

# Results of CCM and EURAMET Comparisons of Primary Standards of Low Pressure Gas Flow

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## Abstract

A key comparison of the gas flow standards of the National Institutes of Metrology was conducted from December 2010 to December 2012. A rotary gas meter type Delta S-Flow G 65 was selected as transfer standard. Laboratories were compared in low pressure gas flow in the range (2 – 100) m<sup>3</sup>/h. Eleven NMIs took part in this key comparison and the KCRV was determined. The results demonstrated degrees of equivalence to the KCRV.

EURAMET comparison were organised simultaneously with the same transfer standard. Sixteen NMIs took part in this regional comparison. Regional reference value was determined also as link to the key comparison.

The presentation reports information about results in comparisons CCM.FF-K6.2011 and EURAMET No.1180.

## Key comparison

A key comparison of standards of the National Institutes of Metrology was conducted from December 2010 to December 2012. Laboratories were compared in low pressure gas flow in the range (2 – 100) m<sup>3</sup>/h. This measurement range is a base for traceability chain for low pressure gas meters and presents enlargement of key comparison CCM.FF-K6 from 2005-2006 with flow range (2 -13) m<sup>3</sup>/h. Eleven independent NMIs took part in this key comparison: **EURAMET**: Germany, Slovakia, France; **SIM**: USA, Mexico; **APMP**: Japan, Korea, China, Australia, Chinese Taipei (Taiwan); **COOMET**: Ukraine.

Equipments of NMIs used in comparison: bell provers, Venturi nozzles and sonic nozzles.

A rotary gas meter type Delta S-Flow G 65 (Fig. 1) was selected as a transfer standard.

## Stability of the transfer standard

The stability of the transfer standard was checked before starting the comparison by LNE-LADG France and during the comparison by the pilot laboratory – SMU Slovakia.

The temperature sensitivity of the transfer standard was checked by PTB Germany. For temperature differences

of  $\pm 10$  °C the meter sensitivity does not exceed  $\pm 0.05$  %. Since the minimum and maximum of temperatures in the laboratories were in the range (18,15 to 23,94) °C, the temperature sensitivity of the transfer standard will introduce lab to lab difference ( $< 0.03$  %). This uncertainty component is negligible compared to the transfer standard long term calibration stability. Therefore, no temperature corrections were made to the data submitted by the participating laboratories.



Figure 1 – Rotary gas meter Actaris Delta S-Flow

## Uncertainty of the corrections and stability of the transfer standard

The standard uncertainties (not expanded) of the error in different laboratories  $u_{x1}, u_{x2}, \dots, u_{xm}$  included the stability of the transfer standard. These uncertainties were calculated by

$$u_{xi} = \sqrt{\left(\frac{U(x_i)}{2}\right)^2 + u_{st}^2} \quad (1)$$

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 standard uncertainty caused by the stability (reproducibility) of the transfer standard.

The transfer standard was tested seven times in the pilot laboratory and from these results  $u_{st}$  was determined. A maximum error of 0,09 % was found during the experiments ( $E_{exp}$ ).

$$u_{st} = \sqrt{\left(\frac{E_{exp}}{2\sqrt{3}}\right)^2} = 0,03 \text{ \%} \quad (2)$$

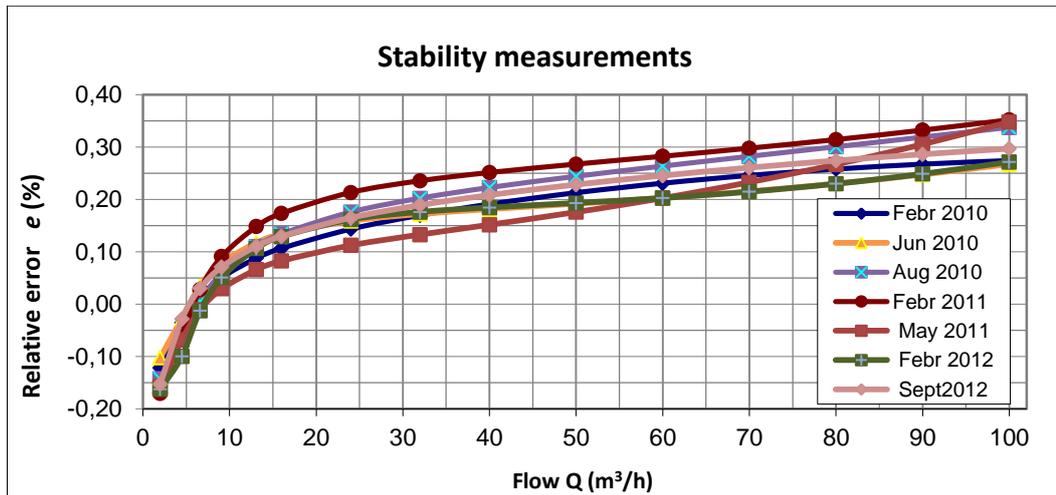


Figure 2. Stability of the transfer standard

### Measurement and ambient conditions

The measured range was (2 - 100) m<sup>3</sup>/h. If the same laboratory was not able to cover the whole flow range they could make measurements in a part of the flow range.

The transfer standard was tested in horizontal position by air near barometric pressure.

The reference pressure from the transfer standard was measured from the output “Pm” (pressure tap located at the outlet of the meter).

The second pressure point to determine the pressure loss of the transfer standard was defined at the inlet of the meter.

The reference temperature from transfer standard should be measured upstream of the transfer standard (Figure 3).

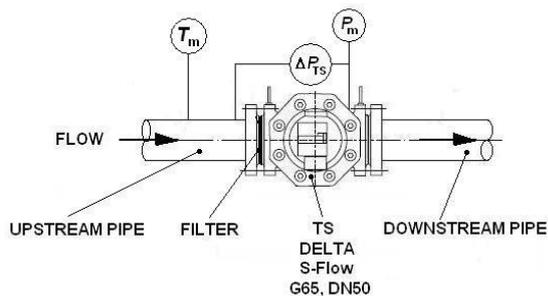


Figure 3. Recommended installation of the meter

It was necessary to use the pulse transmitter. There was no lubrication of the meter.

Reference conditions:

- the calibration medium was air,
- air temperature: (20 ± 5) °C,
- ambient relative humidity range: 25 % to 75 %,
- ambient atmospheric pressure range: 86 kPa to 106 kPa (0,86 bar to 1,06 bar).

The flow had to be in the interval ± 3 % of the required value.

Points of flow : (2; 4,5; 6,6; 9,1; 13,1; 16; 24; 32; 40; 50; 60; 70; 80; 90; 100) m<sup>3</sup>/h.

### Laboratory results

Relative errors of the transfer standard obtained by participating laboratories are summarized in Fig. 4. Uncertainty values of the participating laboratories are stated in [1].

### Evaluation of key comparison

The reference value was determined in each flow separately. The method of determination of the reference value in each flow was corresponded to the procedure A presented by Cox [3]. All laboratories reported their independence, so all results were taken into account for the determination of the key comparison reference value (KCRV) and of the uncertainty of the key comparison reference value.

The determination of the KCRV based on the independent laboratories includes a consistency check according to [3]. If there are reported results with inconsistency then the concept of largest consistent subset explained by Cox [4] was applied.

The determination of the KCRV and its uncertainty, differences “Lab to KCRV” and “Lab to Lab” are given in [1]. Values of the KCRV are in Fig. 6.

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

$$d_i = e_i - e_{ref} \quad (3)$$

and differences between the participating laboratories

$$d_{ij} = e_i - e_j \quad (4)$$

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

$$En_i = \left| \frac{d_i}{U(d_i)} \right| \quad (5)$$

and

$$En_{ij} = \left| \frac{d_{ij}}{U(d_{ij})} \right| \quad (6)$$

respectively.

The degree of equivalence with the KCRV is a measure for the equivalence of the results of each participating laboratory with the KCRV.  $En_i \leq 1$  means that  $i$ -th laboratory is in good agreement with KCRV and  $En_i > 1$  means that  $i$ -th laboratory is not in a good agreement.

## **EURAMET comparison**

EURAMET No. 1180 comparison was organised simultaneously with the key comparison CCM.FF-K6.2011 with the same transfer standard and was conducted from February 2010 to June 2011. The laboratories were compared in low pressure gas flow in the range (2 – 100) m<sup>3</sup>/h. Sixteen NMIs took part in this regional comparison: Germany, Slovakia, France, Spain, Netherlands, Czech Republic, Austria, Poland, Hungary, Sweden, Switzerland, Republic of Serbia, Turkey, Greece, Croatia and Bosnia-Herzegovina. Ten of these laboratories were independent.

Equipments of NMIs used in comparison: bell provers, Venturi nozzles, static weighing system, wet drum meter, rotary piston meter, volumetric device on a positive displacement principle, laminar flow element, rotary gas meter and turbine gas meter.

### **Stability of the transfer standard**

The stability of the transfer standard was checked before starting the comparison by LNE-LADG France and seven times during the comparison by the pilot laboratory – SMU Slovakia and it is described in the part for CCM.FF-K6.2011 comparison.

### **Evaluation of EURAMET comparison**

The EURAMET reference value (ECRV) was determined in each flow separately. The method of determination of this reference value in each flow was correspond to the procedure A presented by Cox [3]. Only results from independent laboratories was taken into an account for the determination of the ECRV and of the uncertainty of ECRV. Then the results from dependent laboratories was compared with the ECRV and with the uncertainty of the ECRV.

The determination of the ECRV based on the independent laboratories includes a consistency check according to [3]. All independent laboratories were succeed in the consistency check.

Determination of the ECRV and its uncertainty, differences “Lab to ECRV” and “Lab to Lab” are given in [2].

## **Link EURAMET to CCM**

Key comparisons CCM.FF-K6 was performed simultaneously with EURAMET No. 1180 in years 2010 and 2012.

The linking procedure and its uncertainty analysis is based on the principles which are given in the papers of Elster et al. [5], Kharitonov et al. [6] and Decker et al. [7].

The EURAMET No. 1180 can be linked to the CCM.FF-K6 by correction the results of three link laboratories with the following procedure. These results are plotted in Fig. 3 with the KCRV. The results from Euramet comparison (ECRV) are corrected by the procedure described by Delahaye and Witt [8].

A correction, which should be applied to the result from ECRV, was obtained by equation:

$$D = \sum_{i=1}^3 w_i D_i \quad (7)$$

where  $D_i$  is the difference between the results from CCM key comparison and EURAMET comparison at a same link laboratory (SMU, PTB, LNE-LADG) as presented by equation (8), and  $w_i$  is the weighing coefficient obtained from the uncertainty at each link laboratory as presented by equation (9).

$$D_i = e_{i,CCM} - e_{i,EURAMET} \quad (8)$$

$$w_i = \frac{\frac{1}{u_i^2}}{\frac{1}{u_{SMU}^2} + \frac{1}{u_{PTB}^2} + \frac{1}{u_{LNE}^2}} \quad (9)$$

Finally, corrected value  $e'_i$  for each participant of EURAMET comparison was calculated as:

$$e'_i = e_{i,EURAMET} + D \quad (10)$$

This correction provides an estimate of what would have been the result from the EURAMET comparison participants, if they had actually participated in CCM key comparison.

## **Degree of Equivalence to KCRV**

For each participating laboratory, the degree of equivalence (*DoE*) was calculated using a following equation.

$$d_i = e'_i - e_{KCRV} = e_{i,EURAMET} + D - e_{KCRV} \quad (11)$$

where

$$e_{KCRV} = \sum_{i=1}^n w_i e_i \quad (12)$$

The expanded uncertainty was obtained using following equations.

## References

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- [8] F. Delahaye and T.J. Witt, “Linking the results of key comparison CCEM-K4 with 10 pF results of EUROMET.EM-K4”, *Metrologia*, Vol. 39, Technical Supplement 01005, 2002.

$$U(d_i) = 2u(d_i) \quad (13)$$

$$u^2(d_i) = u^2(e_i) + u^2(D) + u^2(e_{KCRV}) \quad (14)$$

### Degree of Equivalence between participants

For each combination of two participating laboratories, the DoE was calculating using following equations.

$$d_{ij} = e'_i - e'_j \quad (15)$$

The expanded uncertainty was obtained using following equations.

$$U(d_{ij}) = 2u(d_{ij}) \quad (16)$$

$$u^2(d_i) = u^2(e_i) + u^2(e_j) \quad (17)$$

### Summary

27 countries, including 11 countries in the CCM.FF-K6 and 16 countries in the EURAMET No. 1180 were participating in the comparisons running simultaneous, while 3 states participated in both comparisons. The results showed a very good reproducibility of the transfer standard and also high level of measurement in the participating laboratories. According to the preliminary evaluation 98% results passed in the CCM.FF-K6 and 94 % results passed in the EURAMET No. 1180.

The results of the CCM has served for determination of the KCRV and EURAMET results for the relationship to KCRV. Proposal linking and its implementation will unify the value of regional comparisons with the values of the key comparison.

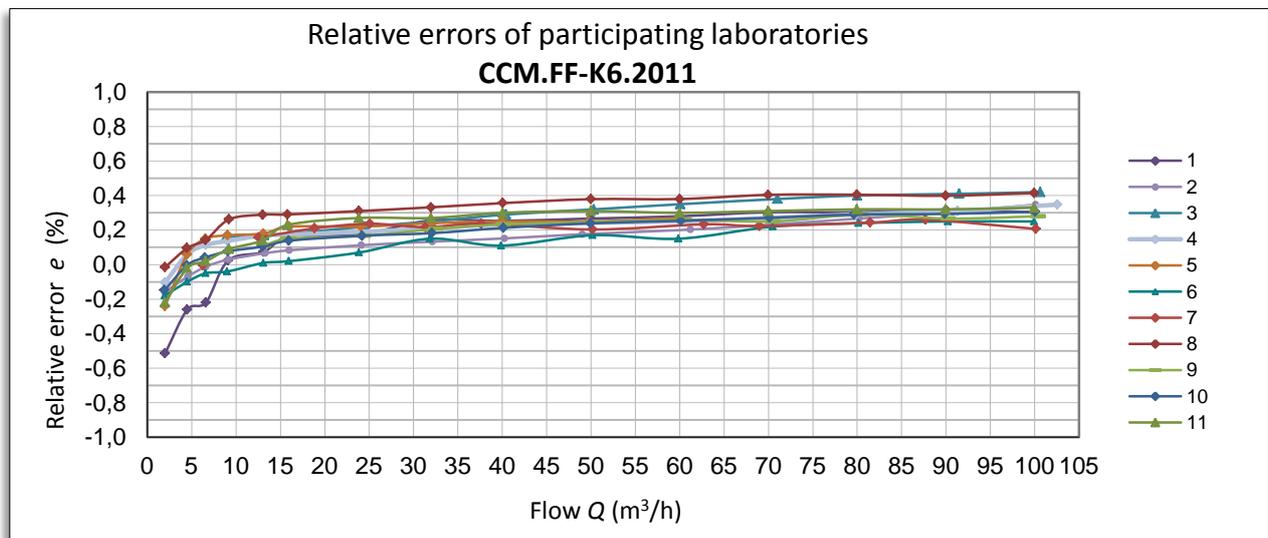


Figure 4 Relative errors of the participating laboratories CCM.FF-K6.2011

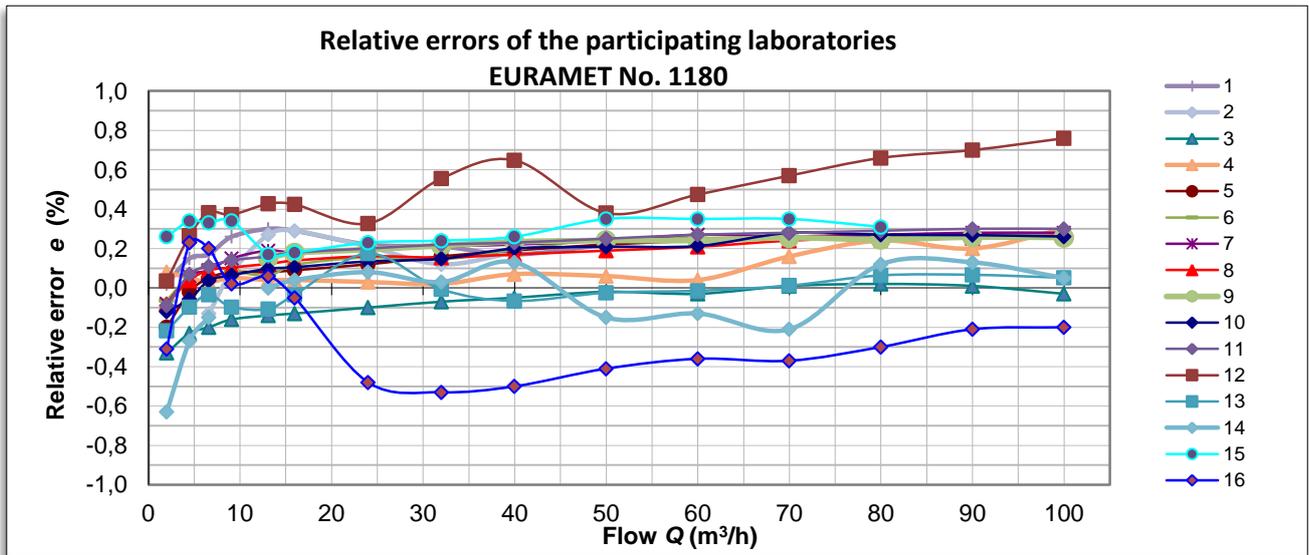


Figure 5 Relative errors of the participating laboratories EURAMET No. 1180

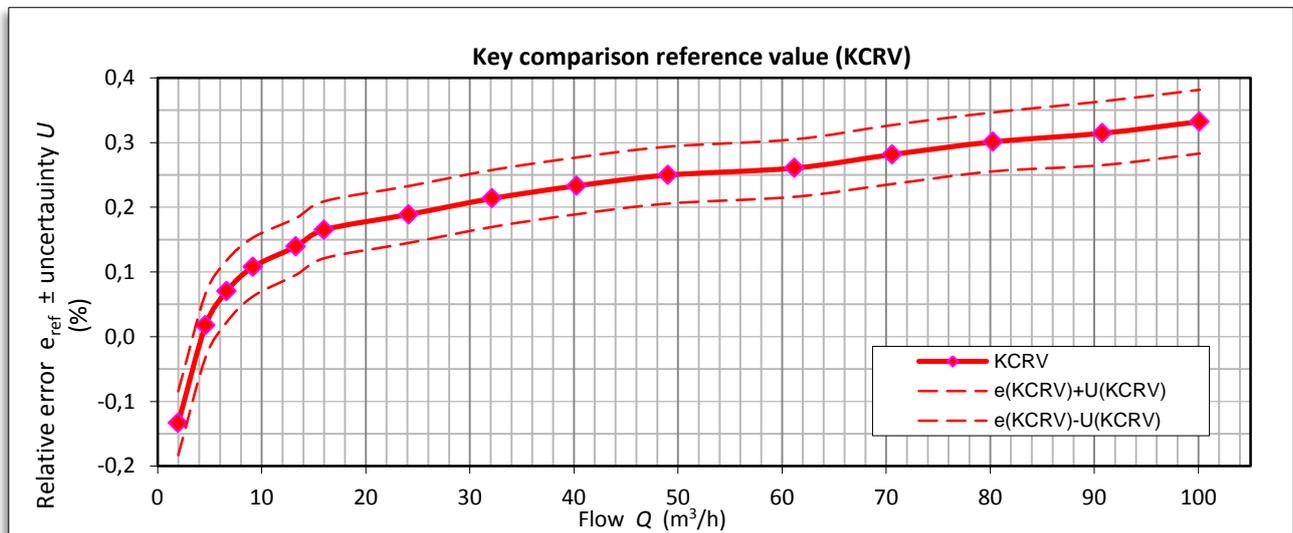


Figure 6 Key comparison reference value (KCRV)