European Comparison of National Water Flow Laboratories

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Abstract: The results of supplementary comparison of European national water flow laboratories - Euramet 1046 - are reviewed. The comparison started in May 2008 and the measurements were finished in June 2009. Eleven laboratories took part in the comparison - namely: Austria (BEV), Bosnia and Herzegovina (IMBH), Czech Republic (CMI - pilot laboratory), France (CETIAT), Greece (EIM), Hungary (MKEH), Lithuania (VMT/LEI), Republic of Macedonia (BoM), Norway (Justervesenet), Slovakia (SMU) and Switzerland (METAS). Two electromagnetic flow-meters were used as transfer standards. Laboratories were compared in a range of flow-rates between 1 m^3/h and 10 m^3/h with water of temperature near to 20°C. The data were evaluated by the standard methods.

Keywords: Inter-laboratory comparisons, Water-flow laboratories

1. Introduction

Inter-laboratory comparisons are important tool for control of correctness of measurement process and uncertainty evaluation of calibration laboratories especially when we talk about primary national laboratories which are the first link in the traceability chain in a country. At the beginning of the year 2008 European national water flow laboratories were invited to take part in an inter-laboratory comparison which should verify their performance in the range of flowrates from 1 m^3/h to 10 m^3/h. The comparison was organized by Czech metrology institute within the Euramet organization as a project No. 1046. Cold water with temperature near to 20°C was used. Laboratories of eleven European countries finally decided to take part in the comparison – namely: Austria (BEV), Bosnia and Herzegovina (IMBH), Czech Republic (CMI - pilot laboratory), France (CETIAT), Greece (EIM), Hungary (MKEH), Lithuania (VMT/LEI), Republic of Macedonia (BoM), Norway (Justervesenet), Slovakia (SMU) and Switzerland (METAS). Two transfer standards – electromagnetic flow-meters Krohne – were circulated among the participants in a period of approximately one year. This article summarizes the results obtained.

2. Transfer standards

Two electromagnetic flowmeters Krohne IFM 5080K of the same parameters were used as the transfer standards (see Fig. 1). The meters belong to Austrian metrology institute BEV in Wien and were borowed by CMI for the purpose of the inter-laboratory comparison. The identical meters were used for a comparison project Euromet No. 669 organized by BEV in years 2002 – 2005.

The meters are denoted as No.857 and No.858 in the text according to their serial numbers. The inside nominal diameter of the meters is DN 25. Ceramic liner is used. The meters are equipped with fixed inlet and outlet straight pipe sections with lenth approximately 17D (inlet) and 11D (outlet) where D is the inner diameter of the meter. The active pulse output was used with the pulse frequency of 1 kHz at the flow rate of 10 m^3/h. Both meters were provided with a power supply stabilizer (see Fig. 1). During transports the meters were packed in wooden boxes depicted in Fig. 1.

Fig. 1 One of the transfer standards – electromagnetic flow-meter Krohne IFM 5080K – with fixed straight pipes and power supply stabilizer (left) and the transport boxes (right)

3. Test procedure and reporting the results of particular measurements

The participating laboratories used their usual calibration procedure, i.e. the procedure which they would use for example for a calibration of a meter for a customer.

Reference conditions was agreed to be (20 ± 5)°C for temperature of the test water and (2 ± 1) bar for the water pressure downstream of the meter. If the conductivity of water was below 200 μS/cm the participant was asked to declare this fact in the report. Even if some of the participants have not fulfilled these requirements the deviations was found not to be significant for the error curve of the meter as compared to the declared uncertainties of the error for particular laboratories.

Both of the transfer standards were examined separately under the same conditions. The use of the two identical meters allowed to do a Youden analysis of the results.

The errors of the meters were determined for five values of flow-rate: (1.0; 2.5; 5.0; 7.5; 10.0) m^3/h. The actual flow-rates were allowed to differ from these nominal values by 3 % at most. The measurement was repeated at least ten times for each flow-rate.

The participants were asked to minimize the flow velocity profile disturbances by appropriate installation of the meter and to include a description of the additional straight pipes and flow conditioners in the report.

Each participant filled a table of results where for each of the nominal flow-rates and for each of the meters the following data were reported: 1) mean, maximal and minimal actual flow-rate, 2) mean relative error of the meter, 3) number of repetitions, 4) mean test volume, 5) mean water temperature, 6) mean water pressure downstream of the meter, 7) type A expanded uncertainty of the error (repeatability) with level of confidence of 95 %, 8) expanded uncertainty of the reference flow-rate value with level of confidence of 95 %. Furthermore information about the ambient conditions, description of the test facility and the test procedure and uncertainty budget were obtained from each of the participants.

4. Results

4.1 Stability measurements

Each laboratory had two weeks for the measurements and sending the transfer standards to the following participant. The final time of the comparison was almost one year due to some complications with the customs documents. The transfer standards have been tested six times in the pilot laboratory during the time of the comparison to get an idea about the long time stability of the meters. The results of the six measurements at CMI are summarized in the graphs Fig. 2.

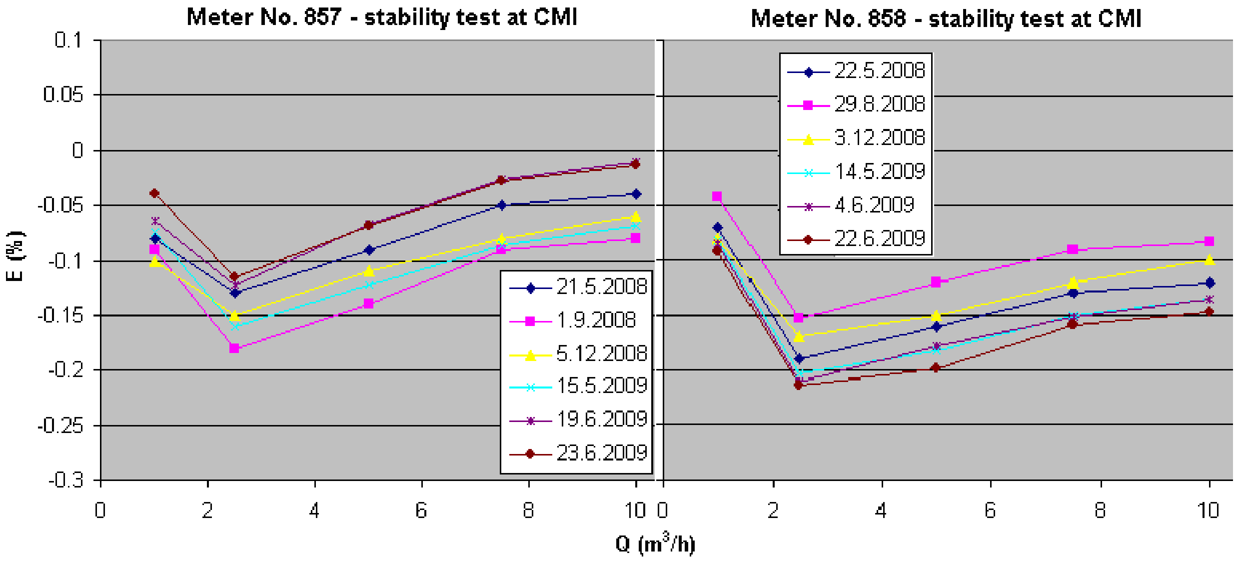

Fig. 2 Results of the repeated measurements at the pilot laboratory during the comparison

If the uniform distribution of the data between the minimal and the maximal value of error is supposed for each flow-rate the standard uncertainty of the meters due to the long time instability u_{st} is calculated according to the formula

$$u_{st} = \frac{(E_{\max} - E_{\min})}{2\sqrt{3}} \,. \qquad (1)$$

In general this uncertainty includes influences of the test rig instability, meter instability and installation effects. In order to separate the test rig instability which should not be included in u_{st} we checked the correlation of the data from both of the meters. No significant influence of the test rig of CMI to the scatter of the data was found. This can be seen e.g. in Youden plot Fig. 3 where the points are distributed along the $x = -y$ diagonal indicating no correlation of the data from the two meters which would be caused by the test rig performance variations. Thus u_{st} is considered to express the meter instability and installation effects only.
The resulting values of u_{st} are summarized in table 1. The values obtained here are comparable to the values (0.015 – 0.03) % obtained by professor Adunka for a standard deviation contribution due to an installation effects during the inter-laboratory comparison Euromet No.669 where the same meters were used [1].

Table. 1 The values of u_{st}

	Meter No.857					Meter No.858				
Q (m^3/h)	1	2.5	5	7.5	10	1	2.5	5	7.5	10
u_{st} (%)	0.017	0.018	0.020	0.020	0.020	0.015	0.018	0.022	0.020	0.019

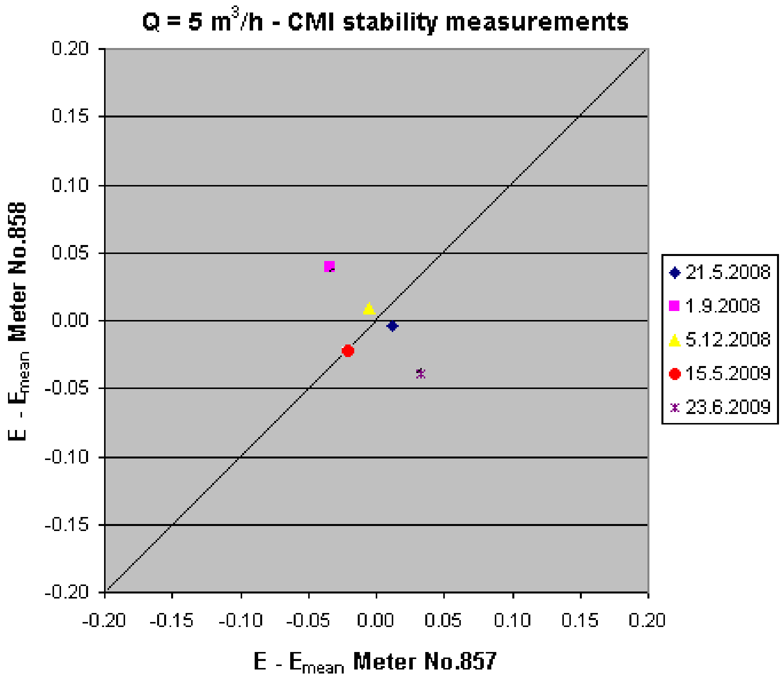

Fig. 3 Youden plot for the repeated measurements in pilot laboratory for Q = 5 m^3/h. This result is quite representative also for the other flow-rates.

4.2 Results of the particular laboratories and their evaluation

The error curves of the meters for all the participating laboratories are summarized in Fig. 4. The errors with uncertainties and reference values are summarized in table 2. The uncertainty U(E) in the table 2 is the expanded uncertainty of the error with confidence level of 95 % as declared by the particular laboratory. This value does not contain any information about variation of the error due to the long time instability of the meters as well as about differences in installations in various labs and therefore possible variations of the error due to the flow profile changes. If the flow profile is more or less developed in all laboratories and the changes of flow profile are given only by imperfections in mounting of the meter then the additional uncertainty covering these effects is assumed to be estimated by u_{st} as given by the formula (1). This uncertainty should be added to the original one if the resulting errors are to be compared. The total standard uncertainty of the *i*-th laboratory was then calculated as

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

where x_i denotes the error of the i-th laboratory for given flow-rate. The values $U(E)_{st}$ in table 2 are calculated as twice the value of u_{xi} given by the formula (2).
The comparison reference value (CRV) was determined according to Cox [2, 3]. The weighted mean was calculated as

$$y = \frac{\dfrac{x_1}{u_{x1}^2} + \dfrac{x_2}{u_{x2}^2} + \ldots\ldots\ldots \dfrac{x_n}{u_{xn}^2}}{\dfrac{1}{u_{x1}^2} + \dfrac{1}{u_{x2}^2} + \ldots\ldots\ldots \dfrac{1}{u_{xn}^2}} \qquad (3)$$

and then the best largest consistent subset of laboratories was found. Consistent means that the subset satisfies the chi-square test condition $\Pr(\chi^2(\nu) > \chi^2_{obs}) \geq 0.05$, largest means that it includes the highest possible number of participants and best means that if there is more than one largest consistent subsets then the one is chosen with the smallest value of χ^2_{obs}. For details see Cox [2,3].
The values of the weighted mean for all the participants (y_{all}) as well as for the best largest consistent subset (y_{blcs}) are included in the table 2. The laboratories excluded to obtain the best largest consistent subset are mentioned in the line “blcs without”. Values of standard uncertainties of y and values of χ^2_{obs} and $\Pr(\chi^2(\nu) > \chi^2_{obs})$ are also included. The value of y_{blcs} is considered to be the comparison reference value (also denoted as x_{ref}).
The CRV was calculated alternatively also by the method described as procedure B in [2] just to have a possibility to compare. Here the median of errors of all the participants was calculated and treated by the Monte Carlo methods.

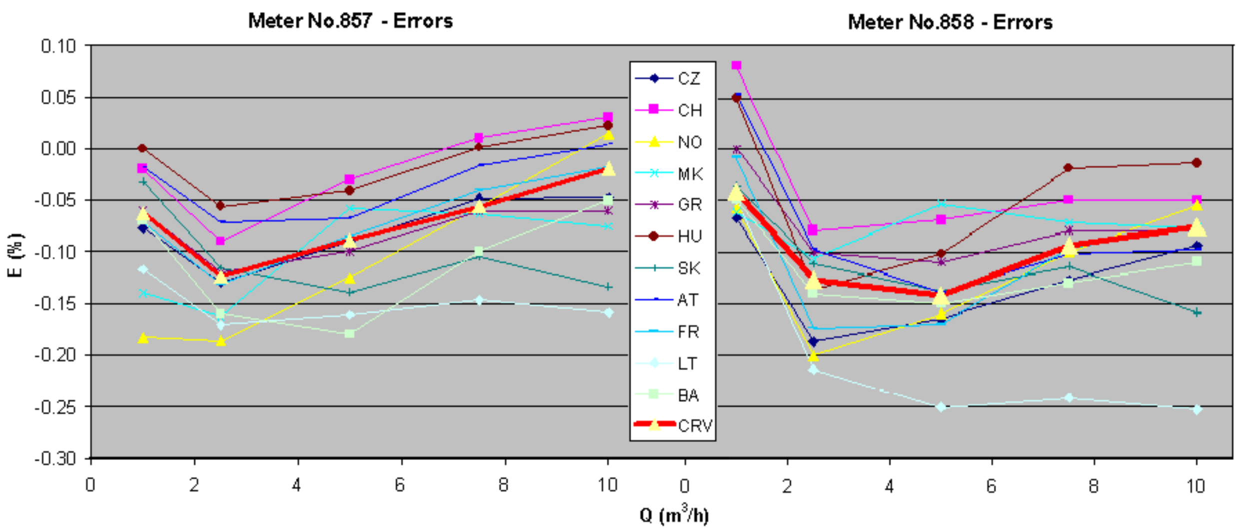

Fig. 4 Error curves of particular laboratories and calculated comparison reference value (CRV)

In the graph Fig. 4 the errors are plotted as a function of nominal flow-rate. The differences in errors caused by the deviations of the actual flow-rate from the nominal flow-rate were mostly evaluated as negligible. The only case where this difference could be significant is the lowest flow-rate for meter No. 857 in Norway. Here the derivative of the real error curve can be large and the error of Norway for the nominal flow-rate of 1 m^3/h could be nearer to CRV in 1 m^3/h then the error for the actual flow-rate of 1.27 m^3/h. However, the error of Norway was not used for calculation of CRV in this case.

		Meter No.857					Meter No.858				
	Q (m^3/h)	1	2.5	5	7.5	10	1	2.5	5	7.5	10
Czechia	**E (%)**	**-0.077**	**-0.130**	**-0.090**	**-0.048**	**-0.047**	**-0.068**	**-0.186**	**-0.164**	**-0.127**	**-0.094**
	U(E) (%)	0.070	0.070	0.070	0.070	0.075	0.067	0.070	0.070	0.070	0.075
	$U(E)_{st}$ (%)	0.078	0.079	0.081	0.080	0.085	0.073	0.078	0.083	0.080	0.084
Switzerland	**E (%)**	**-0.02**	**-0.09**	**-0.03**	**0.01**	**0.03**	**0.08**	**-0.08**	**-0.07**	**-0.05**	**-0.05**
	U(E) (%)	0.050	0.051	0.051	0.051	0.051	0.052	0.051	0.051	0.051	0.051
	$U(E)_{st}$ (%)	0.061	0.063	0.065	0.065	0.065	0.060	0.062	0.068	0.064	0.063
Norway	**E (%)**	**-0.183**	**-0.186**	**-0.125**	**-0.057**	**0.014**	**-0.058**	**-0.200**	**-0.159**	**-0.100**	**-0.055**
	U(E) (%)	0.015	0.009	0.008	0.010	0.009	0.029	0.009	0.008	0.009	0.010
	$U(E)_{st}$ (%)	0.038	0.038	0.041	0.041	0.041	0.041	0.037	0.046	0.040	0.039
Macedonia	**E (%)**	**-0.140**	**-0.163**	**-0.058**	**-0.063**	**-0.075**	**-0.062**	**-0.107**	**-0.054**	**-0.072**	**-0.077**
	U(E) (%)	0.050	0.049	0.052	0.053	0.053	0.052	0.050	0.050	0.053	0.052
	$U(E)_{st}$ (%)	0.061	0.061	0.066	0.066	0.066	0.060	0.061	0.067	0.066	0.064
Greece	**E (%)**	**-0.06**	**-0.12**	**-0.10**	**-0.06**	**-0.06**	**0.00**	**-0.10**	**-0.11**	**-0.08**	**-0.08**
	U(E) (%)	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
	$U(E)_{st}$ (%)	0.071	0.072	0.074	0.074	0.074	0.069	0.071	0.077	0.073	0.072
Hungary	**E (%)**	**0.000**	**-0.056**	**-0.041**	**0.001**	**0.022**	**0.050**	**-0.136**	**-0.102**	**-0.020**	**-0.015**
	U(E) (%)	0.072	0.071	0.070	0.071	0.070	0.071	0.071	0.071	0.070	0.070
	$U(E)_{st}$ (%)	0.080	0.080	0.081	0.081	0.081	0.077	0.079	0.084	0.080	0.079
Slovakia	**E (%)**	**-0.032**	**-0.116**	**-0.139**	**-0.105**	**-0.134**	**-0.036**	**-0.112**	**-0.138**	**-0.114**	**-0.158**
	U(E) (%)	0.124	0.152	0.185	0.139	0.117	0.120	0.150	0.186	0.142	0.117
	$U(E)_{st}$ (%)	0.129	0.156	0.189	0.145	0.124	0.123	0.154	0.191	0.147	0.123
Austria	**E (%)**	**-0.018**	**-0.071**	**-0.067**	**-0.016**	**0.004**	**0.054**	**-0.098**	**-0.139**	**-0.102**	**-0.098**
	U(E) (%)	0.054	0.052	0.052	0.052	0.052	0.053	0.051	0.052	0.052	0.052
	$U(E)_{st}$ (%)	0.064	0.064	0.066	0.065	0.065	0.060	0.062	0.069	0.065	0.064
France	**E (%)**	**-0.071**	**-0.132**	**-0.085**	**-0.040**	**-0.018**	**-0.010**	**-0.173**	**-0.169**	**-0.097**	**-0.076**
	U(E) (%)	0.103	0.101	0.101	0.101	0.101	0.106	0.101	0.101	0.100	0.100
	$U(E)_{st}$ (%)	0.109	0.108	0.109	0.109	0.109	0.110	0.107	0.111	0.107	0.107
Lithuania	**E (%)**	**-0.117**	**-0.171**	**-0.161**	**-0.147**	**-0.159**	**-0.050**	**-0.213**	**-0.251**	**-0.241**	**-0.253**
	U(E) (%)	0.088	0.084	0.084	0.082	0.082	0.085	0.086	0.087	0.086	0.085
	$U(E)_{st}$ (%)	0.095	0.092	0.093	0.091	0.091	0.090	0.093	0.098	0.095	0.093
Bosnia	**E (%)**	**-0.07**	**-0.16**	**-0.18**	**-0.10**	**-0.05**	**-0.05**	**-0.14**	**-0.15**	**-0.13**	**-0.11**
	U(E) (%)	0.028	0.030	0.022	0.023	0.033	0.026	0.030	0.019	0.024	0.026
	$U(E)_{st}$ (%)	0.045	0.048	0.046	0.046	0.052	0.039	0.046	0.049	0.046	0.046
y_{all} (%)		-0.093	-0.140	-0.106	-0.056	-0.026	-0.021	-0.147	-0.134	-0.100	-0.084
$u(y_{all})$ (%)		0.010	0.010	0.010	0.010	0.010	0.009	0.010	0.011	0.010	0.010
$\chi^2_{obs,all}$		45.19	19.67	24.96	15.96	24.85	30.93	22.59	18.49	18.49	22.73
$Pr(\chi^2(\nu)>\chi^2_{obs,all})$ (%)		0.00	3.25	0.54	10.09	0.56	0.06	1.24	4.72	4.73	1.18
blcs without		NO	NO	BA		LT	CH, A	NO	MK	LT	LT
y_{blcs} (%) (=CRV=x_{ref})		**-0.062**	**-0.124**	**-0.089**	**-0.056**	**-0.019**	**-0.041**	**-0.127**	**-0.142**	**-0.094**	**-0.076**
$u(y_{blcs})$ (%)		0.011	0.011	0.011	0.010	0.010	0.010	0.011	0.011	0.010	0.010
$\chi^2_{obs,blcs}$		14.65	11.83	11.99	15.96	15.88	9.36	10.98	12.25	9.20	8.88
$Pr(\chi^2(\nu)>\chi^2_{obs,blcs})$ (%)		10.10	22.28	21.39	10.09	6.94	31.31	27.69	19.94	41.91	44.82
$y_{procedureB}$ (%)		-0.066	-0.131	-0.093	-0.054	-0.035	-0.025	-0.137	-0.137	-0.097	-0.085
$u(y_{procedureB})$ (%)		0.018	0.019	0.019	0.016	0.019	0.019	0.018	0.017	0.016	0.016

Table. 2 Errors, uncertainties and reference values obtained by two methods

4.3 Degrees of equivalence

To compare the laboratories with the reference value and with each other the degrees of equivalence were calculated according to the following formulas

$$E_i = \left| \frac{x_i - x_{ref}}{2u(x_i - x_{ref})} \right|, \qquad E_{ij} = \left| \frac{x_i - x_j}{2u(x_i - x_j)} \right|, \tag{4}$$

where the standard uncertainties $u(x_i - x_{ref})$ and $u(x_i - x_j)$ are given e.g. in [2]. The degrees of equivalence are a measure for the equivalence of the results of any laboratory with the CRV or with any other laboratory, respectively. $Ei \leq 1$ means that i-th laboratory is in good agreement with CRV and $Eij \leq 1$ means that i-th and j-th laboratory are in good agreement. The "lab to CRV" equivalence degrees E_i are summarized in table 3. The tables with "lab to lab" equivalence degrees E_{ij} are included e.g. in [4] and are out of the space capacity of this paper.

Table. 3 Summary of "lab to CRV" equivalence degrees.

		Meter No.857					Meter No.858				
	Q (m³/h)	1	2.5	5	7.5	10	1	2.5	5	7.5	10
Czechia	E_1	0.20	0.08	0.02	0.11	0.34	0.38	0.78	0.27	0.43	0.22
Switzerland	E_2	0.75	0.58	0.97	1.08	0.80	1.93	0.81	1.13	0.71	0.44
Norway	E_3	2.76	1.40	1.06	0.02	0.94	0.47	1.70	0.42	0.18	0.64
Macedonia	E_4	1.37	0.68	0.50	0.11	0.89	0.37	0.35	1.25	0.34	0.01
Greece	E_5	0.03	0.06	0.16	0.05	0.58	0.63	0.40	0.44	0.19	0.05
Hungary	E_6	0.81	0.89	0.62	0.73	0.53	1.24	0.12	0.50	0.95	0.80
Slovakia	E_7	0.24	0.05	0.27	0.34	0.94	0.04	0.10	0.02	0.14	0.67
Austria	E_8	0.73	0.89	0.35	0.65	0.37	1.49	0.50	0.05	0.14	0.36
France	E_9	0.08	0.08	0.04	0.15	0.01	0.29	0.44	0.25	0.03	0.00
Lithuania	E_{10}	0.60	0.53	0.80	1.02	1.50	0.10	0.95	1.14	1.52	1.86
Bosnia	E_{11}	0.20	0.86	1.80	1.06	0.66	0.26	0.32	0.18	0.88	0.82

5. Conclusion

The results of measurement of eleven European water flow laboratories were evaluated by standard methods following the works of Cox. The weighted mean of errors of the laboratories included in the best largest consistent subset was used as the reference value for each flow-rate. The consistency of the results in the sense of chi-square test was satisfactory – mostly only one laboratory of the total number of eleven had to be excluded to obtain the consistent set. Only for one flow-rate and for one of the transfer standards it was two laboratories. The table of the "lab to CRV" equivalence degrees together with the data obtained in particular laboratories indicates however that at least one laboratory will have to review the uncertainty calculation and another one maybe the measurement process. Further details on the comparison can be found in [4].

Acknowledgment

Thanks belong to all the participants of the comparison for their responsible work.

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