Project Title

PTB-VTT MIKES DN100 comparison

Coordinator, Institute, Country

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EURAMET Registration No.

1473

Subject Field

Flow

KCDB Identifier

EURAMET.M.FF-S13

Date

2022-02-14

Final report

EURAMET.M.FF-S13

Water flow: 30 m³/h … 200 m³/h

Pilot laboratory: VTT MIKES
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Kajaani / Braunschweig, January 2022

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1 Introduction and purpose

The purpose of the Supplementary Comparison (S13) for water flow measurement (Euramet 1473 and EURAMET.M.FF-S13) is to support the Calibration and Measurement Capabilities (CMC) entry of VTT MIKES, the National Metrology Institute of Finland. For this goal, a bilateral comparison between VTT MIKES and PTB Braunschweig was realized. The laboratory "Hydrodynamic Test Field" of the department 1.5 "Liquid Flow" will act as the reference facility.

The special issues of supplementary comparisons have been outlined in "Guidelines for CIPM key comparisons" [3] and include:

- Organization of a supplementary comparison;
- The technical protocol for a supplementary comparison;
- Circulation of the transfer standards;
- Reporting the results of a comparison;
- Preparation of the report on a supplementary comparison.

The basic subject of the calibrations was to determine the **meter *K*-factor** of the transfer flowmeters. Depending on the operating principle of the used Kmeters, following meter-*K*-factors were the subject of measurements and hade to be determined during calibrations:

Meter #1:

Turbine flow meter - volume-related frequency output:

K_V [pulses/unit volume]

Meter #2:

Coriolis flow meter:

a) mass-related frequency output:

K_m [pulses/unit mass]

b) volume-related frequency output:

K_V [pulses/unit volume]

<u>**Notes:**</u>

- The official SCDB identifier of the comparison is EURAMET.M.FF-S13.
- The calibration setup of this comparison was preliminary used within the K1 comparison CCM.FF-K1.2015 [1]. Measurement program and data analysis of EURAMET.M.FF-S13 is based on this previous comparison.
- Required inflow conditions could not be achieved at VTT MIKES with full installation of transfer standard. The inflow length for the turbine meter was not satisfactory and it can be seen on the measurement results for the turbine meter. **Thus, the results of Meter #1, Turbine flow meter are not taken into account in the comparison.**

2 Participants and measurement schedule

Participant list and measurement schedule are given in Table 1. After one year of preparation the comparison started officially in July 2019.

Table 1: Participant list and measurement periods of standard calibration program (day #1 until day #3 - Table 4) (* reference laboratory). Additional calibrations at reference laboratory are listed in Table 6.

NMI/DI	Country	RMO	Contact	Calibration period
PTB*	Germany	EURAMET	enrico.frahm@ptb.de	29.07.2019 – 31.07.2019
VTT MIKES	Finland	EURAMET	mika.huovinen@vtt.fi	31.10.2019 – 06.11.2019
PTB*	Germany	EURAMET	enrico.frahm@ptb.de	11.02.2020 – 13.02.2020

3 Description of the transfer standard

3.1 Transfer meter setup

The transfer meter setup (Figure 1) of the comparison consisted of a turbine flow meter (Figure 2) at the inflow and a Coriolis flow meter (Figure 3) at the outflow. The technical details of the meters are listed in Table 2 and Table 3. For flow conditioning, tube bundles were installed before and after the turbine meter. Beside the two transfer flow meters, all additional items were provided by the pilot laboratory:

- Pipework for meter installation (Figure 4)
- Cables for connecting transfer meters and the auxiliary devices to electronic boxes
- Electronic boxes 1 and 2 (Figure 5)

In order to provide optimum reproducibility conditions, the flow meters and the inter-connecting pipework were equipped with pin-in-hole alignment capabilities. The whole pipework consists of elements which were manufactured in stainless steel.

In addition to flow meters #1 and #2, auxiliary measurands for diagnostic purposes were included in the transfer meter setup:

- Water density (based on a signal delivered by the Coriolis flow meter)
- Fluid temperature by a temperature transmitter
- Fluid pressure by a pressure transmitter
- Pressure drop across the turbine meter by a differential pressure transmitter

A detailed description of the setup is given in the Technical Protocol of S13. The transfer standard used during the S13 comparison is the same meter setup as used in KC1 comparison. For more details see [1]

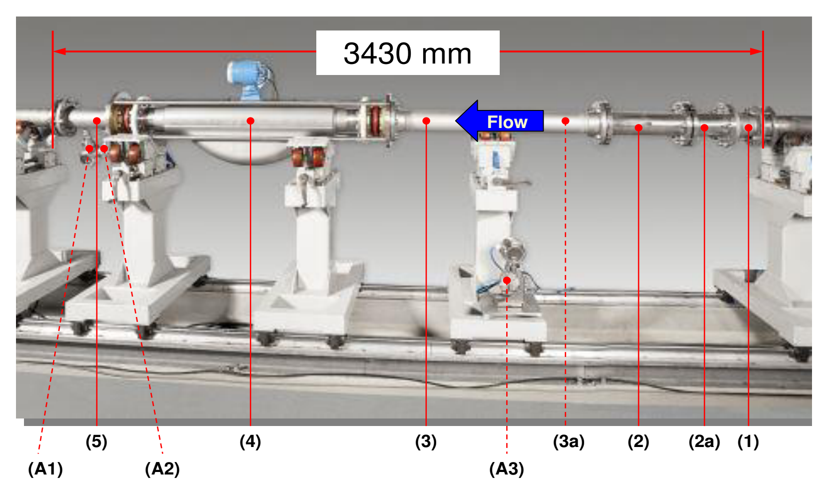


Figure 1: Transfer meter setup and pipework - Sample installation at the reference laboratory

(1) Inlet pipe section	(2) Turbine meter
(2a) Tube-bundle flow conditioner dedicated to the turbine	
(3) Connecting pipe section with	(3a) Integrated tube-bundle flow conditioner
(4) Coriolis flow meter	(5) Outlet pipe section

Auxiliary devices:
(A1) Pressure transmitter
(A2) Temperature transmitter
(A3) Differential pressure transmitter

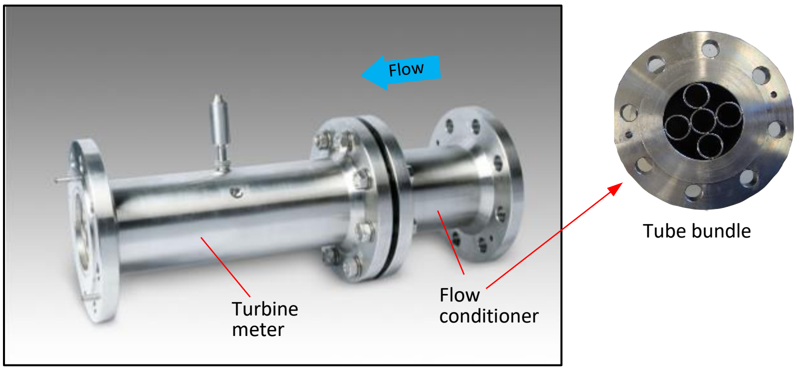


Figure 2: Transfer meter #1 - Turbine meter, DN100 mm

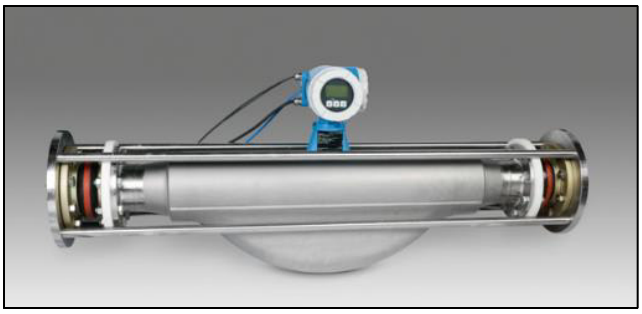


Figure 3: Transfer meter #2 - Coriolis flow meter, DN100 mm

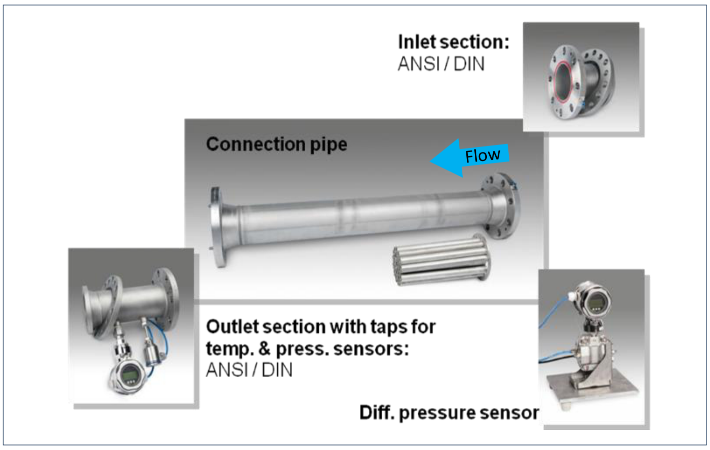


Figure 4: Transfer setup – pipework

Table 2: Transfer meter #1 - Turbine flow meter (Figure 2)

Manufacturer:	KEM Küppers Elektromechanik GmbH	Germany
Type:	HM 100.71.FDB40-TS15-P	
Serial No.:	010995521	
Pipe size:	DN100	Nominal: 100 mm
Signal pick-up:	Type: VTE*/P-Ex Carrier-frequency pulse amplifier Serial No.: 02497623	Signal voltage: ca. 24 V
Output signal:	Frequency	(0 Hz) … 450 Hz (at 240 m³/h)
	Nominal meter *K*-factor: $K_{\mathrm{V,nom}}$	**6.633 Pulses/l**
Additional equipment:	Tube-bundle flow conditioner	Permanently installed at the inflow to meter
Special provision:	Pin-in-hole alignment	Steel pins located in precision holes on both ends

Table 3: Transfer meter #2 - Coriolis flow meter (Figure 3)

Manufacturer:	ENDRESS + HAUSER	Switzerland
Type:	Proline Promass 83 F	
Serial No.:	D702C102000	
Pipe size:	DN100	Nominal: 100 mm
Signal output #1:	Mass-flowrate related: frequency	0 kHz … 10 kHz
	Nominal meter *K*-factor: $K_{m,nom}$	**100 Pulses/kg**
Signal output #2:	Volume-flowrate related: frequency	0 kHz … 10 kHz
	Nominal meter *K*-factor: $K_{V,nom}$	**100 Pulses/l**
Signal output #3:	Fluid density: current signal	4 mA … 20 mA
Communication line:	Reading parameters from flow meter	HART protocol (current output)
Special adoptions:	A cage-like meter extension in order to isolate the meter from external forces and torques	Rubber damping elements included
Special provision:	Pin-in-hole alignment	Steel pins located in precision holes on both ends

3.2 Additional data logging - Electronic boxes 1 and 2

An additional datalogging system was used for the reported S13. Beside standard impulse logging of the laboratory, an electronic device was provided by the reference laboratory for a separate and independent data recording. During the measurement at VTT MIKES, the transfer setup and the auxiliary devices were connected to electronical box 1.

Impulses of transfer meters and an additional process parameter, measured by the auxiliary devices (chapter 3.1), were logged by the electronic box 1 (Figure 5a and Figure 6a). Also, the power supply of the measurement instruments was provided by the box. The detailed use of the electronic box 1 is described in the S13 protocol.

Due to the diverse conditions of the laboratories (e.g. electronical compatibility), it was necessary to provide an alternative junction device. For the scenario, if the use of electronic box 1 did not operate in the intended function (power supply of the transfer meters and data logging), electronic box 2 (Figure 5b and Figure 6b) had to be used. Power supply of both flow meters and auto zero setting of the Coriolis meter were provided by electronic box 2. A detailed description of the box is also given within protocol of S13.

Both boxes were developed as parallel working systems, which do not affect the standard impulse counting recording of the laboratories. Tests at the pilot lab verified the use of both boxes. Any negative influence of the electronics or a significant deviation in impulse counting between the use of both boxes was not detected (Figure 7).

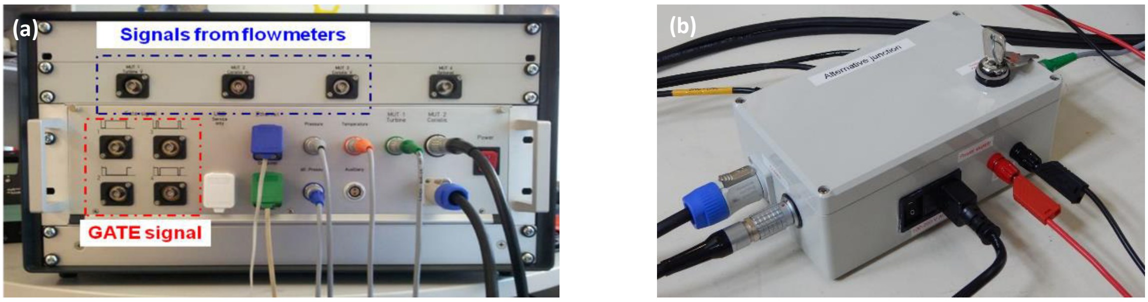


Figure 5: (a) Front side of electronic box 1
(b) Electronic box 2 (alternative junction) for power supply of both transfer meters and auto zero setting for the Coriolis meter

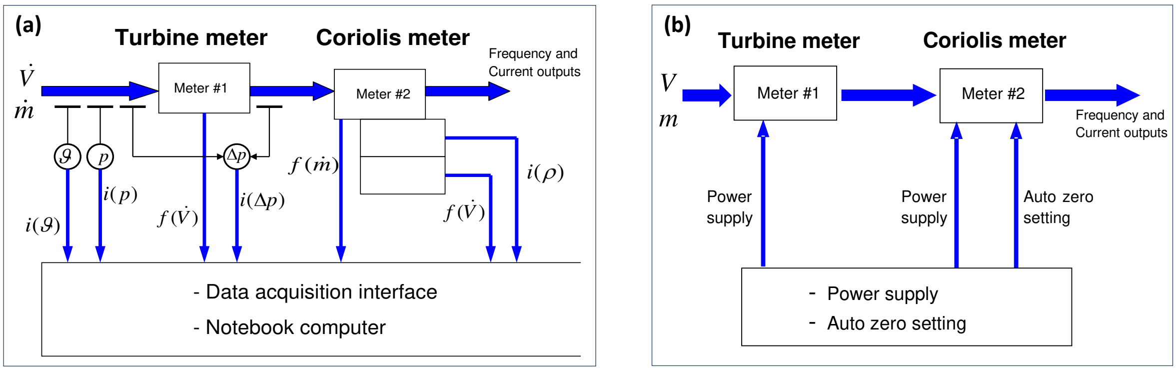


Figure 6: (a) Electronic Box 1 - Signal acquisition
(b) Electronic Box 2 - Power supply and function of auto zero setting

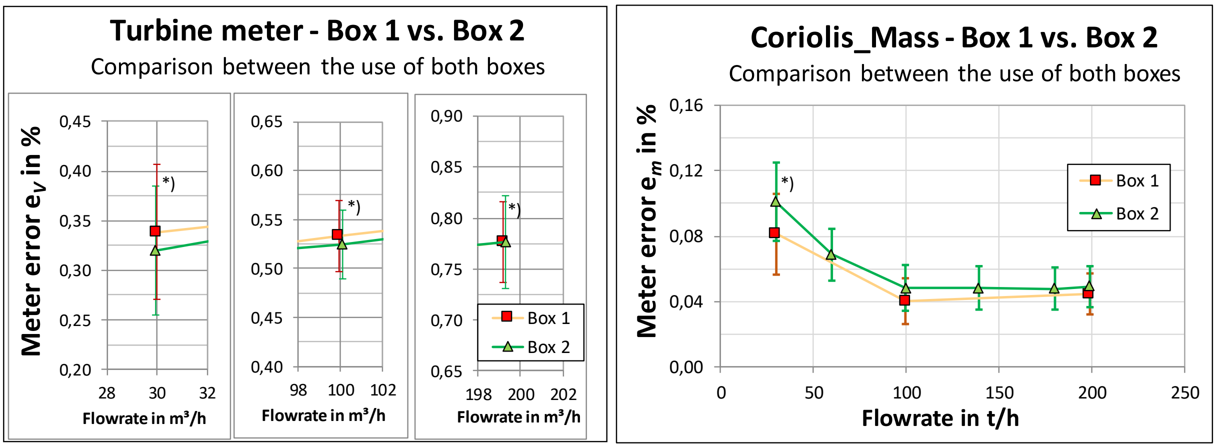


Figure 7: Meter error of repeated calibrations of turbine meter and Coriolis_Mass at reference laboratory – Calibrations using electronic box 1 and box 2 in 08/2016. *) represent uncertainties $u_{x,l}$ - Results are based on calibrations during CCM.FF-K1.2011

4 Measurement program

4.1 Calibration program at participated laboratories

The objective of the measurement program for S13 was to verify the CMC entries of VTT MIKES. Therefore, it was necessary to calibrate the setup under comparable measurement conditions. Both participants were asked to calibrate the transfer setup as far as possible under the following S13 reference conditions.

S13 reference conditions:

Fluid temperature: 20 °C

Line pressure: 3 bar (measured as positive back pressure after Coriolis meter)

Nominal flowrates: listed in Table 4

Setup: using the complete S13 setup (Figure 1).

Table 4: Main tasks and flowrates of calibration days for participated laboratories, defined in S13 manual

Calibration day	Main task	Preparations before calibration	Auto zero setting at Coriolis meter	Repeated measure-ments	Nominal flowrate in m³/h	Post-processing
Day #1	Lab-to-lab reproducibility	Installation of transfer meters	yes	5	30, 60, 100, 140, 180, 200	Transfer package remains in calibration line
Day #2	Main calibration of S13 and day-to-day reproducibility	-	no	5	30, 60, 100, 140, 180, 200	Transfer package remains in calibration line
Day #3	Repeatability at selected flowrates	-	no	10	30, 100, 200	Transfer package is removed from calibration line

4.2 Methods used for calibration in participated laboratories

During S13, each laboratory had to calibrate the setup by using their standard calibration method, which was subjected to the CMC entry (Table 5). Each laboratory provided the pilot laboratory with a description of the calibration procedure and an overview to calibration rig (Chapter 10.1.) All laboratories have an independent traceability in realization of their standards.

Table 5: Participated laboratories, calibration methods and CMC-values within the range of S13 flowrates

NMI/DI	Country	Calibration method and reference	CMC Water CIPM MRA Database (k = 2)	
			U(Mass) in %	U(Volume) in %
PTB	Germany	Gravimetric / flying-start-stop	0.020	0.020
VTT MIKES	Finland	Gravimetric / flying-start-stop	0.050	0.050

4.3 Meter characterisation at reference laboratory

The transfer setup was subjected to extensive characterisation measurements at reference laboratory (Table 6). Because the transfer setup used in the S13 comparison is the same meter as used in the KC1 comparison, some of the characterisation results measured during KC1 were adopted. All of these calibrations were made under clearly defined conditions, which are derived from KC1 reference conditions. The goal of the characterisation measurements was to analyze the impact of the following parameters to transfer meter setup: fluid temperature, line pressure, reproducibility and changing inflow conditions. The results aimed at a detailed knowledge about the meter uncertainties u_{TS}.

During meter characterisation, the influences of different inflow conditions to meter setup were evaluated. In order to simulate a wide range of real flow conditions, transfer setup was calibrated with several flow disturber (Figure 8) and inflow lengths (Figure 9). The calibrations were made in S13 reference conditions as listed in chapter 4.1.

Table 6: Characterisation and extended measurements at reference laboratory

Task of calibrations	Nominal flowrate in m³/h	Temperature in °C	Line pressure in bar	Repeated measu-rements	Measurement periods at reference laboratory
Temperature dependency	30, 60, 100, 140, 180	10, 15, 20, 25, 30	3	5	13.03.2013 - 02.04.2013
	30, 60, 100, 140, 180, 200, 240	15, 20, 25	3	5	13.01.2015 - 19.01.2015
	30, 60, 100, 140, 180, 200	10, 20, 30	3	5	22.02.2019 - 01.03.2019
Pressure dependency	30, 60, 100, 140, 180	20	2, 3, 4	5	02.04.2013 - 04.04.2013
	30, 60, 100, 140, 180, 200	20	2, 3, 4	5	13.04.2018 - 18.04.2018
Inflow conditions	30, 100, 200	20	3	5	11.03.2019 – 29.03.2019

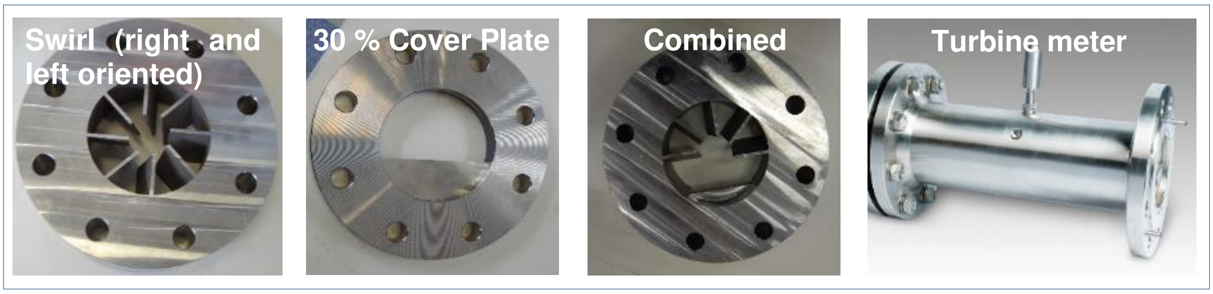


Figure 8: Used flow disturber for meter characterisation – inner diameter: 100 mm

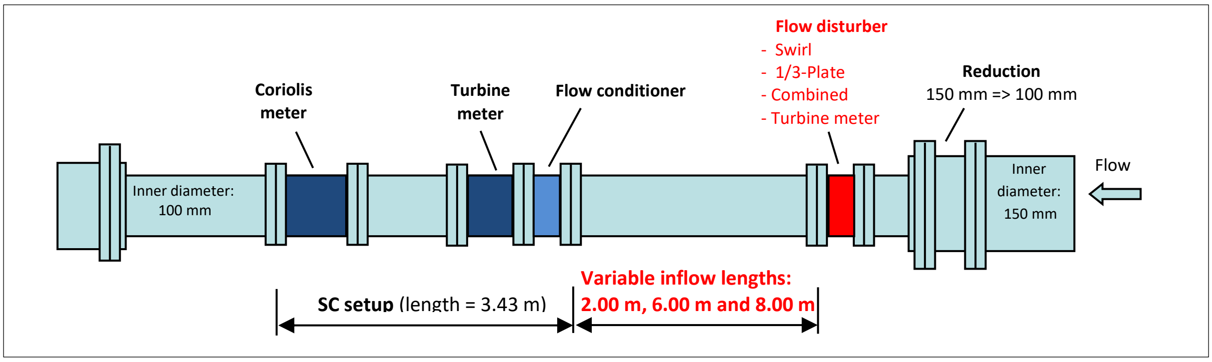


Figure 9: Calibration setup for meter characterisation – influences of different inflow lengths to transfer setup

5 Data calculation and evaluation criteria

5.1 Meter *K*-factor and temperature correction for final meter error x_i

According to the flowrates of Table 4, the meter *K*-factor was calculated for each calibration by using Equation (1) for turbine meter and by Equation (2) for Coriolis meter.

$$K_V = \frac{N}{(V_{ref} \cdot 1000)} \tag{1}$$

$$K_m = \frac{N}{m_{ref}} \tag{2}$$

where K_V - *K*-factor of turbine meter (pulses/l)
K_m - *K*-factor of Coriolis meter (pulses/kg)
N - Counted number of pulses of the transfer meter (pulses)
V_{ref} - Volume, measured by the reference standard (m^3)
m_{ref} - Mass, measured by the reference standard (kg)

The relative measurement error *e* was calculated for each *K*-factor by:

$$e_V = \frac{K_V - K_{V,nom}}{K_{V,nom}} \cdot 100\ \% \tag{3}$$

$$e_m = \frac{K_m - K_{m,nom}}{K_{m,nom}} \cdot 100\ \% \tag{4}$$

where e_V - Relative measurement error for turbine meter (%)
e_m - Relative measurement error for Coriolis meter (%)
$K_{V,nom}$ - Nominal *K*-factor for turbine meter (pulses/l)
$K_{m,nom}$ - Nominal *K*-factor for Coriolis mass (pulses/kg)

Both transfer meters are characterized by a clear and systematic temperature dependency in meter error (for detailed description see Section 6.3). **All reported meter errors of participated laboratories were corrected by applying Equation (19) until (22) and Table 12**, to aim a temperature corrected meter error $e_{V,cor}$ for volume and $e_{m,cor}$ for mass.

For final evaluation of E_N, a mean meter error (x_i) was calculated separately for each laboratory, transfer meter and flowrate (Equation 5), **based on calibration results of Day #1 and Day #2** (Table 4).

$$x_i = \frac{\sum_{i=1}^{n}(e_{cor})}{n} \tag{5}$$

where x_i - Temperature corrected meter error for EN-value evaluation
n - Number of measurements at calibrated test point
i - Laboratory index

5.2 Uncertainty $u_{x,i}$ of reported and temperature corrected value x_i

As described in [2], [3] and [4], the uncertainty of reported value x_i includes uncertainties introduced by the participant`s flow reference ($u_{base,i}$), by transfer meter (u_{TS}) and by repeatability of the reported value (Equation 1). Used input parameter of $u_{base,i}$ are given in Table 5. Uncertainty calculations of u_{TS} are

based on Equation (7) **for Turbine meter, respectively for Coriolis meter, on Equation** (16)**. Final values of u_{TS} are given in Table 7 and**

Table 8. The term $\frac{s}{\sqrt{n}}$ (Equation 6) represents the repeatability of measurements made in the participants laboratory [4], based on calibration results of Day #1 and Day #2 (Table 4).

$$u_{x,i} = \sqrt{u_{base,i}^2 + u_{comp}^2} = \sqrt{u_{base,i}^2 + u_{TS}^2 + \frac{s^2}{n}} \qquad \textbf{(6)}$$

where
$u_{x,i}$ - Uncertainty of reported and temperature corrected meter error (%)
$u_{base,i}$ - Uncertainty of laboratory refence, here it is equal to CMC_i (%)
u_{comp} - Uncertainty of transfer meter measurements (%)
s - Standard deviation of the mean of measurements at one flowrate point (%)
n - Number of calibrations at one flowrate point (%)

All values of *u* are valid for k = 1.

5.3 Determination of Supplementary Comparison reference value (SCRV) and it`s uncertainty

The Supplementary Comparison reference value was calculated at each flow rate of Table 4, following procedure A of [5]. All reported calibration results (day #1 and day #2) were used for determination of SCRV and its uncertainty, because all participated laboratories declared their independent traceability chains to SI.

The reference value y was calculated as weighted mean error of the participated laboratories, including standard uncertainties u(x_i) of the measurements as the weights:

$$y = \frac{\left(\frac{x_1}{u_{x,1}^2} + \frac{x_2}{u_{x,2}^2} + \ldots + \frac{x_i}{u_{x,i}^2}\right)}{\left(\frac{1}{u_{x,1}^2} + \frac{1}{u_{x,2}^2} + \ldots \frac{1}{u_{x,i}^2}\right)} \qquad \textbf{(7)}$$

where y - Reference value of the comparison (%)

The standard uncertainty u_y is given with:

$$\frac{1}{u_y^2} = \frac{1}{u_{x,1}^2} + \frac{1}{u_{x,2}^2} + \ldots + \frac{1}{u_{x,i}^2} \qquad \textbf{(8)}$$

where u_y - Standard uncertainty of y with k = 1 (%)

The expanded uncertainty of y was calculated with:

$$U(y) = 2 \cdot u_y \qquad \textbf{(9)}$$

where U(y) - Expanded uncertainty of y with k = 2 (%)

5.4 Determination of differences „Lab to SCRV“ as degree of equivalence (DoE)

Differences between laboratories results (x_i) and SCRV (x_{SCRV}) were calculated in accordance with Equation (10), separately for each flow meter and flowrate. The results give the degree of equivalence (DoE) of each laboratory.

$$d_i = x_i - x_{SCRV} \qquad \textbf{(10)}$$

where d_i - Degree of equivalence (DoE) for each laboratory *i* in %

Based on differences d_i, the normalized Degree of Equivalence $E_{N,i}$ was calculated for each laboratory and flowrate with:

$$E_{N,i} = \frac{d_i}{U(d_i)} \tag{11}$$

where $E_{N,i}$ - Normalized Degree of Equivalence

The calculated differences of d_i are followed by specific uncertainties, which can be analyzed by a consideration of the general problem of the difference between two values x_1 and x_2. The pure propagation of the uncertainty (with k = 1) is given by Equation (12). Finally, the uncertainty of the difference is the quadratic sum of the uncertainties of u_1 and u_2 and subtracting twice the covariance between the two input values.

$$u_{x1-x2}^2 = \left[\frac{\partial(x_1 - x_2)}{\partial x_1} \quad \frac{\partial(x_1 - x_2)}{\partial x_1}\right] \begin{pmatrix} u_1^2 & cov \\ cov & u_2^2 \end{pmatrix} \begin{bmatrix} \frac{\partial(x_1 - x_2)}{\partial x_1} \\ \frac{\partial(x_1 - x_2)}{\partial x_1} \end{bmatrix} = u_1^2 + u_2^2 - 2 \cdot cov \tag{12}$$

The value of covariance is identical to the value of measurement uncertainty related to SCRV for the independent participating labs which took part in the SCRV determination. Based on Equation (12), the extended uncertainty of d_i was calculated with Equation (13) for laboratories with contribution to the SCRV. Participating labs, which were excluded from the SCRV determination, do not have any interference. In that case, the value of $U(d_i)$ would be calculated according to equation (14).

$$U(d_i) = 2 \cdot \sqrt{u_{x,i}^2 + u_{KCRV}^2 - 2 \cdot u_{KCRV}^2} = 2 \cdot \sqrt{u_{x,i}^2 - u_{KCRV}^2} \tag{13}$$

$$U(d_i) = 2 \cdot \sqrt{u_{x,i}^2 + u_{KCRV}^2} \tag{14}$$

5.5 Evaluation of comparison data

For final data evaluation and decision table, the following criteria were used - based on [3], [4] and [5]:

- The participant **passes the comparison if** $|E_{N,i}| \leq$ **1.0 and** $u_{comp}/u_{base} \leq$ **2**

  The results of participated laboratory *i* agrees within a 95 % confidence level uncertainty expectations with the SCRV (k = 2).

- The participant passes the comparison at **“warning level” if 1.0 <** $|E_{N,i}| \leq$ **1.2 and** $_{comp}/u_{base} \leq$ **2**

- The participant **fails the comparison if** $|E_{N,i}| \leq$ **1.2 and** $u_{TS}/u_{base} >$ **2**

  The results are inconclusive, because the transfer meter did not show sufficiently low uncertainties to discern lab to SCRV below certain level.

- The participant **fails the comparison if** $|E_{N,i}| >$ **1.2**

  The results do indicate that the agreement is outside of uncertainty expectations.

6 Laboratory conditions, transfer meter characteristics and meter uncertainties

In accordance to the WGFF recommendation for comparison calculations [3], the standard uncertainty u_{TS} of the transfer meter is the root-sum-of-squares (RSS) of several transfer meter characteristics. For this comparison the considered meter characteristics and input uncertainties of turbine meter are given in Equation (15), for Coriolis meter in Equation (16). The final values of u_{TS} were calculated separately for each flowrate (Table 7 and Table 8).

<u>Note:</u> The uncertainties of u_{TS} are specified and valid for the presented comparison under the given measurement conditions. The values of u_{TS} may change if the setup or calibration conditions do deviate to this comparison.

$$Turbine\ meter: \quad u_{\mathrm{TS}} = \sqrt{u_{\mathrm{drift}}^2 + u_{\mathrm{reprod}}^2 + u_{\mathrm{temp}}^2 + u_{\mathrm{pres}}^2 + u_{\mathrm{flow}}^2 + u_{\mathrm{inflow}}^2} \qquad \mathbf{(15)}$$

$$Coriolis_{Mass}: \quad u_{\mathrm{TS}} = \sqrt{u_{\mathrm{drift}}^2 + u_{\mathrm{reprod}}^2 + u_{\mathrm{temp}}^2 + u_{\mathrm{pres}}^2 + u_{\mathrm{flow}}^2} \qquad \mathbf{(16)}$$

where

u_{TS}	- Uncertainty of transfer meter (%)
u_{drift}	- Uncertainty due to drift of transfer meter (%)
u_{reprod}	- Uncertainty due to reproducibility characteristics of transfer meter (%)
u_{Temp}	- Uncertainty caused by temperature characteristics of transfer meter (%)
u_{pres}	- Uncertainty caused by pressure characteristics of transfer meter (%)
u_{flow}	- Uncertainty due to sensitivity of transfer meter to instable flow conditions (%)
u_{inflow}	- Uncertainty due to sensitivity of turbine meter to different inflow conditions (%)

All values of *u* are valid for k = 1.

Table 7: Final values of meter uncertainties u_{TS} for turbine meter (with *k* = 1)

	Meter uncertainty u_{TS}		**Input uncertainties for u_{TS}**				
Nominal flowrate in m³/h	**Turbine meter** considering of u_{inflow} **in %**	**Turbine meter** without u_{inflow} **in %**	u_{drift} **in %**	u_{reprod} **in %**	u_{temp} **in %**	u_{pres} **in %**	u_{flow} **in %**
30	0.099	0.020	0.002	0.004	0.012	0.012	0.012
60	0.098	0.018	0.004	0.002	0.005	0.012	0.012
100	0.098	0.019	0.003	0.001	0.009	0.012	0.012
140	0.098	0.019	0.003	0.001	0.010	0.012	0.012
180	0.098	0.017	0.003	0.001	0.003	0.012	0.012
200	0.098	0.017	0.005	0.002	0.002	0.012	0.012

Table 8: Final values of meter uncertainties u_{TS} for Coriolis_Mass (with *k* = 1)

	Meter uncertainty u_{TS}	**Input uncertainties for u_{TS}**				
Nominal flowrate in m³/h	**Coriolis_Mass in %**	u_{drift} **in %**	u_{reprod} **in %**	u_{temp} **in %**	u_{pres} **in %**	u_{flow} **in %**
30	0.016	0.006	0.002	0.013	0.006	0.002
60	0.011	0.005	0.001	0.007	0.006	0.002
100	0.009	0.003	0.001	0.005	0.006	0.002
140	0.008	0.002	0.000	0.004	0.006	0.002

180	0.007	0.002	0.001	0.002	0.006	0.002
200	0.007	0.003	0.001	0.001	0.006	0.002

6.1 Drift of transfer meter - uncertainty u_{drift}

The uncertainty due to meter drift u_{drift} was quantified by performing repeated calibrations at reference laboratory (Table 1), using the reference standard as described in Figure 1. For each calibration period, a mean value was calculated (Figure 10 and Figure 11). The final values of u_{drift} (Table 9) were calculated by using Equation (17), separately for each flow meter and flowrate.

$$u_{drift} = \frac{Max\,(e_{cor}) - Min\,(e_{cor})}{2 \cdot \sqrt{3}} \qquad \textbf{(17)}$$

where u_{drift} - Uncertainty (k = 1) due to long term stability of transfer meter (%)

e_{cor} - Temperature corrected meter error (%)

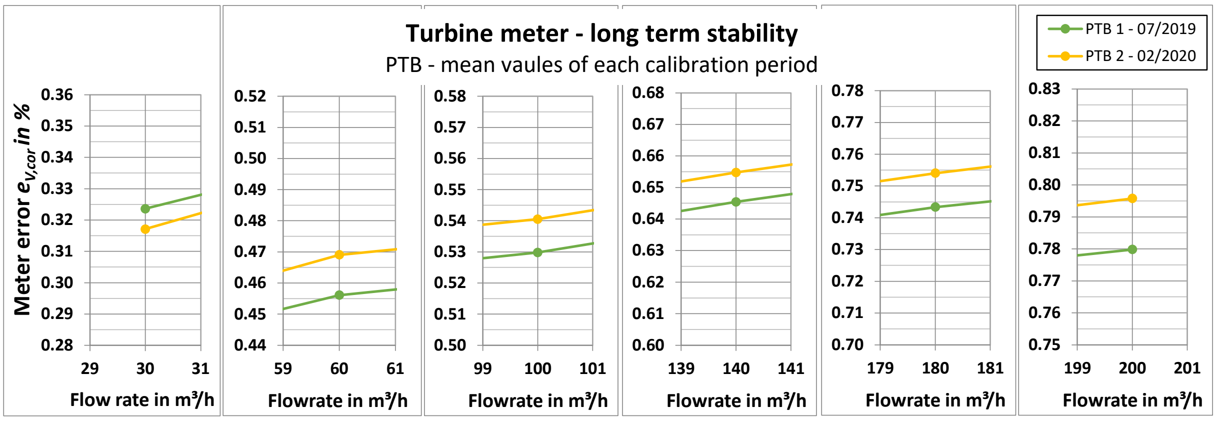


Figure 10: Long term stability of turbine meter - Mean values of temperature corrected meter error $e_{V,cor}$ for each calibration period, measured at PTB laboratory (day #1 until day# 3)

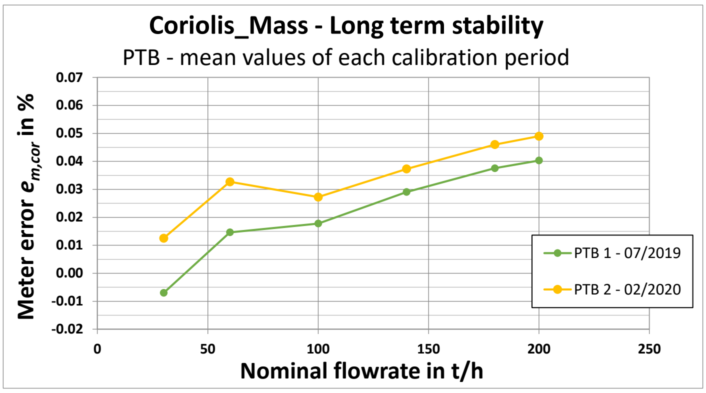


Figure 11: Long term stability of Coriolis_Mass – Mean values of temperature corrected meter error $e_{m,cor}$ for each calibration period, measured at PTB laboratory (day #1 until day# 3)

Table 9: Uncertainties of $u_{TS,drift}$ caused by drift of meter error – turbine meter and Coriolis_Mass

	Nominal Flowrate					
k = 1	**30 m³/h**	**60 m³/h**	**100 m³/h**	**140 m³/h**	**180 m³/h**	**200 m³/h**
u_{drift} **Turbine meter in %**	0.002	0.004	0.003	0.003	0.003	0.005
u_{drift}	0.006	0.005	0.003	0.002	0.002	0.003

Coriolis_Mass in %						

6.2 Quantification of reproducibility - uncertainty u_{reprod}

The uncertainty due to reproducibility characteristics u_{reprod} of the transfer meter were estimated at reference laboratory by additional calibrations during days #4 to #6. For each period of these calibrations, a span of meter error $[Max(e_{cor}) - Min\,(e_{cor})]$ was calculated (Figure 12). Because of non-normal distributed data, the uncertainty u_{reprod} was calculated separately for each flow rate by using maximum values of observed span (Equation 18). It was assumed that the final values of u_{reprod} (Table 10) do include the following sources of uncertainty: short term drift, setting of auto zero (at Coriolis meter) and reassembly of the transfer setup.

The presented results of u_{reprod} are based on data analysis during KC1 comparison.

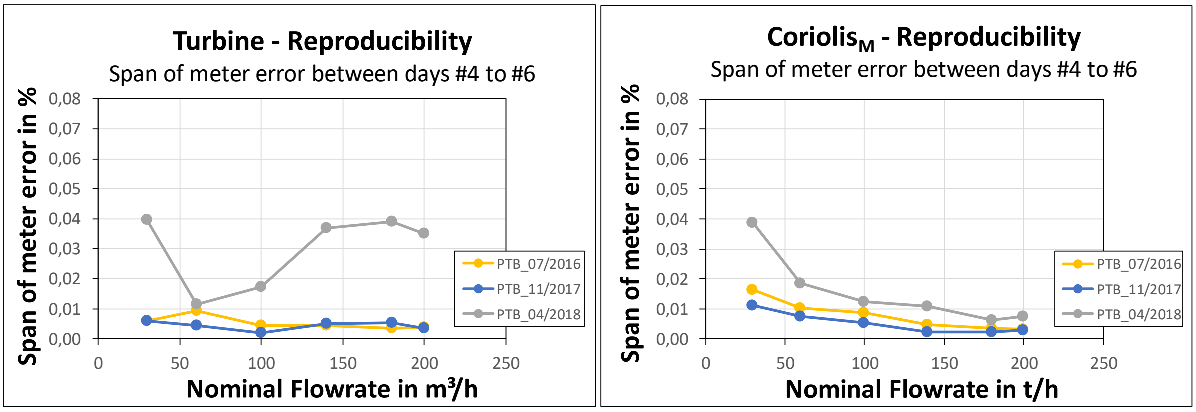


Figure 12: Results of reproducibility calibrations at pilot laboratory – Span of meter error (max – min) between calibration days #4 until #6

$$u_{TS,reprod} = \frac{Max\,[Max(e_{cor}) - Min\,(e_{cor})]}{2\cdot\sqrt{3}} \qquad \textbf{(18)}$$

where u_{reprod} - Uncertainty (k = 1) due to reproducibility characteristics of transfer meter (%)
e_{cor} - Temperature corrected meter error (%)

Table 10: Uncertainties of u_{reprod} due to reproducibility characteristics of the transfer meters

	Nominal Flowrate					
k = 1	**30 m³/h**	**60 m³/h**	**100 m³/h**	**140 m³/h**	**180 m³/h**	**200 m³/h**
$u_{TS,reprod}$ **Turbine meter in %**	0.011	0.003	0.005	0.011	0.011	0.010
$u_{TS,reprod}$ **Coriolis_Mass in %**	0.011	0.005	0.004	0.003	0.002	0.002

6.3 Temperature dependency - uncertainty u_{Temp}

Laboratory conditions

During calibrations, the span of fluid temperature in participated laboratories ranged between 19.81 °C and 21.85 °C. The maximum variation of fluid temperature within a participating lab, expressed as $T_{\mathrm{fluid,max}}$ - $T_{\mathrm{fluid,min}}$, was reported with 2.04 °C (Table 11,
Figure **13**).

Table 11: Fluid temperatures T_{fluid} (°C) in participating laboratories during calibrations

NMI	PTB_1	MIKES
Max	20.12	21.85
Min	19.97	19.81
Max-Min	0.16	2.04
Mean	20.06	20.39

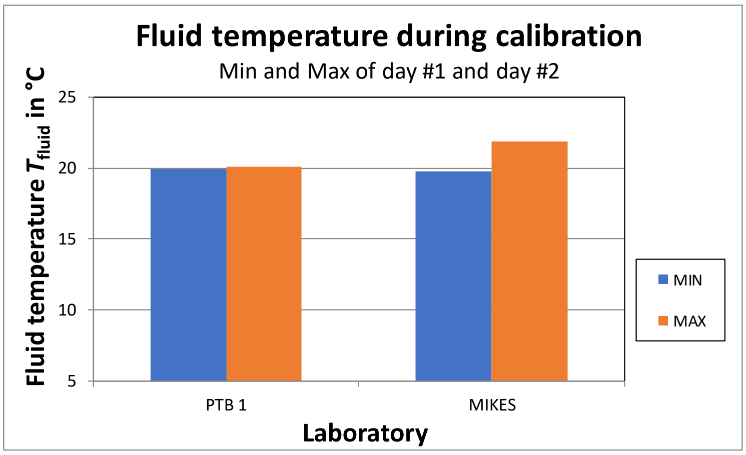


Figure 13: Fluid temperature T_{fluid} during calibrations in participated laboratories – Maximum and minimum of calibration day #1 and day #2

Meter characteristics

The main temperature characterisation measurements were realized in reference laboratory in 2013 (during calibration for KC1). The results were evaluated by calibrations in 2015 and 2019 (Table 6). The goal of characterisation measurements was to analyze meter error characteristics if the fluid temperature deviates from nominal temperature. Both meters showed a distinctive dependency of meter error due to changes in fluid temperature (Figure 14). The maximum range of fluid temperature T_{fluid} at participated laboratories of +/-2 °C (
Figure **13**). Based on data analysis for KC1, the reported calibration data were temperature corrected. The procedure of this correction was practiced as follows.

The correction is based on the relationship between a) the deviation ΔT_{Fluid} (Equation 19) of current fluid temperature T_{Fluid} to nominal temperature T_{nom} and b) the deviation Δe_{nom} (Equation 20) of meter error at current temperature conditions e to meter error e_{nom}, calibrated at nominal temperature. The relationship between ΔT and Δe_{nom} was analyzed separately for each transfer meter and flow rate by fitting a second-degree polynomial function using least squares fits (

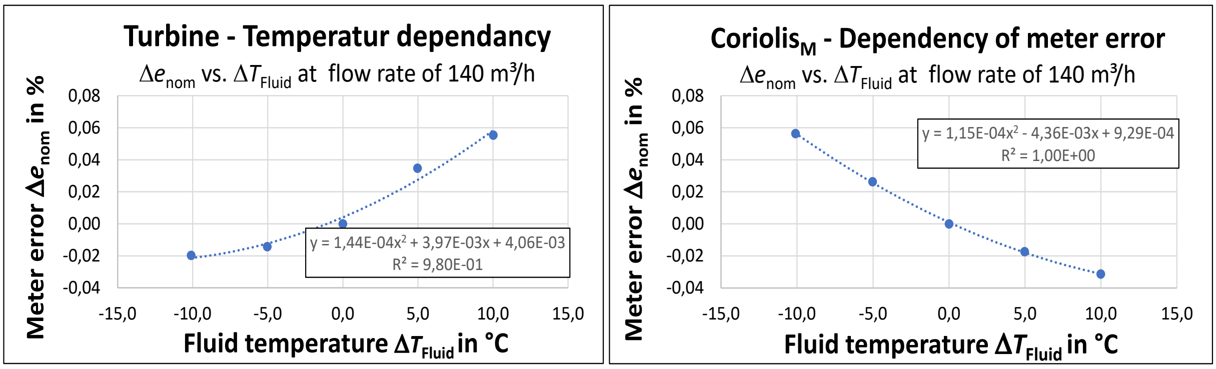


Figure 15). The resulting model parameter of Table (16) were used to calculate a correction value of meter error Δe_{cor} Equation (21). Finally, the meter error e at current temperature conditions was corrected to meter error e_{cor} at nominal temperature conditions by applying Equation (22).

$$\Delta T_{fluid} = T_{fluid} - T_{nom} \tag{19}$$

where ΔT_{fluid} - Difference of current fluid temperature to nominal temperature of 20 °C (°C)
T_{fluid} - Current fluid temperature (°C)
T_{nom} - Nominal temperature of 20°C

$$\Delta e_{nom} = e - e_{nom} \tag{20}$$

where Δe_{nom} - Difference of meter error (%)
e - Meter error at current temperature conditions (%)
e_{nom} - Meter error at nominal temperature of 20 °C (%)

$$\Delta e_{cor} = a + b \cdot \Delta T_{fluid} + c \cdot \Delta T_{fluid} \tag{21}$$

where Δe_{cor} - Correction value of meter error (%)
a, b, c - Parameter of fitted polynomial model (Table 12) (-)

$$e_{cor} = e - \Delta e_{cor} \tag{22}$$

where e_{cor} - Temperature corrected meter error (%)

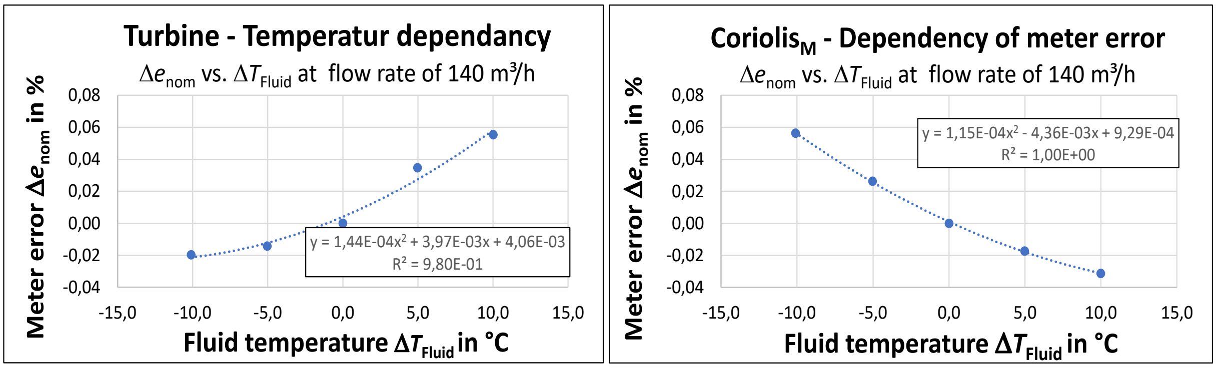


Figure 14: Temperature dependencies of turbine meter and Coriolis_Mass - Differences of meter error Δe_{nom}, expressed as results of Equation (20). All calibrations made at reference laboratory/PTB in 2013.

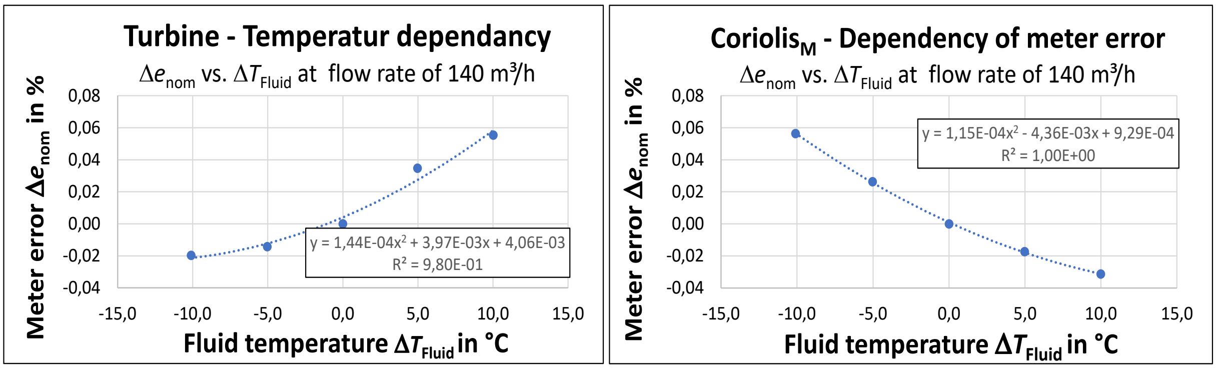


Figure 15: Temperature dependencies of Turbine meter and Coriolis_Mass - Example relationships between ΔT_{Fluid} and Δe_{nom} at flowrate of 140 m^3/h (Equation **19** and Equation **20**) in order to estimate model parameters of Equation **(**21).

Table 12: Model Parameter for temperature dependent correction of meter error *e* by using Equation **(**20) until (22). Because no calibrations at 200 m³/h were made in 2013, parameter at flow rate of 200 m³/h were assumed to be equal to parameter at 180 m³/h.

	Turbine meter – model parameter			**Coriolis_Mass – model parameter**		
Nominal flowrate in m³/h	**a**	**b**	**c**	**a**	**b**	**c**
30	1.41E-02	-2.64E-03	1.09E-04	-6.69E-03	-4.38E-03	9.32E-05
60	-4.89E-03	-1.15E-03	1.89E-04	-4.44E-03	-5.71E-03	1.86E-04
100	2.89E-03	-4.52E-04	1.21E-04	-1.77E-05	-4.57E-03	1.18E-04
140	4.06E-03	3.97E-03	1.44E-04	9.29E-04	-4.36E-03	1.15E-04
180	1.40E-03	3.91E-03	-3.58E-05	4.40E-04	-4.28E-03	5.32E-05
200(*)	1.40E-03	3.91E-03	-3.58E-05	4.40E-04	-4.28E-03	5.32E-05

Meter uncertainty u_{temp}

The presented method was successfully applied during model evaluation by using the temperature characterisation measurements at reference laboratory in 2015 and 2019 (Figure 17). Especially for Coriolis_Mass, a meter uncertainty reduction (u_{temp}) of up to 92 % was gained, if the meter error *e* was corrected by the described method. This clear improvement of u_{temp} over full flow scale can be explained by the distinctive temperature dependency of the Coriolis meter. Additionally, the low variations of u_{temp} between several evaluation years of 2013, 2015 and 2019 (Figure 17) underlines the long term stability of the investigated model parameters, presented in Table 12.

The calculation of u_{TS} itself is based on the following procedure and assumptions. The temperature range of reported laboratory data T_{fluid} does not exceed the investigated range of 20°C +/- 10 °C during characterisation measurements at reference laboratory (

Figure **13**). As already shown, within this range both meters showed a characteristic temperature sensitivity of meter error (Figure 14). The sensitivities of original meter error *e* and corrected meter error e_{cor} can also be expressed as specific model residuals $e_{residiual}$ to mean values over all temperatures (Equation 23 and Figure 16). Maximum and minimum values of $e_{residiual}$ were used to calculate u_{temp} with an assumption of a rectangular probability distribution (Equation 24).

The described procedure was practiced, separately for each flow rate and calibration period in 2013, 2015 and 2019. Based on corrected meter errors, the maximum uncertainties of the years 2013, 2015 and 2019 were taken as final values for u_{temp} (Table 13).

For calculation of E_N values, all reported meter errors *(e_V and e_m)* of participated laboratories were corrected by the described method (Equations 19 until 24).

$$e_{residual} = e - e_{mean} \quad \textbf{(23)}$$

where $e_{residual}$ - Model residuals (%)
e_{mean} - Mean values of meter error at one flow rate over all temperatures (%)

$$u_{temp} = \frac{max(e_{residual}) - min(e_{residual})}{2\sqrt{3}} \quad \textbf{(24)}$$

where u_{temp} - Meter uncertainty caused by temperature effects (%)

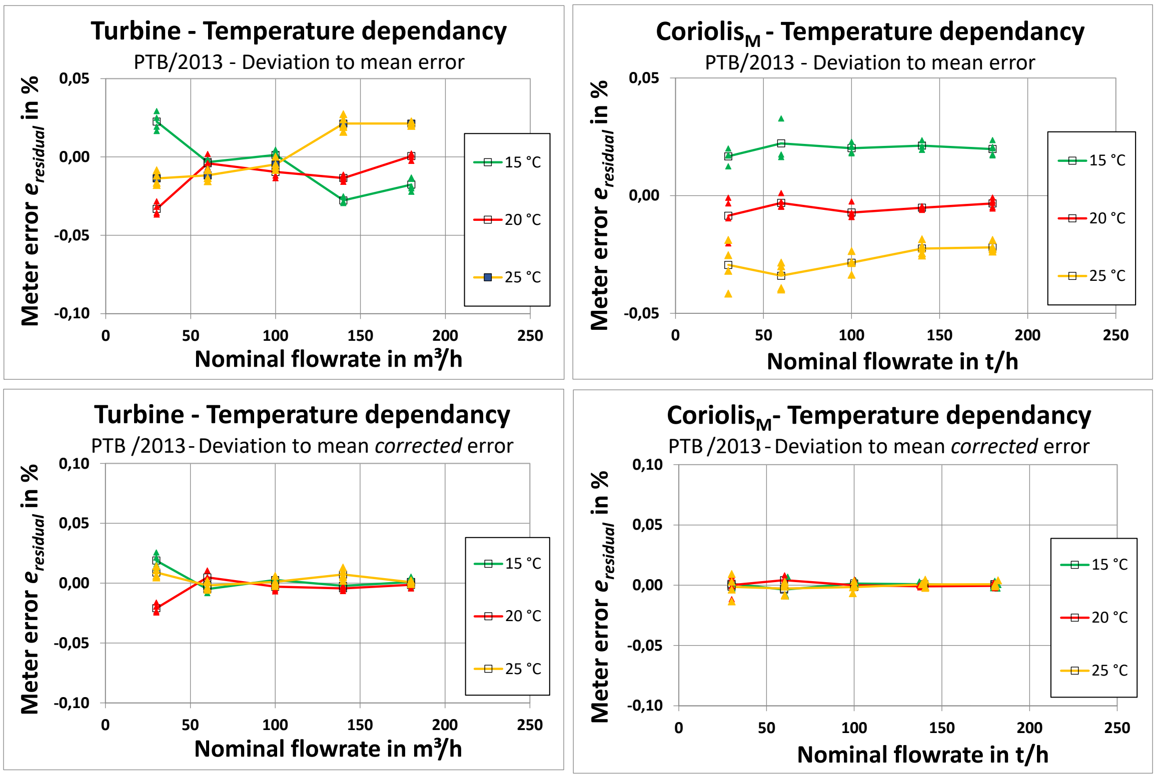


Figure 16: Temperature dependencies of Turbine meter and Coriolis_Mass – Residuals to mean values of Equation (23) for original meter error *e* and corrected meter error e_{cor}

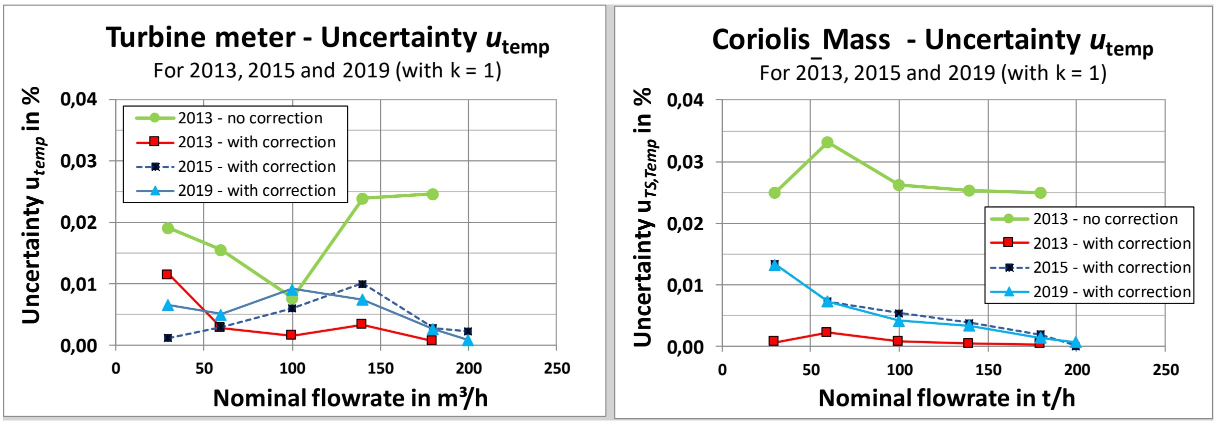


Figure 17: Meter uncertainties u_{temp} for turbine meter and Coriolis_Mass - based on **no corrected** meter error *e* for 2013, respectively, on **corrected** meter error e_{cor} for 2013, 2015 and 2019 by using Equations (19) until (24).

Table 13: Final uncertainties of meter temperature effects u_{temp}

Nominal flow rate	Uncertainty u_{temp} (k = 1)	
	Turbine meter	Coriolis_Mass
in m^3/h	in %	in %
30	0.012	0.013
60	0.005	0.007
100	0.009	0.005
140	0.010	0.004
180	0.003	0.002
200	0.002	0.001

6.4 Pressure dependency - uncertainty u_{pres}

Laboratory conditions

The span of line pressure in participated laboratories p_{fluid} ranged between 2.98 bar and 3.09 bar. The measured value is positive gauge pressure after calibration setup (Figure 18).

Table 14: Line pressure p_{fluid} (bar) in participating laboratories during calibration

NMI	PTB 1	MIKES
Max	*3.04*	*3.09*
Min	*2.94*	*2.97*
Max-Min	*0.10*	*0.12*
Mean	*3.00*	*3.01*

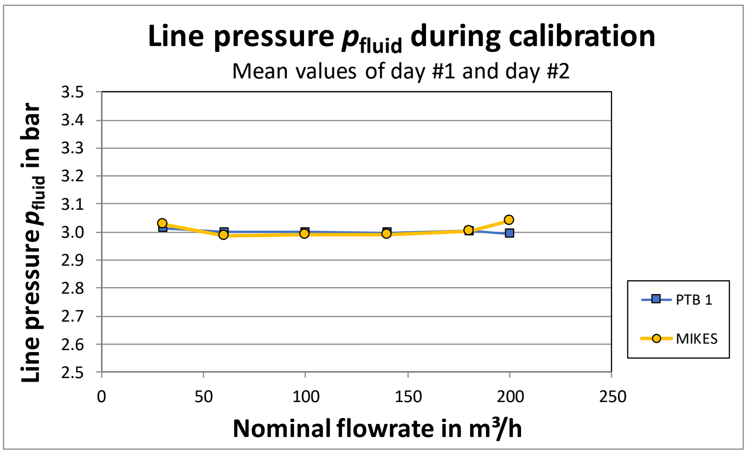


Figure 18: Line pressure during calibrations in participated laboratories – Mean values at each flow rate of calibration day #1 and day #2

Meter characteristics

Pressure dependencies of transfer meters were analyzed at pilot laboratory during characterisation measurements in 2013 and 2018 (Table 6) for KC1 comparison. Due to technical restrictions, calibrations were possible at line pressure between 2 bar and 4 bar, only. For data analysis, mean values over all pressure rates were calculated, separately for each calibration period and flow rate. Both meters showed a very low sensitivity to changes in line pressure (Figure 19 and Figure 20).

The deviations of meter error to mean values, expressed as residuals, were calculated for each calibration period separately. For a final analysis, these residuals were averaged over both calibration periods for each pressure rate (Figure 21). For pressure differences of +/- 1 bar, the sensitivity of meter error does not exceed +/- 0.02 % for turbine meter and +/- 0.01 % for Coriolis_mass.

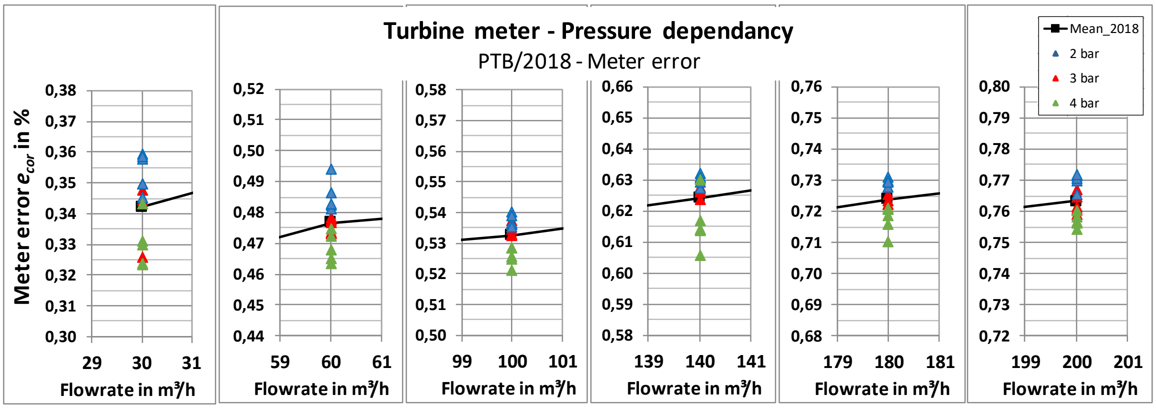


Figure 19: Pressure dependencies of turbine meter - Calibration results and mean values of characterisation measurements at pilot laboratory in 2018

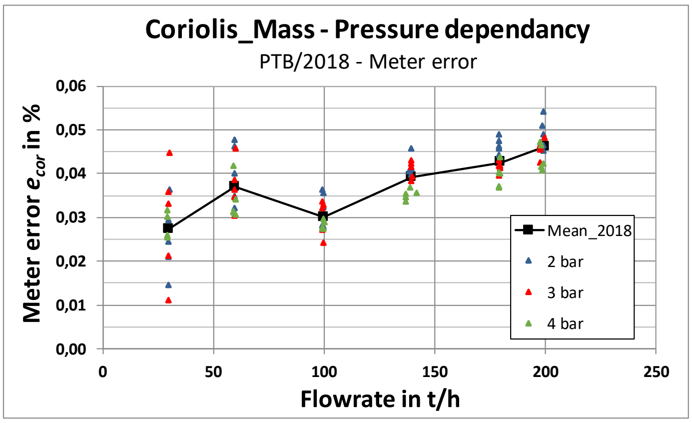


Figure 20: Pressure dependencies of Coriolis_Mass during characterisation measurements at pilot laboratory in 2018 - temperature corrected meter error and mean values

Meter uncertainty u_{pres}

For uncertainty calculation of u_{pres} it was assumed that the following estimation of meter sensitivities do include pressure range between 2.94 bar and 3.09 bar of reported data (Figure 18). The pressure sensitivities were treated as uncertainty contribution for turbine meter by u_{pres} = 0.020 % / $\sqrt{3}$ and for Coriolis by u_{pres} = 0.010 % / $\sqrt{3}$, based on a rectangular probability distribution.

The described method gives constant values for turbine meter (u_{pres} = 0.012 %) and Coriolis (u_{pres} = 0.006 %), which were used for full investigated flow scale. For calculation of E_N values, no pressure corrections were made to the data submitted by participated laboratories.

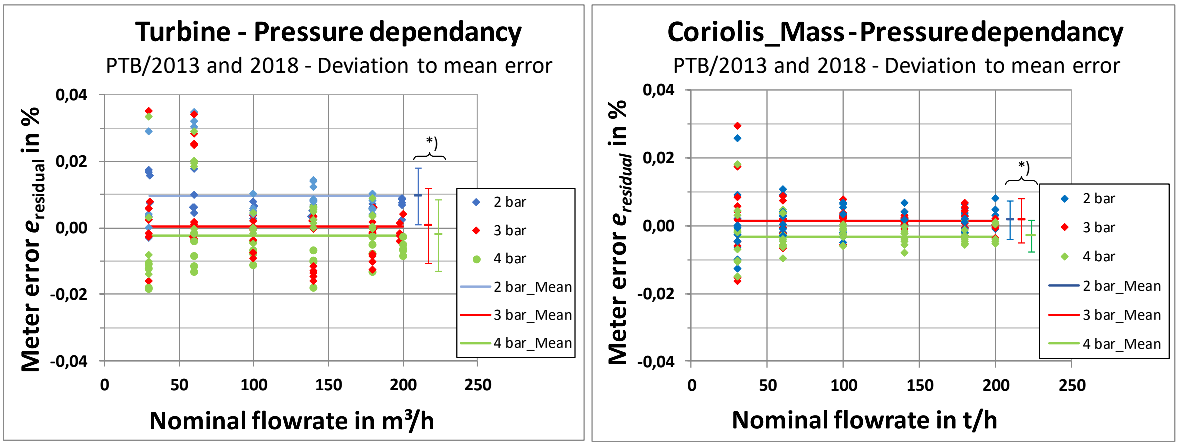


Figure 21: Pressure dependencies of turbine meter and Coriolis_Mass – Residuals to mean values of temperature corrected meter error e_{cor}. *) represents the standard deviation of e_{cor} for each pressure rate

6.5 Dependency on flow stability - uncertainty u_{flow}

Laboratory conditions

For data analysis of flow stability, the deviations of reference flow between PTB laboratory and participated laboratory were used. The mean values of these differences do not exceed +/-3.5 % of flowrate at PTB laboratory (Figure 22).

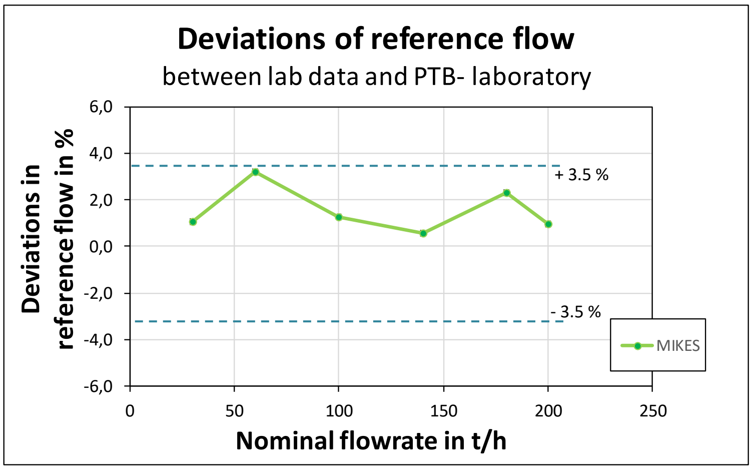


Figure 22: Flow stability $\dot{m}$ (t/h), expressed as deviations of reference flow between pilot laboratory and reported values of participated laboratory

Meter characteristics

For analyzing meter error sensitivity to changes in flow rate, calibration results at reference laboratory were evaluated. Between calibration points, the meter error of a standard calibration (T_{fluid} = 20 °C, p_{fluid} = 3 bar) was linear interpolated. Within this model, the sensitivities of meter error were estimated by varying flowrates to maximum values of +/- 5.0 % with a resolution of 0.5 % (Figure 23). Based on the previously discussed maximum limits of +/- 3.5 % in flowrate stability (Figure 22), the turbine meter showed a sensitivity in meter error of +/- 0.020 %. The Coriolis was much less sensitive, with values lower than +/- 0.004 %.

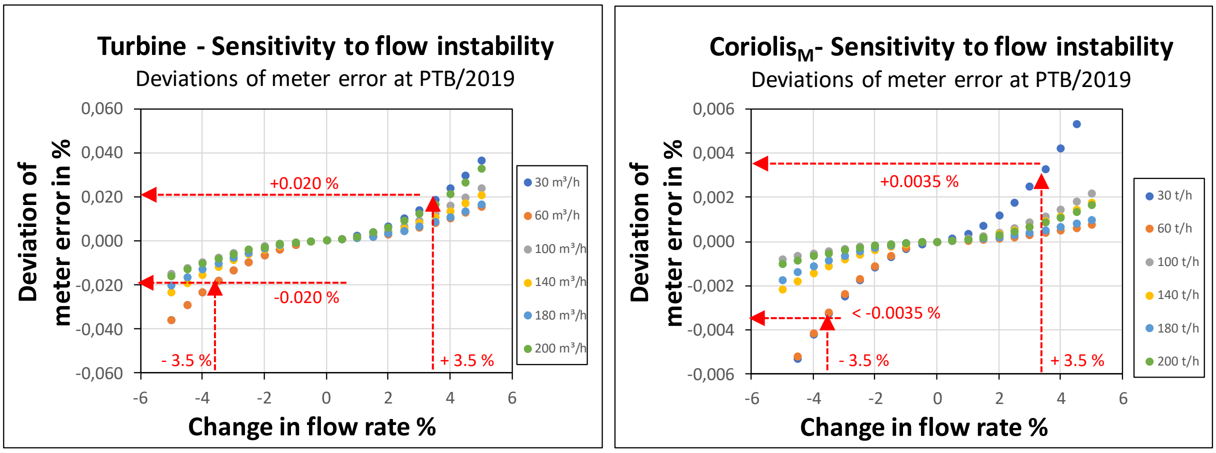


Figure 23: Sensitivity of transfer meters to flow instability – Based on PTB data set 07/2019

Meter uncertainty u_{flow}

The estimated maximum values of flow meter sensitivity were used for calculation of u_{flow}. The flow stability sensitivities were treated as a rectangular uncertainty contribution, for turbine meter with u_{flow} = 0.020 % / $\sqrt{3}$ and for Coriolis by u_{flow} = 0.004 % / $\sqrt{3}$, based on a rectangular probability distribution. It is assumed, that the results for turbine meter (u_{flow} = 0.012 %) and Coriolis (u_{flow} = 0.002 %) are valid for full investigated flow scale. For calculation of E_{N} values, no flow stability corrections were made to the data submitted by participated laboratories.

6.6 Dependency of inflow conditions to Turbine meter - uncertainty u_{inflow}

Laboratory conditions

The span of undisturbed inflow length in participated laboratories ranged between 1.6 m and 8.5 m. Typical fittings like valves, tube bundle or elbows were installed at the inflow of calibration line (Table 15).

Table 15: Reported inflow lengths of undisturbed flow in participating laboratories and pipe installation at the inflow of calibration line

NMI	PTB	MIKES
Undisturbed inflow length	8.5 m	1.6 m
Pipe installation before inflow	tube bundle, line reducer	line reducer

Turbine meter characteristics

For analyzing meter error sensitivity to different inflow conditions, additional calibrations at reference laboratory were evaluated (4.3). All used flow disturbers showed a clear influence to turbine meter error. In comparison to calibrations without any flow disturber, the maximum observed shift of meter error (Figure 24) in positive direction was +0.167 % (disturber type: swirl right oriented, inflow length: 2 m), in negative direction -0.092 % (disturber type: 2nd turbine meter, inflow length: 4 m) Figure 24. For a maximum investigated inflow length of 8 m, the highest shift in meter error was observed with a right oriented swirl (+0.085 %).

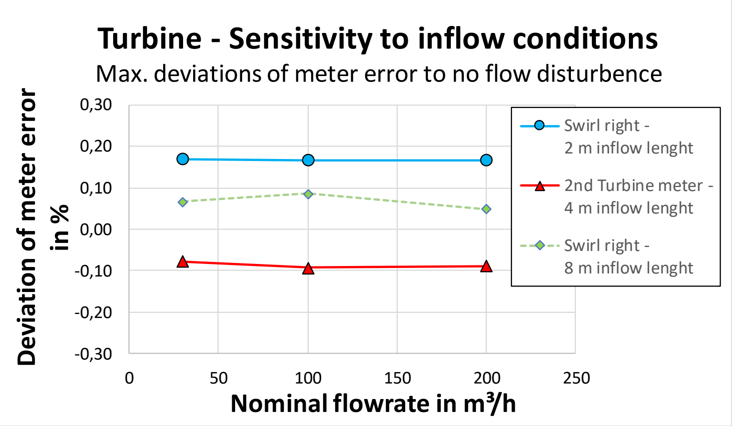


Figure 24: Maximum observed values of Turbine meter sensitivity to different flow disturber and inflow length - Based on PTB-calibration data in 03/2019

Meter uncertainty u_{inflow}

The goal of this investigation was to quantify the influence of different inflow conditions to calibration characteristics of turbine meter. This research was necessary because of significant differences in inflow lengths for turbine meter calibration of participated laboratories. Whereas the maximum span of Coriolis meter error between laboratories reached only 0.038 % (Figure 36), the results of turbine meter differs up to 0.143 % (Figure 26).

Such differences could not be explained by a standard estimation of meter uncertainties. Behind this background, an additional uncertainty parameter (u_{inflow}) was introduced for turbine meter.

With reference to the minimum reported inflow length of 1.6 m at participated laboratories (Table 15), the maximum observed meter error deviation at 2 m inflow length (Figure 24) was used for estimation of turbine meter sensitivity u_{inflow}. The inflow sensitivity was treated as a rectangular uncertainty contribution with $u_{\text{inflow}} = 0.167\ \% / \sqrt{3} = 0.096\ \%$.

It was assumed that the results of u_{inflow} = 0.096 % are valid for full investigated flow scale. For calculation of E_N values, no corrections for different inflow conditions were made to the submitted data of turbine meter.

Notes:

Required inflow conditions could not be achieved at VTT MIKES with full installation of transfer standard. The inflow length for the turbine meter was not satisfactory and it can be seen on the measurement results for the turbine meter. **Thus, the results of Meter #1, Turbine flow meter are not taken into account in the comparison.**

7 Evaluation of comparison results

7.1 Ambient air temperature

Laboratory conditions

The span of air temperature in participated laboratories ranged between 19.90 °C and 24.25 °C. The maximum variation of air temperature within a participating lab, expressed as $T_{\mathrm{air,max}}$ - $T_{\mathrm{air,min}}$, was reported with 1.50 °C (Table 16, Figure 25).

Table 16: Air temperatures T_{air} (°C) in participated laboratories during calibrations on day #1 and day #2.

NMI	PTB 1	MIKES
Max	*24.25*	*21.40*
Min	*23.29*	*19.90*
Max-Min	*0.96*	*1.50*
Mean	*23.89*	*20.41*

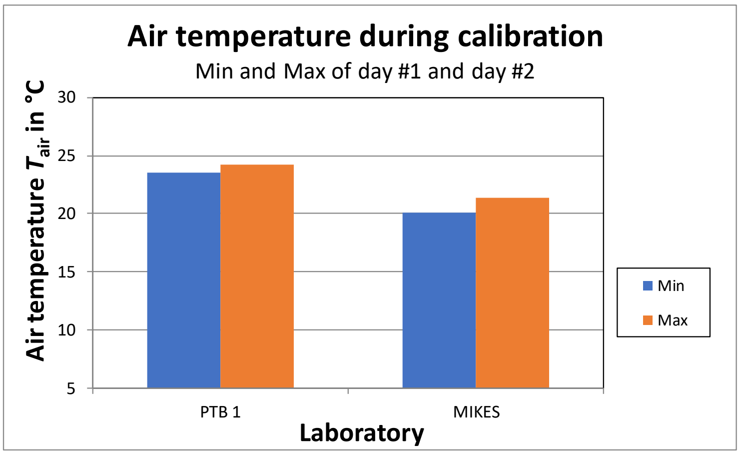


Figure 25: Air temperature T_{air} during calibrations in participated laboratories – Maximum and minimum of calibration day #1 and day #2

7.2 Turbine transfer meter

7.2.1 Summarized results

Laboratory results

Table 17: Relative measurement error x_i (%) of turbine meter at participated laboratories - temperature corrected mean values of day #1 and day #2

Flowrate in m³/h	PTB 1	MIKES
30	0.324	0.358
60	0.456	0.540
100	0.530	0.588
140	0.645	0.719
180	0.743	0.622
200	0.780	0.637

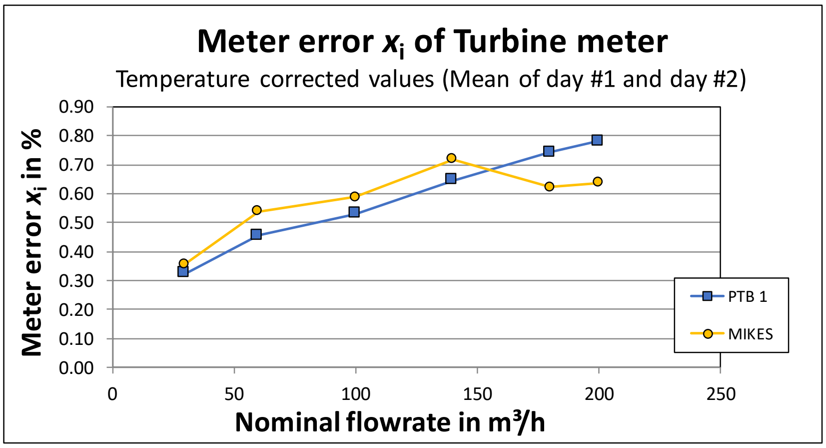


Figure 26: Relative measurement error x_i of turbine meter at participated laboratories - temperature corrected mean values of day #1 and day #2

SCRV, U(SCRV) and E_N-Value

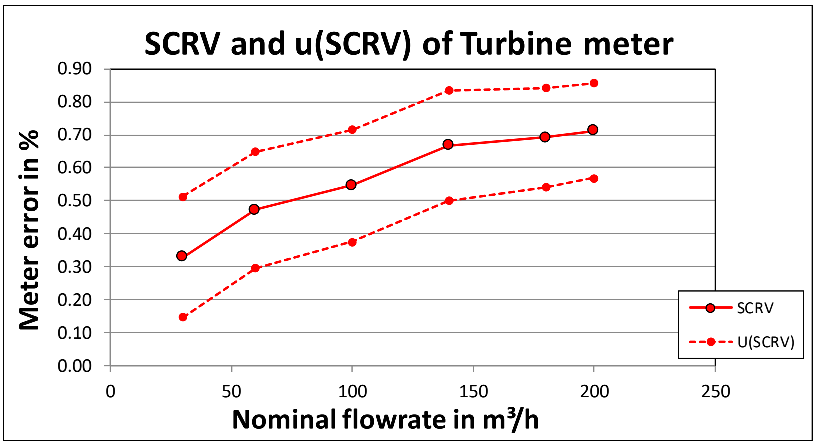


Figure 27: Key Comparison Reference value (SCRV) and its expanded uncertainty U(SCRV) for turbine meter, with k = 2

The degree of equivalence value E_N is a measure of result agreement of each participated laboratory to the SCRV. Expressed as the normalized differences of “lab to SCRV”, the final E_N values of turbine meter are summarized in Table 18 and Figure 28.

Table 18: Summary of E_N-values of each participated laboratory for turbine meter

Flowrate in m³/h	PTB 1	MIKES
30	-0.07	0.07
60	-0.19	0.19
100	-0.15	0.15
140	-0.20	0.20
180	0.40	-0.40
200	0.50	-0.50

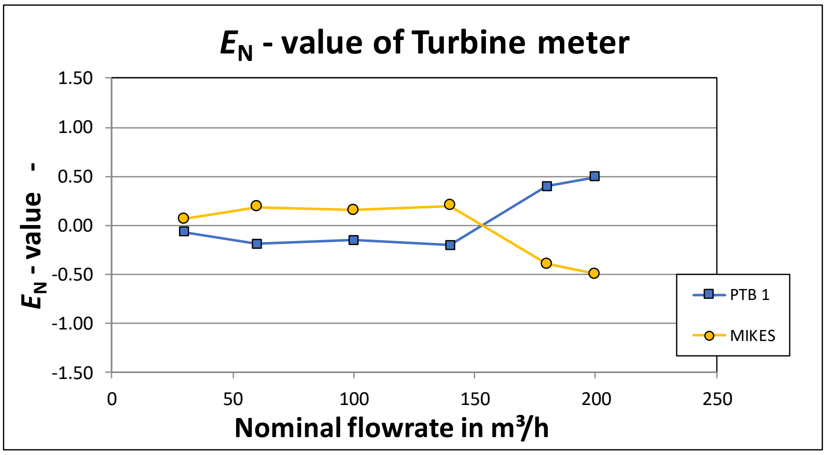


Figure 28: Summarized E_N-values of participated laboratory for turbine meter

Conclusive tests of comparison results u_{comp}/u_{base}

Based on [4], for a conclusive proof of participant results and an agreement with the SCRV, the comparison uncertainty ratio u_{comp}/u_{base} should be < 2.

All participated laboratories can not comply with this limit (Table 19). For the final purpose of S13 the uncertainty $u_{TS,Turb}$ of turbine meter is too high, if calculated as described within this report. A calibration of turbine meter gives inconclusive results for all laboratories. Finally, the meter is not suitable for a confirmation of declared CMC values.

Table 19: Summarized results of conclusive proof u_{comp}/u_{base} of each participated laboratory for turbine meter - * represents inconclusive data

Flowrate in m³/h	PTB	MIKES
30	9.91 *	9.23 *
60	9.80 *	7.99 *
100	9.84 *	6.50 *
140	9.90 *	6.13 *
180	9.85 *	4.54 *
200	9.85 *	4.08 *

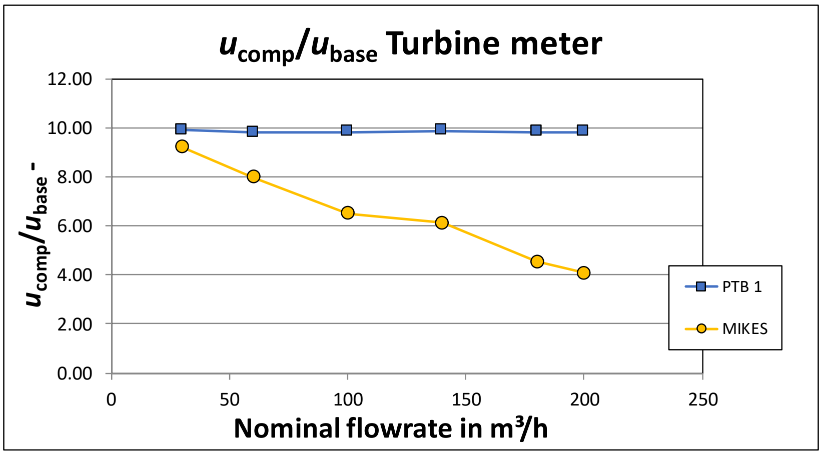


Figure 29: Summarized results of conclusive proof u_{comp}/u_{base} of each participated laboratory for turbine meter

7.2.2 Final CMC-decision tables for participated laboratories

This comparison can not support the declared base uncertainties of the participant for volume calibration, given in Table 20, because of inconclusive data – the ratio of $u_{\text{comp}}/u_{\text{base}}$ is > 2 at all calibrated flowrates.

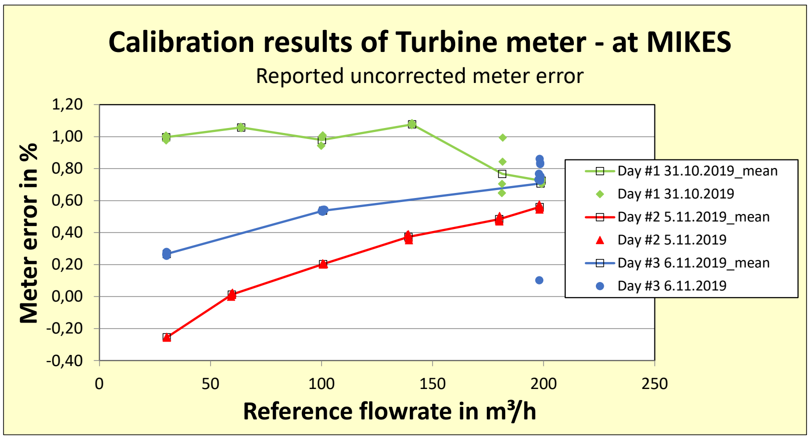


Figure 30: Calibration results of VTT MIKES for turbine meter - reported uncorrected meter error e_V

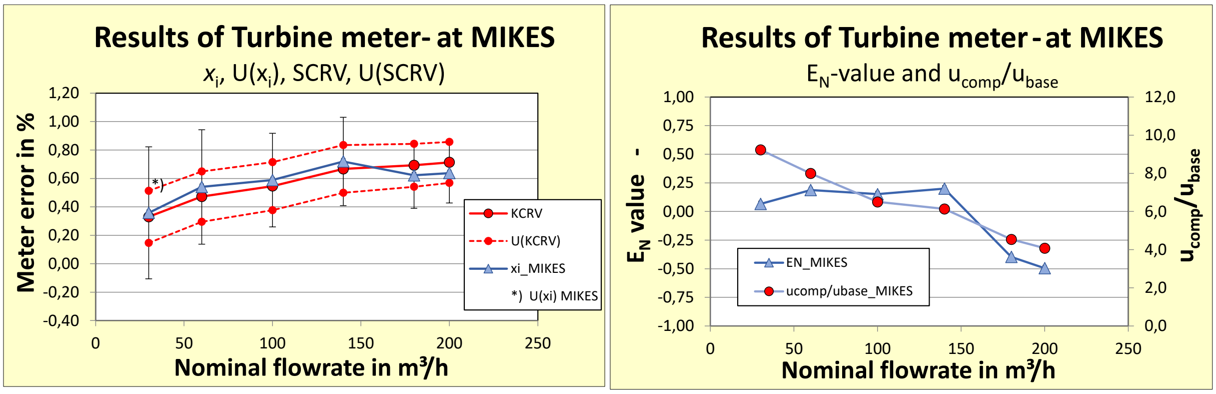


Figure 31: Comparison results of MIKES laboratory for turbine meter

Table 20: Comparison decision table for VTT MIKES (turbine meter), where x_i is the temperature corrected meter error (mean of day #1 and day #2)

	Finland / VTT MIKES						
Nominal flowrate	**Relative measure-ment error**	**Expanded laboratory uncertainty**	**Expanded measurement uncertainty**	**Degree of equivalence**	***Normalized degree of* equivalence**	**$u_{\text{comp}}/u_{\text{base}}$**	**CMC decision status**
	x_i	**U_{base} (k = 2)**	**$U(x_i)$ (k = 2)**	**d_i**	**$E_{N,i}$**		
in m³/h	in %	in %	in %	-	-	-	
30	0.358	0.050	0.464	0.028	0.07	9.23	inconclusive
60	0.540	0.050	0.403	0.068	0.19	7.99	inconclusive
100	0.588	0.050	0.329	0.043	0.15	6.50	inconclusive
140	0.719	0.050	0.311	0.052	0.20	6.13	inconclusive
180	0.622	0.050	0.232	-0.070	-0.40	4.54	inconclusive
200	0.637	0.050	0.210	-0.076	-0.50	4.08	inconclusive

PTB - laboratory (Germany)

This comparison can not support the declared base uncertainties of the participant for volume calibration, given in Table 22, because of inconclusive data - the ratio of u_{comp}/u_{base} is > 2 at all calibrated flowrates.

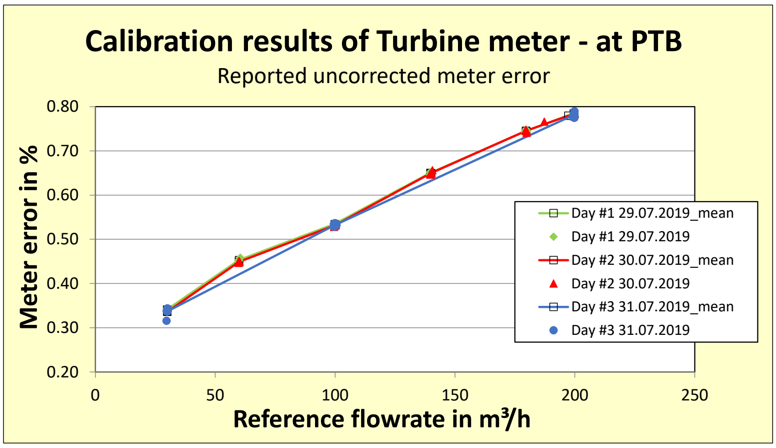


Figure 32: Calibration results of PTB_1 for turbine meter - reported uncorrected meter error e_V

Table 21: Comparison decision table for PTB_1 (turbine meter), where x_i is the temperature corrected meter error (mean of day #1 and day #2)

	Germany / PTB						
Nominal flowrate	**Relative measure-ment error**	**Expanded laboratory uncertainty**	**Expanded measurement uncertainty**	**Degree of equivalence**	***Normalized degree of* equivalence**	**u_{comp}/u_{base}**	**CMC decision status**
	x_i	**U_{base} (k = 2)**	**$U(x_i)$ (k = 2)**	d_i	$E_{N,i}$		
in m³/h	in %	in %	in %	-	-	-	
30	0.324	0.020	0.199	-0.005	-0.07	9.91	inconclusive
60	0.456	0.020	0.197	-0.016	-0.19	9.80	inconclusive
100	0.530	0.020	0.198	-0.015	-0.15	9.84	inconclusive
140	0.645	0.020	0.199	-0.021	-0.20	9.90	inconclusive
180	0.743	0.020	0.198	0.051	0.40	9.85	inconclusive
200	0.780	0.020	0.198	0.067	0.50	9.85	inconclusive

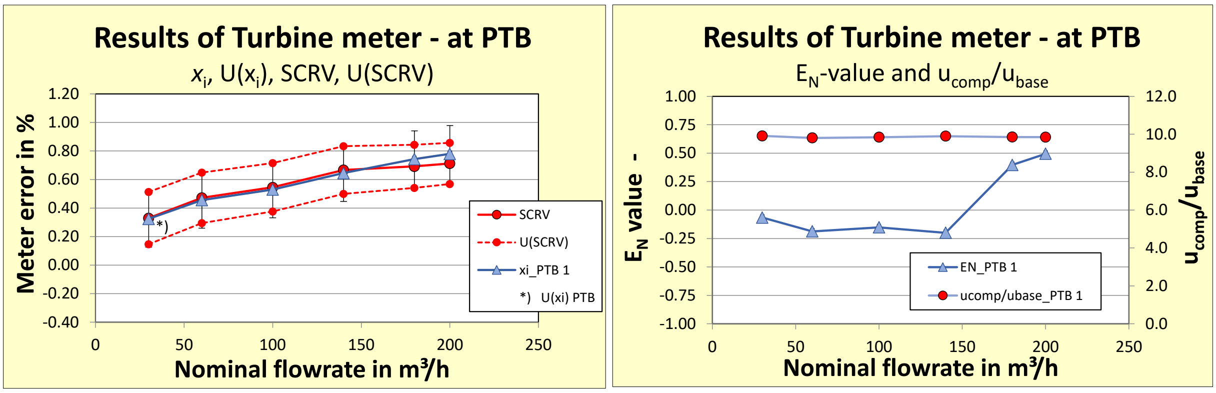


Figure 33: Comparison results of PTB laboratory for turbine meter

PTB - laboratory (Germany)

This comparison can not support the declared base uncertainties of the participant for volume calibration, given in Table 22, because of inconclusive data - the ratio of u_{comp}/u_{base} is > 2 at all calibrated flowrates.

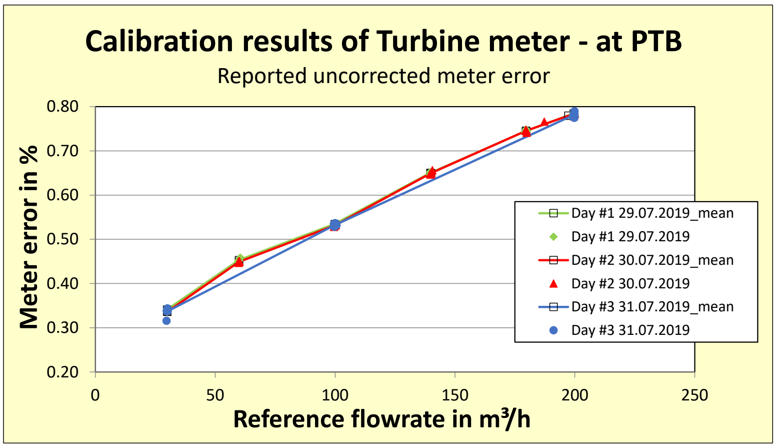


Figure 34: Calibration results of PTB_1 for turbine meter - reported uncorrected meter error e_V

Table 22: Comparison decision table for PTB_1 (turbine meter), where x_i is the temperature corrected meter error (mean of day #1 and day #2)

	Germany / PTB						
Nominal flowrate	**Relative measurement error**	**Expanded laboratory uncertainty**	**Expanded measurement uncertainty**	**Degree of equivalence**	***Normalized degree of equivalence***	u_{comp}/ u_{base}	**CMC decision status**
	x_i	U_{base} (k = 2)	$U(x_i)$ (k = 2)	d_i	$E_{N,i}$		
in m³/h	in %	in %	in %	-	-	-	
30	0.324	0.020	0.199	-0.005	-0.07	9.91	inconclusive
60	0.456	0.020	0.197	-0.016	-0.19	9.80	inconclusive
100	0.530	0.020	0.198	-0.015	-0.15	9.84	inconclusive
140	0.645	0.020	0.199	-0.021	-0.20	9.90	inconclusive
180	0.743	0.020	0.198	0.051	0.40	9.85	inconclusive
200	0.780	0.020	0.198	0.067	0.50	9.85	inconclusive

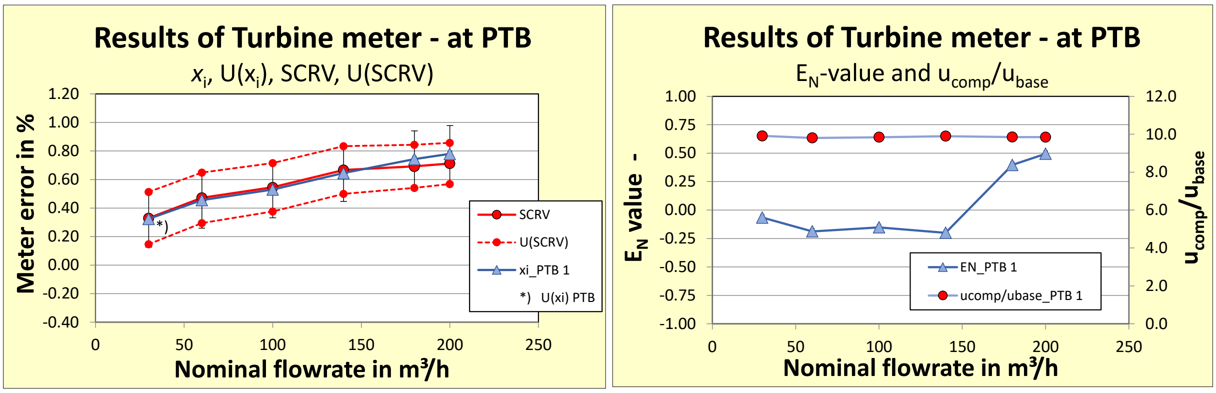


Figure 35: Comparison results of PTB laboratory for turbine meter

7.3 Coriolis_Mass transfer meter

7.3.1 Summarized results

Laboratory results

Table 23: Relative measurement error x_i (%) of Coriolis_Mass at participated laboratories – temperature corrected mean values of day #1 and day #2

Flowrate in t/h	PTB 1	MIKES
30	-0.009	0.005
60	0.015	-0.005
100	0.018	-0.017
140	0.029	-0.009
180	0.038	0.010
200	0.036	0.018

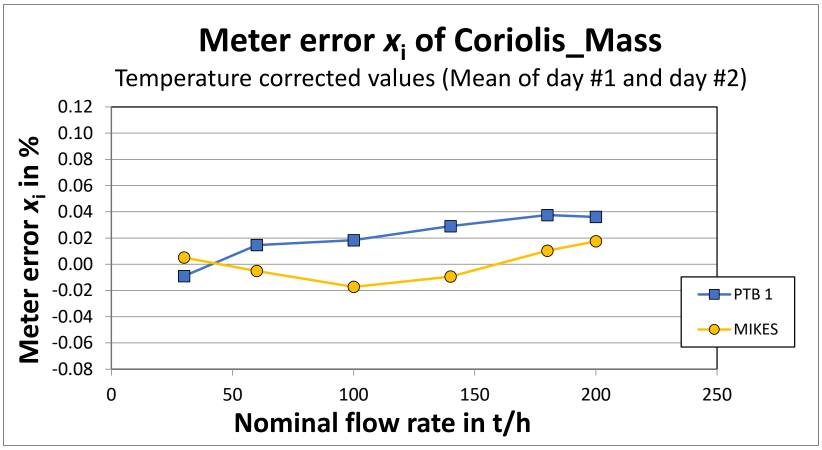


Figure 36: Relative measurement error x_i of Coriolis_Mass at participated laboratories - temperature corrected mean values of day #1 and day #2

SCRV, U(SCRV) and E_N-Value

The weighted mean y and its uncertainty u(y) was calculated based on all laboratory data of calibration day #1 and day #2.

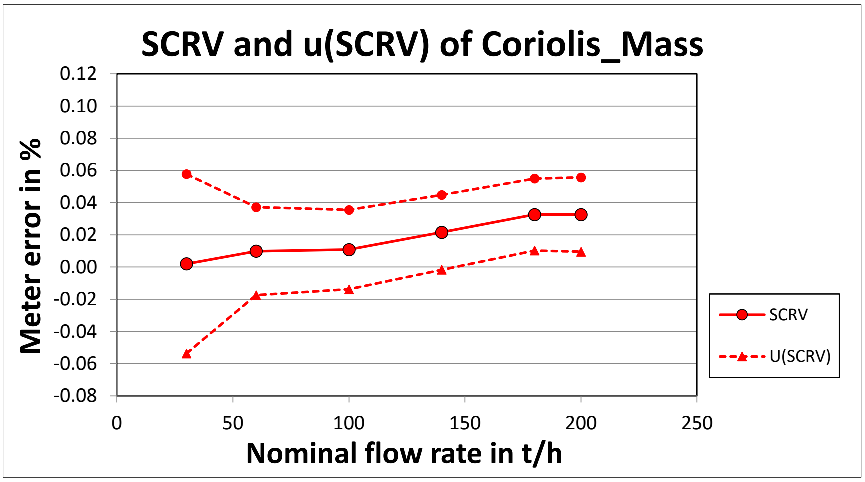


Figure 37: Supplementary Comparison Reference value (SCRV) and its expanded uncertainty U(SCRV) for Coriolis_Mass, with k = 2

The degree of equivalence value E_N is a measure of result agreement of each participated laboratory to the SCRV. Expressed as the normalized differences of “lab to SCRV”, the final E_N values are summarized in Table 24 and Figure 38.

Table 24: Summary of E_N-values of participated laboratories for Coriolis_Mass transfer meter - * represents values at warning level

Flowrate in t/h	**PTB 1**	**MIKES**
30	-0.11	0.11
60	0.31	-0.31
100	0.59	-0.59
140	0.65	-0.65
180	0.47	-0.47
200	0.31	-0.31

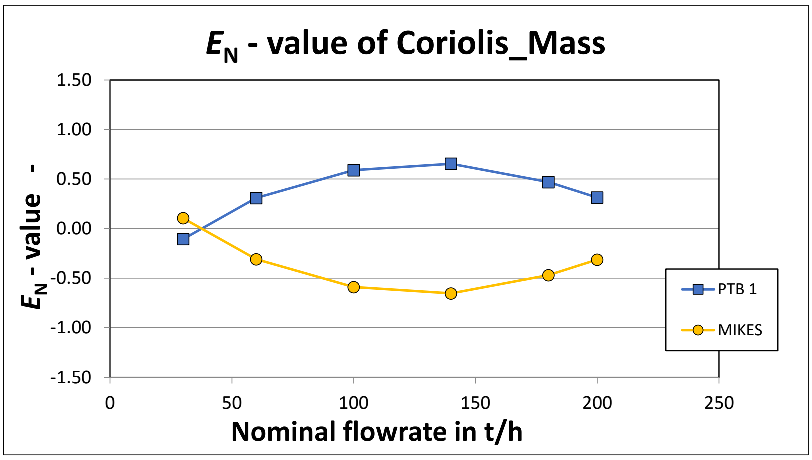


Figure 38: Summarized E_N-values of participated laboratories for Coriolis_Mass transfer meter

Conclusive tests of comparison results u_{comp}/u_{base}

Based on [4], for a conclusive proof of participant results and an agreement with the SCRV, the comparison uncertainty ratio u_{comp}/u_{base} should be < 2. The results for participated laboratories are summarized in Table 25 and Figure 39.

Table 25: Summarized results of conclusive proof u_{comp}/u_{base} of participated laboratories for Coriolis_Mass transfer meter - * represents values with inconclusive data

NMI	PTB 1	MIKES
Flowrate in t/h		
30	5.80 *	0.77
60	1.21	0.48
100	0.96	0.39
140	0.83	0.33
180	0.73	0.32
200	0.80	0.37

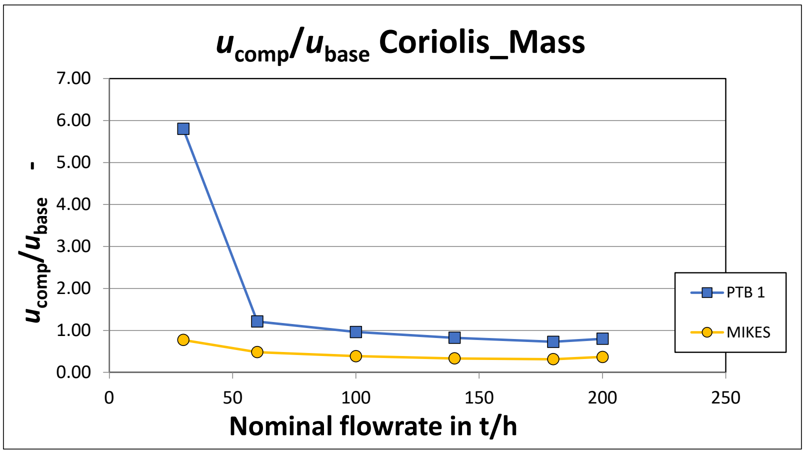


Figure 39: Summarized results of conclusive proof u_{comp}/u_{base} of participated laboratories for Coriolis_Mass transfer meter

7.3.2 Final CMC-decision tables for participated laboratories

VTT MIKES - laboratory (Finland)

This comparison can support the declared base uncertainties of the participant for mass calibration, given in Table 26.

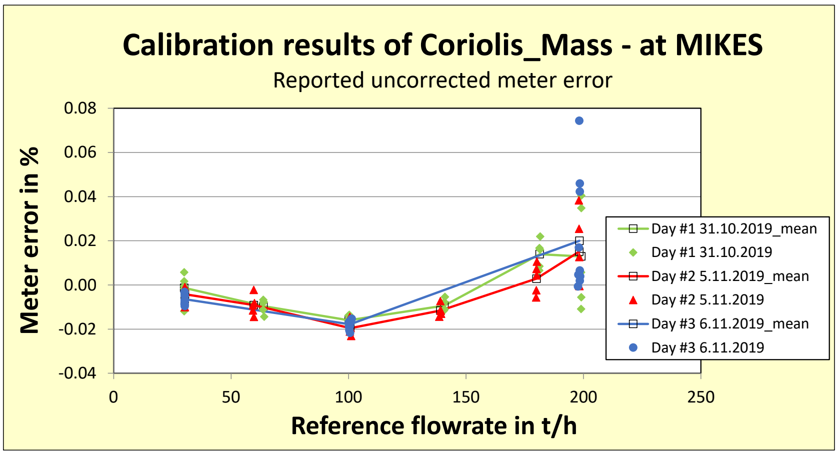


Figure 40: Calibration results of MIKES for Coriolis_Mass transfer meter – reported uncorrected meter error e_m

Table 26: Comparison decision table for MIKES laboratory (Coriolis_Mass transfer meter), where x_i is the temperature corrected meter error (mean of day #1 and day#2)

	Finland / MIKES						
Nominal flowrate	**Relative measure-ment error**	**Expanded laboratory uncertainty**	**Expanded measurement uncertainty**	**Degree of equivalence**	***Normalized degree of* equivalence**	**u_{comp}/ u_{base}**	**CMC decision status**
	x_i	**U_{base} (k = 2)**	**$U(x_i)$ (k = 2)**	d_i	$E_{N,i}$		
in t/h	in %	in %	in %	-	-	-	
30	0.005	0.050	0.063	0.003	0.11	0.77	acceptable
60	-0.005	0.050	0.056	-0.015	-0.31	0.48	acceptable
100	-0.017	0.050	0.054	-0.028	-0.59	0.39	acceptable
140	-0.009	0.050	0.053	-0.031	-0.65	0.33	acceptable
180	0.010	0.050	0.052	-0.022	-0.47	0.32	acceptable
200	0.018	0.050	0.053	-0.015	-0.31	0.37	acceptable

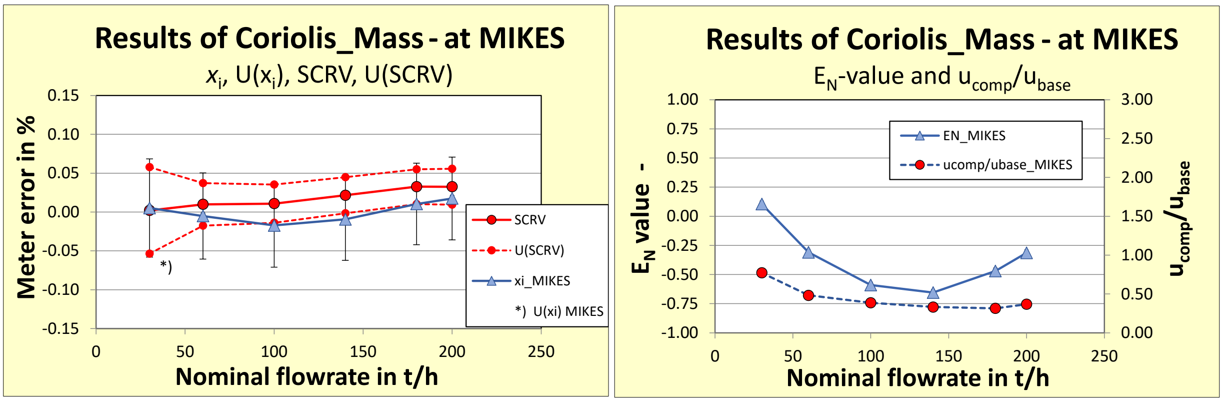


Figure 41: Comparison results of MIKES laboratory for Coriolis_Mass transfer meter

PTB - laboratory (Germany)

This comparison can support the declared base uncertainties of the participant for mass calibration, given in Table 27.

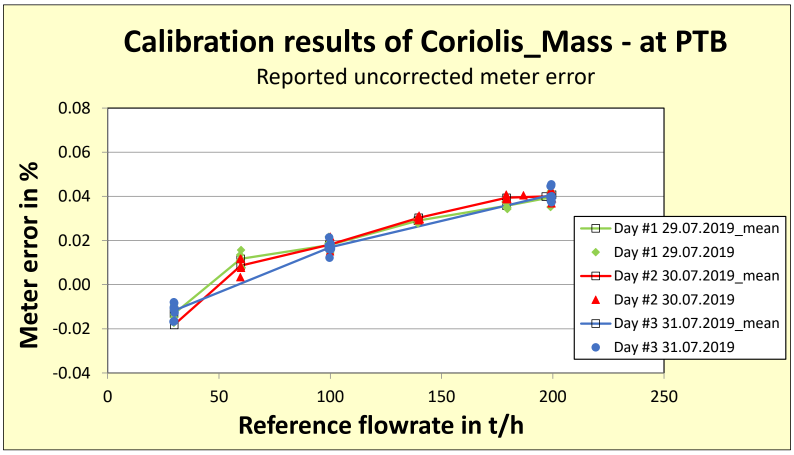


Figure 42: Calibration results of PTB 1 for Coriolis_Mass transfer meter – reported uncorrected meter error e_m

Table 27: Comparison decision table for PTB laboratory (Coriolis_Mass transfer meter), where x_i is the temperature corrected meter error (mean of day #1 and day#2)

	Germany / PTB						
Nominal flowrate	**Relative measure-ment error**	**Expanded laboratory uncertainty**	**Expanded measurement uncertainty**	**Degree of equivalence**	***Normalized degree of* equivalence**	**u_{comp}/ u_{base}**	**CMC decision status**
	x_i	**U_{base} (k = 2)**	**$U(x_i)$ (k = 2)**	**d_i**	**$E_{N,i}$**		
in t/h	in %	in %	in %	-	-	-	
30	-0.009	0.020	0.118	-0.011	-0.11	5.80	inconclusive
60	0.015	0.020	0.031	0.005	0.31	1.21	acceptable
100	0.018	0.020	0.028	0.008	0.59	0.96	acceptable
140	0.029	0.020	0.026	0.007	0.65	0.83	acceptable
180	0.038	0.020	0.025	0.005	0.47	0.73	acceptable
200	0.036	0.020	0.026	0.003	0.31	0.80	acceptable

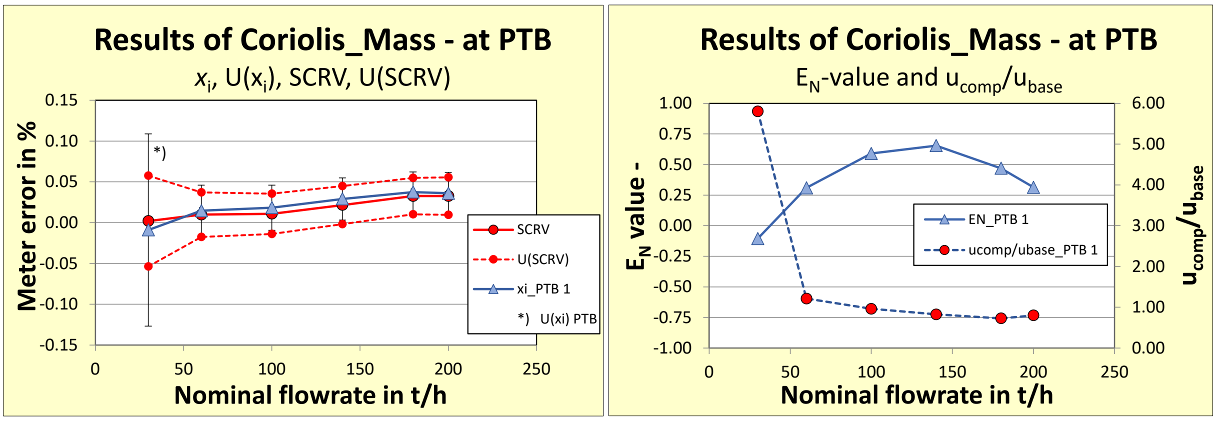


Figure 43: Comparison results of PTB laboratory for Coriolis_Mass transfer meter

8 Nomenclature and unit symbols

Terms and abbreviations

APMP	Asia Pacific Metrology Programme
BIPM	Bureau International des Poids et Mesures
CCM	Consultative Committee for Mass and Related Quantities
CIPM	Comité International des Poids et Mesures
CMC	Calibration and Measurement Capabilities
DI	Designated Institue
DN	Inner pipe diameter (mm)
DoE	Degree of Equivalence
EURAMET	The European Association of National Metrology Institutes
GUM	Guide to the Expression of Uncertainty in Measurement
FF	Fluid flow
KC1	Key comparison CCM.FF-K1.2015
KCRV	Key comparison reference value
MRA	(CIPM) Mutual Recognition Arrangement
NMI	National Metrology Institute
RMO	Regional Metrology Organisation
SIM	Interamerican Metrology System
WGFF	(CCM) Working Group on Fluid Flow

Symbols and units

d_{i}	Degree of equivalence (DoE) for each laboratory *i* (%)
Δe_{nom}	Difference of meter error (%)
e	Meter error at current temperature conditions (%)
$\mathrm{e}_{\mathrm{cor}}$	Temperature corrected meter error (%)
Δe_{cor}	Correction value of meter error (%)
e_{mean}	Mean values of meter error at one flow rate over all temperatures (%)
$E_{\mathrm{N},i}$	Normalized Degree of Equivalence (-)
e_{nom}	Meter error at nominal temperature of 20 °C (%)
e_{m}	Relative measurement error of Coriolis meter (%)
$e_{\mathrm{m,cor}}$	Temperature corrected measurement error of Coriolis meter (%)
$e_{residual}$	Model residuals (%)
e_{V}	Relative measurement error of turbine meter (%)
$e_{\mathrm{V,cor}}$	Temperature corrected measurement error of turbine meter (%)
i	Laboratory index
k	Coverage factor (-)
K_m	meter *K*-factor - mass-related output (Coriolis meter) (pulses/kg)
$K_{\mathrm{m,nom}}$	Nominal *K*-factor of Coriolis mass (pulses/kg)
K_V	meter *K*-factor - volume-related output (turbine meter) (pulses/l)

ΔK_{V}	Difference in meter K-factor of turbine meter (%)
$K_{\mathrm{V,nom}}$	Nominal *K*-factor of turbine meter (pulses/l)
m_{ref}	Mass, measured by the reference standard (kg)
n	Number of calibrations (-)
N	Counted number of pulses of the transfer meter (pulses)
n_{i}	number of evaluated laboratories (-)
p_{fluid}	Line pressure (bar)
s	Standard deviation of the mean of measurements at one flowrate point (%)
$T_{\mathrm{air,max}}$	Maximum of air temperature (°C)
$T_{\mathrm{air,min}}$	Minimum of air temperature (°C)
T_{fluid}	Current fluid temperature (°C)
ΔT_{fluid}	Difference of current fluid temperature to nominal temperature of 20 °C (°C)
T_{nom}	Nominal temperature of 20°C
$u_{\mathrm{base,i}}$	Standard uncertainty of laboratory refence (%)
u_{comp}	Standard uncertainty of transfer meter measurements (%)
u_{TS}	Standard uncertainty of transfer meter (%)
u_{drift}	Standard uncertainty due to drift of transfer meter (%)
u_{reprod}	Standard uncertainty due to reproducibility characteristics of transfer meter (%)
u_{temp}	Standard uncertainty caused by temperature characteristics of transfer meter (%)
u_{pres}	Standard uncertainty caused by pressure characteristics of transfer meter (%)
u_{flow}	Standard uncertainty due to sensitivity of transfer meter to instable flow conditions (%)
u_{inflow}	Standard uncertainty due to sensitivity of turbine meter to different inflow conditions (%)
u_{hyst}	Standard uncertainty due to hysteresis effect (%)
$U(\mathrm{KCRV})$	Expanded uncertainty of Key comparison reference value (%)
u_{y}	Standard uncertainty of y (%)
U(y)	Expanded uncertainty of y (%)
$u_{\mathrm{x,i}}$	Standard uncertainty of reported and temperature corrected meter error (%)
V_{ref}	Volume, measured by the reference standard (m^3)
y	Reference value of the comparison (%)
x_{i}	Temperature corrected meter error for E_{N}-value evaluation
x_{KCRV}	Key Comparison Reference value (%)

υ	Degrees of freedom
X_{obs}^2	Observed chi-squared value
X_v^2	Chi-squerred test value

9 References

[1] Frahm, E., Furuichi, N., Arias, R., Yang, C.-T., Chun, S., Meng, T., Shinder, I., Büker, O., Mill, Chr., Akselli, B., Smits, E. (2022): Final report on Key Comparison CCM.FF-K1.2015. Online: BIPM KCDB https://www.bipm.org/kcdb/comparison. In final review.

[2] GUM – Guide to the Expression of Uncertainty in Measurement, JCGM 100:2008.

[3] BIPM: WGFF Guidelines for CMC Uncertainty and Calibration Report Uncertainty. 21. Oktober 2013, http://www.bipm.org/utils/en/pdf/ccm-wgff-guidelines.pdf

[4] WRIGHT, J. et al. (2016): Transfer standard uncertainty can cause inconclusive inter-laboratory comparisons. In: Metrologia 53 (2016) 1243–1258

[5] Cox M. G.: Evaluation of key comparison data, Metrologia, 39, 589 to 595, 2002.

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

10 Appendices

10.1 Information about participated laboratories

NMI/DI	Country	RMO	Contact	Address
VTT MIKES	Finland	EURAMET	Mika Huovinen mika.huovinen@ vtt.fi	**VTT MIKES Kajaani** Tehdaskatu 15, Puristamo 9P19 87100 Kajaani, Finland
PTB	Germany	EURAMET	Enrico Frahm enrico.frahm@ ptb.de	**PTB - Physikalisch-Technische Bundesanstalt** Department 1.5 Liquid Flow Bundesallee 100 38116 Braunschweig, Germany

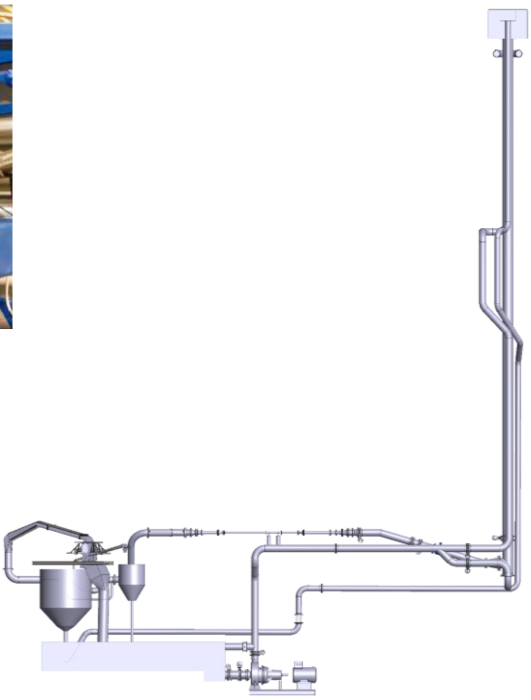
<table>
<tr><th>Characteristic information of primary standard used during S13</th><th>Working procedure</th></tr>
<tr><td>

VTT MIKES – Finland

<table>
<tr><td>Range of flowrate</td><td>0.36 m³/h … 720 m³/h</td></tr>
<tr><td>Fluid temperature</td><td>15 °C … 25 °C</td></tr>
<tr><td>Line pressure</td><td>2 bar … 4 bar</td></tr>
<tr><td>Uncertainty (k = 2)</td><td>0.05
volume, mass</td></tr>
<tr><td>Reference</td><td>gravimetric</td></tr>
<tr><td>Operating method</td><td>Direct pumping , constant head tank flying-/ standing-start-stop</td></tr>
<tr><td>Calibration line diameter</td><td>15 mm … 200 mm</td></tr>
<tr><td>Test fluid</td><td>water</td></tr>
</table>

</td><td>VTT MIKES water flow laboratory maintains the national standards in Finland. Laboratory has the gravimetric reference system based on two separate diverters and balances (6000 kg and 800 kg). The flow for calibrated meter can be generated either by direct pumping or via head tank, at a height of 20 m. Internal working instructions are followed during calibrations. The temperature of the water is controlled by heat exchanger system.</td></tr>
<tr><td colspan="2">

Water flow through diverter



D200 calibration rig

</td></tr>
</table>

Characteristic information of primary standard used during S13

PTB – Germany

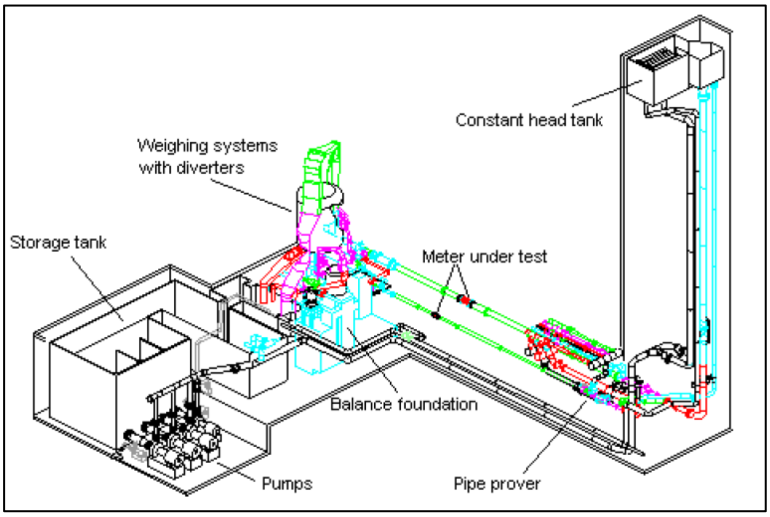
Range of flowrate	0.3 m³/h … 2,100 m³/h
Fluid temperature	10 °C … 35 °C
Line pressure	2 bar … 6 bar
Uncertainty (k = 2)	0.02 volume, mass
Reference	gravimetric
Operating method	Direct pumping , constant head tank flying-/ standing-start-stop
Calibration line diameter	25 mm … 400 mm
Test fluid	water

Working procedure

The PTB hydrodynamic test field (HDP) represents the national primary standard of Germany for the realization of the measurands volumetric and mass flow rate as well as the total volume and mass of flowing liquids (water).
The gravimetric reference consists of three independent diverter and balance systems with max. loads of 30 t, 3 t and 300 kg. For generating and stabilizing flow rates, the supply system consists of a 400 m³ storage tank, of a frequency controlled pumping system, a constant head tank (30 m³, at a height of 30 m) and two calibration lines. For each diameter an upstream straight pipeline with a length of 50D and downstream of 20D is available. The fluid temperature is adjusted and controlled by two separate heat exchanger systems.


Upstream view to calibration lines


3 t balance and diverter system



Principle drawing of the Hydrodynamic Test Field

10.2 Detailed results of participated laboratories

VTT MIKES Laboratory – Day#1

Data report MIKES: Day#1

*Original data set

												Turbine meter			Coriolis_Mass			Coriolis_Vol			Temperature correction of meter error		
												$K_{V,nom}$	6,6330	Pulses/ Liter	$K_{m,nom}$	100,0000	Pulses/ kg	$K_{V,nom}$	100,0000	Pulses/ Liter	T_{nom}	20	°C
		Laboratory reference					Fluid			Ambient conditions												Corrected meter error	
Date	Nominal flowrate	Measurement time	Standard mass flowrate	Standard volume flowrate	Mass	Volume	Water density	Line pressure	Water temp.	Air temp.	Air pressure	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	(T_{fluid} - T_{nom})	Turbine meter	Coriolis _Mass
	V^*_{nom}	t	m^*_{ref}	V^*_{ref}	m_{ref}	V_{ref}	ρ_{fluid}	p_{fluid}	T_{fluid}	T_{air}	p_{Air}	N	K_V	e_V	N	K_m	e_m	N	K_V	e_V	ΔT_{fluid}	$e_{V,cor}$	$e_{m,cor}$
	[m³/h]	[s]	[t/h]	[m³/h]	[kg]	[m³]	[kg/m³]	[bar]	[°C]	[°C]	[bar]	[Pulses]	[Pulses/Liter]	[%]	[Pulses]	[Pulses/kg]	[%]	[Pulses]	[Pulses/Liter]	[%]	[°C]	[%]	[%]
31.10.2019	30	330,136	30,048	30,100	2755,554	2,760	998,290	3,03	20,35	20,25	0,99	18491	6,6990	0,995	275551	99,9984	-0,002	276193	100,0600	0,060	0,348	0,981	0,007
31.10.2019	30	330,136	30,028	30,079	2753,725	2,758	998,313	3,03	20,24	20,25	0,99	18475	6,6978	0,977	275377	100,0016	0,002	276013	100,0635	0,063	0,239	0,963	0,009
31.10.2019	30	330,136	30,022	30,073	2753,194	2,758	998,305	3,03	20,27	20,20	0,99	18476	6,6994	1,001	275318	99,9995	0,000	275958	100,0621	0,062	0,275	0,987	0,007
31.10.2019	30	330,136	30,009	30,059	2751,956	2,757	998,325	3,03	20,18	20,20	0,99	18468	6,6996	1,004	275163	99,9882	-0,012	275798	100,0511	0,051	0,179	0,991	-0,004
31.10.2019	30	330,137	30,008	30,058	2751,833	2,756	998,308	3,03	20,26	20,20	0,99	18468	6,6998	1,007	275199	100,0057	0,006	275836	100,0676	0,068	0,262	0,994	0,014
31.10.2019	60	160,135	63,588	63,693	2828,518	2,833	998,359	2,99	20,02	20,25	0,99	18992	6,7035	1,062	282820	99,9888	-0,011	283457	100,0495	0,049	0,018	1,067	-0,007
31.10.2019	60	160,135	64,068	64,173	2849,869	2,855	998,360	2,99	20,01	20,30	0,99	19134	6,7030	1,055	284946	99,9856	-0,014	285588	100,0466	0,047	0,011	1,060	-0,010
31.10.2019	60	160,134	63,959	64,063	2844,999	2,850	998,369	2,99	19,97	20,25	0,99	19101	6,7029	1,054	284478	99,9923	-0,008	285118	100,0538	0,054	-0,031	1,059	-0,003
31.10.2019	60	160,134	63,710	63,814	2833,920	2,839	998,371	2,99	19,96	20,35	0,99	19028	6,7034	1,062	283373	99,9933	-0,007	284009	100,0544	0,054	-0,040	1,067	-0,002
31.10.2019	60	160,135	63,688	63,791	2832,954	2,838	998,376	3,00	19,93	20,35	0,99	19020	6,7029	1,054	283273	99,9921	-0,008	283907	100,0532	0,053	-0,066	1,059	-0,004
31.10.2019	100	100,133	100,550	100,717	2796,760	2,801	998,345	2,99	20,09	20,40	0,99	18769	6,6999	1,008	279624	99,9814	-0,019	280256	100,0415	0,042	0,085	1,005	-0,018
31.10.2019	100	100,133	100,306	100,473	2789,978	2,795	998,335	2,99	20,13	20,50	0,99	18722	6,6993	0,999	278960	99,9864	-0,014	279596	100,0476	0,048	0,132	0,996	-0,013
31.10.2019	100	100,133	100,137	100,306	2785,283	2,790	998,318	2,99	20,21	20,50	0,99	18691	6,6993	1,000	278478	99,9820	-0,018	279115	100,0421	0,042	0,213	0,997	-0,017
31.10.2019	100	100,133	99,952	100,121	2780,135	2,785	998,310	3,00	20,25	20,50	0,99	18646	6,6955	0,943	277975	99,9862	-0,014	278615	100,0470	0,047	0,252	0,940	-0,013
31.10.2019	100	100,133	99,724	99,894	2773,783	2,779	998,298	3,00	20,31	20,50	0,99	18604	6,6957	0,945	277334	99,9840	-0,016	277976	100,0450	0,045	0,307	0,942	-0,015
31.10.2019	140	72,132	141,036	141,281	2825,873	2,831	998,263	3,00	20,48	20,50	0,99	18979	6,7045	1,078	282572	99,9946	-0,005	283231	100,0537	0,054	0,476	1,072	-0,004
31.10.2019	140	72,132	140,775	141,023	2820,657	2,826	998,242	3,00	20,57	20,50	0,99	18944	6,7044	1,076	282044	99,9923	-0,008	282706	100,0508	0,051	0,575	1,069	-0,006
31.10.2019	140	72,132	140,826	141,075	2821,686	2,827	998,234	3,00	20,61	20,30	0,99	18951	6,7043	1,075	282138	99,9891	-0,011	282804	100,0482	0,048	0,612	1,069	-0,009
31.10.2019	140	72,132	140,685	140,936	2818,852	2,824	998,219	3,00	20,68	20,40	0,99	18934	6,7050	1,085	281854	99,9889	-0,011	282524	100,0481	0,048	0,681	1,078	-0,009
31.10.2019	140	72,132	140,657	140,910	2818,276	2,823	998,203	3,00	20,75	20,30	0,99	18928	6,7041	1,072	281795	99,9884	-0,012	282468	100,0472	0,047	0,754	1,065	-0,009
31.10.2019	180	55,131	181,602	181,932	2781,061	2,786	998,184	3,00	20,84	20,30	0,99	18664	6,6989	0,994	278167	100,0219	0,022	278823	100,0757	0,076	0,844	0,989	0,025
31.10.2019	180	55,131	181,526	181,861	2779,915	2,785	998,156	3,00	20,97	20,20	0,99	18629	6,6889	0,843	278036	100,0160	0,016	278700	100,0700	0,070	0,974	0,838	0,020
31.10.2019	180	55,131	181,295	181,632	2776,365	2,782	998,141	3,00	21,04	20,30	0,99	18580	6,6798	0,705	277683	100,0167	0,017	278354	100,0720	0,072	1,044	0,700	0,021
31.10.2019	180	55,131	181,198	181,539	2774,888	2,780	998,120	3,00	21,14	20,30	0,99	18560	6,6760	0,648	277507	100,0065	0,007	278185	100,0624	0,062	1,139	0,642	0,011
31.10.2019	180	55,131	181,235	181,579	2775,444	2,781	998,103	3,00	21,22	20,30	0,99	18564	6,6760	0,648	277568	100,0085	0,008	278256	100,0662	0,066	1,217	0,642	0,013
31.10.2019	200	50,130	199,108	199,496	2772,557	2,778	998,055	3,00	21,43	20,50	0,99	18556	6,6797	0,704	277368	100,0405	0,040	278055	100,0932	0,093	1,434	0,697	0,046
31.10.2019	200	50,130	199,113	199,507	2772,644	2,778	998,023	3,00	21,58	20,50	0,99	18562	6,6815	0,731	277361	100,0349	0,035	278058	100,0880	0,088	1,578	0,723	0,041
31.10.2019	200	50,130	199,029	199,430	2771,481	2,777	997,993	3,00	21,71	20,60	0,99	18553	6,6808	0,721	277164	100,0057	0,006	277876	100,0614	0,061	1,711	0,713	0,012
31.10.2019	200	50,130	199,023	199,425	2771,392	2,777	997,984	3,00	21,75	20,60	0,99	18556	6,6821	0,740	277109	99,9891	-0,011	277830	100,0472	0,047	1,752	0,731	-0,004
31.10.2019	200	50,130	199,044	199,450	2771,673	2,777	997,962	3,00	21,85	20,70	0,99	18556	6,6812	0,727	277152	99,9945	-0,006	277881	100,0531	0,053	1,850	0,719	0,002

VTT MIKES Laboratory – Day#2

Data report MIKES: Day#2

***Original data set**

Temperature correction of meter error

		Laboratory reference					Fluid			Ambient conditions		Turbine meter			Coriolis_Mass			Coriolis_Vol				Corrected meter error	
												$K_{V,nom}$	6,6330	Pulses/ Liter	$K_{m,nom}$	100,0000	Pulses/ kg	$K_{V,nom}$	100,0000	Pulses/ Liter	T_{nom}	20	°C
Date	**Nominal flowrate**	**Measu- rement time**	**Standard mass flowrate**	**Standard volume flowrate**	**Mass**	**Volume**	**Water density**	**Line pressure**	**Water temp.**	**Air temp.**	**Air pressure**	**Pulse count**	**K-factor**	**Meter error**	**Pulse count**	**K-factor**	**Meter error**	**Pulse count**	**K-factor**	**Meter error**	$(T_{fluid} - T_{nom})$	**Turbine meter**	**Coriolis _Mass**
	V^*_{nom}	t	m^*_{ref}	V^*_{ref}	m_{ref}	V_{ref}	ρ_{fluid}	p_{fluid}	T_{fluid}	T_{air}	p_{Air}	N	K_V	e_V	N	K_m	e_m	N	K_V	e_V	ΔT_{fluid}	$e_{V,cor}$	$e_{m,cor}$
	[m³/h]	[s]	[t/h]	[m³/h]	[kg]	[m³]	[kg/m³]	[bar]	[°C]	[°C]	[bar]	[Pulses]	[Pulses/Liter]	[%]	[Pulses]	[Pulses/Liter]	[%]	[Pulses]	[Pulses/Liter]	[%]	[°C]	[%]	[%]
5.11.2019	30	330,136	30,354	30,405	2783,599	2,788	998,310	3,03	20,25	21,15	0,99	18448	6,6162	-0,253	278332	99,9900	-0,010	278940	100,0391	0,039	0,251	-0,267	-0,002
5.11.2019	30	330,136	30,340	30,392	2782,297	2,787	998,293	3,03	20,33	21,30	0,99	18439	6,6159	-0,257	278227	99,9990	-0,001	278835	100,0465	0,047	0,333	-0,270	0,007
5.11.2019	30	330,136	30,323	30,374	2780,744	2,785	998,303	3,03	20,29	21,40	0,99	18429	6,6161	-0,255	278054	99,9927	-0,007	278658	100,0398	0,040	0,286	-0,268	0,001
5.11.2019	30	330,137	30,297	30,348	2778,349	2,783	998,299	3,02	20,30	21,30	0,99	18413	6,6160	-0,256	277832	99,9989	-0,001	278432	100,0444	0,044	0,304	-0,269	0,007
5.11.2019	30	330,136	30,299	30,350	2778,542	2,783	998,304	3,02	20,28	21,30	0,99	18415	6,6163	-0,251	277850	99,9985	-0,002	278449	100,0441	0,044	0,280	-0,265	0,006
5.11.2019	60	160,135	59,749	59,847	2657,724	2,662	998,355	2,99	20,04	20,70	0,99	17660	6,6339	0,013	265734	99,9856	-0,014	266293	100,0310	0,031	0,038	0,018	-0,010
5.11.2019	60	160,135	59,941	60,040	2666,289	2,671	998,358	2,98	20,02	20,40	0,99	17719	6,6347	0,025	266607	99,9918	-0,008	267166	100,0369	0,037	0,022	0,030	-0,004
5.11.2019	60	160,135	59,343	59,440	2639,713	2,644	998,374	2,98	19,94	20,20	0,99	17541	6,6342	0,019	263947	99,9908	-0,009	264497	100,0363	0,036	-0,057	0,024	-0,005
5.11.2019	60	160,135	59,677	59,774	2654,559	2,659	998,383	2,98	19,90	20,00	0,99	17638	6,6337	0,010	265450	99,9978	-0,002	266001	100,0433	0,043	-0,098	0,015	0,002
5.11.2019	60	160,135	59,316	59,411	2638,474	2,643	998,392	2,99	19,86	19,90	0,99	17529	6,6329	-0,001	263817	99,9885	-0,012	264365	100,0351	0,035	-0,142	0,004	-0,008
5.11.2019	100	100,133	101,151	101,313	2813,491	2,818	998,402	2,98	19,81	19,90	0,99	18730	6,6466	0,205	281284	99,9769	-0,023	281870	100,0251	0,025	-0,192	0,202	-0,024
5.11.2019	100	100,133	100,920	101,084	2807,055	2,812	998,373	2,99	19,95	20,10	0,99	18687	6,6463	0,201	280651	99,9806	-0,019	281244	100,0288	0,029	-0,048	0,198	-0,020
5.11.2019	100	100,133	100,599	100,765	2798,131	2,803	998,352	2,99	20,05	19,90	0,99	18628	6,6463	0,201	279754	99,9789	-0,021	280357	100,0293	0,029	0,052	0,198	-0,021
5.11.2019	100	100,133	100,563	100,730	2797,134	2,802	998,340	2,99	20,11	20,30	0,99	18623	6,6468	0,209	279673	99,9855	-0,014	280284	100,0376	0,038	0,109	0,206	-0,014
5.11.2019	100	100,133	100,534	100,703	2796,336	2,801	998,324	2,99	20,19	20,30	0,99	18617	6,6465	0,203	279579	99,9805	-0,020	280199	100,0342	0,034	0,187	0,200	-0,019
5.11.2019	140	72,132	139,369	139,602	2792,494	2,797	998,334	2,97	20,14	20,50	0,99	18619	6,6564	0,353	279213	99,9870	-0,013	279831	100,0413	0,041	0,138	0,348	-0,013
5.11.2019	140	72,132	139,186	139,421	2788,818	2,794	998,314	2,97	20,23	20,50	0,99	18597	6,6572	0,364	278850	99,9886	-0,011	279476	100,0441	0,044	0,233	0,359	-0,011
5.11.2019	140	72,132	139,249	139,487	2790,078	2,795	998,294	2,98	20,33	20,50	0,99	18607	6,6576	0,371	278975	99,9883	-0,012	279607	100,0438	0,044	0,327	0,366	-0,011
5.11.2019	140	72,132	139,115	139,355	2787,404	2,792	998,282	2,98	20,38	20,50	0,99	18593	6,6589	0,391	278720	99,9927	-0,007	279356	100,0487	0,049	0,385	0,385	-0,007
5.11.2019	140	72,132	138,631	138,872	2777,709	2,783	998,269	2,98	20,45	20,40	0,99	18528	6,6587	0,387	277731	99,9856	-0,014	278369	100,0418	0,042	0,449	0,382	-0,013
5.11.2019	180	56,132	180,181	180,479	2809,423	2,814	998,348	3,00	20,07	20,30	0,99	18760	6,6665	0,505	280972	100,0106	0,011	281564	100,0558	0,056	0,068	0,503	0,010
5.11.2019	180	56,131	180,068	180,363	2807,608	2,812	998,366	3,00	19,99	20,30	0,99	18741	6,6642	0,470	280773	100,0043	0,004	281367	100,0521	0,052	-0,015	0,469	0,004
5.11.2019	180	56,131	179,998	180,295	2806,516	2,811	998,353	3,00	20,05	20,20	0,99	18736	6,6649	0,481	280672	100,0073	0,007	281275	100,0571	0,057	0,046	0,479	0,007
5.11.2019	180	56,132	179,921	180,222	2805,378	2,810	998,334	3,00	20,14	20,10	0,99	18728	6,6646	0,477	280531	99,9976	-0,002	281141	100,0481	0,048	0,136	0,475	-0,002
5.11.2019	180	56,131	179,834	180,138	2803,947	2,809	998,311	3,00	20,25	20,10	0,99	18721	6,6654	0,488	280379	99,9944	-0,006	280996	100,0451	0,045	0,249	0,486	-0,005
5.11.2019	200	50,130	198,136	198,464	2759,069	2,764	998,350	3,08	20,06	20,20	0,99	18431	6,6691	0,545	275977	100,0254	0,025	276549	100,0673	0,067	0,060	0,543	0,025
5.11.2019	200	51,131	198,088	198,415	2813,432	2,818	998,351	3,08	20,06	20,30	0,99	18800	6,6712	0,576	281451	100,0383	0,038	282038	100,0817	0,082	0,056	0,574	0,038
5.11.2019	200	51,130	198,259	198,592	2815,845	2,821	998,324	3,09	20,18	20,30	0,99	18813	6,6699	0,557	281620	100,0126	0,013	282224	100,0592	0,059	0,183	0,555	0,013
5.11.2019	200	51,130	198,181	198,519	2814,740	2,820	998,296	3,08	20,32	20,30	0,99	18808	6,6706	0,567	281473	99,9996	0,000	282094	100,0495	0,049	0,320	0,564	0,001
5.11.2019	200	51,130	198,269	198,613	2815,993	2,821	998,266	3,09	20,46	20,40	0,99	18815	6,6699	0,556	281598	99,9995	0,000	282232	100,0509	0,051	0,459	0,553	0,001

Data report MIKES: Day#3

***Original data set**

		Laboratory reference					Fluid			Ambient conditions		Turbine meter			Coriolis_Mass			Coriolis_Vol			Temperature correction of meter error		
												$K_{V,nom}$	6,6330	Pulses/ Liter	$K_{m,nom}$	100,0000	Pulses/ kg	$K_{V,nom}$	100,0000	Pulses/ Liter	T_{nom}	20	°C
																						Corrected meter error	
Date	Nominal flowrate	Measu- rement time	Standard mass flowrate	Standard volume flowrate	Mass	Volume	Water density	Line pressure	Water temp.	Air temp.	Air pressure	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	$(T_{fluid} - T_{nom})$	Turbine meter	Coriolis _Mass
	V^*_{nom}	t	m^*_{ref}	V^*_{ref}	m_{ref}	V_{ref}	ρ_{fluid}	p_{fluid}	T_{fluid}	T_{air}	p_{Air}	N	K_V	e_V	N	K_m	e_m	N	K_V	e_V	ΔT_{fluid}	$e_{V,cor}$	$e_{m,cor}$
	[m³/h]	[s]	[t/h]	[m³/h]	[kg]	[m³]	[kg/m³]	[bar]	[°C]	[°C]	[bar]	[Pulses]	[Pulses/Liter]	[%]	[Pulses]	[Pulses/Liter]	[%]	[Pulses]	[Pulses/Liter]	[%]	[°C]	[%]	[%]
6.11.2019	30	330,137	30,265	30,317	2775,419	2,780	998,290	3,04	20,35	21,00	0,99	18492	6,6514	0,277	277517	99,9910	-0,009	278133	100,0416	0,042	0,346	0,264	-0,001
6.11.2019	30	330,137	30,234	30,285	2772,578	2,777	998,321	3,03	20,20	21,00	0,99	18473	6,6516	0,280	277239	99,9932	-0,007	277844	100,0432	0,043	0,199	0,266	0,001
6.11.2019	30	330,137	30,219	30,270	2771,209	2,776	998,318	3,03	20,21	21,10	0,99	18462	6,6509	0,269	277112	99,9968	-0,003	277720	100,0476	0,048	0,214	0,256	0,004
6.11.2019	30	330,137	30,214	30,265	2770,778	2,775	998,310	3,03	20,25	21,10	0,99	18458	6,6504	0,262	277054	99,9914	-0,009	277659	100,0404	0,040	0,254	0,249	-0,001
6.11.2019	30	330,137	30,201	30,252	2769,557	2,774	998,307	3,03	20,27	21,10	0,99	18451	6,6508	0,268	276947	99,9968	-0,003	277552	100,0456	0,046	0,266	0,255	0,005
6.11.2019	30	330,137	30,258	30,309	2774,840	2,780	998,323	3,03	20,19	21,10	0,99	18485	6,6505	0,263	277464	99,9928	-0,007	278066	100,0417	0,042	0,190	0,250	0,000
6.11.2019	30	330,137	30,247	30,298	2773,785	2,778	998,308	3,03	20,26	21,00	0,99	18479	6,6507	0,268	277365	99,9951	-0,005	277965	100,0419	0,042	0,262	0,254	0,003
6.11.2019	30	330,137	30,239	30,290	2773,045	2,778	998,312	3,03	20,24	20,60	0,99	18473	6,6504	0,262	277278	99,9904	-0,010	277884	100,0398	0,040	0,244	0,249	-0,002
6.11.2019	30	330,137	30,239	30,290	2773,091	2,778	998,326	3,03	20,18	20,50	0,99	18473	6,6504	0,262	277296	99,9953	-0,005	277899	100,0450	0,045	0,176	0,248	0,003
6.11.2019	30	330,137	30,233	30,284	2772,508	2,777	998,317	3,03	20,22	20,80	0,99	18468	6,6499	0,255	277231	99,9928	-0,007	277829	100,0399	0,040	0,220	0,241	0,000
6.11.2019	100	100,134	101,339	101,505	2818,721	2,823	998,363	2,99	20,00	20,90	0,99	18829	6,6690	0,543	281829	99,9847	-0,015	282414	100,0282	0,028	-0,001	0,540	-0,015
6.11.2019	100	100,136	100,963	101,130	2808,354	2,813	998,351	2,99	20,06	20,80	0,99	18760	6,6691	0,544	280788	99,9831	-0,017	281373	100,0262	0,026	0,058	0,541	-0,017
6.11.2019	100	100,133	100,632	100,799	2799,056	2,804	998,340	3,00	20,11	20,80	0,99	18697	6,6687	0,538	279845	99,9783	-0,022	280434	100,0225	0,022	0,108	0,535	-0,021
6.11.2019	100	100,133	100,320	100,488	2790,384	2,795	998,332	3,00	20,15	20,70	0,99	18640	6,6689	0,542	278981	99,9794	-0,021	279572	100,0241	0,024	0,147	0,539	-0,020
6.11.2019	100	100,133	100,859	101,029	2805,379	2,810	998,323	3,00	20,19	20,70	0,99	18740	6,6688	0,540	280493	99,9840	-0,016	281089	100,0284	0,028	0,191	0,537	-0,015
6.11.2019	100	100,133	100,582	100,751	2797,652	2,802	998,319	3,00	20,21	20,50	0,99	18687	6,6683	0,532	279713	99,9813	-0,019	280312	100,0270	0,027	0,210	0,529	-0,018
6.11.2019	100	100,134	100,458	100,627	2794,232	2,799	998,319	3,00	20,21	20,40	0,99	18664	6,6682	0,531	279377	99,9835	-0,017	279978	100,0302	0,030	0,208	0,529	-0,016
6.11.2019	100	100,133	100,364	100,534	2791,603	2,796	998,313	3,00	20,24	20,20	0,99	18647	6,6684	0,534	279114	99,9834	-0,017	279717	100,0304	0,030	0,239	0,531	-0,015
6.11.2019	100	100,133	100,191	100,360	2786,795	2,791	998,318	3,00	20,22	20,20	0,99	18615	6,6685	0,535	278627	99,9812	-0,019	279232	100,0297	0,030	0,215	0,532	-0,018
6.11.2019	100	100,133	100,094	100,263	2784,081	2,789	998,311	3,00	20,25	20,10	0,99	18597	6,6685	0,535	278361	99,9831	-0,017	278970	100,0326	0,033	0,247	0,532	-0,016
6.11.2019	200	51,131	198,054	198,377	2812,962	2,818	998,370	3,08	19,97	20,00	0,99	18708	6,6398	0,102	281344	100,0170	0,017	281921	100,0587	0,059	-0,034	0,101	0,016
6.11.2019	200	51,131	198,485	198,816	2819,095	2,824	998,332	3,09	20,15	20,10	0,99	18887	6,6885	0,837	282039	100,0460	0,046	282618	100,0841	0,084	0,148	0,835	0,046
6.11.2019	200	51,131	198,453	198,790	2818,637	2,823	998,305	3,09	20,28	20,10	0,99	18883	6,6880	0,829	281983	100,0423	0,042	282575	100,0824	0,082	0,278	0,826	0,043
6.11.2019	200	51,131	198,202	198,546	2815,086	2,820	998,271	3,09	20,44	20,10	0,99	18866	6,6902	0,862	281718	100,0744	0,074	282313	100,1124	0,112	0,436	0,859	0,076
6.11.2019	200	51,131	197,868	198,215	2810,330	2,815	998,248	3,09	20,54	20,20	0,99	18817	6,6839	0,768	281046	100,0046	0,005	281671	100,0515	0,051	0,544	0,764	0,007
6.11.2019	200	51,131	198,598	198,951	2820,700	2,826	998,223	3,08	20,66	20,30	0,99	18884	6,6829	0,752	282081	100,0039	0,004	282720	100,0523	0,052	0,665	0,748	0,006
6.11.2019	200	51,131	198,463	198,820	2818,786	2,824	998,204	3,08	20,75	20,40	0,34	18868	6,6816	0,733	281890	100,0040	0,004	282539	100,0542	0,054	0,754	0,729	0,007
6.11.2019	200	51,131	198,419	198,783	2818,156	2,823	998,168	3,08	20,92	20,40	0,99	18863	6,6811	0,726	281834	100,0065	0,007	282496	100,0578	0,058	0,918	0,721	0,010
6.11.2019	200	51,131	198,427	198,796	2818,296	2,824	998,145	3,08	21,02	20,40	0,99	18866	6,6817	0,734	281835	100,0019	0,002	282506	100,0541	0,054	1,024	0,729	0,006
6.11.2019	200	51,131	197,681	198,054	2807,688	2,813	998,116	3,09	21,16	20,40	0,99	18795	6,6815	0,731	280767	99,9994	-0,001	281449	100,0534	0,053	1,157	0,725	0,004

Data report PTB: Day#1

*Original data set

		Laboratory reference					Fluid			Ambient conditions		Turbine meter			Coriolis_Mass			Coriolis_Vol			Temperature correction of meter error		
												$K_{V,nom}$	6,6330	Pulses/ Liter	$K_{m,nom}$	100,0000	Pulses/ kg	$K_{V,nom}$	100,0000	Pulses/ Liter	T_{nom}	20	°C
																						Corrected meter error	
Date	Nominal flowrate	Measu- rement time	Standard mass flowrate	Standard volume flowrate	Mass	Volume	Water density	Line pressure	Water temp.	Air temp.	Air pressure	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	(T_{fluid} - T_{nom})	Turbine meter	Coriolis _Mass
	V^*_{nom}	t	m^*_{ref}	V^*_{ref}	m_{ref}	V_{ref}	ρ_{fluid}	p_{fluid}	T_{fluid}	T_{air}	p_{Air}	N	K_V	e_V	N	K_m	e_m	N	K_V	e_V	ΔT_{fluid}	$e_{V,cor}$	$e_{m,cor}$
	[m^3/h]	[s]	[t/h]	[m^3/h]	[kg]	[m^3]	[kg/m^3]	[bar]	[°C]	[°C]	[bar]	[Pulses]	[Pulses/Liter]	[%]	[Pulses]	[Pulses/kg]	[%]	[Pulses]	[Pulses/Liter]	[%]	[°C]	[%]	[%]
29.7.2019	30	326,327	29,812	29,862	2702,337	2,707	998,316	3,02	19,97	24,25	1,00	18016	6,6556	0,341	270203	99,9886	-0,011	270654	99,9869	-0,013	-0,035	0,326	-0,005
29.7.2019	30	326,306	29,863	29,914	2706,809	2,711	998,310	3,01	19,99	24,23	1,00	18046	6,6556	0,341	270641	99,9853	-0,015	271097	99,9845	-0,016	-0,006	0,327	-0,008
29.7.2019	30	326,301	29,727	29,778	2694,457	2,699	998,301	3,04	20,04	24,22	1,00	17963	6,6553	0,337	269399	99,9827	-0,017	269860	99,9836	-0,016	0,041	0,323	-0,010
29.7.2019	30	326,301	29,856	29,907	2706,130	2,711	998,313	3,02	19,98	24,21	1,00	18042	6,6558	0,344	270577	99,9867	-0,013	271042	99,9896	-0,010	-0,020	0,330	-0,007
29.7.2019	30	326,318	29,802	29,852	2701,377	2,706	998,311	3,02	19,99	24,21	1,00	18010	6,6557	0,342	270113	99,9909	-0,009	270581	99,9950	-0,005	-0,012	0,328	-0,003
29.7.2019	60	162,092	59,483	59,584	2678,273	2,683	998,306	3,01	20,01	24,24	1,00	17875	6,6628	0,449	267857	100,0111	0,011	268333	100,0191	0,019	0,013	0,454	0,016
29.7.2019	60	162,117	59,954	60,056	2699,896	2,704	998,308	3,00	20,00	24,22	1,00	18020	6,6630	0,453	270032	100,0157	0,016	270512	100,0240	0,024	0,003	0,458	0,020
29.7.2019	60	162,094	59,521	59,622	2679,998	2,685	998,309	3,01	20,00	24,20	1,00	17887	6,6630	0,452	268036	100,0135	0,013	268514	100,0224	0,022	0,000	0,457	0,018
29.7.2019	60	162,118	60,300	60,402	2715,482	2,720	998,311	2,99	19,99	24,20	1,00	18125	6,6634	0,459	271569	100,0076	0,008	272056	100,0177	0,018	-0,008	0,463	0,012
29.7.2019	60	162,118	59,701	59,802	2688,502	2,693	998,310	3,01	20,00	24,18	1,00	17944	6,6631	0,453	268879	100,0107	0,011	269361	100,0207	0,021	-0,003	0,458	0,015
29.7.2019	100	97,299	100,195	100,366	2708,003	2,713	998,297	3,00	20,06	24,19	1,00	18089	6,6684	0,534	270849	100,0180	0,018	271334	100,0264	0,026	0,061	0,532	0,018
29.7.2019	100	97,317	99,206	99,375	2681,777	2,686	998,296	3,00	20,06	24,20	1,00	17914	6,6685	0,536	268228	100,0188	0,019	268709	100,0274	0,027	0,061	0,533	0,019
29.7.2019	100	97,319	100,026	100,197	2704,010	2,709	998,295	3,00	20,07	24,18	1,00	18062	6,6683	0,532	270440	100,0144	0,014	270925	100,0229	0,023	0,070	0,530	0,015
29.7.2019	100	97,316	99,345	99,514	2685,507	2,690	998,297	3,00	20,06	24,16	1,00	17939	6,6686	0,536	268609	100,0217	0,022	269092	100,0309	0,031	0,060	0,533	0,022
29.7.2019	100	97,298	99,249	99,419	2682,421	2,687	998,296	3,00	20,06	24,16	1,00	17918	6,6684	0,534	268287	100,0167	0,017	268771	100,0265	0,026	0,061	0,531	0,017
29.7.2019	140	69,531	139,754	139,993	2699,215	2,704	998,294	3,00	20,07	24,18	1,00	18051	6,6761	0,650	270000	100,0291	0,029	270480	100,0359	0,036	0,074	0,645	0,028
29.7.2019	140	69,549	139,328	139,566	2691,676	2,696	998,292	3,01	20,08	24,17	1,00	18000	6,6759	0,646	269245	100,0287	0,029	269722	100,0348	0,035	0,081	0,642	0,028
29.7.2019	140	69,528	139,402	139,640	2692,300	2,697	998,293	3,00	20,08	24,15	1,00	18005	6,6762	0,651	269310	100,0297	0,030	269790	100,0369	0,037	0,077	0,647	0,029
29.7.2019	140	69,571	139,353	139,591	2693,023	2,698	998,294	3,00	20,07	24,15	1,00	18010	6,6762	0,652	269377	100,0277	0,028	269856	100,0347	0,035	0,073	0,648	0,027
29.7.2019	140	69,531	139,480	139,719	2693,930	2,699	998,294	2,99	20,07	24,14	1,00	18016	6,6762	0,652	269473	100,0297	0,030	269952	100,0366	0,037	0,072	0,647	0,029
29.7.2019	180	54,106	179,097	179,404	2691,742	2,696	998,289	3,01	20,10	24,14	1,00	18018	6,6823	0,744	269274	100,0371	0,037	269739	100,0383	0,038	0,099	0,742	0,037
29.7.2019	180	54,127	179,611	179,918	2700,514	2,705	998,290	3,00	20,09	24,16	1,00	18077	6,6825	0,746	270144	100,0343	0,034	270612	100,0362	0,036	0,094	0,744	0,034
29.7.2019	180	54,125	179,335	179,642	2696,265	2,701	998,289	3,00	20,09	24,16	1,00	18049	6,6826	0,748	269721	100,0351	0,035	270188	100,0369	0,037	0,094	0,746	0,035
29.7.2019	180	54,105	178,803	179,109	2687,282	2,692	998,289	3,01	20,10	24,16	1,00	17988	6,6823	0,743	268829	100,0375	0,037	269294	100,0391	0,039	0,095	0,741	0,037
29.7.2019	180	54,106	179,664	179,971	2700,265	2,705	998,290	2,99	20,09	24,15	1,00	18075	6,6823	0,744	270121	100,0350	0,035	270588	100,0366	0,037	0,092	0,742	0,035
29.7.2019	200	48,708	199,453	199,795	2698,616	2,703	998,286	3,00	20,11	24,18	1,00	18071	6,6849	0,783	269971	100,0405	0,041	270428	100,0381	0,038	0,112	0,781	0,041
29.7.2019	200	48,710	198,992	199,334	2692,496	2,697	998,286	3,01	20,11	24,18	1,00	18030	6,6849	0,783	269359	100,0406	0,041	269815	100,0382	0,038	0,111	0,781	0,041
29.7.2019	200	48,729	199,072	199,414	2694,630	2,699	998,286	3,00	20,11	24,18	1,00	18045	6,6852	0,787	269558	100,0352	0,035	270014	100,0327	0,033	0,111	0,785	0,035
29.7.2019	200	48,687	199,150	199,492	2693,359	2,698	998,285	3,00	20,12	24,15	1,00	18036	6,6850	0,784	269450	100,0424	0,042	269906	100,0398	0,040	0,116	0,782	0,042
29.7.2019	200	48,708	199,267	199,610	2696,106	2,701	998,284	3,00	20,12	24,15	1,00	18055	6,6852	0,787	269716	100,0391	0,039	270173	100,0367	0,037	0,119	0,785	0,039

PTB Laboratory – Day#2

Data report PTB: Day#2

*Original data set

												Turbine meter			Coriolis_Mass			Coriolis_Vol			Temperature correction of meter error		
												$K_{V,nom}$	6,6330	Pulses/ Liter	$K_{m,nom}$	100,0000	Pulses/ kg	$K_{V,nom}$	100,0000	Pulses/ Liter	T_{nom}	20	°C
		Laboratory reference					Fluid			Ambient conditions												Corrected meter error	
Date	Nominal flowrate	Measu-rement time	Standard mass flowrate	Standard volume flowrate	Mass	Volume	Water density	Line pressure	Water temp.	Air temp.	Air pressure	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	(T_{fluid} - T_{nom})	Turbine meter	Coriolis _Mass
	V^*_{nom}	t	m^*_{ref}	V^*_{ref}	m_{ref}	V_{ref}	ρ_{fluid}	p_{fluid}	T_{fluid}	T_{air}	p_{Air}	N	K_V	e_V	N	K_m	e_m	N	K_V	e_V	ΔT_{fluid}	$e_{V,cor}$	$e_{m,cor}$
	[m³/h]	[s]	[t/h]	[m³/h]	[kg]	[m³]	[kg/m³]	[bar]	[°C]	[°C]	[bar]	[Pulses]	[Pulses/Liter]	[%]	[Pulses]	[Pulses/kg]	[%]	[Pulses]	[Pulses/Liter]	[%]	[°C]	[%]	[%]
30.7.2019	30	326,342	30,149	30,200	2733,012	2,738	998,299	2,98	20,05	23,30	1,00	18220	6,6553	0,336	273256	99,9835	-0,017	273757	99,9964	-0,004	0,047	0,322	-0,010
30.7.2019	30	326,303	29,889	29,940	2709,151	2,714	998,307	2,99	20,01	23,29	1,00	18060	6,6550	0,332	270873	99,9844	-0,016	271372	99,9990	-0,001	0,010	0,318	-0,009
30.7.2019	30	326,301	29,724	29,774	2694,171	2,699	998,314	3,03	19,98	23,29	1,00	17961	6,6554	0,337	269357	99,9777	-0,022	269852	99,9925	-0,007	-0,023	0,323	-0,016
30.7.2019	30	326,321	29,998	30,049	2719,180	2,724	998,307	2,98	20,01	23,31	1,00	18128	6,6554	0,338	271849	99,9746	-0,025	272350	99,9894	-0,011	0,008	0,324	-0,019
30.7.2019	30	326,297	29,748	29,798	2696,269	2,701	998,309	3,04	20,00	23,33	1,00	17975	6,6553	0,337	269597	99,9889	-0,011	270098	100,0054	0,005	-0,002	0,323	-0,004
30.7.2019	60	162,097	59,944	60,046	2699,096	2,704	998,302	3,00	20,03	23,41	1,00	18014	6,6628	0,449	269941	100,0116	0,012	270445	100,0282	0,028	0,034	0,454	0,016
30.7.2019	60	162,117	59,989	60,091	2701,473	2,706	998,311	3,00	19,99	23,44	1,00	18030	6,6629	0,450	270168	100,0076	0,008	270671	100,0246	0,025	-0,009	0,455	0,012
30.7.2019	60	162,114	59,656	59,757	2686,424	2,691	998,308	3,01	20,00	23,47	1,00	17929	6,6626	0,447	268674	100,0118	0,012	269174	100,0284	0,028	0,005	0,452	0,016
30.7.2019	60	162,099	59,816	59,917	2693,371	2,698	998,310	3,00	19,99	23,53	1,00	17976	6,6629	0,451	269360	100,0085	0,008	269862	100,0256	0,026	-0,005	0,455	0,013
30.7.2019	60	162,116	59,644	59,745	2685,888	2,690	998,310	3,00	19,99	23,56	1,00	17926	6,6629	0,450	268598	100,0034	0,003	269099	100,0206	0,021	-0,005	0,455	0,008
30.7.2019	100	97,299	99,970	100,140	2701,921	2,707	998,297	2,99	20,06	23,61	1,00	18048	6,6683	0,532	270233	100,0151	0,015	270732	100,0292	0,029	0,059	0,530	0,015
30.7.2019	100	97,298	99,452	99,621	2687,895	2,692	998,297	3,00	20,06	23,62	1,00	17954	6,6682	0,531	268840	100,0188	0,019	269338	100,0334	0,033	0,058	0,528	0,019
30.7.2019	100	97,319	100,059	100,230	2704,901	2,710	998,297	3,00	20,06	23,62	1,00	18068	6,6683	0,533	270549	100,0218	0,022	271053	100,0374	0,037	0,060	0,530	0,022
30.7.2019	100	97,299	99,353	99,523	2685,263	2,690	998,296	3,00	20,06	23,62	1,00	17936	6,6680	0,528	268573	100,0174	0,017	269073	100,0329	0,033	0,063	0,525	0,018
30.7.2019	100	97,318	100,131	100,302	2706,819	2,711	998,295	2,99	20,07	23,64	1,00	18081	6,6684	0,534	270730	100,0178	0,018	271234	100,0331	0,033	0,069	0,531	0,018
30.7.2019	140	69,529	139,350	139,588	2691,335	2,696	998,294	3,00	20,07	23,67	1,00	17998	6,6760	0,648	269216	100,0306	0,031	269708	100,0425	0,043	0,072	0,644	0,030
30.7.2019	140	69,550	139,519	139,757	2695,408	2,700	998,294	3,00	20,07	23,69	1,00	18025	6,6759	0,647	269623	100,0305	0,030	270115	100,0420	0,042	0,074	0,642	0,030
30.7.2019	140	69,551	139,703	139,942	2699,000	2,704	998,293	3,00	20,08	23,69	1,00	18049	6,6759	0,646	269979	100,0293	0,029	270473	100,0412	0,041	0,076	0,642	0,029
30.7.2019	140	69,530	140,304	140,544	2709,796	2,714	998,292	2,99	20,08	23,70	1,00	18123	6,6765	0,656	271060	100,0297	0,030	271557	100,0419	0,042	0,083	0,652	0,029
30.7.2019	140	69,554	139,939	140,178	2703,674	2,708	998,291	3,00	20,09	23,70	1,00	18081	6,6761	0,650	270452	100,0313	0,031	270948	100,0434	0,043	0,089	0,646	0,031
30.7.2019	180	54,104	179,306	179,613	2694,791	2,699	998,289	3,01	20,10	23,70	1,00	18039	6,6826	0,747	269585	100,0393	0,039	270063	100,0452	0,045	0,098	0,746	0,039
30.7.2019	180	54,147	179,552	179,860	2700,636	2,705	998,289	3,00	20,10	23,71	1,00	18077	6,6822	0,741	270169	100,0390	0,039	270647	100,0445	0,045	0,099	0,739	0,039
30.7.2019	180	54,086	179,139	179,447	2691,392	2,696	998,288	3,01	20,10	23,72	1,00	18016	6,6825	0,746	269249	100,0408	0,041	269727	100,0469	0,047	0,100	0,744	0,041
30.7.2019	180	54,104	179,559	179,867	2698,593	2,703	998,289	3,01	20,10	23,75	1,00	18064	6,6824	0,745	269964	100,0388	0,039	270441	100,0441	0,044	0,096	0,743	0,039
30.7.2019	180	54,082	179,091	179,398	2690,464	2,695	998,289	3,01	20,10	23,74	1,00	18010	6,6826	0,747	269151	100,0389	0,039	269627	100,0443	0,044	0,099	0,745	0,039
30.7.2019	200	48,709	186,898	187,218	2528,795	2,533	998,287	2,94	20,11	23,74	1,00	16931	6,6838	0,766	252982	100,0405	0,041	253425	100,0441	0,044	0,106	0,764	0,041
30.7.2019	200	48,729	199,440	199,783	2699,605	2,704	998,285	3,00	20,12	23,78	1,00	18078	6,6851	0,785	270060	100,0368	0,037	270526	100,0376	0,038	0,115	0,783	0,037
30.7.2019	200	48,728	199,293	199,635	2697,555	2,702	998,286	3,00	20,11	23,77	1,00	18064	6,6850	0,783	269872	100,0432	0,043	270337	100,0438	0,044	0,113	0,781	0,043
30.7.2019	200	48,710	199,287	199,630	2696,487	2,701	998,285	3,00	20,12	23,78	1,00	18056	6,6846	0,778	269757	100,0402	0,040	270221	100,0404	0,040	0,117	0,777	0,040
30.7.2019	200	48,708	199,691	200,035	2701,845	2,706	998,284	2,99	20,12	23,78	1,00	18093	6,6850	0,785	270290	100,0391	0,039	270755	100,0392	0,039	0,121	0,783	0,039

Data report PTB: Day#3

*Original data set

Turbine meter $K_{V,nom}$ 6,6629 Pulses/ Liter

Coriolis_Mass $K_{m,nom}$ 100,0076 Pulses/ kg

Coriolis_Vol $K_{V,nom}$ 100,0246 Pulses/ Liter

Temperature correction of meter error

T_{nom} 20 °C

		Laboratory reference					Fluid			Ambient conditions		Turbine meter			Coriolis_Mass			Coriolis_Vol				Corrected meter error	
Date	Nominal flowrate	Measu-rement time	Standard mass flowrate	Standard volume flowrate	Mass	Volume	Water density	Line pressure	Water temp.	Air temp.	Air pressure	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	Pulse count	K-factor	Meter error	(T_{fluid} - T_{nom})	Turbine meter	Coriolis _Mass
	V^{*}_{nom}	t	m^{*}_{ref}	V^{*}_{ref}	m_{ref}	V_{ref}	ρ_{fluid}	p_{fluid}	T_{fluid}	T_{air}	p_{Air}	N	K_V	e_V	N	K_m	e_m	N	K_V	e_V	ΔT_{fluid}	$e_{V,cor}$	$e_{m,cor}$
	[m³/h]	[s]	[t/h]	[m³/h]	[kg]	[m³]	[kg/m³]	[bar]	[°C]	[°C]	[bar]	[Pulses]	[Pulses/Liter]	[%]	[Pulses]	[Pulses/kg]	[%]	[Pulses]	[Pulses/Liter]	[%]	[°C]	[%]	[%]
31.7.2019	30	326,318	29,752	29,803	2696,875	2,701	998,317	3,03	19,96	23,29	1,00	17979	6,6554	0,338	269666	99,9920	-0,008	270147	100,0018	0,002	-0,040	0,323	-0,001
31.7.2019	30	326,320	29,882	29,933	2708,678	2,713	998,310	3,01	20,00	23,29	1,00	18058	6,6555	0,338	270836	99,9883	-0,012	271320	99,9976	-0,002	-0,003	0,324	-0,005
31.7.2019	30	326,324	29,629	29,679	2685,709	2,690	998,302	3,04	20,04	23,30	1,00	17901	6,6540	0,316	268526	99,9833	-0,017	269011	99,9937	-0,006	0,036	0,302	-0,010
31.7.2019	30	326,323	29,944	29,994	2714,240	2,719	998,313	3,02	19,98	23,30	1,00	18096	6,6558	0,344	271395	99,9893	-0,011	271883	100,0002	0,000	-0,021	0,330	-0,004
31.7.2019	30	326,299	30,038	30,089	2722,570	2,727	998,308	2,96	20,00	23,32	1,00	18151	6,6556	0,340	272225	99,9882	-0,012	272717	99,9995	-0,001	0,003	0,326	-0,005
31.7.2019	30	326,301	30,095	30,146	2727,744	2,732	998,308	2,97	20,01	23,31	1,00	18185	6,6554	0,338	272740	99,9874	-0,013	273238	100,0004	0,000	0,007	0,324	-0,006
31.7.2019	30	326,319	29,951	30,002	2714,897	2,719	998,309	3,00	20,00	23,33	1,01	18100	6,6556	0,341	271445	99,9835	-0,016	271942	99,9972	-0,003	-0,001	0,327	-0,010
31.7.2019	30	326,300	29,724	29,774	2694,149	2,699	998,313	3,03	19,98	23,36	1,01	17961	6,6554	0,338	269386	99,9893	-0,011	269879	100,0033	0,003	-0,020	0,324	-0,004
31.7.2019	30	326,304	29,925	29,976	2712,445	2,717	998,304	3,00	20,02	23,37	1,01	18083	6,6554	0,337	271222	99,9917	-0,008	271724	100,0069	0,007	0,023	0,323	-0,001
31.7.2019	30	326,301	29,782	29,832	2699,383	2,704	998,309	3,03	20,00	23,40	1,01	17996	6,6554	0,338	269911	99,9899	-0,010	270410	100,0054	0,005	-0,002	0,324	-0,003
31.7.2019	100	97,298	99,674	99,844	2693,891	2,698	998,295	3,00	20,07	23,55	1,01	17994	6,6682	0,530	269422	100,0122	0,012	269918	100,0255	0,025	0,069	0,527	0,013
31.7.2019	100	97,298	99,782	99,953	2696,824	2,701	998,295	3,00	20,07	23,65	1,01	18014	6,6683	0,533	269728	100,0169	0,017	270225	100,0304	0,030	0,067	0,530	0,017
31.7.2019	100	97,319	99,937	100,108	2701,599	2,706	998,295	3,00	20,07	23,68	1,01	18046	6,6684	0,533	270207	100,0174	0,017	270705	100,0309	0,031	0,069	0,530	0,018
31.7.2019	100	97,296	99,366	99,536	2685,525	2,690	998,295	3,00	20,07	23,65	1,01	17939	6,6685	0,535	268596	100,0162	0,016	269094	100,0308	0,031	0,069	0,532	0,017
31.7.2019	100	97,296	99,572	99,742	2691,093	2,696	998,296	3,00	20,06	23,69	1,01	17975	6,6681	0,529	269167	100,0214	0,021	269665	100,0357	0,036	0,062	0,526	0,022
31.7.2019	100	97,299	99,320	99,489	2684,357	2,689	998,297	3,00	20,06	23,70	1,01	17930	6,6681	0,529	268483	100,0176	0,018	268980	100,0321	0,032	0,060	0,526	0,018
31.7.2019	100	97,318	100,211	100,382	2708,978	2,714	998,294	3,00	20,07	23,70	1,01	18095	6,6682	0,531	270941	100,0159	0,016	271444	100,0307	0,031	0,071	0,529	0,016
31.7.2019	100	97,318	99,763	99,933	2696,853	2,701	998,294	3,00	20,07	23,71	1,01	18015	6,6686	0,537	269729	100,0162	0,016	270230	100,0310	0,031	0,073	0,534	0,017
31.7.2019	100	97,320	100,369	100,540	2713,297	2,718	998,296	3,00	20,06	23,71	1,01	18124	6,6683	0,532	271374	100,0163	0,016	271878	100,0313	0,031	0,063	0,530	0,017
31.7.2019	100	97,297	100,214	100,385	2708,456	2,713	998,296	3,00	20,07	23,71	1,01	18092	6,6684	0,534	270896	100,0186	0,019	271399	100,0335	0,034	0,065	0,531	0,019
31.7.2019	200	48,709	199,246	199,588	2695,878	2,701	998,287	3,01	20,11	23,72	1,01	18053	6,6850	0,785	269690	100,0379	0,038	270152	100,0376	0,038	0,106	0,783	0,038
31.7.2019	200	48,688	199,029	199,371	2691,778	2,696	998,286	3,01	20,11	23,73	1,01	18025	6,6848	0,782	269298	100,0447	0,045	269760	100,0446	0,045	0,109	0,780	0,045
31.7.2019	200	48,729	199,486	199,828	2700,223	2,705	998,285	3,00	20,11	23,73	1,01	18083	6,6854	0,790	270125	100,0380	0,038	270590	100,0384	0,038	0,114	0,788	0,038
31.7.2019	200	48,709	199,502	199,845	2699,342	2,704	998,285	3,00	20,12	23,76	1,01	18076	6,6850	0,783	270040	100,0392	0,039	270504	100,0392	0,039	0,116	0,782	0,039
31.7.2019	200	48,707	199,327	199,669	2696,860	2,701	998,286	3,00	20,11	23,77	1,01	18059	6,6848	0,781	269807	100,0449	0,045	270271	100,0451	0,045	0,111	0,780	0,045
31.7.2019	200	48,706	199,385	199,727	2697,583	2,702	998,284	3,01	20,12	23,78	1,01	18064	6,6849	0,782	269881	100,0455	0,045	270346	100,0459	0,046	0,122	0,780	0,046
31.7.2019	200	48,709	199,440	199,783	2698,503	2,703	998,285	2,99	20,12	23,79	1,01	18070	6,6848	0,781	269951	100,0373	0,037	270414	100,0370	0,037	0,116	0,779	0,037
31.7.2019	200	48,707	199,440	199,782	2698,385	2,703	998,285	3,00	20,11	23,74	1,01	18068	6,6844	0,775	269946	100,0398	0,040	270411	100,0403	0,040	0,115	0,773	0,040
31.7.2019	200	48,710	198,883	199,225	2691,017	2,696	998,284	3,01	20,12	23,73	1,01	18019	6,6845	0,776	269209	100,0399	0,040	269671	100,0396	0,040	0,122	0,774	0,040
31.7.2019	200	48,727	199,505	199,847	2700,368	2,705	998,284	3,00	20,12	23,74	1,01	18082	6,6846	0,778	270145	100,0401	0,040	270608	100,0396	0,040	0,120	0,777	0,040