Final Report

Evaluation of a comparison between PTB and NEL in water flow rates from 30 m³/h to 180 m³/h

EURAMET Project No. E 1201

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1. INTRUDUCTION

The only way to quantify the equivalence of the water flow measurement standards maintained in the world's National Metrology Institutes (NMIs) is by performing key comparisons (KCs), in which participating NMIs can compare their performance through their calibration data.

The quality of the KC is highly correlated with the behaviour of transfer standards to different installation effects, operating conditions, etc.

The purpose of this bilateral comparison is to find the best available transfer standard for the upcoming KC of the water flow measurement standards (CCM.FF-K1.2015). Therefore, the performance of the three different flowmeters in two different facilities was compared, in order to realize if these flowmeters are suitable as transfer standards for the KC. A turbine and two coriolis flowmeters were used in this project. Each country performed the calibration using their regular calibration procedure.

PTB was the pilot laboratory for this bilateral comparison, due to the fact that PTB also serve as a pilot laboratory for the key comparison CCM.FF-K1.2015.

Additionally, the CMC entrance of both facilities were investigated by a comparison of the used meters.

Table 1: Time schedule

Country	Laboratory	Address of the Place of calibration	Calibration periods	Responsible
Germany	PTB Physikalisch-Technische Bundesanstalt	PTB Bundesallee 100 38116 Braunschweig Germany	02/2012 until 04/2012 05/2012 until 06/2012 03/2013 until 05/2013	Rainer Engel
United Kingdom	NEL National Engineering Laboratory	NEL Scottish Enterprise Technology Park East Kilbride GLASGOW G75 0QF United Kingdom	04/2012	Richard Paton

2. THE INSTRUMENT

The transfer standard package (TSP) used in this bilateral comparison (see *Fig. 1*) was composed of a KEM **turbine flow meter** (model HM 100.71.FDB040-TS15-P), in conjunction with an Endress+Hauser **coriolis flow meter** (model PROMASS 83 F1-H) and respectively, with a Rota-Yokogawa **coriolis flow meter** (model ROTA MASS_MASSFLOW METER RCCS39/IR-L/K5/Z) and 3 pipe units (DIN flanges: DN 100, PN 10). The package was 100 mm in diameter and 4,96 m long.

The TSP was operated in following configuration: the turbine flow meter (TM) was placed upstream of the coriolis flow meter (CM). The presence of two flow meters at all times guarded against possible malfunction of the transfer standard.

The description of these meters (*Figure 1*) is given in *Table 2*.

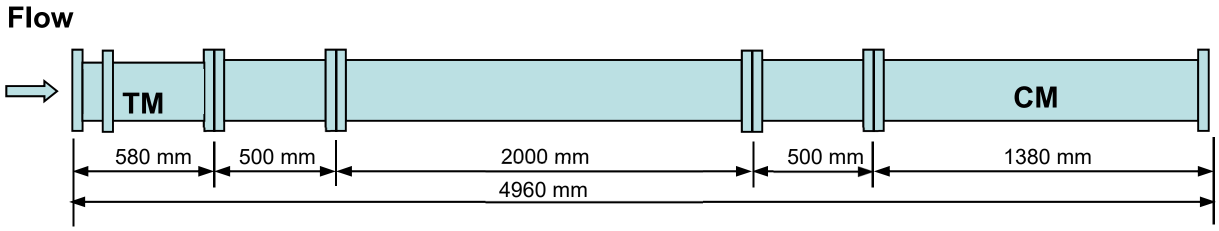

Figure 1: Schematic of transfer standard package (flow from left to right)

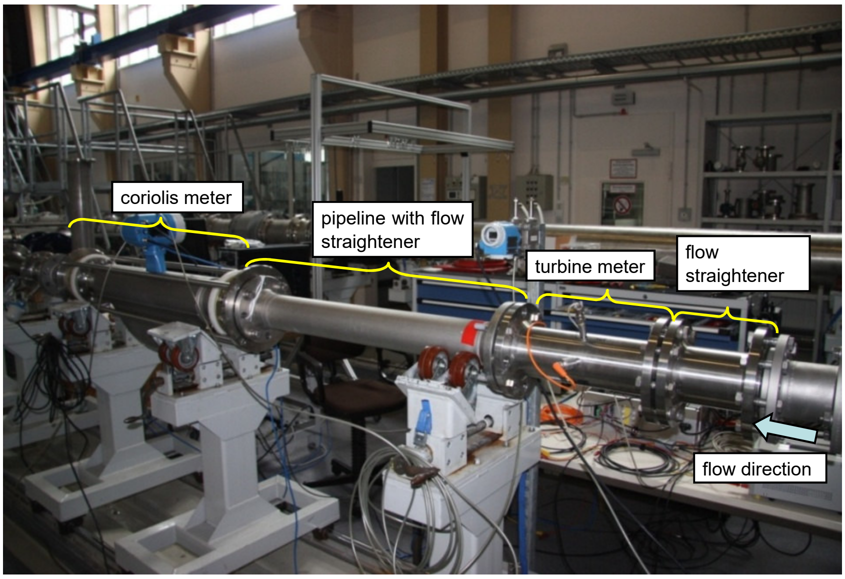

Figure 2: View on the transfer standard package at PTB test field (setup in May 2013)

Table 2: Description of the meters

Meter #1: Turbine meter	
Manufacturer: KEM Küppers Elektromechanik GmbH, Germany	
Type: HM 100.71 FDE040	Signal output: pulses / frequency
Size: DN 100	K-factor: 6.633 pulses/litre
Serial number: 1095521	Q_{min}: 15 m^3/h (250 l/min)
Weight: 50 kg	Q_{max}: 300 m^3/h (5000 l/min)
Meter #2: Coriolis meter	
Manufacturer: Rota Yokogawa GmbH & Co. KG, Germany	
Type: ROTA MASS_MASSFLOW METER, RCCS39/IR-L/K5/Z	Signal output: pulses / frequency
Size: DN 100	K-factor: 144 pulses/kg 30.150 pulses/litre
Serial number: D1L701796	Q_{min}: 0 m^3/h
Weight: 110 kg	Q_{max}: 300 m^3/h (5000 l/min)
Meter #3: Coriolis meter	
Manufacturer: Endress+Hauser Messtechnik GmbH&Co.KG, Switzerland	
Type: PROMASS 83 F1-H	Signal output: pulses / frequency
Size: DN 100	K-factor: 50 pulses/kg 50 pulses/litre
Serial number: D702C102000	Q_{min}: 0 m^3/h
Weight: 155 kg	Q_{max}: 350 m^3/h (5833 l/min)

Table 3: Operating times of the used meters

No.	Type	PTB (characterisation measurements)	NEL	PTB (reproducibility measurements)	PTB (characterisation measurements)
Meter #1	Turbine, DN100		17.04 and 25.04.2012	31.05./07.06.2012 and 11.06./12.06.2012	13.03.2013 - 15.05.2013
Meter #2	Coriolis, DN100	22.02.2012 - 04.04.2012	25.04.2012	11.06 and 12.06.2012	
Meter #3	Coriolis, DN100		17.04.2012	31.05 and 07.06.2012	13.03.2013 - 15.05.2013

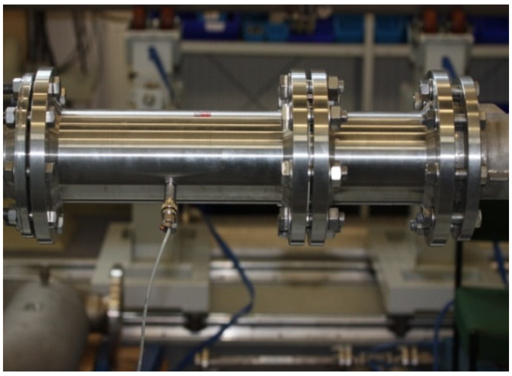

Figure 3: Turbine meter (**Meter#1**)

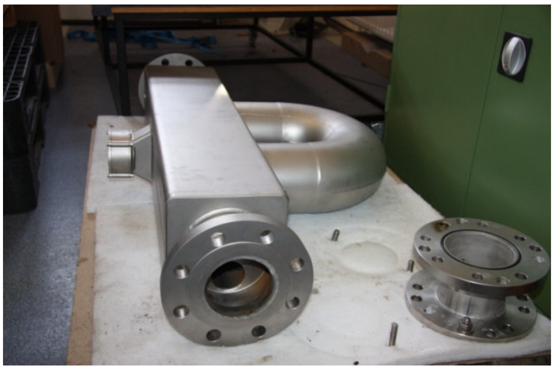

Figure 4: Coriolis meter (**Meter #2**)

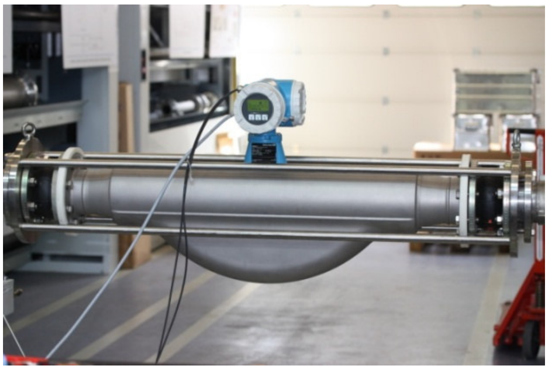

Figure 5: Coriolis meter (**Meter #3**)

3. TEST FACILITIES

3.1 NEL

The facility is based around two pairs of parallel test lines, with one pair comprising of 50 and 100 mm nominal bore pipework and the second pair comprising of 200 and 250 mm nominal bore pipework (Figure 6). The test lines are lengths (~30 m) of replaceable stainless steel pipe, with flanged Class 150 raised face flanges. The parallel test lines can be configured to function simultaneously, but with only one test line operating in each. A pair of storage tanks provides the lines with a continuous water source, with suitably rated pump sets generating flow. Primary reference sources are provided by three weigh tanks with capacities of 0.3, 1.5 and 12 tonnes. Turbine flow meters are installed to provide secondary reference calibrations (Figure 7).

Figure 6: *NEL water flow calibration facility.*

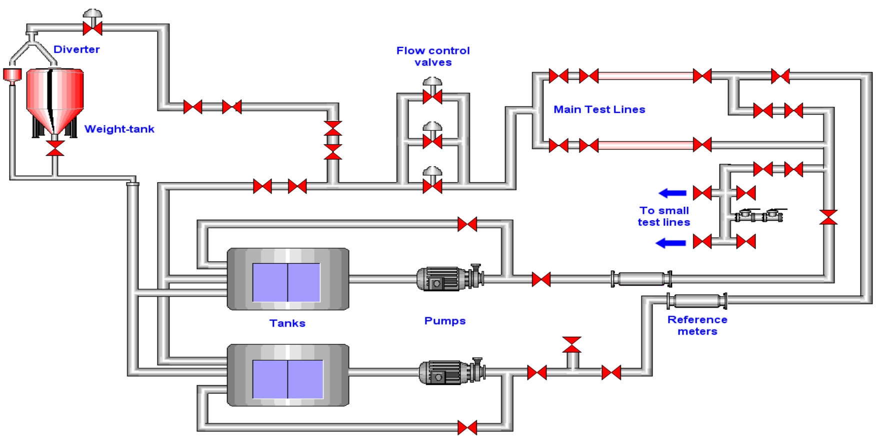

Figure 7: *Schematic of NEL's water flow calibration facility.*

The facility, controlled by an automated Supervisory Control and Data Acquisition (SCADA) system, allows a single operator to control the entire facility from a Personal Computer (PC) workstation (Figure 8). The PC, linked to a Programmable Logic Control (PLC) via Ethernet, permits a response time from command to action of less than one second. All field instruments within the facility are linked to the PLC.

Table 4: *Uncertainty Budget of the NEL facility*

Measured quantity, instrument or gauge	**Range**	**Calibration and measurement capability (*k*=2)**	**Remarks**
Water	1,000 kg/m^3	0.03 %	Density of water flowing through test device
Water quantity and flowrate (mass and volume)	0.1 to 200 l/s 0.1 to 400 l/s	0.10 % 0.15 %	Gravimetric diverter standards 0 to 10 bar g 15 °C to 35 °C Reference meter standards 0 to 10 bar, up to 200 l/s 0 to 5 bar, 200 to 400 l/s 15 °C to 35 °C

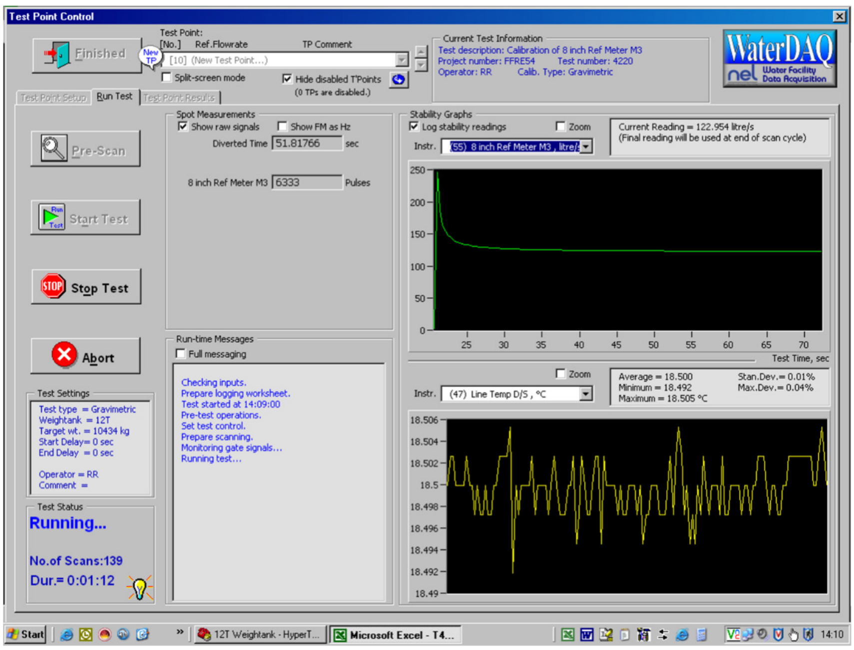

Figure 8: *Data acquisition screen during a test point*

Operational Conditions

The operating temperature range is 10 °C to 40 °C, with a tolerance of ±1 °C.

The nominal flow ranges when using the primary systems of are:

- 12 tonne weigh system: 20 l/s to 200 l/s;
- 1.5 tonne weigh system: 3 l/s to 35 l/s;
- 0.3 tonne weigh system: 0.1 l/s to 4.5 l/s.

The 200 and 250 mm lines are each fitted with a 8 inch turbine flow meter. This provides a nominal flow range of 30 to 200 l/s through each line, although the maximum flowrate can be increased to 400 l/s using a pair of pumps running in parallel.

The 100 mm line is fitted with a 100 mm turbine flow meter and provides a nominal flow range of 10 to 75 l/s. The 50 mm line is fitted with a 50 mm turbine flow meter providing a nominal flow range of 2 to 18 l/s.

CMC claims (Source: BIPM)

Liquid flowrate mass. Any flow measurement instrument or flow device, 0.4 l/s to 1600 l/s
Relative expanded uncertainty (*k* = 2, level of confidence 95%) in %: 0.1
Pulsed, electrical, digital and optical outputs, various methods

Liquid: **water**
Temperature: ambient to 30 °C
Pipe size: up to 1000 mm
Internal NMI service identifier: UK19
Liquid flowrate volume. Any flow measurement instrument or flow device, 0.4 l/s to 1600 l/s
Relative expanded uncertainty (*k* = 2, level of confidence 95 %) in %: 0.1
Pulsed, electrical, digital and optical outputs, various methods

Liquid: **water**
Temperature: ambient to 30 °C
Pipe size: up to 1000 mm
Internal NMI service identifier: UK20

3.2 PTB

The PTB water flow facility was designed as a closed hydraulic loop to operate in the range from 0.3 m³/h to 2100 m³/h for water flow meter calibrations (Figure 9 and Figure 10). For generating and stabilising these flow rates the supply system has a 380 m³ storage tank, a set of eight pumps (all frequency controlled), a constant head tank (30 m³, at a height of 30 m) and two measuring sections - lane A for nominal diameters from DN 200 to DN 400 mm and lane B for DN 20 to DN 150 mm. For each diameter an upstream straight pipe length more than 50D and downstream 20D is available. All the pipe work and the valves consist of stainless steel. The pressure in the measuring section is at about 3 bars when using the constant head tank, whereas the pressure is adjustable by set-point control from 2 through 5 bars when feeding the water directly by pump into the measuring section. For stabilising the liquid temperature a heat exchanging system was installed. Both flow rate, pressure and temperature control will be performed by computer.

The gravimetric measurement part consists of three branches. Each branch is accessible from one of the two measuring sections and consist a diverter and balance, thermometer and density meter:

a) Diverter DN 400 for 24 m³/h...2100 m³/h, weighing system 3,0...30,0 t, resolution 10 g,

b) Diverter DN 150 for 3 m³/h...320 m³/h, weighing system 300,0…3000,0 kg, resolution 1 g,

c) Diverter DN 50 for 0,3 m³/h...30 m³/h, weighing system 30,0...300,0 kg, resolution 0.1 g.

Figure 9: Water flow calibration facility at PTB

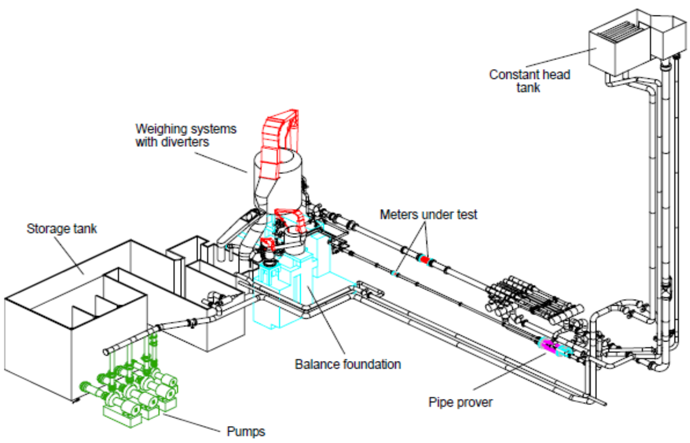

Figure 10: Cut-away view of PTB's water flow calibration facility

The automatic control of measurement process, data collection and calculation is carried out by computer system. In Figure 11 depicts, as an example, the on-screen PLANT OVERVIEW display, which shows the most relevant items: sensing and actuating devices, their status and the actual measurement values. Virtual on-screen buttons are the "entry points" to start calibration or to dial zoomed views of certain plant areas presenting more detailed information.

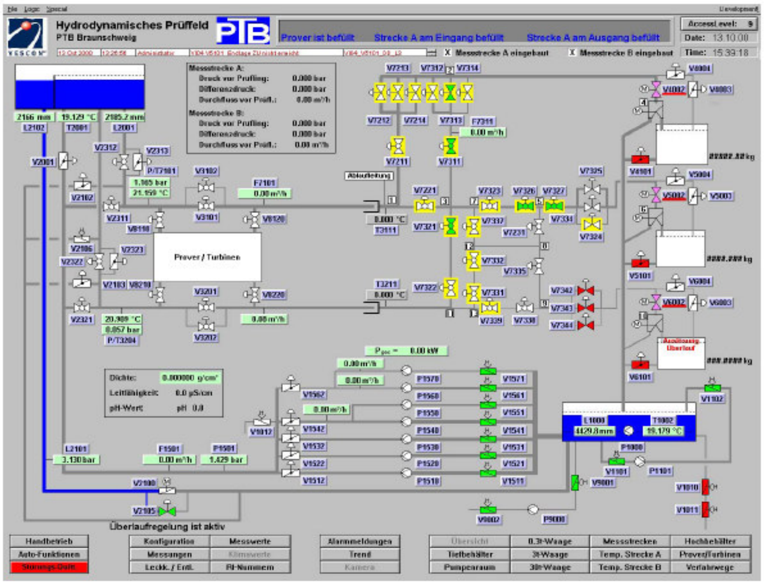

Figure 11: Video graphics display - PLANT OVERVIEW.

CMC claims (Source: BIPM)

Volume flowrate. *Flow sensors, 0.3 m³/h to 2100.0 m³/h*
Relative expanded uncertainty (k = 2, level of confidence 95 %) in %: 0.02
e.g. mechanical, electromagnetic, ultrasonic meters
Liquid: water
Temperature: ambient
Maximum pressure: 6 bar
Pipe size: DN 20 to DN 400
Approved on 16 November 2012
Internal NMI service identifier: DE21

Mass flowrate. *Flow sensors, 0,3 t/h to 2100 t/h*
Relative expanded uncertainty (k = 2, level of confidence 95 %) in %: 0.02
e.g. Coriolis-type flowmeters
Liquid: water
Temperature: ambient
Maximum pressure: 6 bar
Pipe size: DN 20 to DN 400
Approved on 16 November 2012
Internal NMI service identifier: DE22

4. CALIBRATION PROCEDURE

Each facility performed the calibration using their routine procedures, personel, instruments, software, so close as possible to the reference conditions specified by PTB during characterisation measurements. At both laboratories, a gravimetric calibration was performed.

During the comparison the calibration procedure was defined as follows:

- The meters were tested at 5 flow rates: 30 m^3/h, 60 m^3/h, 100 m^3/h, 140 m^3/h, 180 m^3/h, with additional measurements at 10 m^3/h, 200 m^3/h, 220 m^3/h 240 m^3/h
- reference conditions:
  - T_{ref} = 20 °C;
  - p_{ref} = 3,0 bar (PTB) and 1,5 bar (NEL).
- The test at one flow rate was repeated 5 times at PTB and 3 times at NEL. The results where used for the calculation of mean values for each flow point – equations (4) or (5).

At each test flow rate, PTB and NEL determined the K-factor for each flow meter by applying their normal flow meter calibration procedures – for volume measurements by using equation (1) and for mass measurements by equation (2):

$$K_{Vol} = \frac{N_{Pulses} \cdot \rho_{Fluid}}{m_{REF} \cdot 1000} \qquad \textit{(1)}$$

$$K_{Mass} = \frac{N_{Pulses}}{m_{REF}} \qquad \textit{(2)}$$

Where K_{Vol} [pulses/liter] is the K-factor for volume flow measurements and K_{Mass} [pulses/kg] is the K-factor for mass flow measurements, m_{REF} [kg] is the reference mass of water which passed through the flow meters, measured by the gravimetric reference. The values ρ_{Fluid} [kg/m³] is the density of the water and N_{Pulses} [pulses] are counted pulses which were delivered by the respective flowmeter during measurement time.

The K-factors from each calibration point was averaged to $\overline{K}$ [pulses/litre] or [pulses/kg] as follows, where n is the number of measurements at each flow point and i are the single measurements:

$$\overline{K} = \frac{\sum_{i=1}^{n} K_i}{n} \qquad \textit{(3)}$$

The measurement error of the mass indication e_{Mass} [%] in equation (4) is the value which shows the relationship between the mass indicated by the flow meter (m_{MUT} [kg]) and the reference mass which passed though the flow meter (m_{REF}) during the observation period:

$$e_{Mass} = \frac{m_{MUT} - m_{REF}}{m_{REF}} \cdot 100\,\% \qquad \textit{(4)}$$

The measurement error of the volume indication e_{Vol} [%] in equation (5) is the value which shows the relationship between the volume indicated by the flow meter - V_{MUT} [m³] - and the reference volume which passed though the flow meter (m_{VOL}) during the observation period:

$$e_{Vol} = \frac{V_{MUT} - V_{REF}}{V_{REF}} \cdot 100\,\% \qquad \textbf{(5)}$$

The values of m_{MUT} and V_{MUT} were estimated by using equation (6), respectively equation (7):

$$\mathrm{m_{MUT}} = \frac{\mathrm{N_{Pulses}}}{\mathrm{K_{MUT,\ Mass}}} \qquad \textbf{(6)}$$

$$\mathrm{V_{MUT}} = \frac{\mathrm{N_{Pulses}}}{\mathrm{K_{MUT,\ Vol}} \cdot 1000} \qquad \textbf{(7)}$$

Where $K_{MUT,Mass}$ [pulses/kg] is the reported K-factor for mass of the researched meter, respectively $K_{MUT, Vol}$ [pulses/liter] is the reported K-factor for volume.

The values of e_{Mass} and e_{Vol} from each calibration point were averaged to $\bar{e}_{Mass}$ [%], respectively $\bar{e}_{Vol}$ [%] by using equation (8), where *n* is the number of measurements at each flow point and *i* are the single measurements:

$$\bar{e} = \frac{\sum_{i=1}^{n} e_i}{n} \qquad (8)$$

4.1 Characterisation of the meters and comparison procedure

The setup was tested before and after the comparison measurements, in order to quantify the performance characteristics of the transfer package. The characterisations included measurements of temperature and pressure dependency, repeatability and reproducibility. Additionally, for the coriolis meter (Meter # 3) the influence of setting “Auto-Zero” was tested. For detailed operation times see Table *3*. Based on the estimation of e_{Vol} and e_{Mass}, the results where compared in four different levels (Figure 12): Laboratory I - characterisation measurements, Laboratory II - internal laboratory reproducibility 1, Laboratory III - internal laboratory reproducibility 2 and finally the Lab-to-Lab reproducibility.

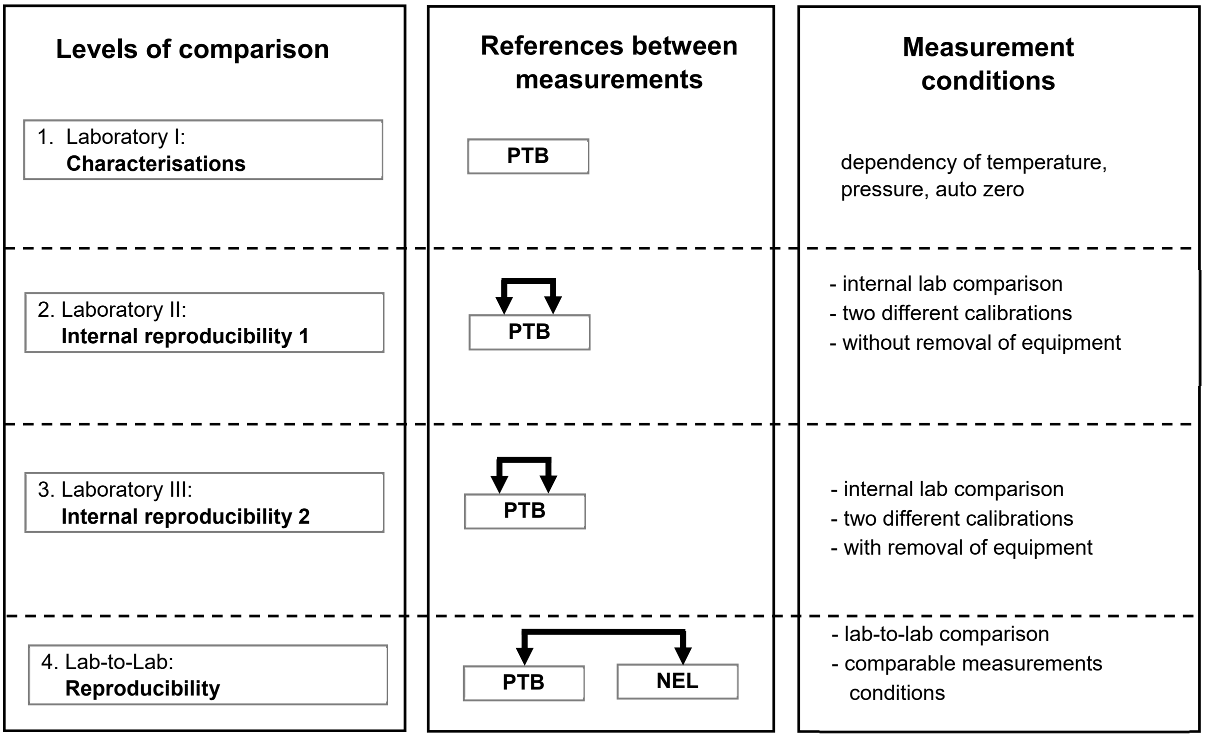

Figure 12: *Practiced evaluation procedure of the four comparison stages*

4.2 Estimation Degree of Equivalence and CMC-evaluation

The following procedure of the comparison calculations between the test facilities of PTB and NEL is based on [1],[2], [3], [4] and [5].

The procedure is applied separately for each flow rate, meter under test and laboratory.

In general, the combined standard uncertainties *u* (*k* = 1) [%] includes the uncertainty introduced by the meter under test and the standard deviation of the mean at each set point - equation (9):

$$u^2 = \frac{1}{n(n-1)} \sum_{i=1}^{n} \left(e_i - \bar{e}\right)^2 \qquad (9)$$

Where n are the numbers of measurements, e_i is the single measurement error e_{Mass} or e_{Vol} of the meter under test calculated by using Equation (5) and $\bar{e}$ are the average values represented by $\bar{e}_{Mass}$ [%] or $\bar{e}_{Vol}$.

To determine the reference value (e_{RV}) for each flow point of this bilateral comparison, the weighted mean was selected using the inverses of squares of the associated standard uncertainties - equation (10). Here the values of $\bar{e}_i$ represents the laboratory depended values of $\bar{e}_{Mass}$ [%], respectively $\bar{e}_{Vol}$ [%].

$$e_{RV} = \frac{\frac{\bar{e}_1}{u_{e,1}^2} + \frac{\bar{e}_2}{u_{e,2}^2} + \ldots + \frac{\bar{e}_i}{u_{e,i}^2}}{\frac{1}{u_{e,1}^2} + \frac{1}{u_{e,2}^2} + \ldots + \frac{1}{u_{e,i}^2}} \qquad (10)$$

The combined standard uncertainties of the participating laboratories $u_{e1}, u_{e2}, \ldots u_{e,i}$ in euqation (10) were calculated according to Equation (11), taking into account the uncertainty of the participant`s flow reference ($u_{base,i}$), which represents the participant`s official reported CMC value. As described by [4] the combined uncertainties u_{comp} of the meter under test and of the repeatability of the reported value at each set point are included additionally:

$$u_{e,i} = \sqrt{u_{base,i}^2 + u_{comp}^2} = \sqrt{u_{base,i}^2 + u_{MUT}^2 + \frac{s^2}{n}} \qquad (11)$$

The standard uncertainty u_{MUT} is the root-sum-of-squares (RSS) of specific uncertainties of the meter under test itself. The values of u_{MUT} are calculated by using equation (12). In case of analysing coriolis meter (meter #2 and meter #3) for u_{MUT} data sets of measurements with one equal zero point are compared only:

$$u_{MUT} = \sqrt{u_{reprodce1}^2 + u_{reproduce2}^2 + u_{temp}^2 + u_{press}^2 + u_{drift}^2} \qquad (12)$$

In general, the input parameters of Equation (12) are calculated according to Equation (9).

The reproducibility characteristics of the meter under test are considered by the values of $u_{reproduce1}$ and $u_{reproduce2}$. The reproducibility 1 $u_{reproduce1}$ is estimated for each separate flow point by the results of two different measurements days, where the equipment was not removed. In contrast, the reproducibility 2 $u_{reproduce2}$ is also estimated for each separate flow point, but with a removal of the equipment between the two measurements.

In order to consider the temperature sensitivity, u_{temp} is calculated from all measurements under the conditions between 15 °C ≤ T ≤ 25 °C and p = 3 bar performed at PTB facility. Similar, the pressure sensitivity u_{press} is obtained by using all data under the conditions between 2 bar ≤ p ≤ 3 bar and T = 30 °C. The values of u_{drift} are calculated by equation (13) and are based on all comparable measurements under reference conditions (T = 20 °C and p = 3 bar) performed at PTB facility during the project period:

$$u_{drift} = \frac{(\varepsilon_{max} - \varepsilon_{min})}{2\sqrt{3}} \qquad (13)$$

The standard uncertainty u_y of the reference value e_{RV} is given by:

$$\frac{1}{u_{e,RV}^2} = \frac{1}{u_{e,1}^2} + \frac{1}{u_{e,2}^2} + \ldots + \frac{1}{u_{e,i}^2}. \qquad (14)$$

The expanded uncertainty of weighted mean with k = 2 and approx. 95 % confidence level $U(e_{RV})$ [%] is:

$$U(e_{RV}) = 2 \cdot u_{e,RV}. \qquad (15)$$

The combination of equations (14) and (15) gives equation (16) for the estimation of $U(e_{RV})$:

$$U(e_{RV}) = 2 \cdot \sqrt{\frac{1}{\frac{1}{u_{e,1}^2} + \frac{1}{u_{e,2}^2} + \ldots + \frac{1}{u_{e,i}^2}}} \tag{16}$$

If the reference value (e_{RV}) [%] of the comparison is determined, the differences d_i [%] at each flow point between the results of PTB, respectively of NEL, and the e_{RV} were calculated by using euqation (17). Based on d_i and on the expanded uncertainty $U(d_i)$ of equation the standardized degree of equivalence $E_{n,i}$ [-] of each laboratory was calculated by equation (19):

$$d_i = \bar{e}_i - e_{RV} \tag{17}$$

$$U(d_i) = 2 \cdot \sqrt{u_{e,i}^2 - u_{e,RV}^2} \tag{18}$$

$$E_{n,i} = \frac{d_i}{U(d_i)} \tag{19}$$

5. RESULTS

5.1 Laboratory I - Meter characterisations

5.1.1 Meter #1 (Turbine, KEM)

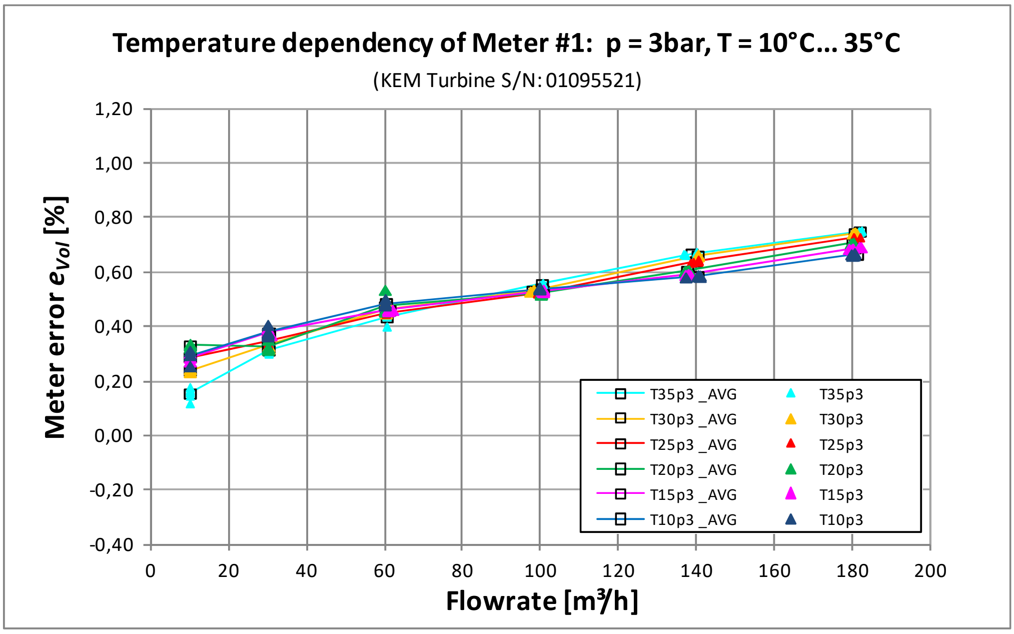

Figure 13: *Temperature dependency of* ***Meter #1*** *(Turbine, KEM), measured at PTB in March and April 2013, fluid temperature: 10 °C, 15 °C, 20 °C, 25 °C, 30 °C and 35 °C, line pressure: 3 bar*

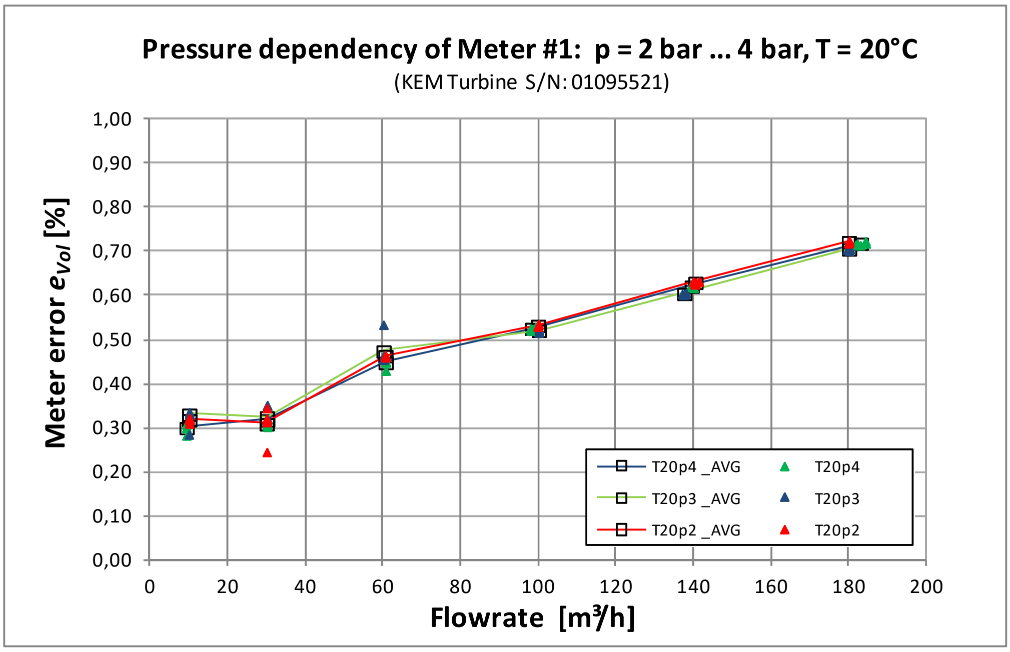

Figure 14: *Pressure dependency of* ***Meter#1*** *(Turbine, KEM), measured at PTB in March and April 2013, line pressure: 2 bar, 3 bar and 4 bar, fluid temperature: 20 °C*

5.1.2 Meter #2 (CORIOLIS FLOWMETER, Rota Yokogawa)

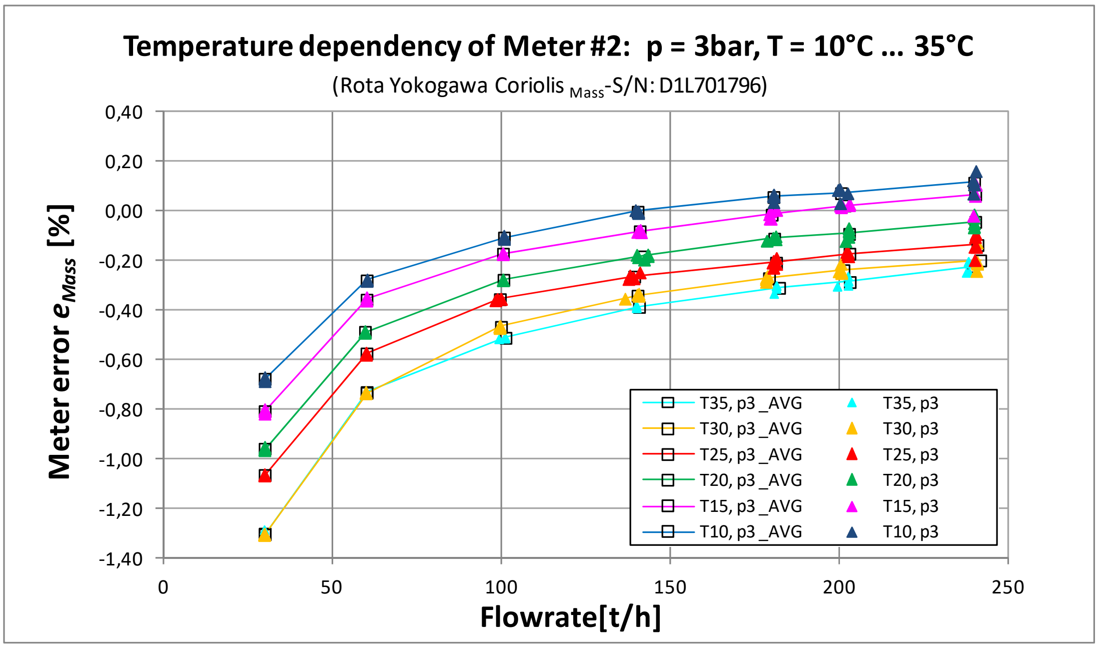

Figure 15: *Temperature dependency of **Meter #2** (Coriolis$_{Mass}$), measured at PTB in February and March 2012, fluid temperature: 10 °C, 15 °C, 20 °C, 25 °C, 30 °C and 35 °C, line pressure: 3 bar.*

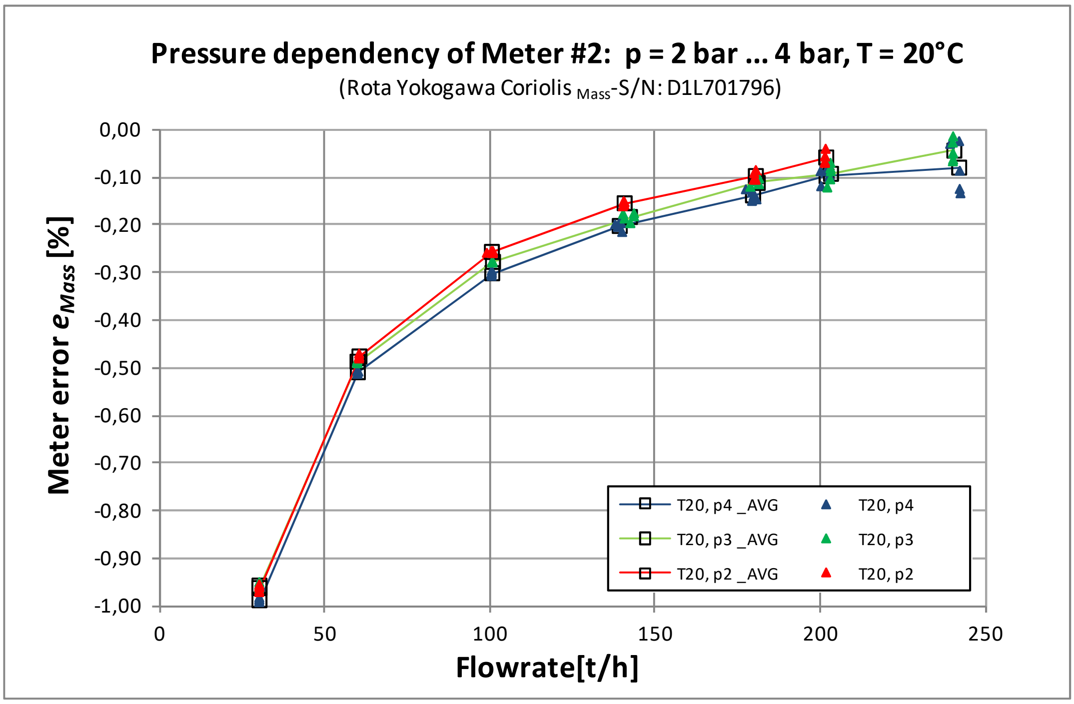

Figure 16: *Pressure dependency of **Meter #2** (Coriolis$_{Mass}$), measured at PTB in March 2012, line pressure: 2 bar, 3 bar and 4 bar, fluid temperature: 20 °C.*

5.1.3 Meter #3 (Coriolis flowmeter, Endress+Hauser)

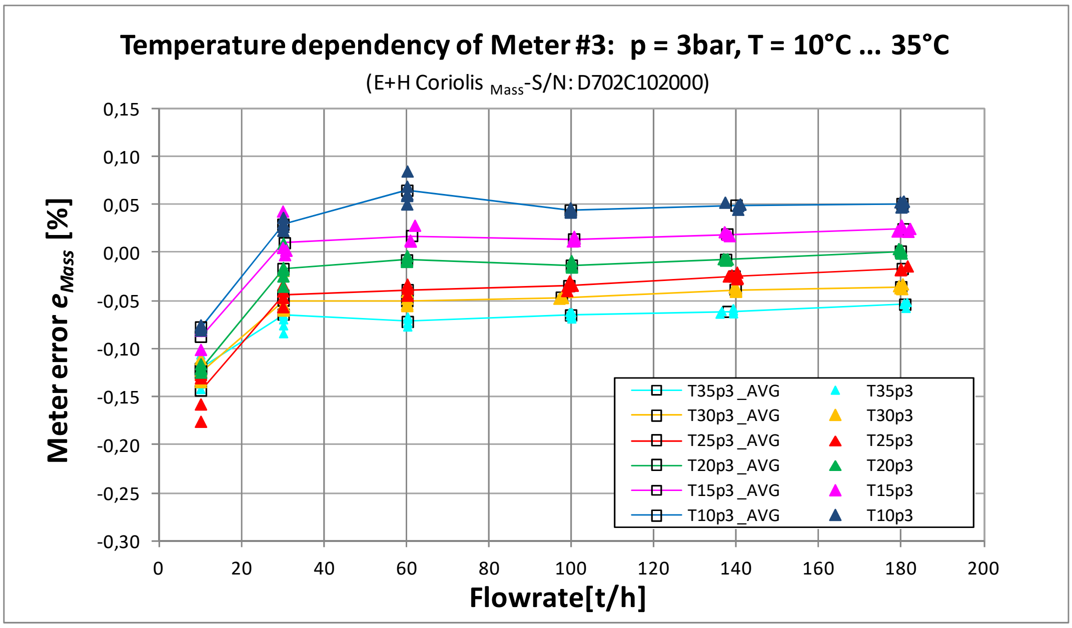

Figure 17: *Temperature dependency of **Meter #3** (Coriolis$_{Mass}$), measured at PTB in March and April 2013, fluid temperature: 10 °C, 15 °C, 20 °C, 25 °C, 30 °C and 35 °C, line pressure: 3 bar.*

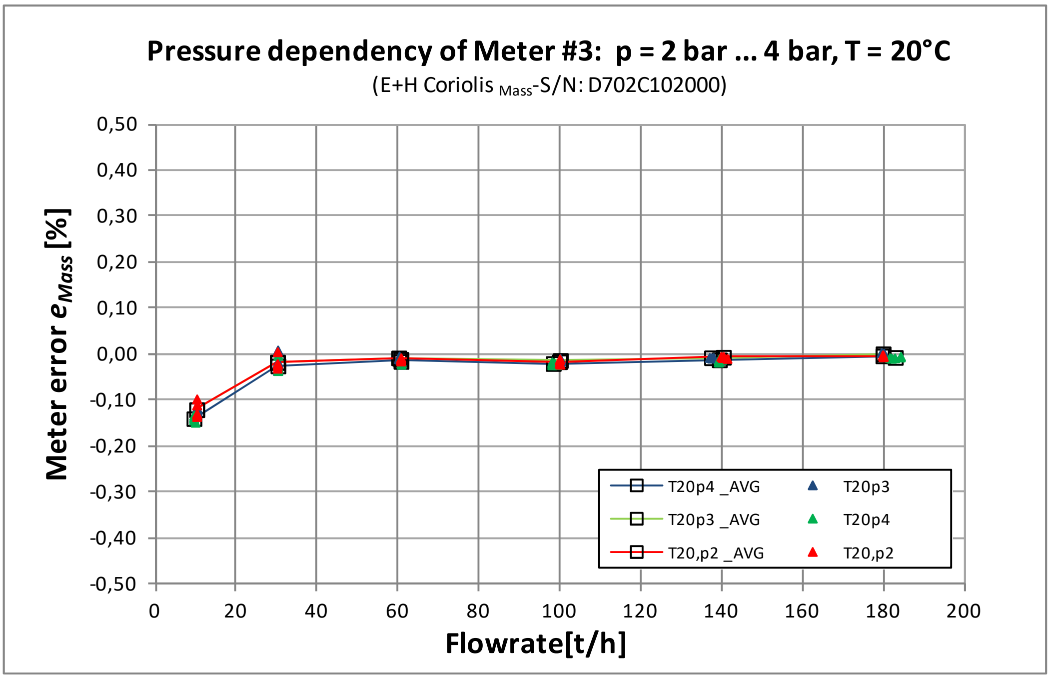

Figure 18: *Pressure dependency of **Meter #3** (Coriolis$_{Mass}$), measured at PTB in March and April 2013, line pressure: 2 bar, 3 bar and 4 bar, fluid temperature: 20 °C*

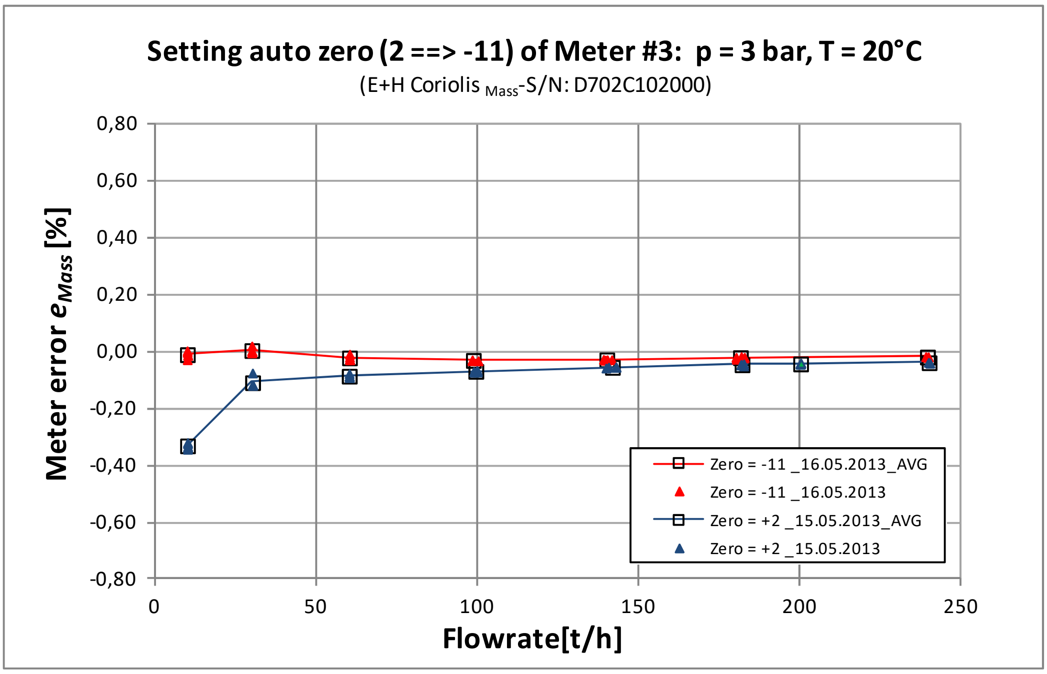

Figure 19: *Influence of setting zero point from "+2" to auto zero value "-11" of Meter #3, measured at PTB in May 2013, line pressure: 3 bar, fluid temperature: 20 °C.*

5.1.4 Conclusion of the characterisation measurements

Temperature effects:

- All the three flowmeters show significant temperature effects.
- Maximum differences occurred within the range $\bar{e}_{10°}$ and $\bar{e}_{35°}$.

  ➔ **Meter #1:** 0,18 % at 10 m³/h;

  ➔ **Meter #2:** 0,63 % at 10 m³/h

  ➔ **Meter #3**: 0,18 % at bei 180 m³/h
- The highest deviation from linearity (linearity error) over the whole range revealed **Meter #2**.
- **Meter #3** provided the best proximity to zero error line.

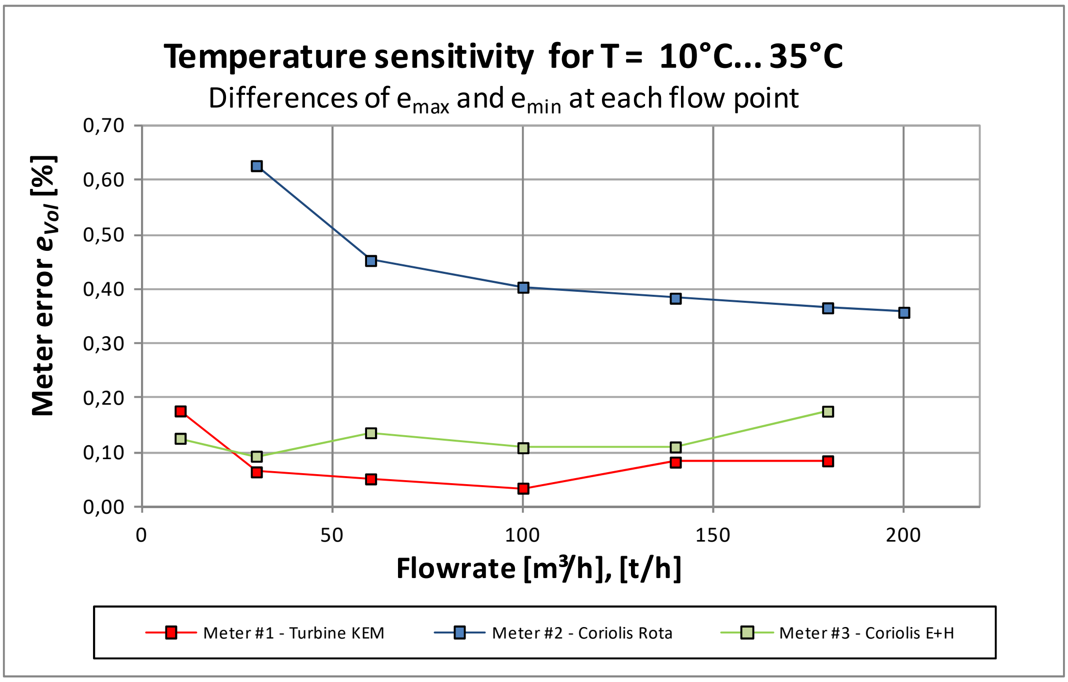

Figure 20: *Temperature sensitivities of Meter #1, #2 and #3: differences of maximum and minimum* $\bar{e}$ *for the fluid temperature range of 10 °C, 15 °C, 20 °C, 25 °C, 30 °C and 35 °C at each flow point, measured at PTB in March and April 2013, line pressure: 3 bar.*

Pressure effects:

- **Meter #1** and **Meter #3** showing no remarkable pressure sensitivity effects, the error curve of **Meter #2** showed a systematic shift within the flow range between 60 m³/h and 200 m³/h.
- Maximum differences between $\bar{e}_{2bar}$ and $\bar{e}_{4bar}$ occur:

  ➔ **Meter #1:** 0,15 % at 10 m³/h

  ➔ **Meter #2:** 0,61 % at 10 m³/h

  ➔ **Meter #3:** 0,13 % at 60 m³/h

5.2 Laboratory II and III - Internal reproducibility 1 and 2

5.2.1 Meter #1 (Turbine, KEM)

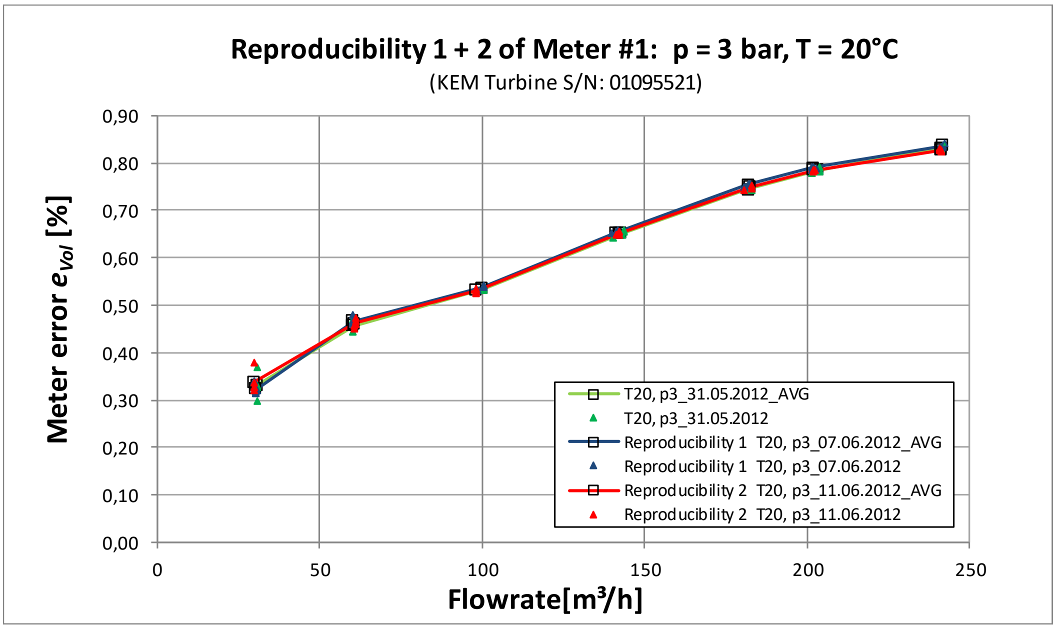

Figure 21: *Internal reproducibility 1 and 2 of* ***Meter #1*** *(Turbine) measured at PTB in May and June 2012 (line pressure: 3 bar, fluid temperature: 20 °C)*

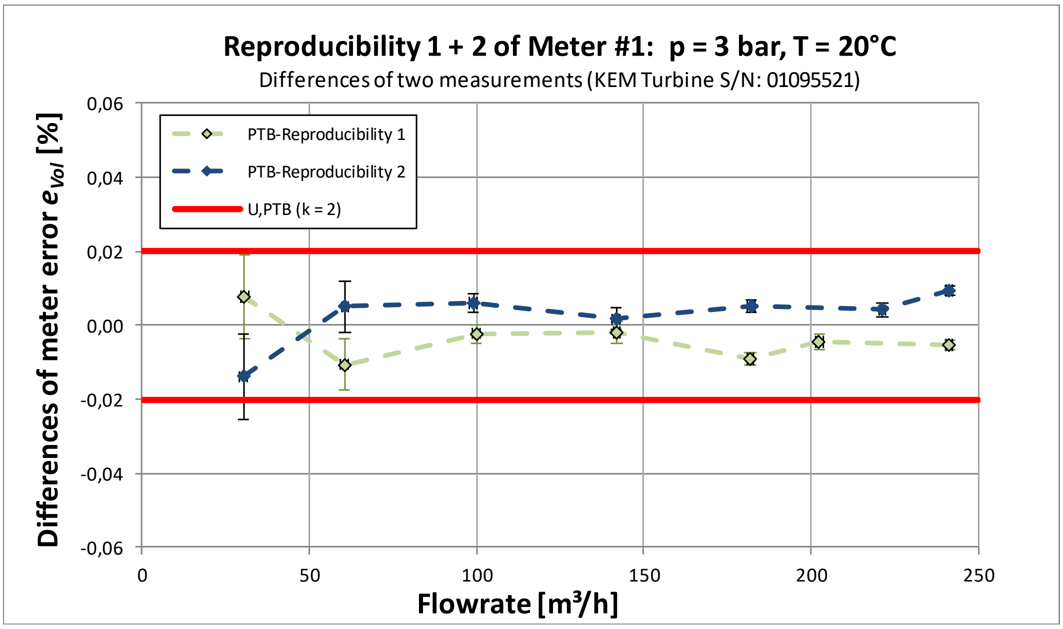

Figure 22: *Internal reproducibility 1 and 2 of* ***Meter #1*** *- Differences of measurement error e_{Vol} for repeatability data (07.06.2012 vs. 31.05.2012) and for reproducibility data (11.06.2012 vs. 07.06.2012) of Figure 21 including error bars of maximum standard deviation for one of each pairs*

5.2.2 Meter #2 (Coriolis flowmeter, Rota Yokogawa)

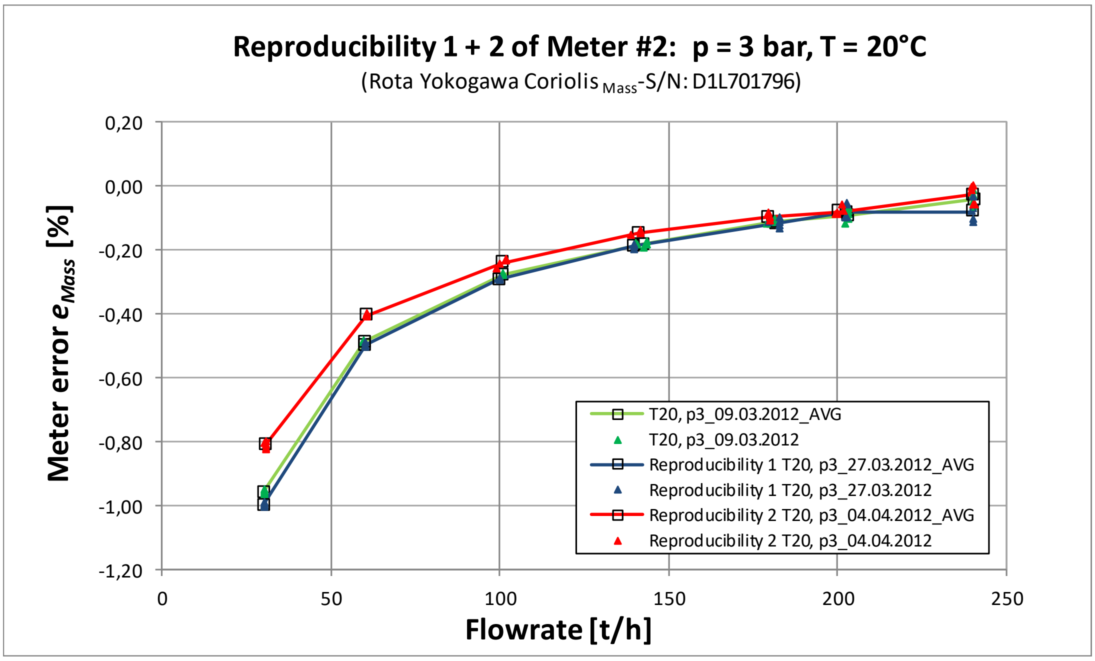

Figure 23: *Internal reproducibility 1 and 2 of* ***Meter #2*** *(Coriolis$_{Mass}$, Rota Yokogawa - S/N: D1L701796) measured at PTB in March and April 2013, line pressure: 3 bar, fluid temperature: 20 °C.*

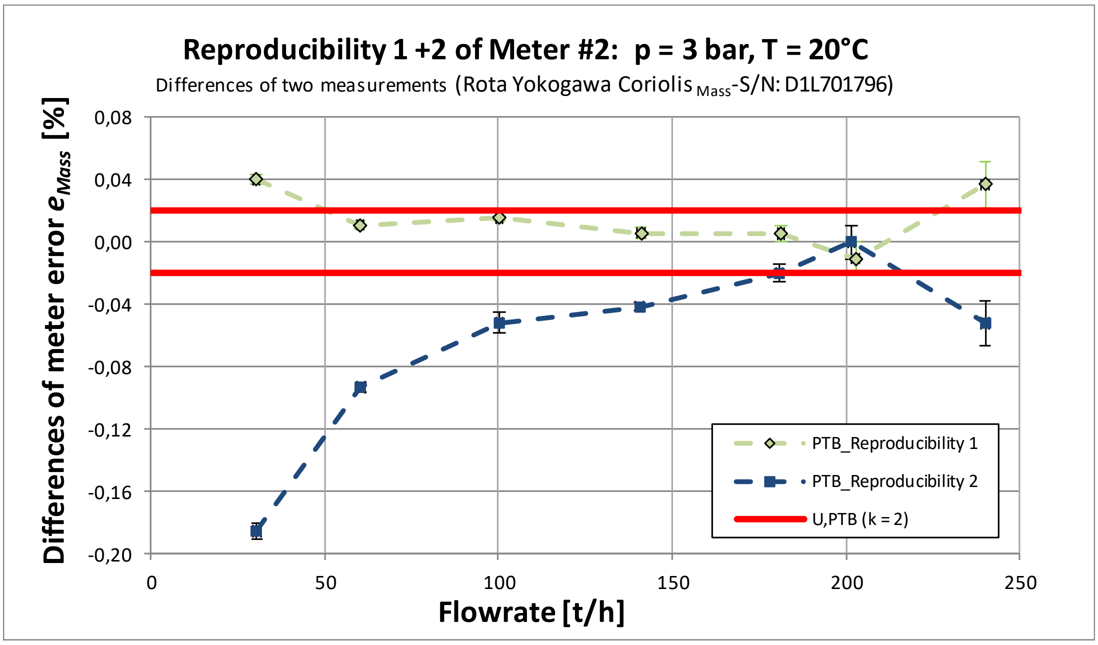

Figure 24: *Internal reproducibility 1 and 2 of* ***Meter #1*** *- Differences of measurement error e_{Mass} for repeatability data (27.03.2012 vs. 09.03.2012) and for reproducibility data (04.04.2012 vs. 27.03.2012) of* Figure 23 including error bars of maximum standard deviation for one of each pairs

5.2.3 Meter #3 (Coriolis flowmeter, Endress+Hauser)

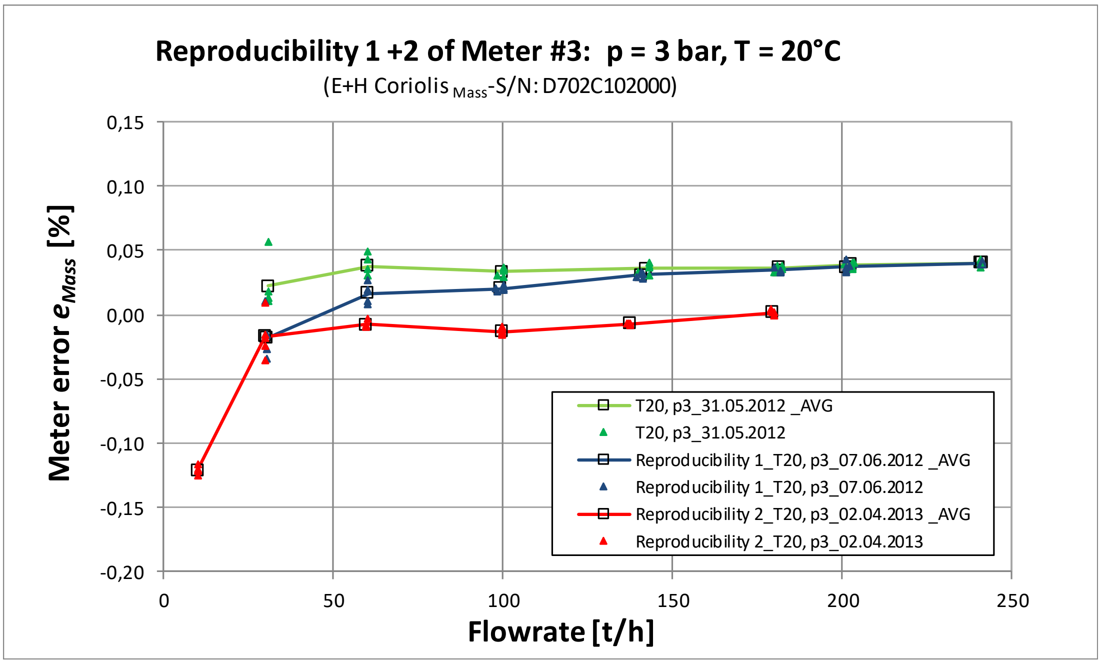

Figure 25: *Internal reproducibility 1 and 2 of **Meter #3** (Coriolis$_{Mass}$, Endress+Hauser - S/N: D702C102000) measured at PTB in May/June 2012 and March 2013, line pressure: 3 bar, fluid temperature: 20 °C.*

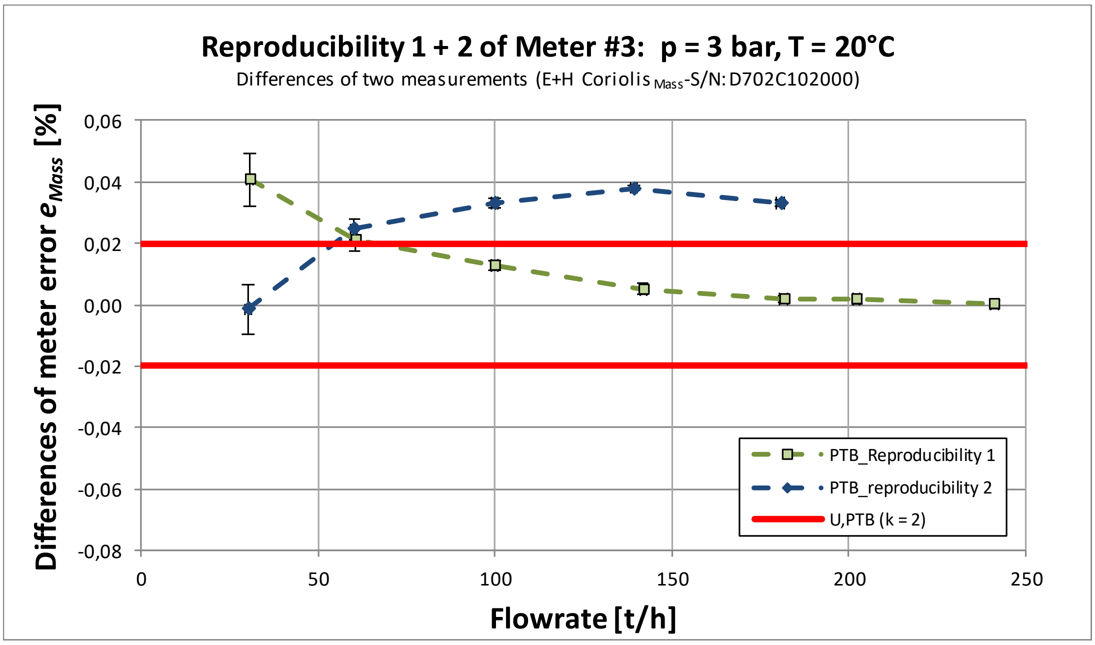

Figure 26: *Internal reproducibility 1 and 2 of **Meter #3** - Differences of measurement error e_{Mass} for repeatability data (07.06.2012 vs. 31.05.2012) and for reproducibility data (02.04.2013 vs. 07.06.2012) of Figure 25 including error bars of maximum standard deviation for one of each pairs*

5.3 Lab-to-Lab reproducibility

5.3.1 Meter #1 (Turbine, KEM)

Test data NEL - Test date: 25.04.2012
Air pressure: 969,50 hPa Air humidity: 29,15 % Air temperature: 18,21 °C
Calibration method: gravimetric

Test-flow-rates [m³/h]	**Indicated flow rate** [m³/h]	**Reference volume flow rate** [m³/h]	**T water** [°C]	**P water** [bar]	**Water density** [kg/m³]	**Reference mass** [kg]	**Reference volume** [m³]	**K-factor** [Pulses/ Liter]	**K-factor stdev** [Pulses/ Liter]	**Error** e_{Vol} [%]
30	28,029	27,940	20,430	1,506	998,302	6107,169	6,118	6,654	1,69E-03	0,319
60	60,433	60,135	20,512	1,457	998,286	6066,067	6,076	6,666	9,13E-04	0,496
100	99,723	99,179	21,345	1,546	998,115	6087,551	6,099	6,669	3,62E-03	0,549
140	137,344	136,471	21,999	1,577	997,981	6079,727	6,092	6,675	4,36E-04	0,640
180	178,623	177,303	22,343	1,576	997,915	6120,599	6,133	6,682	2,50E-04	0,745

Test data PTB - Test date: 31.05.2012
Air pressure: 1005,87 hPa Air humidity: 58,94 % Air temperature: 22,68 °C
Calibration method: gravimetric

Test-flow-rates [m³/h]	**Indicated flow rate** [m³/h]	**Reference volume flow rate** [m³/h]	**T water** [°C]	**P water** [bar]	**Water density** [kg/m³]	**Reference mass** [kg]	**Reference volume** [m³]	**K-factor** [Pulses/ Liter]	**K-factor stdev** [Pulses/ Liter]	**Error** e_{Vol} [%]
30	31,086	30,983	19,949	2,964	998,365	2785,359	2,790	6,655	1,05E-04	0,332
60	60,759	60,483	19,939	2,998	998,367	2720,251	2,725	6,663	2,66E-04	0,457
100	100,571	100,106	19,963	3,001	998,362	2703,145	2,708	6,667	4,98E-04	0,535
140	143,550	142,767	19,970	2,971	998,361	2755,561	2,760	6,676	4,06E-05	0,652
180	182,964	181,832	19,981	2,991	998,358	2731,428	2,736	6,682	3,92E-04	0,745

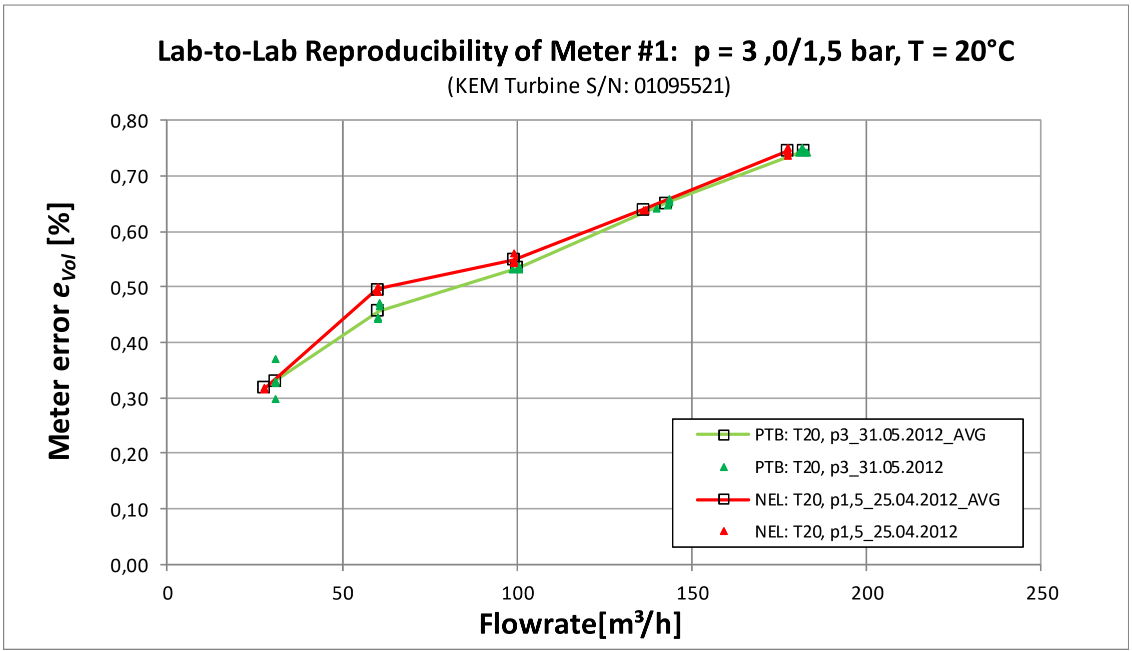

***Figure 27:** Lab-to-Lab reproducibility of **Meter #1**, measured at PTB on 31.05.2012 and at NEL on 25.04.2012. Fluid temperature 20 °C (both at PTB and NEL), line pressure: 3,0 bar at PTB and 1,5 bar at NEL. K-factor: 6,633 pulses/l (both at PTB and NEL)*

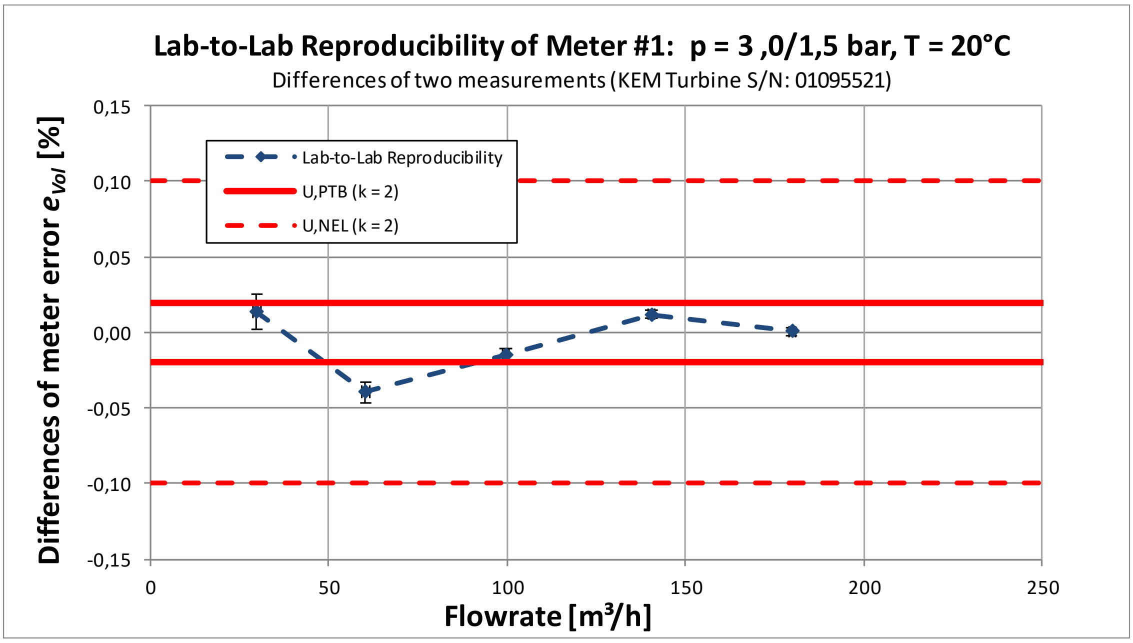

***Figure 28:** Lab-to-Lab reproducibility* of **Meter #1** *- Differences of measurement error data (25.04.2012 vs. 31.05.2012) of Figure 27 including error bars of maximum standard deviation for one of the comparison pairs*

5.3.2 Meter #2 (CoriolisMass, Rota Yokogawa)

Test data PTB - Test date: 04.04.2012
Air pressure: 999,01 hPa Air humidity: 39,80 % Air temperature: 21,82 °C
Calibration method: gravimetric

Test-flow-rates [t/h]	Indicated flow rate [t³/h]	Reference mass rate [t/h]	T Water [°C]	P water [bar]	Water density [kg/m³]	Reference mass [kg]	Reference volume [m³]	K-factor [Pulses/kg]	k-factor stdev [Pulses/kg]	Error [%]
30	30,362	30,611	19,943	2,921	998,366	2756,423	2,761	142,831	1,52E-02	-0,812
60	60,220	60,464	19,918	2,995	998,371	2723,620	2,728	143,418	5,91E-03	-0,404
100	100,516	100,759	19,932	2,995	998,369	2725,351	2,730	143,653	1,80E-02	-0,241
140	141,019	141,227	19,945	2,986	998,366	2730,581	2,735	143,788	6,58E-03	-0,147
180	179,573	179,747	19,963	2,999	998,362	2704,877	2,709	143,861	1,25E-02	-0,097

Test data NEL - Test date: 25.04.2012
Air pressure: 969,50 hPa Air humidity: 29,15 % Air temperature: 18,21 °C
Calibration method: gravimetric

Test-flow-rates [t/h]	Indicated flow rate [t³/h]	Reference mass flow rate [t/h]	T Water [°C]	P water [bar]	Water density [kg/m³]	Reference mass [kg]	Reference volume [m³]	K-factor [Pulses/kg]	k-factor stdev [Pulses/kg]	Error [%]
30	27,774	27,892	20,430	1,506	998,302	6107,169	6,118	143,392	1,14E-02	-0,422
60	59,929	60,032	20,512	1,457	998,286	6066,067	6,076	143,754	9,45E-03	-0,171
100	98,931	98,992	21,345	1,546	998,115	6087,551	6,099	143,912	1,34E-02	-0,061
140	136,130	136,195	21,999	1,577	997,981	6079,727	6,092	143,931	4,62E-03	-0,048
180	176,890	176,933	22,343	1,576	997,915	6120,599	6,133	143,965	5,62E-03	-0,024

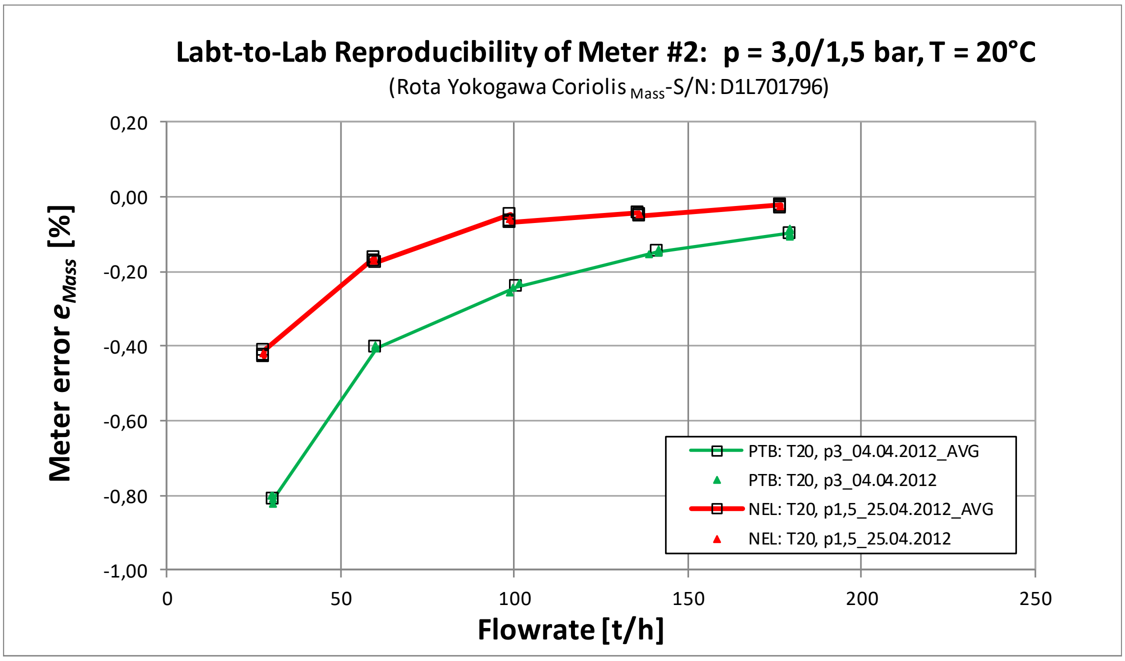

Figure 29: *Lab-to-Lab reproducibility of* **Meter #2**, *measured at PTB on 04.04.2012 and at NEL on 25.04.2012. Fluid temperature 20°C (both at PTB and NEL), line pressure: 3,0 bar at PTB and 1,5 bar at NEL. K-factor: 144 pulses/kg (both at PTB and NEL).*

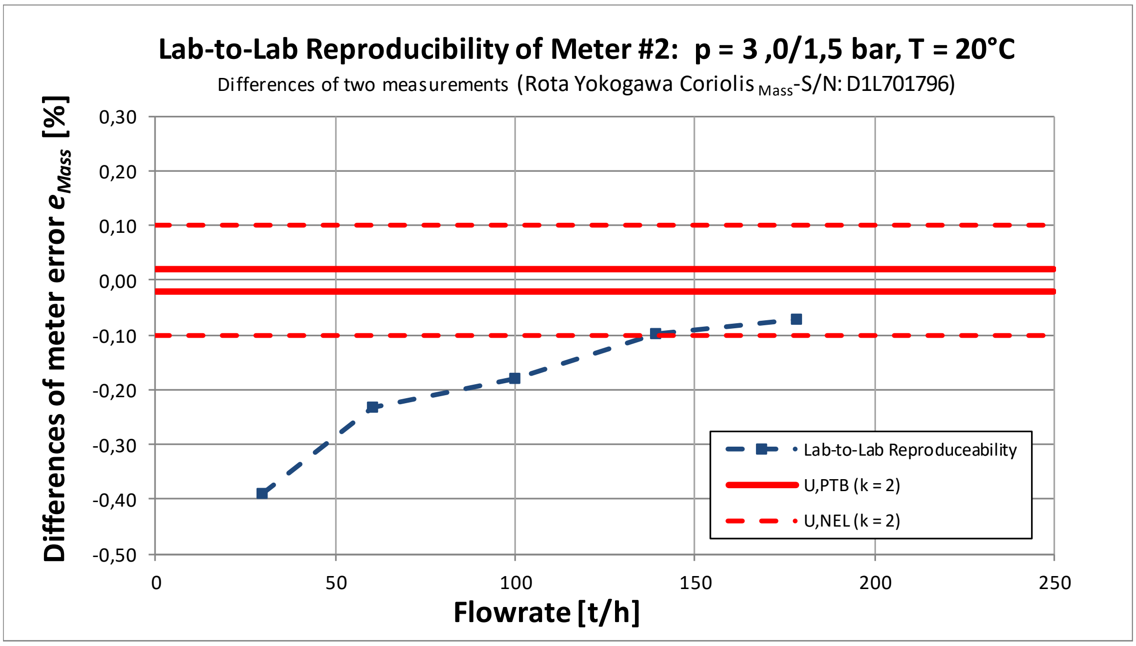

Figure 30: *Lab-to-Lab reproducibility* of **Meter #2** *- Differences of measurement error data (25.04.2012 vs. 04.04.2012) of Figure 29 including error bars of maximum standard deviation for one of the comparison pairs*

5.3.3 Meter #3 (CoriolisMass, Endress+Hauser)

Test data PTB - Test date: 31.05.2012
Air pressure: 1006,71 hPa Air humidity: 57,56 % Air temperature: 22,68 °C
Calibration method: gravimetric

Test-flow-rates [t/h]	**Indicated flow rate** [t³/h]	**Reference mass flow rate** [t/h]	**T Water** [°C]	**P water** [bar]	**Water density** [kg/m³]	**Reference mass** [kg]	**Reference volume** [m³]	**K-factor** [Pulses/kg]	**k-factor stdev** [Pulses/kg]	**Error** [%]
30	30,939	30,932	19,949	2,964	998,365	2785,359	2,790	50,011	9,66E-03	0,022
60	60,400	60,377	19,940	2,998	998,367	2719,884	2,724	50,019	4,09E-03	0,038
100	99,975	99,942	19,963	3,001	998,362	2703,145	2,708	50,017	1,69E-03	0,033
140	142,584	142,533	19,970	2,971	998,361	2755,561	2,760	50,018	1,98E-03	0,036
180	181,599	181,533	19,981	2,991	998,358	2731,428	2,736	50,018	9,69E-04	0,036

Test data NEL - Test date: 17.04.2014
Air pressure: 962,857 hPa Air humidity: 29,31 % Air temperature: 18,09 °C
Calibration method: gravimetric

Test-flow-rates [t/h]	**Indicated flow rate** [t³/h]	**Reference mass flow rate** [t/h]	**T Water** [°C]	**P water** [bar]	**Water density** [kg/m³]	**Reference mass** [kg]	**Reference volume** [m³]	**K-factor** [Pulses/kg]	**k-factor stdev** [Pulses/kg]	**Error** [%]
30	30,236	30,220	22,117	1,792	997,944	6018,408	6,031	50,027	7,13E-04	0,054
60	59,858	59,815	21,346	1,783	998,120	6018,355	6,030	50,036	1,07E-03	0,072
100	99,208	99,127	20,456	1,770	998,318	6021,133	6,031	50,041	7,34E-04	0,082
142	138,149	138,034	20,388	1,791	998,343	6025,031	6,035	50,042	3,24E-04	0,083
180	180,126	180,008	21,154	1,806	998,192	6035,377	6,046	50,033	1,13E-03	0,066

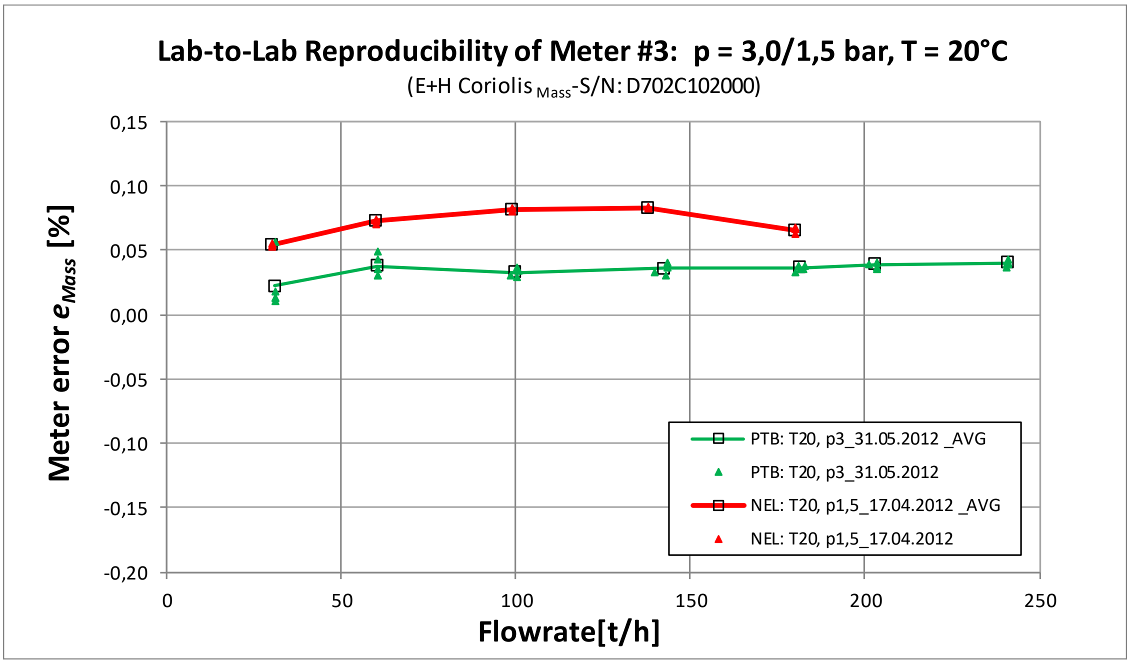

Figure 31: *Lab-to-Lab Reproducibility of **Meter #3**, measured at PTB on 31.05.2012 and at NEL on 17.04.2012. Fluid temperature 20°C (both at PTB and NEL), line pressure: 3.0 bar at PTB and 1.5 bar at NEL. K-factor: 50 pulses/kg (both at NEL and PTB).*

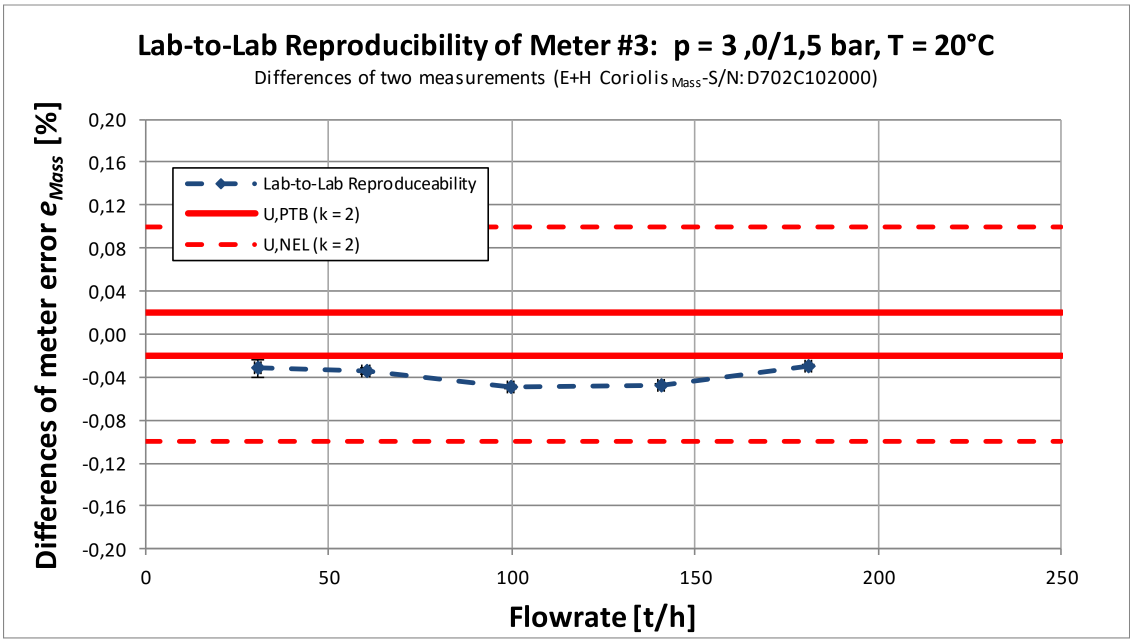

Figure 32: *Lab-to-Lab reproducibility of **Meter #3** - Differences of measurement error data (17.04.2012 vs. 31.05..2012) of Figure 31 including error bars of maximum standard deviation for one of the comparison pairs*

5.4 Determination of reference value (e_{RV}) and Evaluation

5.4.1 Meter #1 (Turbine, KEM)

Date of measurement at PTB: 31.05.2012

Date of measurement at NEL: 25.04.2012

Flow measurement points: 30 m³/h, 60 m³/h, 100 m³/h, 140 m³/h, 180 m³/h

Standard uncertainty of PTB facility: $u_{base,PTB}$ = 0.01 % (k =1)

Standard uncertainty of NEL facility: $u_{base,NEL}$ = 0.05 % (k =1)

Table 5: *Estimation of standard uncertainty u_{MUT} for meter #1 - all values are based on the explanations to equations (12) and (13) with k = 1*

Nominal flowrate	u(reproduce1)		u(reproduce2)		u(temp)		u(press)		u(drift)		uMUT
	Dates of test	u(repeat)	Dates of test	u(reprod.)	Dates of test	u(temp)	Dates of test	u(press)	Dates of test	u(drift)	
[m³/h]		[%]		[%]		[%]		[%]		[%]	[%]
30	31.05.12 07.06.12	0.006	07.06.12 11.06.12	0.006	15.03.13 02.04.13 25.03.13	0.009	02.04.13 03.04.13 04.04.13	0.004	31.05.12 07.06.12 11.06.12 12.06.12 02.04.13 15.05.13 16.05.13	0.024	0.027
60		0.004		0.003		0.008		0.006		0.026	0.029
100		0.001		0.002		0.008		0.006		0.012	0.016
140		0.002		0.001		0.002		0.002		0.021	0.021
180		0.002		0.001		0.015		0.003		0.020	0.025

Table 6: *Estimation of the comparison reference value e_{RV} for meter #1 - based on using equation (11)*

Nominal flowrate	Measurement error $\overline{e}_{Vol}$						Uncertainty of $u_{e,i}$		Reference-value	Uncertainty of e_{RV}
	Mean		Standarddev.		Number of measurements					k = 2
	$\overline{e}_{Vol}$ PTB	$\overline{e}_{Vol}$ NEL	σ - PTB	σ - NEL	n - PTB	n - NEL	$u_{e,PTB}$	$u_{e,NEL}$	e_{RV}	U_{eRV}
[m³/h]	[%]	[%]	[%]	[%]	[-]	[-]	[%]	[%]	[%]	[%]
30	0.332	0.319	0.025	0.002	5	3	0.031	0.057	0.329	0.027
60	0.457	0.496	0.014	0.004	4	3	0.031	0.058	0.466	0.027
100	0.535	0.549	0.003	0.008	4	4	0.019	0.053	0.536	0.018
140	0.652	0.640	0.007	0.001	5	3	0.024	0.054	0.650	0.022
180	0.745	0.745	0.004	0.006	5	4	0.027	0.056	0.745	0.024

Table 7: *Estimation of the Degree of equivalence $E_{n.i}$ for meter #1 - based on equation (19)*

Nominal flowrate	Differences to e_{RV}		Uncertainty of d_i		Uncertainty range of e_{RV}		Degree of equivalenz	
	$d_i = \bar{e}_{Vol} - e_{RV}$		k = 2		k = 2		k = 2	
	d_{PTB}	d_{NEL}	$U(d_{PTB})$	$U(d_{NEL})$	$e_{RV} - U_{eRV}$	$e_{RV} - U_{eRV}$	$E_{n.\,PTB}$	$E_{n.\,NEL}$
[m³/h]	[%]	[%]	[%]	[%]	[%]	[%]	[-]	[-]
30	0.003	-0.010	0.029	0.100	0.275	0.383	0.105	-0.105
60	-0.009	0.031	0.029	0.101	0.411	0.520	-0.301	0.301
100	-0.002	0.013	0.013	0.099	0.501	0.572	-0.132	0.132
140	0.002	-0.010	0.019	0.100	0.607	0.693	0.101	-0.101
180	0.000	0.000	0.023	0.101	0.696	0.794	0.005	-0.005

Table 8: *Recommended CMC decision status based on comparison measurements of meter #1*

Nominal flowrate	u_{comp}		comparison uncertainty ratio $u_{comp}/u_{base.i}$		CMC decision status	
	k = 1		k = 1			
	PTB	**NEL**	**PTB**	**NEL**	**PTB**	**NEL**
[m³/h]	[%]	[%]	[-]	[-]		
30	0.027	0.027	2.697	0.537	base uncertainty warning	base uncertainty supported
60	0.029	0.029	2.859	0.571	base uncertainty warning	base uncertainty supported
100	0.016	0.016	1.582	0.317	base uncertainty supported	base uncertainty supported
140	0.021	0.021	2.126	0.425	base uncertainty warning	base uncertainty supported
180	0.025	0.025	2.506	0.501	base uncertainty warning	base uncertainty supported

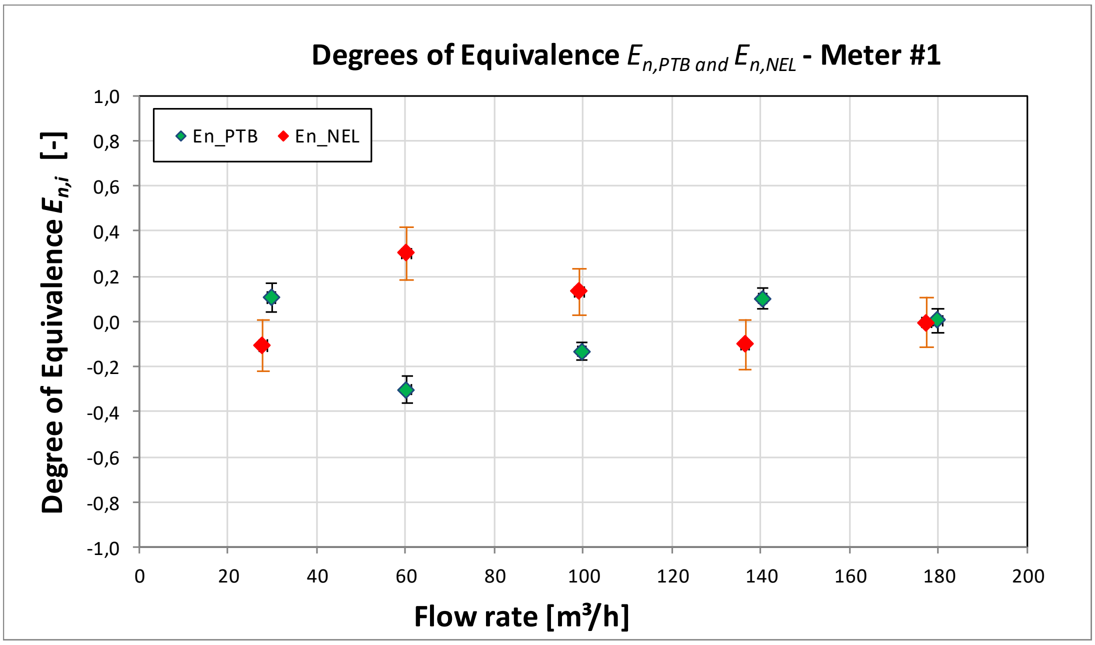

Figure 33: *Degrees of equivalence $E_{N.PTB}$ and $E_{n.NEL}$ of **Meter #1** with error bars of $u_{e.PTB}$.* respectively $u_{e.PTB}$

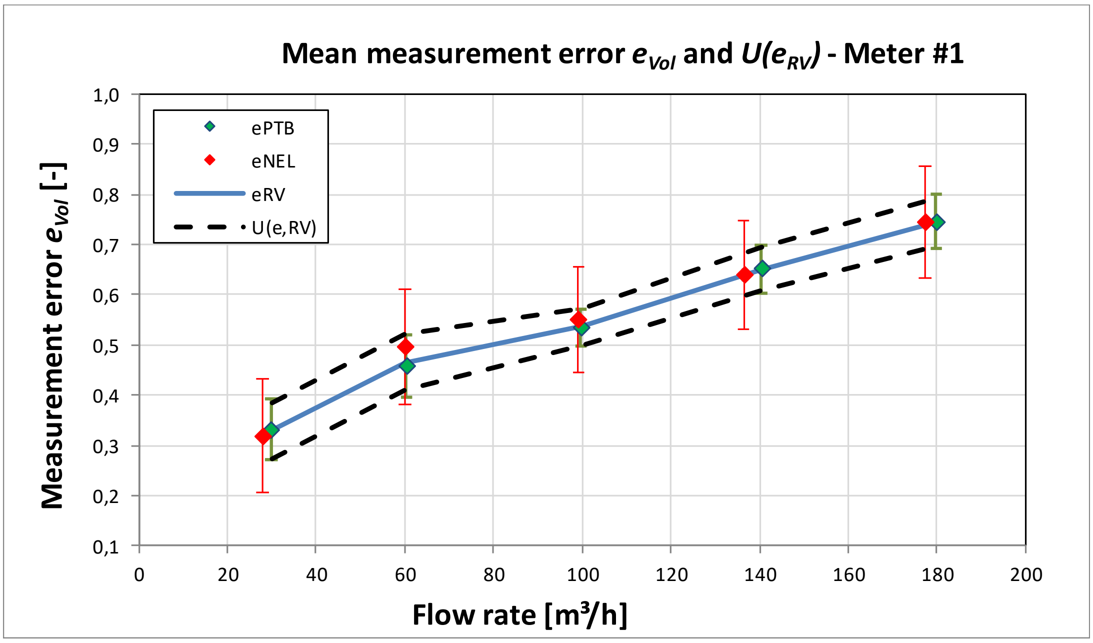

Figure 34: *Measurement error of $\overline{e}_{Vol}$ with error bars $U(\overline{e}_{Vol})$ for PTB and NEL of **Meter #1**. reference value e_{RV} and the area of the extended uncertainty of the reference value $U(e_{RV})$ – for **Meter #1***

5.4.2 Meter #2 (Coriolis. Rota Yokogawa)

Date of measurement at PTB: 04.04.2012

Date of measurement at NEL: 25.04.2012

Flow measurement points: 30 m³/h. 60 m³/h. 100 m³/h. 140 m³/h. 180 m³/h

Standard uncertainty of PTB facility: $u_{base.PTB}$ = 0.01 % (k =1)

Standard uncertainty of NEL facility: $u_{base.NEL}$ = 0.05 % (k =1)

Table 9: *Estimation of standard uncertainty u_{MUT} for **Meter #2** - all values are based on the explanations to equations (12) and (13) with k = 1*

Nominal flowrate	u(repeat)		u(reproduce)		u(temp)		u(press)		u(drift)		uMUT
	Dates of test	u(repeat)	Dates of test	u(reprod.)	Dates of test	u(temp)	Dates of test	u(press)	Dates of test	u(drift)	
[m³/h]		[%]		[%]		[%]		[%]		[%]	[%]
30	09.03.12 27.03.12	0.007	27.03.12 04.04.12	0.031	24.02.12 19.03.12 25.03.12	0.030	09.03.12 12.03.12 13.03.12	0.004	09.03.12 27.03.12 04.04.12 11.06.12 12.06.13	0.024	0.045
60		0.002		0.016		0.024		0.004		0.011	0.029
100		0.003		0.010		0.020		0.005		0.006	0.023
140		0.002		0.007		0.020		0.006		0.004	0.022
180		0.003		0.005		0.021		0.004		0.003	0.023

Table 10: *Estimation of the comparison reference value e_{RV} for **Meter #2** - based on using equation (11)*

Nominal flowrate	Measurement error $\bar{e}_{Vol}$						Uncertainty of $u_{e.i}$		Reference-value	Uncertainty of e_{RV}
	Mean		Standarddev.		Number of measurements					k = 2
	$\bar{e}_{Mass}$ PTB	$\bar{e}_{Mass}$ NEL	σ - PTB	σ - NEL	n - PTB	n - NEL	$u_{e.PTB}$	$u_{e.NEL}$	e_{RV}	U_{eRV}
[m³/h]	[%]	[%]	[%]	[%]	[-]	[-]	[%]	[%]	[%]	[%]
30	-0.812	-0.422	0.011	0.008	5	3	0.046	0.067	-0.687	0.076
60	-0.404	-0.171	0.004	0.007	5	3	0.031	0.058	-0.353	0.054
100	-0.241	-0.061	0.013	0.009	4	4	0.026	0.055	-0.209	0.047
140	-0.147	-0.048	0.005	0.003	5	3	0.024	0.055	-0.131	0.045
180	-0.097	-0.024	0.009	0.004	5	4	0.025	0.055	-0.084	0.045

Table 11: *Estimation of the Degree of equivalence $E_{n.i}$ for* ***Meter #2*** *- based on equation (19)*

Nominal flowrate	Differences to e_{RV}		Uncertainty of d_i		Uncertainty range of e_{RV}		Degree of equivalenz	
	$d_i = \overline{e}_{Vol} - e_{RV}$		k = 2		k = 2		k = 2	
	d_{PTB}	d_{NEL}	$U(d_{PTB})$	$U(d_{NEL})$	$e_{RV} - U_{eRV}$	$e_{RV} - U_{eRV}$	$E_{n.PTB}$	$E_{n.NEL}$
[m³/h]	[%]	[%]	[%]	[%]	[%]	[%]	[-]	[-]
30	-0.124	0.265	0.052	0.111	-0.763	-0.611	**-2.389**	**2.389**
60	-0.051	0.182	0.029	0.102	-0.407	-0.299	**-1.779**	**1.779**
100	-0.032	0.147	0.022	0.100	-0.256	-0.162	**-1.471**	**1.471**
140	-0.017	0.083	0.020	0.100	-0.175	-0.086	**-0.829**	**0.829**
180	-0.012	0.060	0.021	0.100	-0.130	-0.039	**-0.601**	**0.601**

Table 12: *Recommended CMC decision status based on comparison measurements of* ***Meter #2***

Nominal flowrate	u_{comp}		comparison uncertainty ratio $u_{comp}/u_{base.i}$		CMC decision status	
	k = 1		k = 1			
	PTB	NEL	PTB	NEL	PTB	NEL
[m³/h]	[%]	[%]	[-]	[-]		
30	0.045	0.045	4.472	0.894	comparison is inconclusive	comparison is inconclusive
60	0.029	0.029	2.896	0.579	comparison is inconclusive	comparison is inconclusive
100	0.023	0.023	2.309	0.461	comparison is inconclusive	comparison is inconclusive
140	0.022	0.022	2.222	0.444	base uncertainty warning	base uncertainty supported
180	0.023	0.023	2.255	0.451	base uncertainty warning	base uncertainty supported

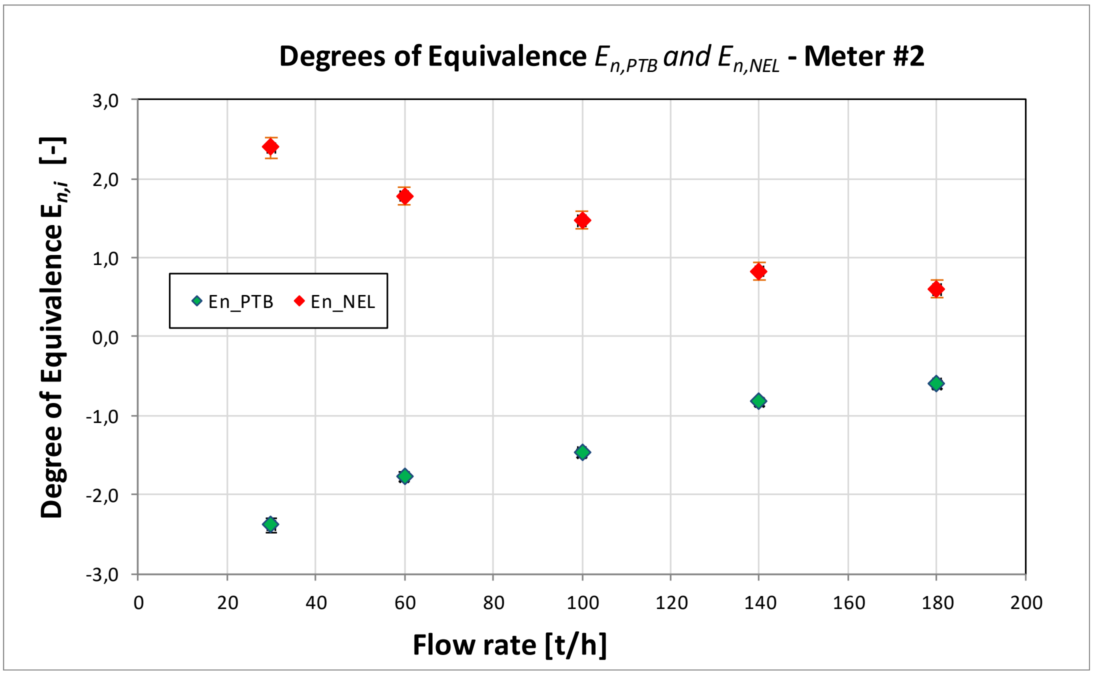

Figure 35: *Degrees of equivalence $E_{N.PTB}$ and $E_{n.NEL}$ of **Meter #2** with error bars of $u_{e.PTB}$.* respectively *$u_{e.PTB}$*

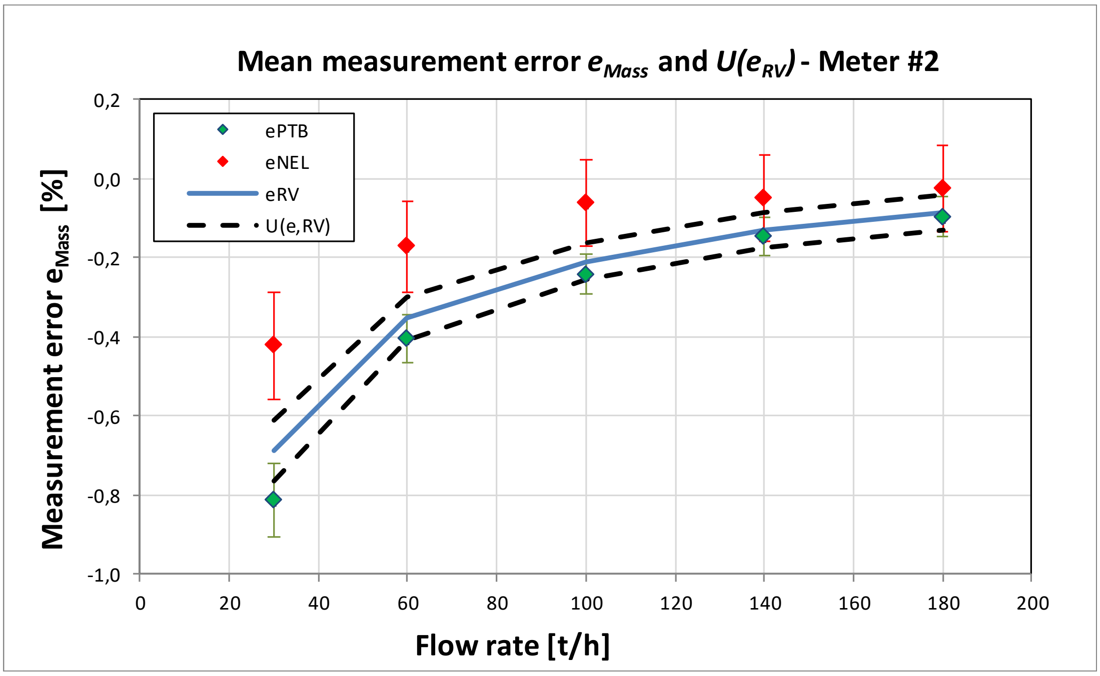

Figure 36: *Measurement error of $\overline{e}_{Vol}$ with error bars $U(\overline{e}_{Mass})$ for PTB and NEL of **Meter #2**. reference value e_{RV} and the area of the extended uncertainty of the reference value $U(e_{RV})$ – for **Meter #2***

5.4.3 Meter #3 (Coriolis. Endress+Hauser)

Date of measurement at PTB: 31.05.2012

Date of measurement at NEL: 17.04.2012

Flow measurement points: 30 m³/h. 60 m³/h. 100 m³/h. 140 m³/h. 180 m³/h

Standard uncertainty of PTB facility: $u_{base.PTB}$ = 0.01 % (k =1)

Standard uncertainty of NEL facility: $u_{base.NEL}$ = 0.05 % (k =1)

Table 13: *Estimation of standard uncertainty u_{MUT} for **Meter #3** - all values are based on the explanations to equations (12) and (13) with k = 1*

Nominal flowrate	**u(repeat)**		**u(reproduce)**		**u(temp)**		**u(press)**		**u(drift)**		**uMUT**
	Dates of test	**u(repeat)**	Dates of test	**u(reprod.)**	Dates of test	**u(temp)**	Dates of test	**u(press)**	Dates of test	**u(drift)**	
[m³/h]		[%]		[%]		[%]		[%]		[%]	[%]
30		0.009		0.005		0.007		0.003		0.051	0.052
60		0.004		0.004		0.007		0.004		0.041	0.042
100	31.05.12 07.06.12	0.002	07.06.12 02.04.12	0.006	15.03.13 02.04.13 25.03.13	0.006	02.04.13 03.04.13 04.04.13	0.001	31.05.12 07.06.12 02.04.13 15.05.13 16.05.13	0.032	0.033
140		0.001		0.006		0.006		0.001		0.028	0.030
180		0.001		0.006		0.005		0.001		0.026	0.027

Table 14: *Estimation of the comparison reference value e_{RV} for **Meter #2** - based on using equation (11)*

Nominal flowrate	**Measurement error $\bar{e}_{Vol}$**						**Uncertainty of $u_{e.i}$**		**Reference-value**	**Uncertainty of e_{RV}**
	Mean		Standarddev.		Number of measurements					k = 2
	$\bar{e}_{Mass}$ PTB	$\bar{e}_{Mass}$ NEL	σ - PTB	σ - NEL	n - PTB	n - NEL	$u_{e.PTB}$	$u_{e.NEL}$	e_{RV}	U_{eRV}
[m³/h]	[%]	[%]	[%]	[%]	[-]	[-]	[%]	[%]	[%]	[%]
30	0.022	0.054	0.019	0.001	5	3	0.054	0.072	0.034	0.086
60	0.038	0.072	0.008	0.002	5	3	0.043	0.065	0.048	0.072
100	0.033	0.082	0.003	0.001	5	3	0.034	0.060	0.045	0.060
142	0.036	0.083	0.004	0.001	5	3	0.031	0.058	0.047	0.055
180	0.036	0.066	0.002	0.002	5	3	0.028	0.057	0.042	0.051

***Table 15:** Estimation of the Degree of equivalence $E_{n.i}$ for **Meter #3** - based on equation (19)*

Nominal flowrate	**Differences to e_{RV}**		**Uncertainty of d_i**		**Uncertainty range of e_{RV}**		**Degree of equivalenz**	
	$d_i = \overline{e}_{Vol} - e_{RV}$		k = 2		k = 2		k = 2	
	d_{PTB}	d_{NEL}	$U(d_{PTB})$	$U(d_{NEL})$	$e_{RV} - U_{eRV}$	$e_{RV} - U_{eRV}$	$E_{n.PTB}$	$E_{n.NEL}$
[m³/h]	[%]	[%]	[%]	[%]	[%]	[%]	[-]	[-]
30	-0.011	0.020	0.064	0.116	-0.053	0.120	**-0.176**	**0.176**
60	-0.011	0.024	0.048	0.109	-0.024	0.120	**-0.221**	**0.221**
100	-0.012	0.037	0.034	0.104	-0.014	0.105	**-0.355**	**0.355**
140	-0.011	0.037	0.030	0.102	-0.009	0.102	**-0.360**	**0.360**
180	-0.006	0.024	0.026	0.101	-0.009	0.093	**-0.233**	**0.233**

Table 16:** Recommended CMC decision status based on comparison measurements of **Meter #3

Nominal flowrate	**u_{comp}**		**comparison uncertainty ratio $u_{comp}/u_{base.i}$**		**CMC decision status**	
	k = 1		k = 1			
	PTB	**NEL**	**PTB**	**NEL**	**PTB**	**NEL**
[m³/h]	[%]	[%]	[-]	[-]		
30	0.052	0.052	5.230	1.045	base uncertainty warning	base uncertainty supported
60	0.042	0.042	4.183	0.836	base uncertainty warning	base uncertainty supported
100	0.033	0.033	3.282	0.656	base uncertainty warning	base uncertainty supported
140	0.030	0.030	2.980	0.596	base uncertainty warning	base uncertainty supported
180	0.027	0.027	2.664	0.533	base uncertainty warning	base uncertainty supported

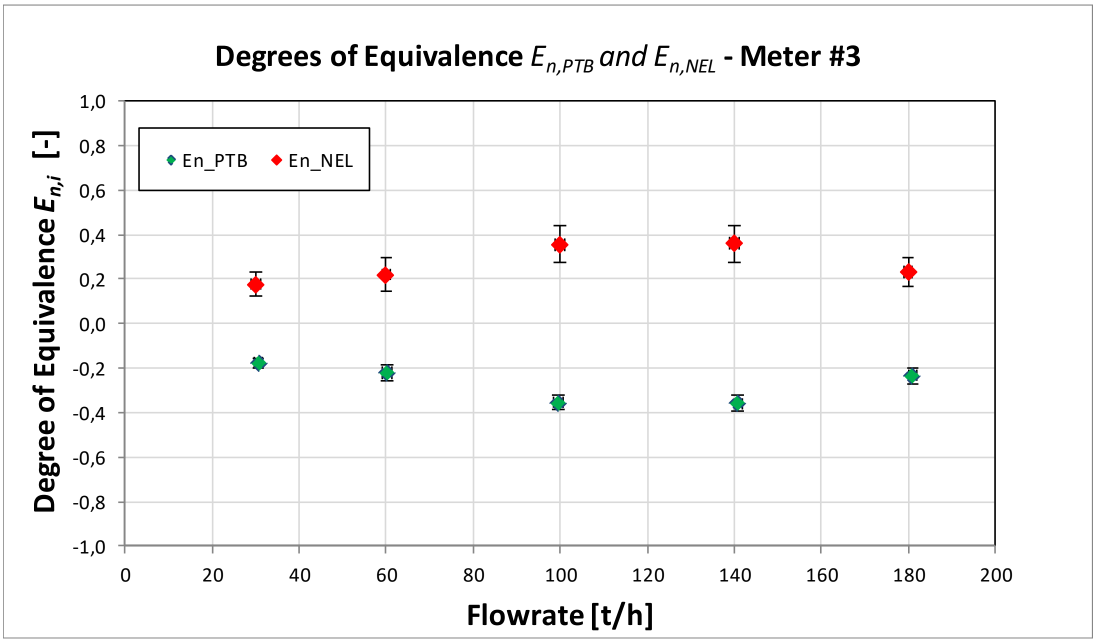

Figure 37: *Degrees of equivalence $E_{N.PTB}$ and $E_{n.NEL}$ of **Meter #3** with error bars of $u_{e.PTB}$. respectively $u_{e.PTB}$*

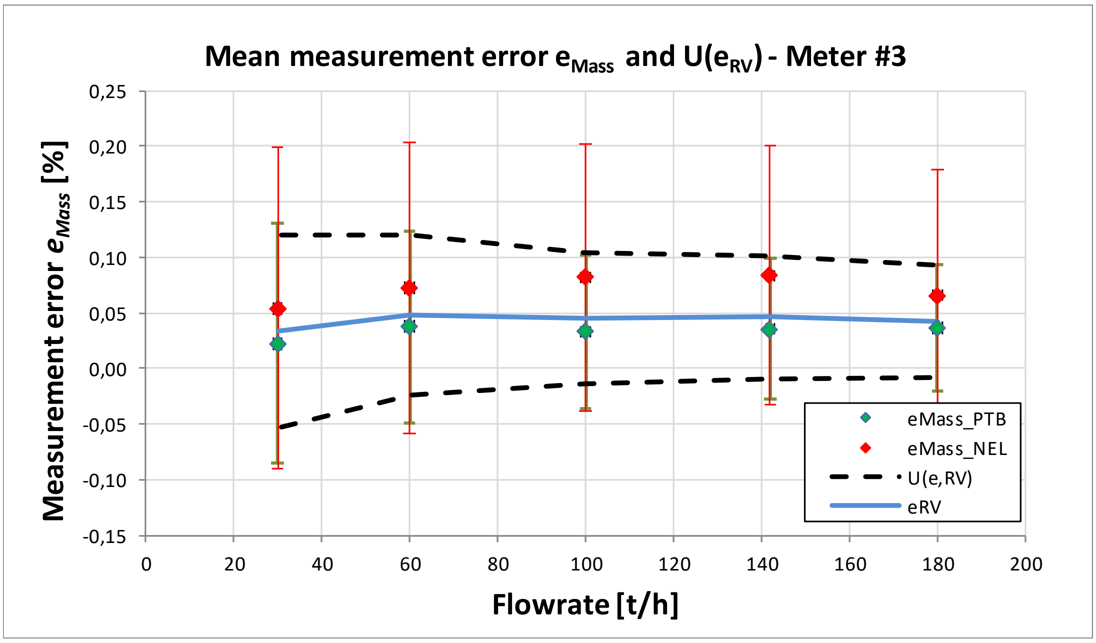

Figure 38: *Measurement error of $\overline{e}_{Vol}$ with error bars $U(\overline{e}_{Mass})$ for PTB and NEL of **Meter #3**. reference value e_{RV} and the area of the extended uncertainty of the reference value $U(e_{RV})$ – for **Meter #2***

6. CONCLUSION

Finally, it can be stated:

For NEL, the E_N values of meter #1 and meter #3 can be used for a verification of the facility CMC value (0.10 %, k = 2). For both meters the requirements of $|E_n| \leq 1$ and $u_{comp}/u_{base,i} \leq 2$ were complied.

For PTB CMC entries, the ratio of u_{comp}/u_{base} is larger than 2 for all meters. Which means, that all three meters in the present configuration of the measurement setup are not suitable for a confirmation of very low facility uncertainties. The data set show, that the meter drift is the most important parameter within the current investigation. An uncertainty u_{drift} of up to 0,056 % is to high for the given purpose within an international key comparison. It is recommended, that the instrumentation setup has to be refined to improve the meter uncertianty, especially u_{drift}. For that purpose, running investigations showed a positive influence of optimized flange connections to meter reproducibility.

7. REFERENCES

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