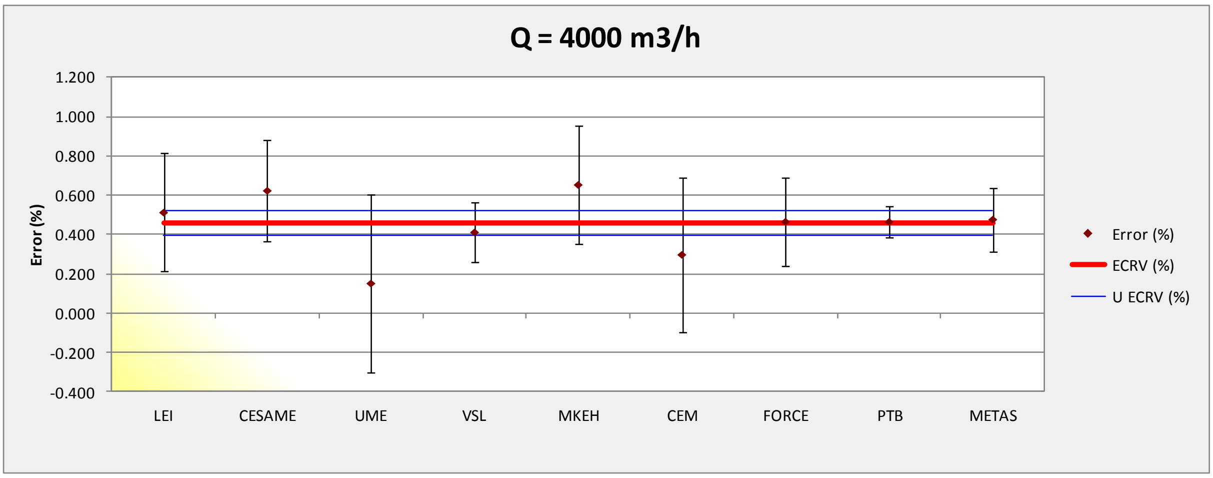
WME = y = 0.461

U(y) = 0.0623

χ^2_{obs} = 3.9172

CHIINV = 9.4877

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.51	0.30	0.05	0.30	0.18
CESAME	0.62	0.26	0.16	0.25	0.64
UME	0.15	0.45	-0.31	0.45	0.69
VSL	0.41	0.15	-0.05	0.14	0.36
MKEH	0.65	0.30	0.19	0.29	0.66
CEM	0.30	0.39	-0.16	0.39	0.42
FORCE	0.47	0.22	0.01	0.22	0.02
PTB	0.47	0.08	0.00	0.05	0.08
METAS	0.48	0.16	0.02	0.15	0.11



6.1.2 Flow rate 3000 m^3/h

Results of the independent laboratories:

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.40	0.26	0.1306
UME	0.16	0.45	0.7398
VSL	0.35	0.15	0.0041
PTB	0.36	0.08	0.0130
METAS	0.35	0.16	0.0054

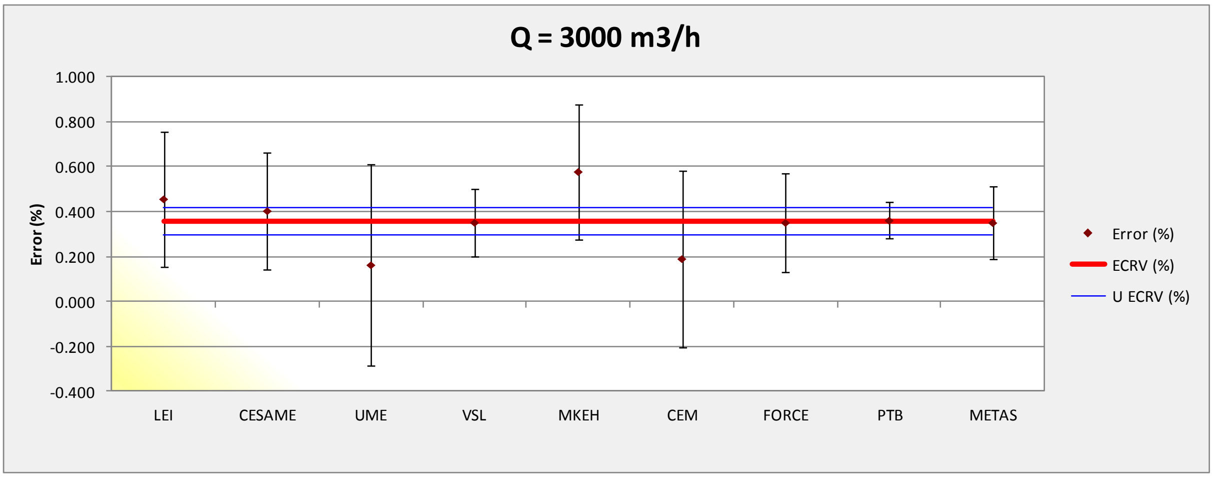
WME = y = 0.357

U(y) = 0.0627

χ^2_{obs} = 0.8928

CHIINV = 9.4877

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.46	0.30	0.10	0.30	0.34
CESAME	0.40	0.26	0.05	0.25	0.19
UME	0.16	0.45	-0.19	0.45	0.43
VSL	0.35	0.15	0.00	0.14	0.04
MKEH	0.58	0.30	0.22	0.29	0.75
CEM	0.19	0.39	-0.17	0.39	0.43
FORCE	0.35	0.22	-0.01	0.21	0.03
PTB	0.36	0.08	0.00	0.05	0.09
METAS	0.35	0.16	-0.01	0.15	0.04



6.1.3 Flow rate 2000 m^3/h

Results of the independent laboratories:

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.17	0.26	0.0886
UME	0.16	0.45	0.0196
VSL	0.09	0.15	0.3101
PTB	0.14	0.08	0.1045
METAS	0.11	0.16	0.0792

WME = y = 0.132

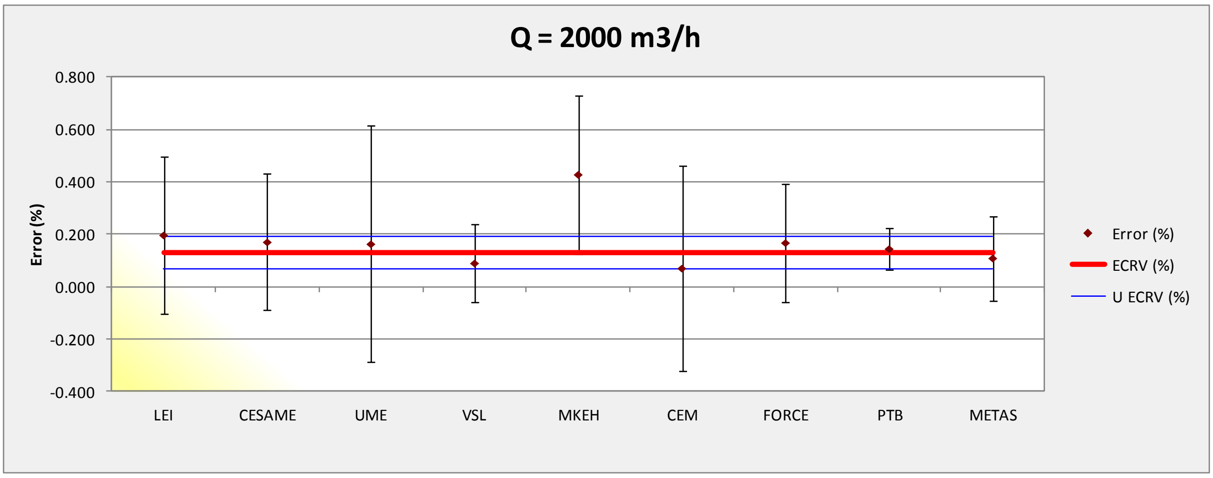
U(y) = 0.0626

χ^2_{obs} = 0.6019

CHIINV = 9.4877

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.20	0.30	0.07	0.29	0.22
CESAME	0.17	0.26	0.04	0.25	0.15
UME	0.16	0.45	0.03	0.45	0.07
VSL	0.09	0.15	-0.04	0.14	0.31
MKEH	0.43	0.30	0.30	0.29	1.01
CEM	0.07	0.39	-0.06	0.39	0.16
FORCE	0.17	0.22	0.04	0.21	0.17
PTB	0.14	0.08	0.01	0.05	0.26
METAS	0.11	0.16	-0.02	0.15	0.15

One result has a “warning level”.



6.1.4 Flow rate 1000 m^3/h

Results of the independent laboratories:

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	-0.15	0.26	2.1587
UME	0.16	0.45	4.7933
VSL	-0.40	0.15	0.6835
PTB	-0.34	0.08	0.0258
METAS	-0.38	0.16	0.2456

WME = y = -0.338

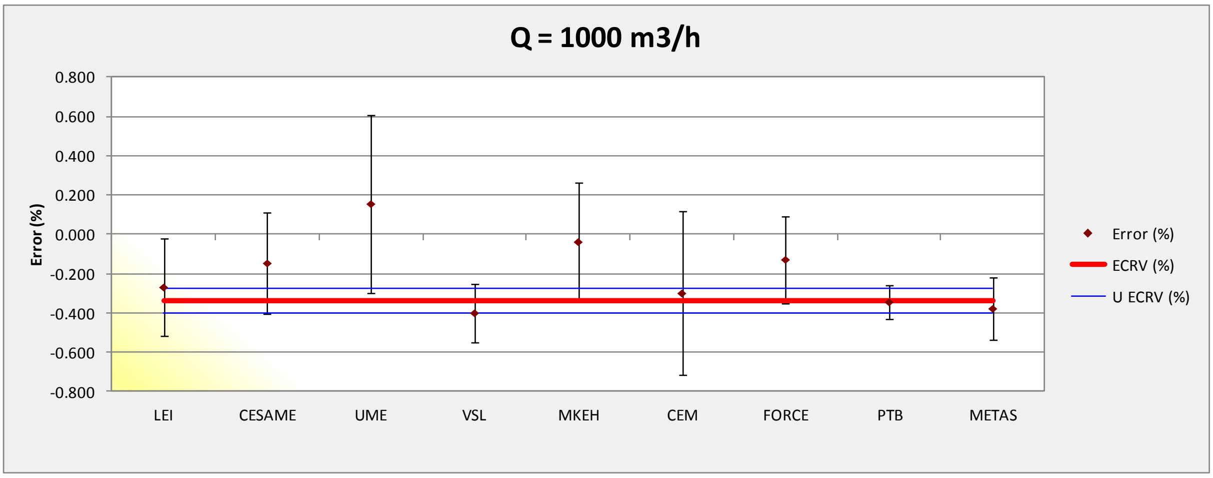
U(y) = 0.0637

χ^2_{obs} = 7.9069

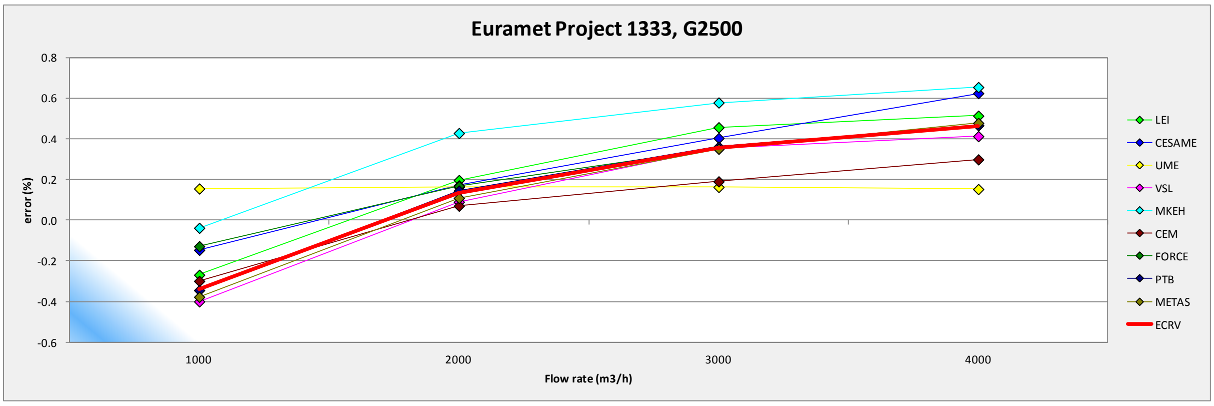
CHIINV = 9.4877

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	-0.27	0.25	0.07	0.24	0.28
CESAME	-0.15	0.26	0.19	0.25	0.76
UME	0.16	0.45	0.49	0.45	1.11
VSL	-0.40	0.15	-0.06	0.14	0.46
MKEH	-0.04	0.30	0.30	0.29	1.02
CEM	-0.30	0.42	0.04	0.41	0.09
FORCE	-0.13	0.22	0.21	0.21	0.99
PTB	-0.34	0.08	-0.01	0.05	0.12
METAS	-0.38	0.16	-0.04	0.15	0.27

Two results have a “warning level”.



6.1.5 All test results with the G2500



6.2 G6500

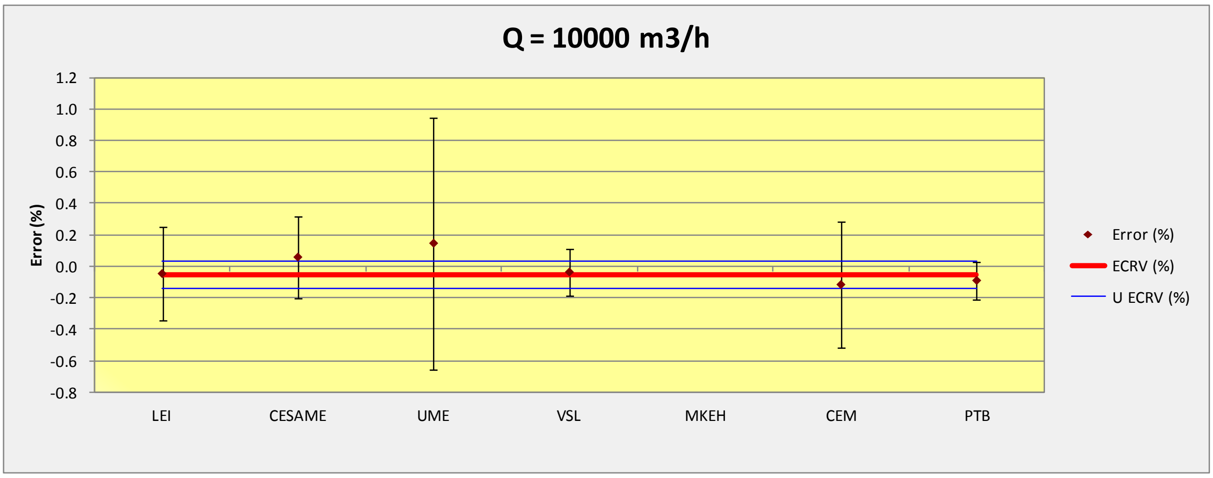
All results of the independent laboratories passed the ChiSquare-test.

6.2.1 Flow rate 10000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.06	0.26	0.7070
UME	0.15	0.80	0.2463
VSL	-0.04	0.15	0.0438
PTB	-0.09	0.12	0.3943

WME = y = -0.052
U(y) = 0.0883
χ^2_{obs} = 1.3914
CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	-0.05	0.30	0.01	0.29	0.02
CESAME	0.06	0.26	0.11	0.25	0.45
UME	0.15	0.80	0.20	0.80	0.25
VSL	-0.04	0.15	0.02	0.12	0.13
CEM	-0.12	0.40	-0.06	0.39	0.16
PTB	-0.09	0.12	-0.04	0.08	0.46



6.2.2 Flow rate 9000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.04	0.26	0.1364
UME	0.14	0.80	0.1527
VSL	0.03	0.15	0.3662
PTB	-0.06	0.12	0.4991

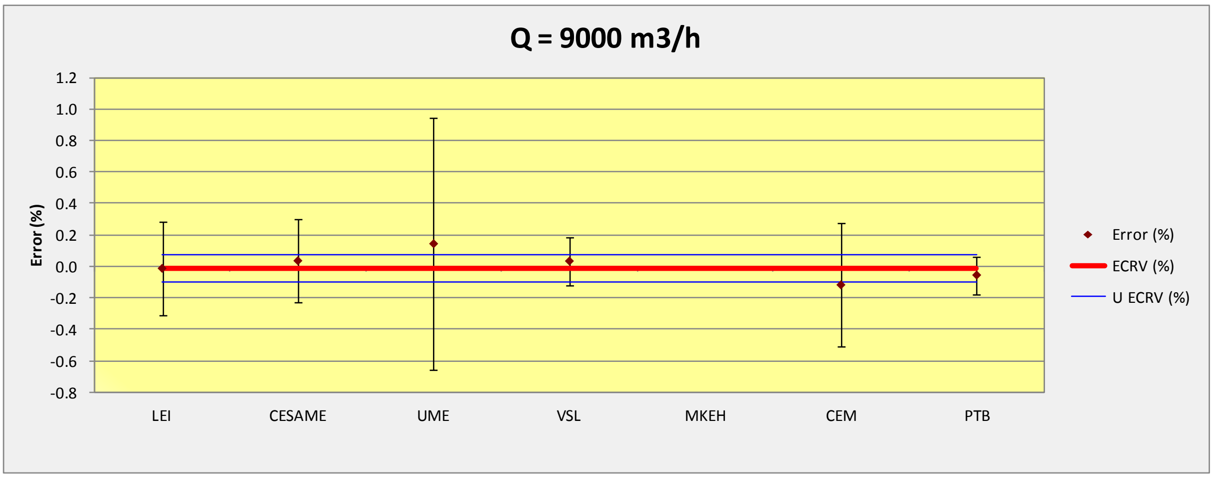
WME = y = -0.013

U(y) = 0.0886

χ^2_{obs} = 1.1544

CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	-0.01	0.30	0.00	0.29	0.00
CESAME	0.04	0.26	0.05	0.25	0.20
UME	0.14	0.80	0.16	0.80	0.20
VSL	0.03	0.15	0.05	0.12	0.37
CEM	-0.12	0.39	-0.10	0.38	0.27
PTB	-0.06	0.12	-0.04	0.08	0.52



6.2.3 Flow rate 8000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.07	0.26	0.1919
UME	0.17	0.80	0.1461
VSL	0.05	0.15	0.1889
PTB	-0.02	0.12	0.3744

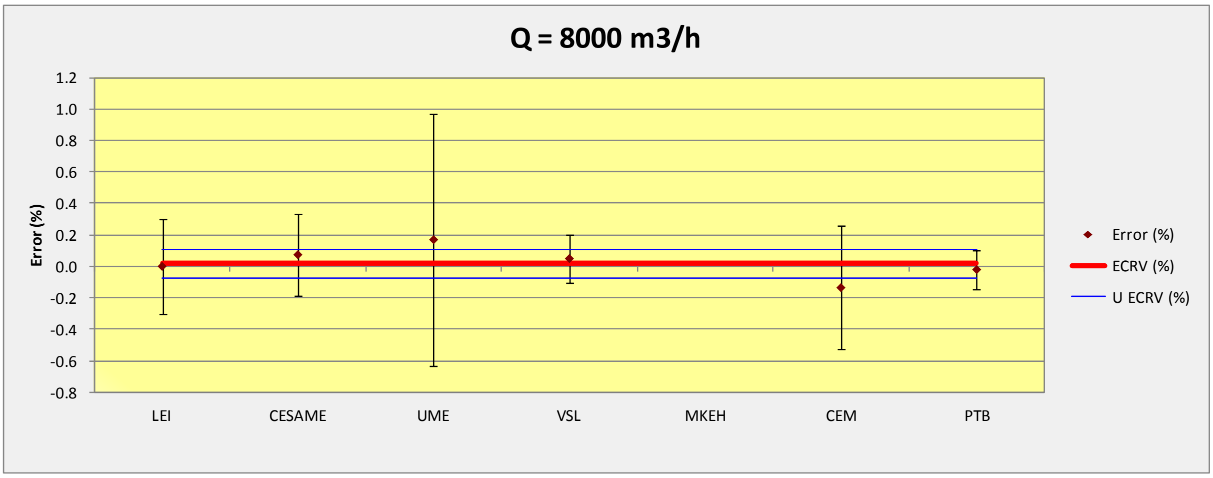
WME = y = 0.016

U(y) = 0.0886

χ^2_{obs} = 0.9014

CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.00	0.30	-0.02	0.29	0.06
CESAME	0.07	0.26	0.06	0.25	0.23
UME	0.17	0.80	0.15	0.80	0.19
VSL	0.05	0.15	0.03	0.12	0.27
CEM	-0.14	0.39	-0.15	0.38	0.40
PTB	-0.02	0.12	-0.04	0.08	0.45



6.2.4 Flow rate 7000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.20	0.26	1.1411
UME	0.14	0.80	0.0378
VSL	0.10	0.15	0.2189
PTB	0.01	0.12	0.8088

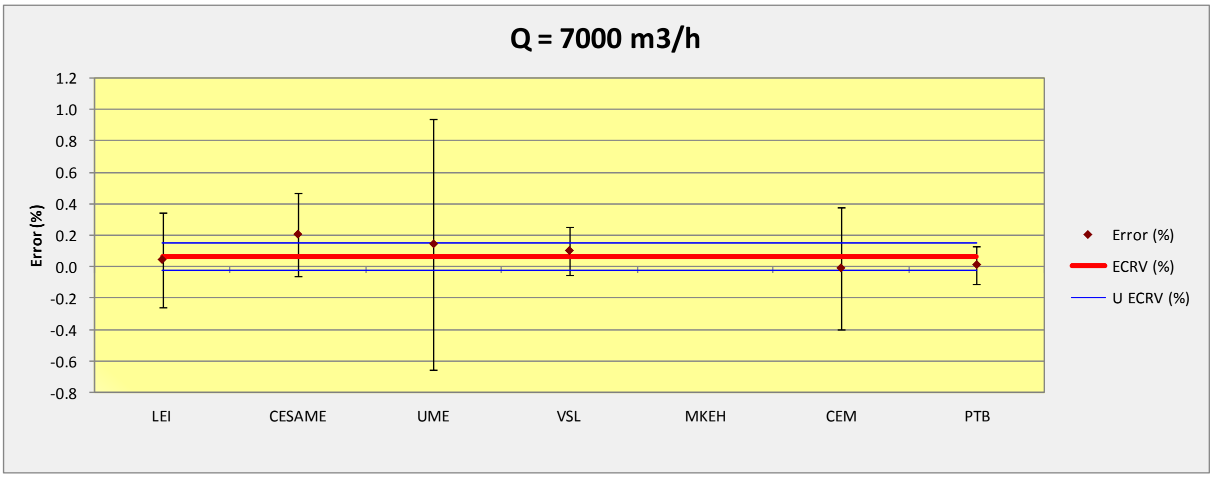
WME = y = 0.065

U(y) = 0.0881

χ^2_{obs} = 2.2067

CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.04	0.30	-0.02	0.29	0.08
CESAME	0.20	0.26	0.14	0.25	0.57
UME	0.14	0.80	0.08	0.80	0.10
VSL	0.10	0.15	0.04	0.12	0.29
CEM	-0.01	0.39	-0.08	0.38	0.20
PTB	0.01	0.12	-0.05	0.08	0.66



6.2.5 Flow rate 6000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.19	0.26	0.3310
UME	0.14	0.80	0.0065
VSL	0.16	0.15	0.5197
PTB	0.06	0.12	0.7381

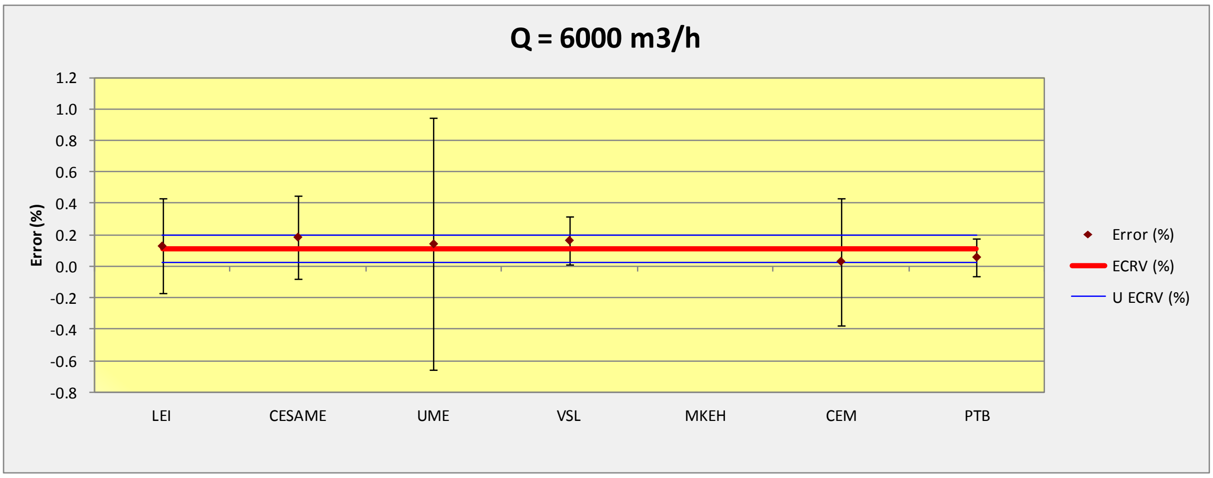
WME = y = 0.110

U(y) = 0.0884

χ^2_{obs} = 1.5953

CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.13	0.30	0.02	0.29	0.06
CESAME	0.19	0.26	0.08	0.25	0.31
UME	0.14	0.80	0.03	0.80	0.04
VSL	0.16	0.15	0.05	0.12	0.44
CEM	0.03	0.40	-0.08	0.39	0.20
PTB	0.06	0.12	-0.05	0.08	0.63



6.2.6 Flow rate 5000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.20	0.26	0.3235
UME	0.17	0.80	0.0088
VSL	0.21	0.15	1.0468
PTB	0.06	0.12	1.2189

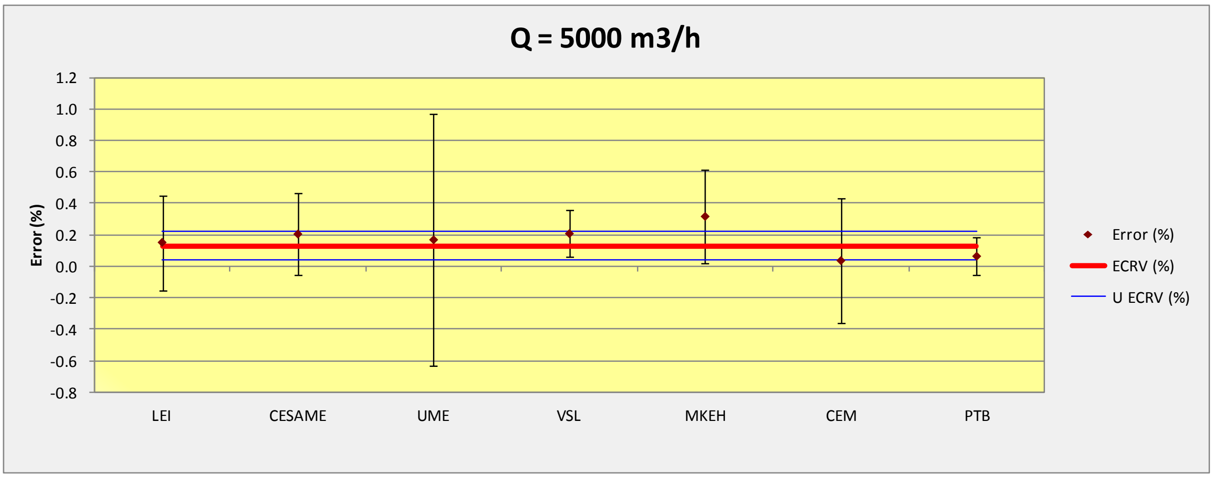
WME = y = 0.131

U(y) = 0.0882

χ^2_{obs} = 2.5980

CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.15	0.30	0.02	0.29	0.07
CESAME	0.20	0.26	0.07	0.24	0.30
UME	0.17	0.80	0.04	0.80	0.05
VSL	0.21	0.15	0.08	0.12	0.63
MKEH	0.32	0.30	0.19	0.29	0.65
CEM	0.04	0.40	-0.09	0.39	0.24
PTB	0.06	0.12	-0.07	0.08	0.80



6.2.7 Flow rate 4000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.27	0.26	0.6622
UME	0.16	0.80	0.0000
VSL	0.22	0.15	0.6755
PTB	0.10	0.12	1.0900

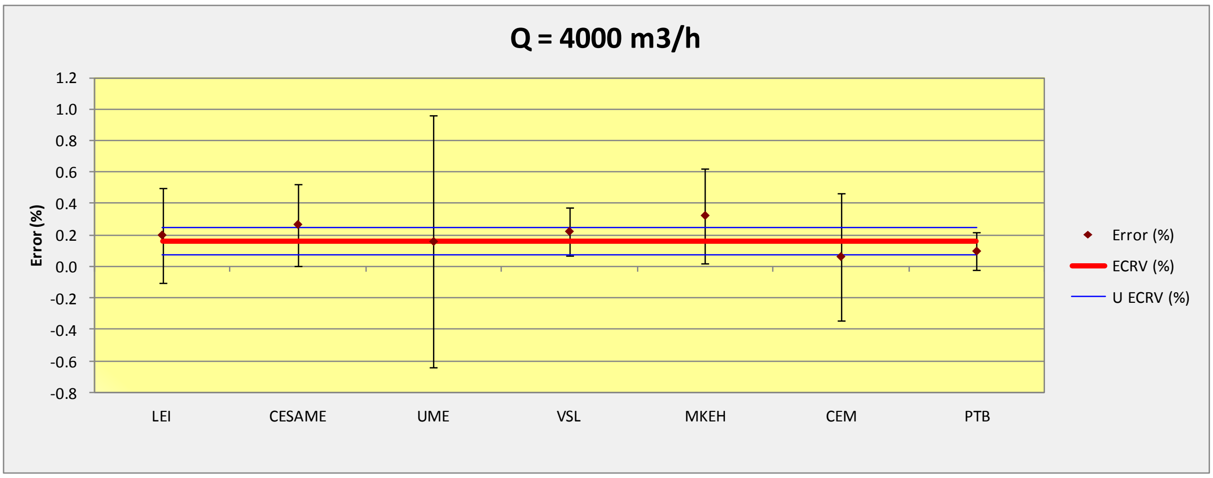
WME = y = 0.161

U(y) = 0.0884

χ^2_{obs} = 2.4278

CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.20	0.30	0.04	0.29	0.13
CESAME	0.27	0.26	0.11	0.25	0.43
UME	0.16	0.80	0.00	0.80	0.00
VSL	0.22	0.15	0.06	0.12	0.51
MKEH	0.32	0.30	0.16	0.29	0.57
CEM	0.06	0.40	-0.10	0.39	0.25
PTB	0.10	0.12	-0.06	0.08	0.76



6.2.8 Flow rate 3000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.18	0.26	0.0147
UME	0.14	0.80	0.0031
VSL	0.22	0.15	0.4995
PTB	0.13	0.12	0.3794

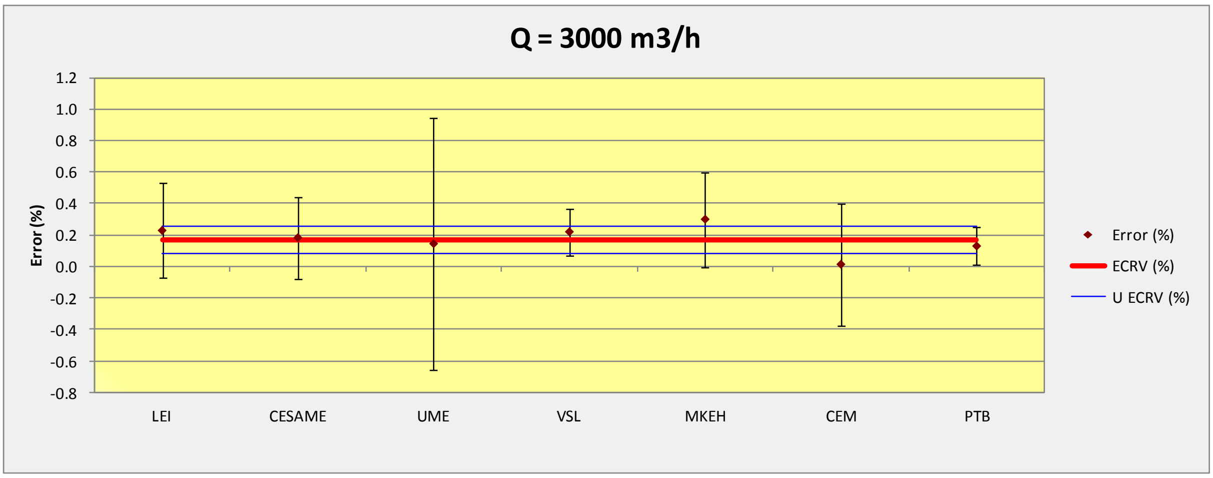
WME = y = 0.167

U(y) = 0.0883

χ^2_{obs} = 0.8967

CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.23	0.30	0.06	0.29	0.21
CESAME	0.18	0.26	0.02	0.25	0.06
UME	0.14	0.80	-0.02	0.80	0.03
VSL	0.22	0.15	0.05	0.12	0.44
MKEH	0.30	0.30	0.13	0.29	0.46
CEM	0.01	0.39	-0.15	0.38	0.40
PTB	0.13	0.12	-0.04	0.08	0.45



6.2.9 Flow rate 2000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.15	0.26	0.2775
UME	0.14	0.80	0.0182
VSL	0.13	0.15	0.3987
PTB	0.06	0.08	0.2785

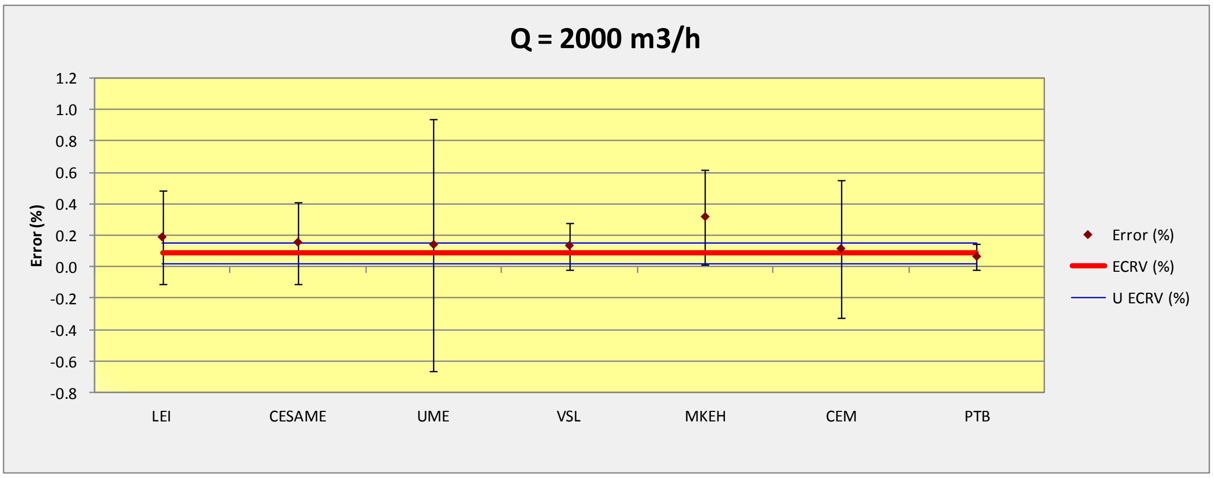
WME = y = 0.085

U(y) = 0.0695

χ^2_{obs} = 0.9729

CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.19	0.30	0.10	0.29	0.35
CESAME	0.15	0.26	0.07	0.25	0.27
UME	0.14	0.80	0.05	0.80	0.07
VSL	0.13	0.15	0.05	0.13	0.36
MKEH	0.32	0.30	0.23	0.30	0.78
CEM	0.11	0.44	0.03	0.43	0.06
PTB	0.06	0.08	-0.02	0.04	0.49



6.2.10 Flow rate 1000 m^3/h

Laboratory	Error (%)	U(error) (%)	(xi-y)^2/u2 --
CESAME	0.34	0.26	2.3510
UME	0.21	0.80	0.0372
VSL	0.03	0.15	1.8374
PTB	0.15	0.08	0.0554

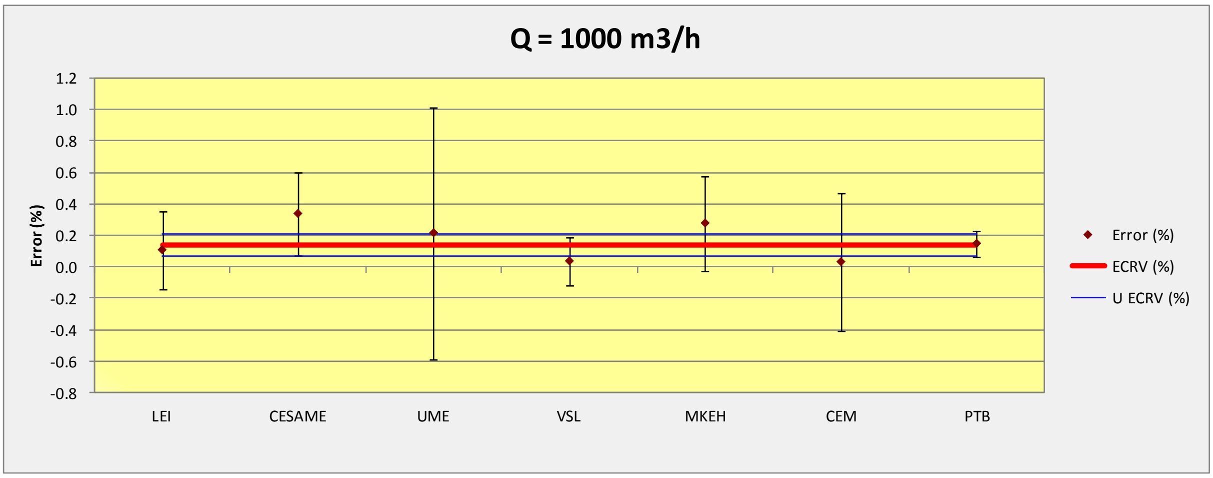
WME = y = 0.137

U(y) = 0.0690

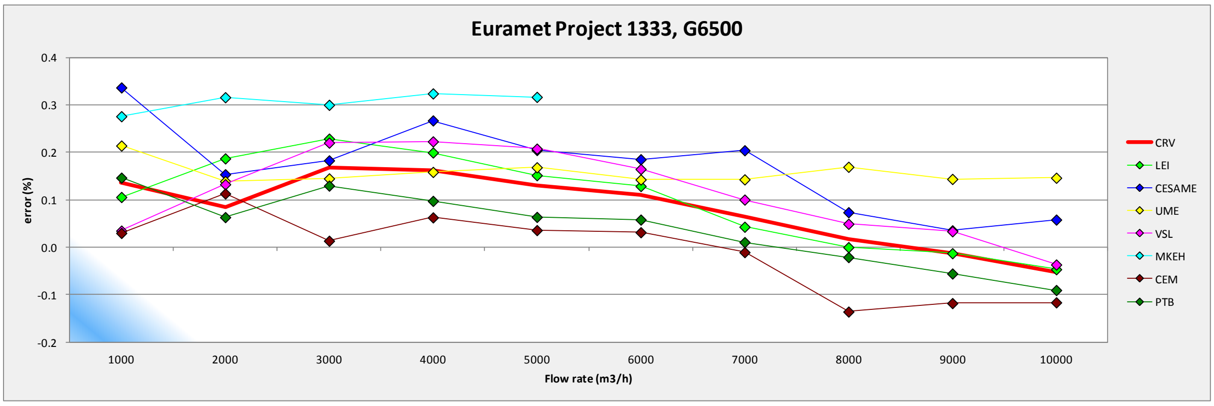
χ^2_{obs} = 4.2810

CHIINV = 7.8147

Laboratory	Error (%)	U(error) (%)	di (%)	U(di) (%)	Ei --
LEI	0.11	0.25	-0.03	0.24	0.13
CESAME	0.34	0.26	0.20	0.25	0.80
UME	0.21	0.80	0.08	0.80	0.10
VSL	0.03	0.15	-0.10	0.13	0.76
MKEH	0.28	0.30	0.14	0.30	0.47
CEM	0.03	0.44	-0.11	0.43	0.25
PTB	0.15	0.08	0.01	0.04	0.22



6.2.11 All results of the tests with the G6500



7 Conclusion

For the G2500 as well for the G6500 all results of the laboratories that contributed to the ECRV pass the ChiSquare-test.

Regarding the E_n-value two laboratories produced results with the G2500 that led to a 'Warning Level'. One laboratory has a 'warning level' for the 2000 m^3/h test point and both laboratories for the 1000 m^3/h test point.

The laboratories that have a "warning" with the results of the G2500 have E_n-values < 1 at 1000 m^3/h and 2000 m^3/h with the results of the G6500.

All laboratories except CEM used their CMC or a lower uncertainty as basis for the uncertainty calculation of the reference flow rate . Overall the results support the CMC claims of the participating laboratories. The results of the comparison support the uncertainty as reported by CEM.

8 References

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[2] Valeta, T., EURAMET project 1296, pilot CMI, final report can be found via http://www.euramet.org/technical-committees/search-tc-projects/details/?eurametCtcp_project_show[project]=1072&eurametCtcp_project[back]=250&cHash=396e0c9d91554c515b7fc53eab883b7f

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

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

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[6] Valeta, T., EURAMET project 1006, pilot CMI: Inter-laboratory calibration comparison of the turbine gas meter in flow rates from 1000 m^3/h to 10000 m^3/h http://www.euramet.org/technical-committees/search-tc-projects/details/?page%5BeurametCtcp_project_listTc%5D=2&eurametCtcp_project_show%5Bproject%5D=6&eurametCtcp_project%5Bback%5D=250&cHash=514a5819b5009bd0352cd3e04a296996