FINAL REPORT

COOMET 680/RU/16

COOMET Supplementary Comparison

COOMET.M.FF-S9

Comparisons of national standards in the field of gas flow rate and volume, gas flow rates from 20 to 6500 m^3/h

Pilot

Aidar Mingaleev, AnatolyYakovlev – VNIIM-VNIIR, Russia

Participants

Bodo Mickan – PTB, Germany

Alexander Bardonov – BELGIM, Belarus

Denis Serediuk – IFSM, Ukraine

Arunas Stankevicius – LEI, Lithuania

Ibrahim Busuladžić – LABSAGAS, Bosnia and Herzegovina

2020

Contents

1 Introduction

The aim of this project is to implement a comparison in the field of gas consumption in the laboratories that are participants of the working group of TC 1.4 of the metrological organization COOMET establish the degree of equivalence of national standards and evaluate the calibration and measurement capabilities of the laboratories of national metrology institutes in the field of gas flow. Comparisons were made in the range of gas flow (20 – 6500) m^3/h.

2 Participants

The participants and the schedule of comparisons are shown in Table 1. The comparison measurements started in May 2019 and finished in January 2020.

Each laboratory had 3 weeks for providing the measurements and for sending the transfer standard to the next laboratory. Due to some problems with customs documents the transfer standard shipment was delayed several times. The transfer standards were calibrated by the pilot laboratory before, during and after the comparison to assess their calibration stability.

Table 1 - Schedule of comparisons.

Country	Laboratory	Place of comparisons	Notes	Date of comparison	Contact
Russia	VNIIR – Affiliated Branch of the D.I. Mendeleyev Institute for Metrology* (Pilot Laboratory)	VNIIM-VNIIR, 7a Vtoraya Azinskaya str., 420088 Kazan	whole range of comparisons, independent laboratory	May 08 – May 24, 2019	Aidar Mingaleev, Anatoly Yakovlev E-mail: nio13@vniir.org; aydarmv@gmail.com Phone. +7 843 272 11 24 Fax. +7 843 272 60 33
Belarus	Belarusian State Institute of Metrology	BelGIM, Starovilensky tract 93 220053 Minsk	whole range of comparisons, traceability to PTB	May 30 – June 16, 2019	Alexander Bardonov E-mail: bardonov@belgim.by Phone. +375 17 233 03 92 Fax.+375 17 288 09 38
Ukraine	DP "Ivano-Frankivskstandartmetrologija"	IFSM, 127 Vovchynetska str., 76006 Ivano-Frankivsk	whole range of comparisons, independent laboratory	July 04 – July 15, 2019	Denis Serediuk E-mail: nmzv@ukr.net Phone. +380 342 56 89 89 Fax. +380 342 53 02 00
Lithuania	Lithuanian Energy Institute	LEI, 3 Breslaujos str. LT – 44403 Kaunas	whole range of comparisons, traceability to PTB	July 17 – July 29, 2019	Arunas Stankevicius E-mail: Arunas.Stankevicius@lei.lt Phone. +370 37 401 862 Fax. +370 37 351 271
Germany	Physikalisch-Technische Bundesanstalt	PTB, Bundesallee 100 D-38116 Braunschweig	whole range of comparisons, independent laboratory	July 30 – August 26, 2019	Bodo Mickan E-mail: Bodo.Mickan@ptb.de Phone. +49 531 592 13 31 Fax. +49 531 592 13 31
Russia	VNIIR – Affiliated Branch of the D.I. Mendeleyev Institute for Metrology* (Pilot Laboratory)	VNIIM-VNIIR, 7a Vtoraya Azinskaya str., 420088 Kazan	whole range of comparisons, independent laboratory	October 26 – December 06, 2019	Aidar Mingaleev, Anatoly Yakovlev E-mail: nio13@vniir.org Phone. +7 843 272 11 24 Fax. +7 843 272 60 33
Bosnia and Herzegovina	KJKP Sarajevogas d.o.o. Sarajevo	LABSAGAS, Rajlovacka bb 71000 Sarajevo	(20 – 400) m^3/h, traceability to CMI	December 11, 2019 – January 7, 2020	Ibrahim Busuladžić E-mail: ibusuladzic@sarajevogas.ba Phone. + 387 33 568 125
Russia	VNIIR – Affiliated Branch of the D.I. Mendeleyev Institute for Metrology* (Pilot Laboratory)	VNIIM-VNIIR, 7a Vtoraya Azinskaya str., 420088 Kazan	whole range of comparisons, independent laboratory	January 14 – January 23, 2020	Aidar Mingaleev, Anatoly Yakovlev E-mail: nio13@vniir.org Phone. +7 843 272 11 24 Fax. +7 843 272 60 33

* Before 2020: All-Russian Research Institute of Flow Metering (VNIIR)

3 Comparison standards

As reference standards were used:

- rotary gas meter IRM-A-DUO G250 №20528453 manufactured by "Elster –Instromet B.V.", Netherlands;
- turbine gas meter TRZ G4000 №11092523, LLC "Elster Gazelectronika", Arzamas, Russia.

3.1 IRM-A-DUO G250

Measuring range of the meter is from 20 to 400 m^3/h. Pressure class is PN16, flanges correspond to DIN EN 1092-1. Physical form and design format of the meter are shown in Figure 1. Its dimensions are shown in Figure 2. The measuring instrument also includes inlet and outlet pipelines with the same diameter DN as the meter.

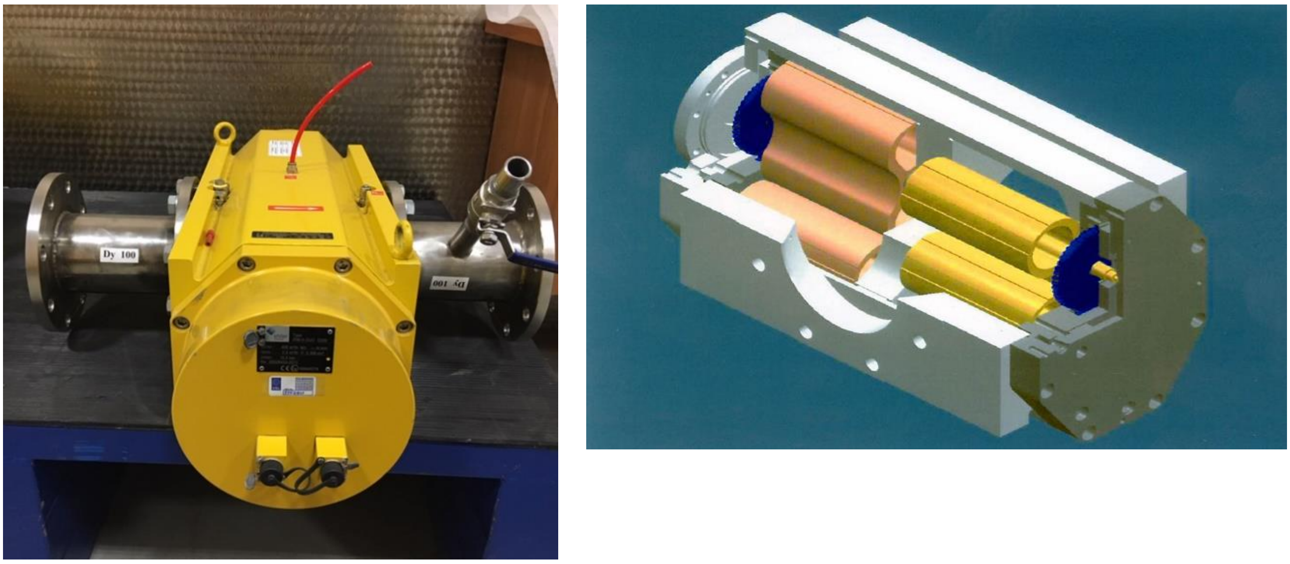
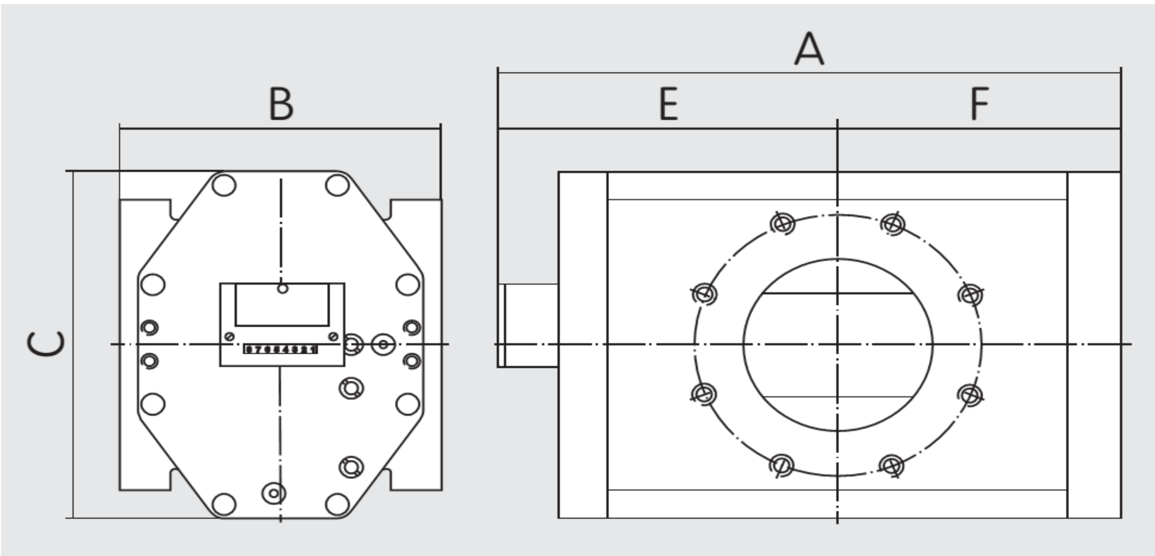


Figure 1 – Rotary gas meter IRM-A-DUO



Dimensions of measurement instruments	Dimensions [mm]						Weight, kg
	DN	A	B	C	E	F	
	100	*723*	*241*	*238*	*368*	*355*	*67*

Figure 2 – Dimensions and weight of the meter IRM-A-DUO G250

A prerequisite for the normal operation of the meter is the horizontal operating position of the meter on the test equipment. Tests are carried out without lubrication of the meter bearings with oil.

3.2 TRZ G4000

The measuring range of the meter is from 320 to 6500 m^3/h. Pressure class is PN16, flanges correspond to DIN EN 1092-1. Physical form and design of the meter are shown in Figure 3. Its dimensions are shown in Figure 4. Input and output pipelines are not included in the meter package. Each laboratory should use its own pipelines: an inlet straight section with a length of at least 20 x DN or >10DN with flow starightener (CPA, Zanker or equivalent) and an output section of at least 5 x DN. The internal diameter of the input pipeline should be 300 mm with a deviation of no more than ±0.5%. Tests are carried out without lubricating the meter bearings.

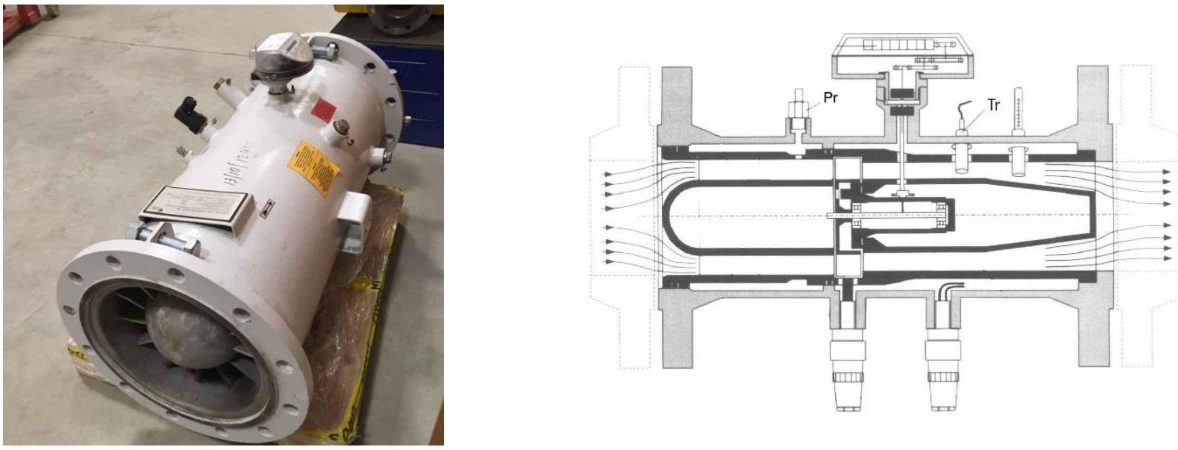
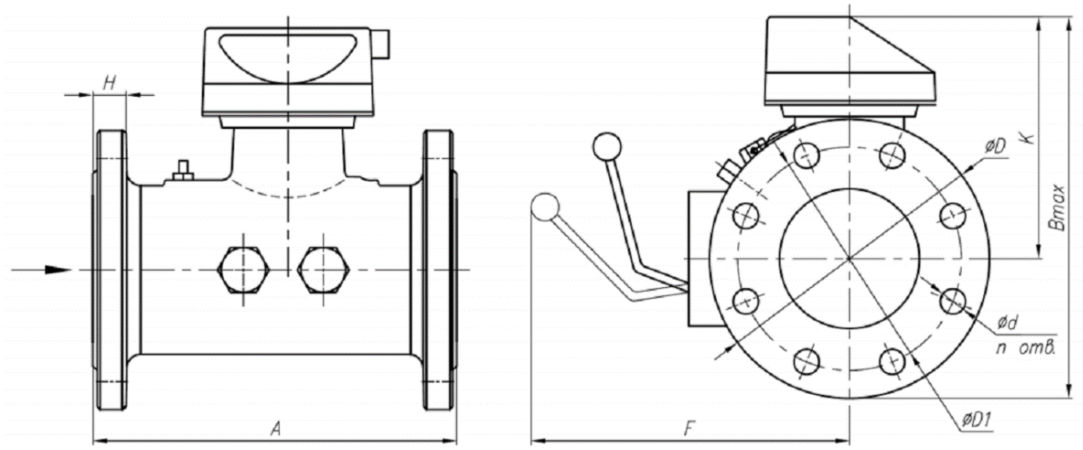


Figure 3 – Turbine gas meter TRZ



Dimensions of measurement instruments	Dimensions [mm]										Weight, kg
	DN	A	B	D	D1	d	n	K	F	H	
	300	*900*	*640*	*460*	*410*	*26*	*12*	*410*	*not*	*31*	*230*

Figure 4 – Dimensions and weight of the meter TRZ G4000.

4 Measurement technique

Working conditions in the laboratory must meet the following requirements:
- the test should be performed in the laboratory where the temperature is from 18 to 26°C;
- temperature variations during one measurement should not exceed 0.2°C;
- test pressure should be close to atmospheric pressure;
- the meters must be tested in a horizontal position;
- prior to testing the meters should run for at least 20 minutes at a nominal expense**.**

The rotary gas meter IRM-A-DUO is tested at the following flow rates: 20 m^3/h, 40 m^3/h, 60 m^3/h, 100 m^3/h, 150 m^3/h, 200 m^3/h, 250 m^3/h, 300 m^3/h, 350 m^3/h, 400 m^3/h – only ten points.

The spread of the required flow rate is ±5%. At one test point, the test is repeated 3 times from Q_{max} to Q_{min}.

From the measured results, the average value of the flow rate, the relative error of the measuring instrument and the expanded uncertainty of measurement of each measured point are calculated, which are written to the table modeled on the table 3.

The turbine gas meter TRZ is tested at the following flow rates: 320 m^3/h, 650 m^3/h, 1000 m^3/h, 1500 m^3/h, 2500 m^3/h, 3500 m^3/h, 4500 m^3/h, 5500 m^3/h, 6500 m^3/h – only nine points.

Deviation from the required flow rate is ±5%. At one test point, the test is repeated 3 times from Q_{max} to Q_{min}.

From the measured results, the average value of the flow, the relative error of the measuring instrument and the expanded uncertainty of measurement of each measured point are calculated, which are written to the table modeled on the table 4.

5 Test facilities

5.1 Russia

Place of calibration: VNIIR – Affiliated Branch of D.I. Mendeleyev Institute for Metrology (VNIIM-VNIIR), 7a Vtoraya Azinskaya str., 420088 Kazan, Russia.

The automated nozzle test rig (Figure 5, 6) with flow range from 10 to 16000 m^3/h was used for the calibration of the rotary gas meter IRM-A-DUO G250 №20528453 and turbine gas meter TRZ G4000 №11092523.

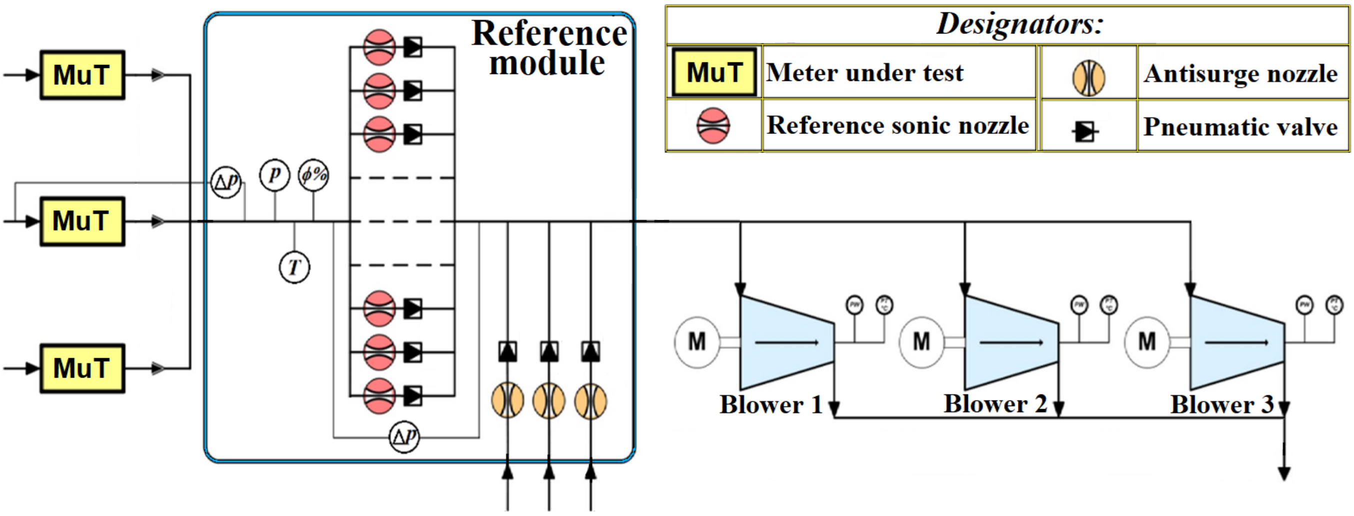


Figure 5 – The scheme of VNIIM-VNIIR test rig

The transfer of the gas flow rate units is carried out by comparing the mass air flow through the sequentially placed meter under test and reference module, which includes 45 parallelly installed reference sonic nozzles of various typical sizes.

The change in air flow rate is ensured with the inclusion of various combinations of reference nozzles. Each reference nozzle is connected and disconnected by means of pneumatic actuated valves.

Air is pumped on the suction line by means of three air blowers.

The test rig TR-2 ensures the reproduction of volume and mass gas flow rate units with an expanded uncertainty of no more than 0.1%.

The sonic nozzle test rig is traced to the bell prover, which is the initial test rig of Russian State primary measurement standard for the units of volumetric and mass gas flow rates. The bell prover allows reproducing the air flow in the flow range from 1 to 65 m^3/h with an expanded uncertainty of no more than 0.06%.

Figure 6 – The reference module of VNIIM-VNIIR test rig

5.2 Belarus

Place of the test: Laboratory of gas flow measurements, Republican Unitary Enterprise "Belarusian State Institute of Metrology" (BelGIM), Starovilensky trakt 93, 220053, Minsk, Belarus.

During the test the turbine gas meters were calibrated by the method of comparison the meters readings with readings of a standard gas meters.

According to the Technical Protocol for COOMET Project No. 680/RU/16 “Comparisons of national standards in the field of gas flow rate and volume, gas flow rates from 20 to 6500 m^3/h” the rotary gas meter G250 was calibrated at 10 values of flow rate: (20, 40, 60, 100, 150, 200, 250, 300, 350, 400) m^3/h, and gas turbine meter G4000 was calibrated at 9 values of flow rate: (320, 650, 1000, 1500, 2500, 3500, 4500, 5500, 6500) m^3/h.

The deviation of real flow rate values did not exceed ±3 % of the required values. The test at each flow rate was repeated 3 times and then the means values were calculated.

The standard facility No. 2010-0054 with reference gas meters was used for calibration. The manufacture of the test rig is Inotech Meter Calibration Systems GmbH, Germany. The main characteristics of the facility: measurement range is (1.5 – 6500) m^3/h, the expanded uncertainty is U = 0.25 % (k = 2), diameters of meters under test – (50 – 300) mm. Reference meters are: rotary meter Delta S-Flow G 100, (1.5 – 140) m^3/h, turbine meter TRZ03-G650, (100 – 1000) m^3/h, turbine meter TRZ03-G4000, (650 – 6500) m^3/h. The test rig is equipped with sensors to measure the temperature, the pressure and the differential pressure. The software using the information from the process control system monitors the system condition and carry out a permanent plausibility check for all measured values. The general view of the facility is presented in Figure 7.

Figure 7 – The general view of BelGIM standard facility

The scheme of the facility is presented in Figure 8.

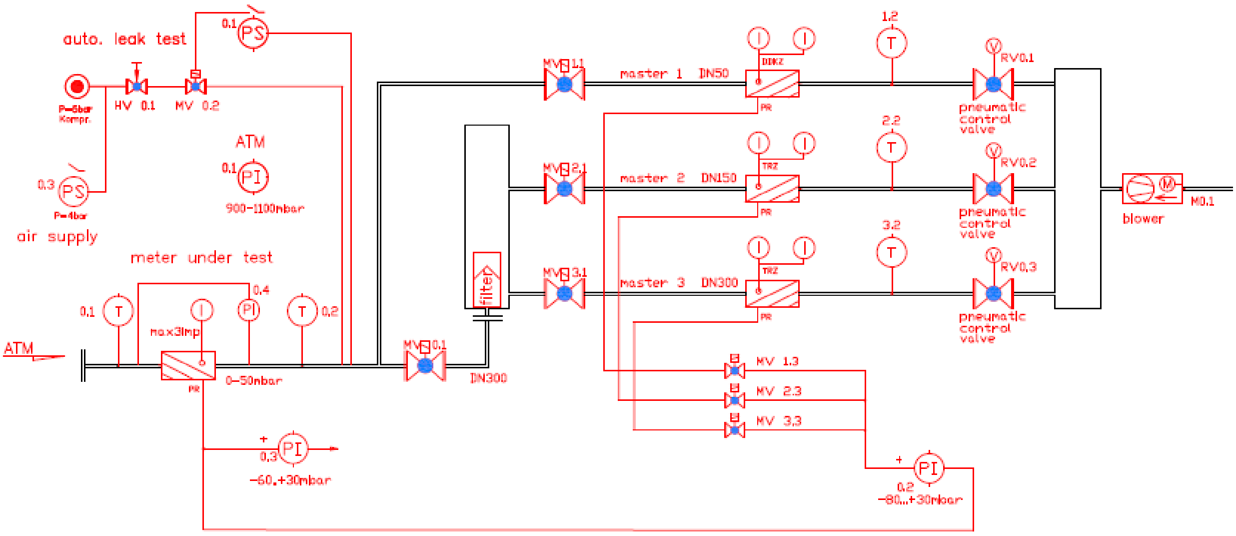


Figure 8 – The scheme of BelGIM facility

Ambient conditions: atmospheric pressure (98.2 – 100) kPa; temperature 20.0±2 °C; relative air humidity 43±5 %.

The test rig was calibrated using 3 reference transfer meters:

- Rotary gas meter Delta S-Flow G10, DN50, Q_{max}= 160 m^3/h, S/N 7ITR34 0297 4743 calibrated by PTB (Germany), expanded uncertainty of calibration U = 0.10 %,
- Turbine gas meter TRZ03 G650, DN150, Q_{max}= 1000 m^3/h, S/N 721168, calibrated by PTB (Germany), expanded uncertainty of calibration U = 0.10 %,
- Turbine gas meter TRZ03 G4000, DN300 , Q_{max}= 6500 m^3/h, S/N 721169, calibrated by PTB (Germany), expanded uncertainty of calibration U = 0.12 %,

- The temperature, pressure and time measurement devices are traceable to the BelGIM national standards.

5.3 Ukraine

Place of calibration: DP "Ivano-Frankivskstandartmetrologija", 127 Vovchynetska str., 76006 Ivano-Frankivsk, Ukraine.

Calibration work was perform using:

- the State standard of the unit of gas volume and volume flow (bell prover) DETU 03-01-15 with the range of volume flow from 4 to 200 m^3/h and uncertainty $U \leq 0.1$ % (k = 2) (KCDB service identifier – UA1);

- the secondary reference standards of the unit of gas volume and volume flow (of turbine type and rotary type) VETU 03-01-03-11 and VETU 03-01-04-12 with the range of volume flow from 1 to 7800 m^3/h and uncertainty $U \leq 0.12$ % (k = 2).

The use of the national standard DETU 03-01-15 (Figures 9 and 10) is based on the principle of measuring the time interval required to displacement a known volume of gas at measured temperature and pressure. Gas volume that passes through the meter under test is determined based on gas law:

$$V_{MuT} = V_S \frac{p}{p_0} \frac{T_0}{T},$$

where V_S – gas volume reproduced by standard;
p, p_0 – inlet meter under test absolute pressure and absolute pressure under bell, respectively;
T, T_0 – gas temperature on meter under test and under bell, respectively.

Gas volume measured by meter under test is determined by:

$$V_M = \frac{N}{K_{nom}},$$

where N – number of pulses from meter under test; K_{nom} – gas meter k-factor, pulses/m^3.

Error of gas meter reading is calculated by:

$$e_r = \frac{V_M - V_{MuT}}{V_{MuT}} \cdot 100.$$

Figure 9 – The general view of bell prover DETU 03-01-15

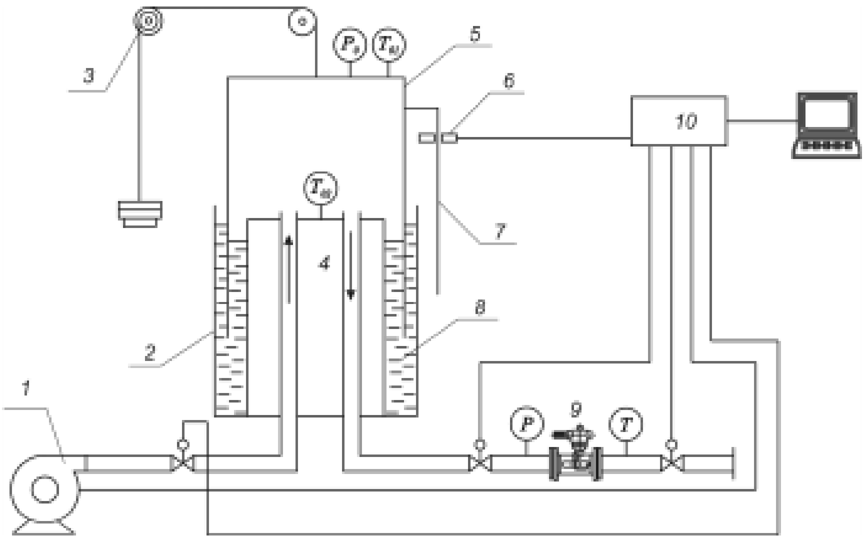


Figure 10 – The scheme of bell prover:
1 – blower; *2* – tank; *3* – buoyancy effect (Archimedean force) compensator (cam); *4* – displacer; *5* – bell; *6* – linear bell displacement transducer; *7* – scale; *8* – sealing liquid (low vapor mineral oil); *9* – meter under test; *10* – control, data collection and processing System

The secondary reference standards VETU 03-01-03-11 and VETU 03-01-04-12 with parallel gas meters as standard devices are used for testing and calibration of gas meters of up to 7800 m³/h. Each standard gas meter is traced to a bell prover DETU 03-01-15 through a continuous chain of calibrations.

The mimic diagram and general view of VETU 03-01-03-11 and VETU 03-01-04-12 are shown in Figures 11 and 12.

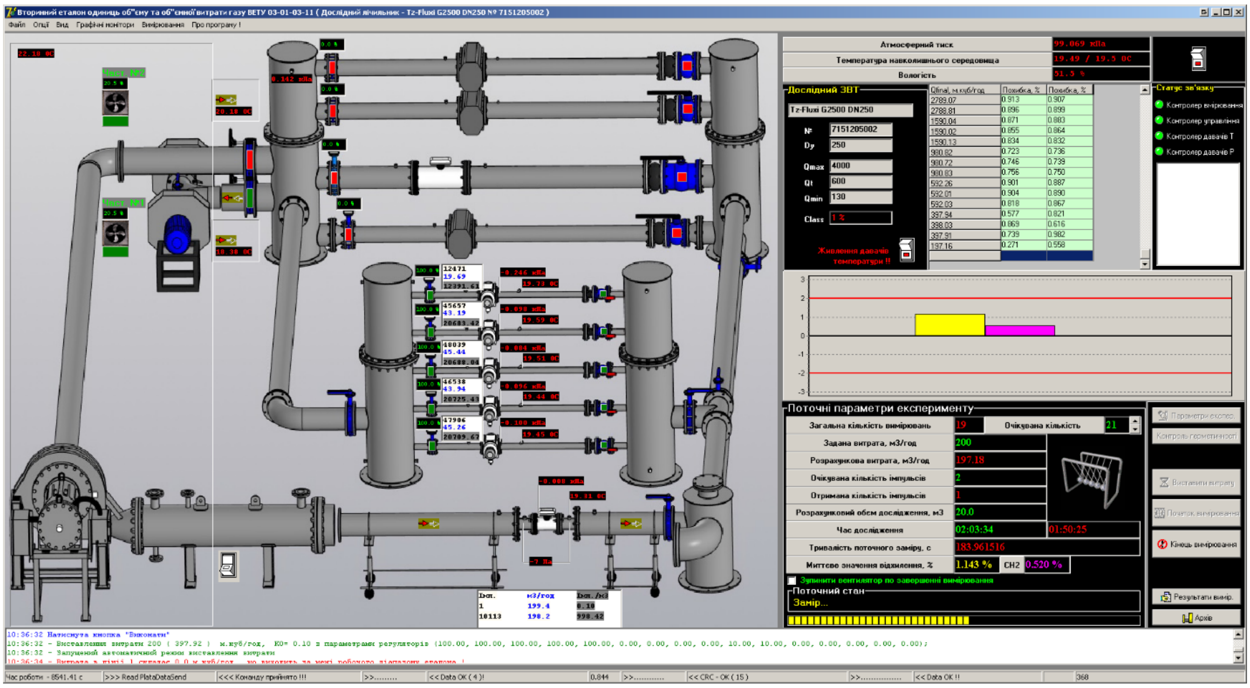


Figure 11 – The mimic diagram of VETU 03-01-03-11 and VETU 03-01-04-12

Figure 12 – The General view of VETU 03-01-03-11 and VETU 03-01-04-12

5.4 Lithuania

Place of the test: Heat equipment research and testing laboratory of Lithuanian Energy Institute, 3 Breslaujos str. LT-44403 Kaunas-35, Lithuania.

During the test the turbine gas meters were calibrated by the method of comparison the meters readings with readings of a standard gas meters. The calibration was carried out according to the document KM-2E/3-MP01:2004 “Air (gases) volume and flow rate meters, (1 – 9700) m^3/h. Methods of calibration”. According to the Technical Protocol for COOMET Project No. 680/RU/16 “Comparisons of national standards in the field of gas flow rate and volume, gas flow rates from 20 to 6500 m^3/h” the rotary gas meter G250 was calibrated at 10 values of flow rate: (20, 40, 60, 100, 150, 200, 250, 300, 350, 400) m^3/h, and gas turbine meter G4000 was calibrated at 9 values of flow rate: (320, 650, 1000, 1500, 2500, 3500, 4500, 5500, 6500) m^3/h. The deviation of real flow rate values did not exceed ±3% of the required values. The test at each flow rate was repeated 3 times and then the means values were calculated.

The standard facility No. 2E/3 with reference gas meters was used for calibration. The main measurement capability in the range of flow rate (1 – 1600) m^3/h is ±0.25 %, in the range (1600 – 9700) m^3/h - ±0.30 %, calibration certificate No. 154/18-L of 12-12-2018, issued by LEI. The general view of the facility is presented in Figure 13.

The scheme of the facility is presented in Figure 14.

Figure 13 – The general view of LEI standard facility

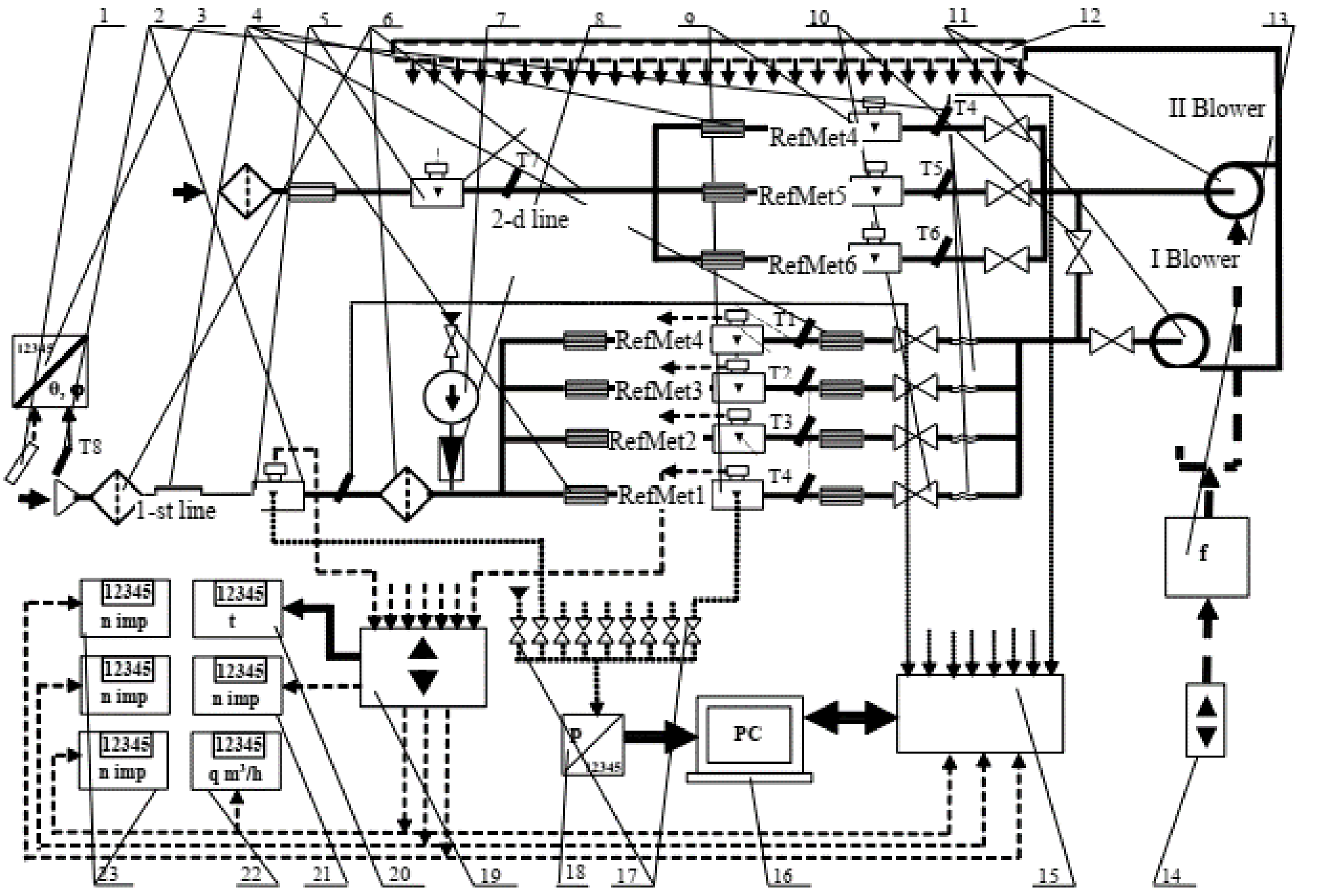


Figure 14 – The scheme of LEI standard facility:
1 – humidity sensor; *2* – thermometers; *3* – temperature and humidity transducer; *4* – flow straightener; *5* – meter under calibration; *6* – air filter; *7* – compressor; *8* – pressure reducer; *9* – reference gas meters; *10* – valves; *11* – fans; *12* – distributing air collector; *13* – frequency converter; *14* – controller of frequency converter; *15* – data acquisition and measurement device; *16* – personal computer; *17* – pressure tapping connecting valves; *18* – absolute pressure meter; *19* – device of synchronization of time measurement and pulses counting; *20* – timer; *21* – meter under calibration pulses counter; *22* – electronic flow rate indicator; *23* – reference meters pulses counters

5.5 Germany

Place of calibration: Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, D-38116 Braunschweig, Germany

The nozzle test rig (Figure 15) for large gas meters (2 – 5600 m³/h) was used for the calibration of the rotary gas meter IRM-A-DUO G250 №20528453 and TRZ G4000 №11092523 up to a flow rate of 5550 m^3/h.

Figure 15 – PTB test bench for large gas meters

The computer-controlled nozzle test rig consists of an echelon of 16 Venturi nozzles connected in parallel and operated at sound velocity. This mode of operation guarantees a very high stability of the flow rate selected, with short-term reproducibilities of 0.002%. The uncertainty of measurement amounts to $U < 0.08\%$.

The sonic nozzle test bench is a secondary standard with traceability to the bell prover (1 – 80 m³/h). A bell prover which allows volume flow rates of air at atmospheric pressure to be realized with a measurement uncertainty of $U < 0.045\%$ serves as the primary standard in Germany.

For the calibration of gas meters of up to 30000 m³/h, a test rig (Figure 16) is available which is equipped with two turbine gas meters as standard devices and allows a measurement uncertainty of $U < 0.12\%$ to be attained. The traceability to the bell prover is given by a scaling procedure via the sonic nozzle test rig described above. It was used for the highest flow point in the comparison of 6500 m^3/h for the TRZ G4000 №11092523.

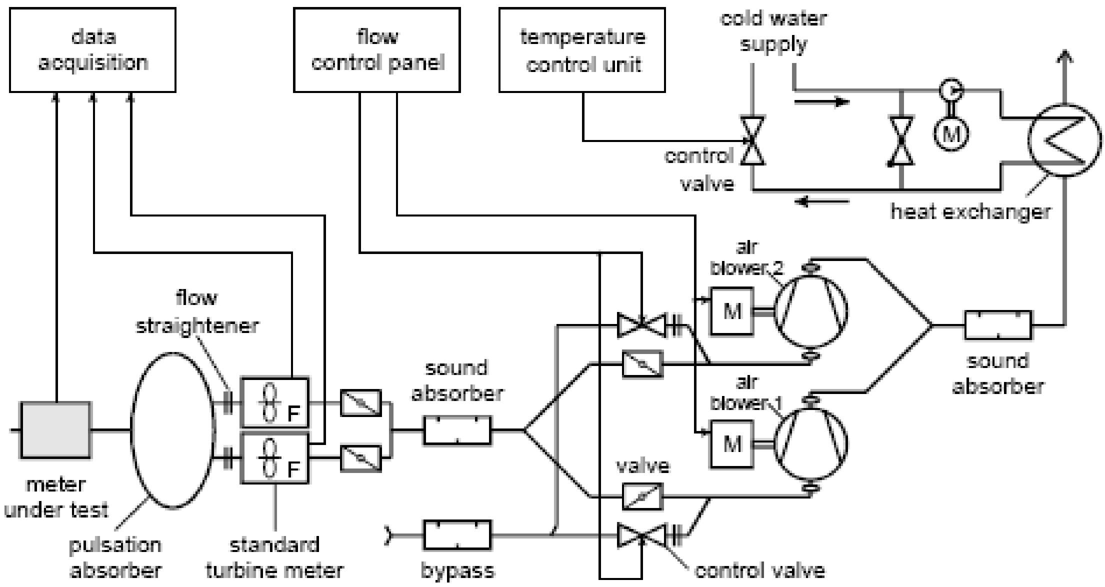


Figure 16 – PTB turbine meter test rig

5.6 Bosnia and Herzegovina

Place of the test: LABSAGAS, KJKP Sarajevogas d.o.o. Sarajevo, Rajlovacka bb, 71000 Sarajevo, Bosnia and Herzegovina

During the comparisons the calibration was performed using the master meter method.

The test line for turbine and rotary gas meters, with reference gas meters was used for calibration. The main characteristics of the facility: measurement range is (0.35 – 4000) m^3/h, the calibration and measurement capability in the range of flow rate (0.35 – 4000) m^3/h is ±0.35%. The general view of the facility is presented in Figure 17.

Figure 17 – The general view of LABSAGAS standard facility

The scheme of the facility is presented in Figure 18.

Ambient conditions: atmospheric pressure 965±10 mbar; temperature 22.5±1^{0}C; relative air humidity 29±5 %.

Reference gas meters were used for calibration:

1. Turbine gas meter SM-RI-X-MI G2500, DN300, Q_{max}= 4000 m^3/h production of the company “Elster Instromet”, S/N 10515038, calibrated by CMI (Czech Metrology Institute), uncertainty of calibration U = 0.24 – 0.36 %, calibration certificate 5012-KL-P2306-15 of 17.12.2015.

2. Turbine gas meter SM-RI-X-MI G1000, DN200, Q_{max}= 1600 m^3/h production of the company “Elster Instromet”, S/N 10515039, calibrated by CMI (Czech Metrology Institute), uncertainty of calibration U = 0.24%, calibration certificate 5012-KL-P2314-15 of 02.12.2015.

3. Rotary piston gas meter IRM-A-DUO G250 (used for this comparison), DN80, Q_{max}=400 m^3/h production of the company “Elster”, S/N 20540475, calibrated by CMI (Czech Metrology Institute), uncertainty of calibration U = 0.15%, calibration certificate 5012-KL-P0099-19 of 16.10.2019.

4. Rotary piston gas meter IRM-A-G40, DN50, Q_{max}= 65 m^3/h production of the company “Elster Instromet”, S/N 20513142, calibrated by CMI (Czech Metrology Institute), uncertainty of calibration U = 0.24 – 0.33%, calibration certificate 5012-KL-P3078-15 of 08.12.2015.

5. Rotary piston gas meter IRM-A-G16, DN50, Q_{max}= 25 m^3/h production of the company “Elster Instromet”, S/N 20511138, calibrated by CMI (Czech Metrology Institute), uncertainty of calibration U = 0.25 – 0.27%, calibration certificate 5012-KL-P3076-15 of 07.12.2015.

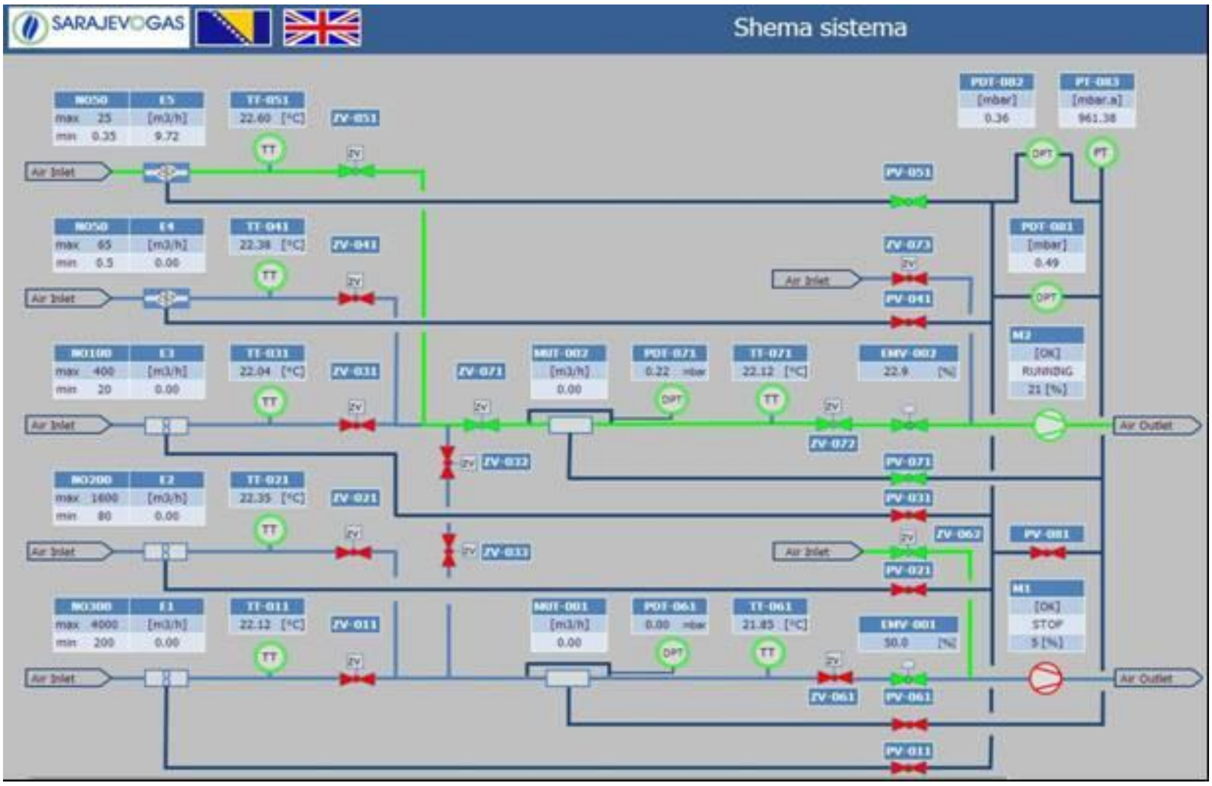


Figure 18 – Scheme of LABSAGAS facility

The temperature and pressure measurement devices are traceable to the Czech Metrology Institute standards.

6 Dependency of laboratories

Three independent laboratories have participated in this comparison: Russia (VNIIM-VNIIR), Germany (PTB) and Ukraine (IFSM). These laboratories took part in a determination of reference value (RV) for each test point. Bosnia and Herzegovina (LABSAGAS) participating in this comparison at gas flow rate from 20 to 400 m^3/h and traceable to the Czech Institute of Metrology (CMI) also contributed to the reference values in the gas flow range of (20 – 300) m^3/h, because CMI is an independent laboratory in this range and is traceable to the PTB at gas flow rate of more than 300 m^3/h (according to calibration certificate 5012-KL-P0099-19 of 16.10.2019 for rotary piston gas meter IRM-A-DUO G250 used by LABSAGAS as a reference gas meter in this comparison).

Belarus (BelGIM) and Lithuania (LEI) are the dependent laboratories of PTB, Germany.

7 Processing results

The relative measurement error e_r is the difference between the data obtained from the benchmark V_M and the volume value V_E reproduced by the standard of the NMI-participant, reduced to the value V_E expressed as a percentage:

$$e_r = \frac{V_M - V_E}{V_E} \cdot 100 \quad . \qquad (1)$$

Expanded uncertainty (k=2) with multiple measurements U_{meas} (in %) calculated by:

$$U_{meas} = \sqrt{U_{lab}^2 + \left(2 \cdot u_{repeat}\right)^2} \ , \qquad (2)$$

where U_{lab} – expanded uncertainty (k=2) of measurement declared by laboratory, in %;

u_{repeat} – repeatability of e_r value (type A uncertainty), in %.

Repeatability u_{repeat} calculated by:

$$u_{repeat} = \sqrt{\frac{\sum_{j=1}^{n}(e_j - e_r)^2}{n \cdot (n-1)}}, \quad (3)$$

where e_j – the relative error of a single measurement at each test point, in %;
n – number of measurements at each test point, in %.

The uncertainty of measurements is calculated according to the method in accordance with the publication of M.G. Cox[1]. The Reference Value (RV) y calculated as weighted mean error (WME):

$$y = \frac{\frac{x_1}{u_{x1}^2} + \frac{x_2}{u_{x2}^2} + ... + \frac{x_n}{u_{xn}^2}}{\frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + ... + \frac{1}{u_{xn}^2}}, \quad (4)$$

where x_1, x_2, ... x_n – are errors (e_r) of the meter in one flow rate in different independent laboratories *1,2, ...n*;

u_{x1}, u_{x2}, ...u_{xn} – are standard uncertainties (not expanded) of the error in different independent laboratories *1,2, ...n* including the uncertainty caused by stability of the meter.

Standard uncertainties (not expanded) of the error in different laboratories u_{x1}, u_{x2}, ...u_{xn} include the stability of the meter. These uncertainties calculated by

$$u_{xi} = \sqrt{\left(\frac{U_{meas(i)}}{2}\right)^2 + u_{rs}^{\ 2}}, \quad (5)$$

where $U_{meas(i)}$ – expanded uncertainty (k=2) with multiple measurements presented in results of laboratory i, in %;

u_{rs} – standard uncertainty (not expanded) caused by the stability of the reference standards in %.

Reference standards were calibrated several times in the pilot laboratory on the same reference standard, before and after the comparison. Standard uncertainty u_{rs} calculated from the average of the absolute values of the differences of the relative errors ($e_{r,\max} - e_{r,\min}$) at each flow point of the first, second and third measurements. This data is based on a uniform (rectangular) distribution between maximum and minimum value of the relative error:

$$u_{rs} = \frac{e_{r,\max} - e_{r,\min}}{2 \cdot \sqrt{3}}. \quad (6)$$

The standard uncertainty of the reference value u_y is given by

$$\frac{1}{u_y^2} = \frac{1}{u_{x1}^2} + \frac{1}{u_{x2}^2} + ... + \frac{1}{u_{xn}^2}. \quad (7)$$

The expanded uncertainty of the reference value U_y is

$$U_y = 2 \cdot u_y. \quad (8)$$

The chi-squared test for consistency check performed using values of errors of the meter in each flow rate. At first the chi-squared value χ_{obs}^2 calculated by

$$\chi_{obs}^2 = \frac{(x_1 - y)^2}{u_{x1}^2} + \frac{(x_2 - y)^2}{u_{x2}^2} + ... + \frac{(x_n - y)^2}{u_{xn}^2}. \quad (9)$$

The degrees of freedom ν assigned

$$\nu = i - 1. \quad (10)$$

where i – number of evaluated laboratories.

To realize the initial value, the participating labs must fulfill the following conditions:

1) Cox M. G., *Evaluation of key comparison data*, Metrologia, 2002, 39, 589-595

$$CHIINV(0{,}05;\nu) > \chi^2_{obs}. \qquad (11)$$

If the consistency check fails then the laboratory with the highest value of $\frac{(x_i - y)^2}{u_{xi}^2}$ will be excluded for the next round of evaluation and the new reference value y (WME), the new standard uncertainty of the reference value u_y and the chi-squared value χ^2_{obs} will be calculated again without the values of excluded laboratory. The consistency check will be calculated again, too. This procedure will be repeated untill the consistency check will pass.

The function *CHIINV(0.05; ν)* in MS Excel were used.

The difference d_i between the value of the laboratory and the initial value of RV is necessary to calculate the result of the comparison, which is the degree of equivalence E_i. It is calculated according to the following equation:

$$d_i = x_i - y. \qquad (12)$$

To calculate the degree of equivalence E_i, it is necessary to calculate the uncertainty related to the difference d_i. When applying the law of uncertainty expansion, the expression of the desired parameter follows from the equation:

$$u^2_{x_1 - x_2} = \begin{pmatrix} \frac{\partial(x_1 - x_2)}{\partial x_1} & \frac{\partial(x_1 - x_2)}{\partial x_2} \end{pmatrix} \begin{pmatrix} u_1^2 & \text{cov} \\ \text{cov} & u_2^2 \end{pmatrix} \begin{pmatrix} \frac{\partial(x_1 - x_2)}{\partial x_1} \\ \frac{\partial(x_1 - x_2)}{\partial x_2} \end{pmatrix} = u_1^2 + u_2^2 - 2 \cdot \text{cov}. \qquad (13)$$

It is obvious that the standard deviation of the measurements is obtained using the crosstalk between two dependent inputs when RV is defined. It is formed as a sum of the squares of the standard deviation values corresponding to the separate input values minus double their covariance.

In case of the independent laboratories which took part in the determination of the RV the covariance value is identically equal to the measurement uncertainty corresponding to the RV value[2], i.e. the $u(d_i)$ value can be written according to the following equation:

$$u(d_i) = \sqrt{u_{xi}^2 + u_y^2 - 2 \cdot u_y^2} = \sqrt{u_{xi}^2 - u_y^2}. \qquad (14)$$

Independent participating laboratories that have been excluded from the RV determination have no interaction, so $u(d_i)$ value is written according to the following equation:

$$u(d_i) = \sqrt{u_{xi}^2 + u_y^2}. \qquad (15)$$

In case of the dependent participating laboratories we have covariance between the laboratory and the RV because the laboratory is linked to the RV via the source of traceability. Although we have no detailed information about it, we can determine a conservative estimation of an upper limit of this covariance. The upper limit is determined for the theoretical case if we have no additional stochastic influence in the traceability of the laboratory from its source (which is the independent laboratory contributing to the RV). Then the results of the dependent laboratory would be strongly correlated with the results of the laboratory contributing to the RV (correlation coefficient = 1) and there would be the same covariance to the RV as in case of the independent laboratories which took part in the determination of the RV. In any case of additional uncertainty caused stochastically the correlation and consequently the covariance is smaller. Thus $u(d_i)$ value for dependent laboratory is written according to the equation (14) too.

Expanded uncertainty is calculated according to the equation:

$$U(d_i) = k \cdot u(d_i) = 2 \cdot u(d_i). \qquad (16)$$

The basis for assessing the successful participation of the laboratory in comparisons is the Degree of Equivalence DoE E_i, which is calculated according to the following equation:

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

$$E_i = \left| \frac{d_i}{U(d_i)} \right|. \qquad (17)$$

Moreover, the intended meaning of uncertainty $U(d_i)$ is guided by the terms described above.

The limit in the E_i<=1 expression is usually used in order to estimate the success of the participating laboratory. For each laboratory the degree of the equivalency to the RV value is evaluated according to the following assessment:

For assessing the success of the participating laboratory, the use of the limit in the expression $E_i \leq 1$ is accepted. The degree of equivalence to RV is set for results of each laboratory according to the following assessment:

- laboratory results are acceptable if $E_i \leq 1$;
- laboratory results are unacceptable if $E_i > 1.2$; such an assessment signals serious laboratory problems that need to be analyzed and eliminated;
- for E_i values in the interval $1 < E_i \leq 1.2$ the so-called warning level is set, which signals to the participating laboratory the shortcomings of a less serious nature, but is the reason for the implementation of corrective measures.

In the case of gas flow comparisons, the boundary value of 1.2 was chosen, reflecting the predominance of non-stochastic "elements" of uncertainty over stochastic "elements" (Reproducibility is usually much better than the lab's overall uncertainty). [3]

3) D. Dopheide, B. Mickan, R. Kramer, H.-J. Hotze, J.-P. Vallet, M.R. Harris, Jiunn-Haur Shaw, Kyung-Am Park, *CIPM Key Comparisons for Compressed Air and Nitrogen, CCM.FF-5.b – Final Report*, 07/09/2006 http://kcdb.bipm.org/appendixB/appbresults/ccm.ff-k5.b/ccm.ff-k5.b_final_report.pdf

8 Stability of comparison gas meters

During the project, the rotary gas meter IRM-A-DUO G250 with serial number 20528453 was tested three times in the pilot laboratory VNIIM-VNIIR. The results are presented in Table 2 (the initial data of May 09, 2019 were presented as the results of VNIIM-VNIIR in this comparison).

Table 2 – Results of measurements of the rotary gas meter IRM-A-DUO G250 in pilot laboratory

Date: 09.05.2019				
Nominal flowrate (m^3/h)	**Error e_r (%)**	**Standard deviation error (%)**	**Uncertainty of the calibration (*k*=2) (%)**	
400	0.23	0.007	0.101	
350	0.16	0.010	0.102	
300	0.13	0.005	0.101	
250	0.10	0.007	0.101	
200	0.06	0.007	0.101	
150	0.04	0.004	0.101	
100	0.01	0.003	0.101	
60	-0.02	0.006	0.101	
40	-0.02	0.007	0.101	
20	-0.05	0.007	0.101	
Date: 05.11.2019				
Nominal flowrate (m^3/h)	**Error e_r (%)**	**Standard deviation error (%)**	**Uncertainty of the calibration (*k*=2) (%)**	
400	0.21	0.010	0.102	
350	0.15	0.007	0.101	
300	0.10	0.006	0.101	
250	0.10	0.007	0.101	
200	0.05	0.004	0.101	
150	0.01	0.004	0.101	
100	0.02	0.006	0.101	
60	-0.02	0.007	0.101	
40	-0.05	0.007	0.101	
20	-0.08	0.007	0.101	
Date: 23.01.2020				
Nominal flowrate (m^3/h)	**Error e_r (%)**	**Standard deviation error (%)**	**Uncertainty of the calibration (*k*=2) (%)**	u_{rs}
400	0.27	0.004	0.101	0.018
350	0.16	0.000	0.1	0.003
300	0.13	0.004	0.101	0.009
250	0.08	0.006	0.101	0.006
200	0.06	0.007	0.101	0.003
150	0.04	0.004	0.101	0.009
100	0.01	0.004	0.101	0.003
60	-0.01	0.010	0.102	0.003
40	0.00	0.009	0.102	0.015
20	-0.03	0.012	0.103	0.015
			average	**0.009**

During the project, the turbine gas meter TRZ G4000 with serial number 11092523 was tested two times in the pilot laboratory VNIIM-VNIIR. The results are presented in Table 3 (the initial data of May 08, 2019 were presented as the results of VNIIM-VNIIR in this comparison).

Table 3 – Results of measurements of the turbine gas meter TRZ G4000 in pilot laboratory

Date: 08.05.2019				
Nominal flowrate (m³/h)	**Error e_r (%)**	**Standard deviation error (%)**	**Uncertainty of the calibration (*k*=2) (%)**	
6500	-0.07	0.005	0.101	
5500	-0.02	0.003	0.101	
4500	0.07	0.002	0.101	
3500	0.13	0.004	0.101	
2500	0.16	0.001	0.101	
1500	0.21	0.004	0.101	
1000	0.18	0.006	0.101	
650	0.00	0.006	0.101	
320	-0.08	0.004	0.101	
Date: 11.11.2019				
Nominal flowrate (m³/h)	**Error e_r (%)**	**Standard deviation error (%)**	**Uncertainty of the calibration (*k*=2) (%)**	u_{rs}
6500	-0.06	0.002	0.101	0.003
5500	-0.01	0.001	0.101	0.003
4500	0.08	0.002	0.101	0.003
3500	0.14	0.003	0.101	0.003
2500	0.17	0.001	0.101	0.003
1500	0.21	0.006	0.101	0
1000	0.19	0.007	0.101	0.003
650	0.01	0.010	0.102	0.003
320	-0.10	0.007	0.101	0.006
			average	**0.003**

9 Laboratory results

9.1 Rotary gas meter IRM-A-DUO G250

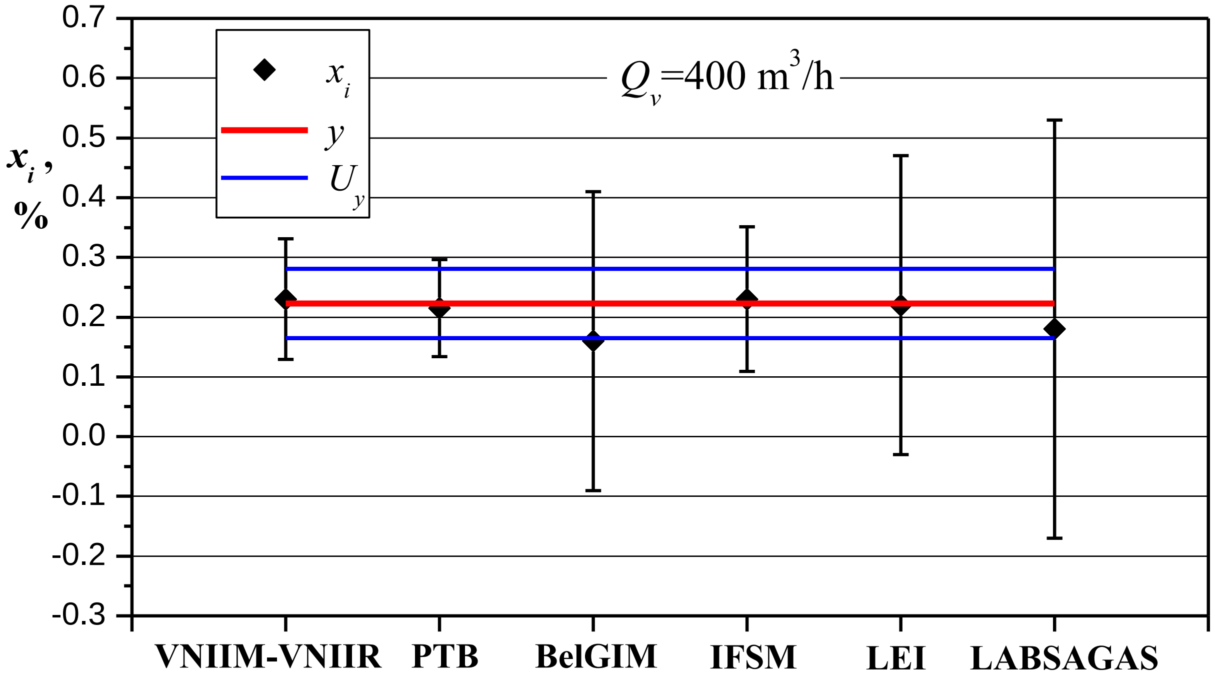
All results of the independent laboratories passed the chi-squared test.

9.1.1 Flow rate 400 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.23	0.0513	0.0186
PTB	0.215	0.0415	0.0372
IFSM	0.23	0.0612	0.0131

y = 0.223 %
U_y = 0.058 %
χ^2_{obs} = 0.0689
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.23	0.101	0.0513	0.01	0.085	0.08
BelGIM	0.16	0.25031	0.1255	-0.06	0.245	0.26
IFSM	0.23	0.121	0.0612	0.01	0.108	0.06
LEI	0.22	0.25	0.1254	0.00	0.245	0.01
PTB	0.215	0.081	0.0415	-0.01	0.060	0.13
LABSAGAS	0.18	0.35	0.1753	-0.04	0.346	0.12

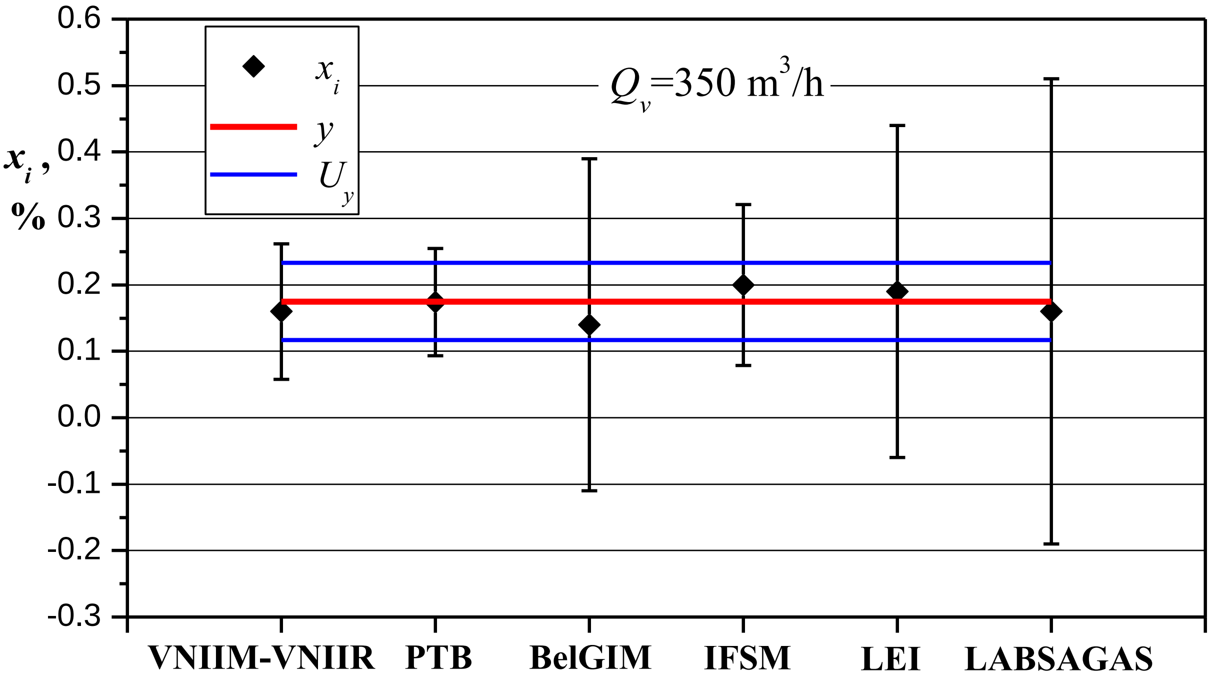


9.1.2 Flow rate 350 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.16	0.0518	0.0839
PTB	0.174	0.0415	0.0006
IFSM	0.20	0.0612	0.1669

y = 0.175 %
U_y = 0.058 %
χ^2_{obs} = 0.2513
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.16	0.102	0.0518	-0.02	0.086	0.17
BelGIM	0.14	0.25013	0.1254	-0.04	0.245	0.14
IFSM	0.20	0.121	0.0612	0.03	0.108	0.23
LEI	0.19	0.25	0.1254	0.02	0.245	0.06
PTB	0.174	0.081	0.0415	0.00	0.060	0.02
LABSAGAS	0.16	0.35	0.1753	-0.02	0.346	0.04

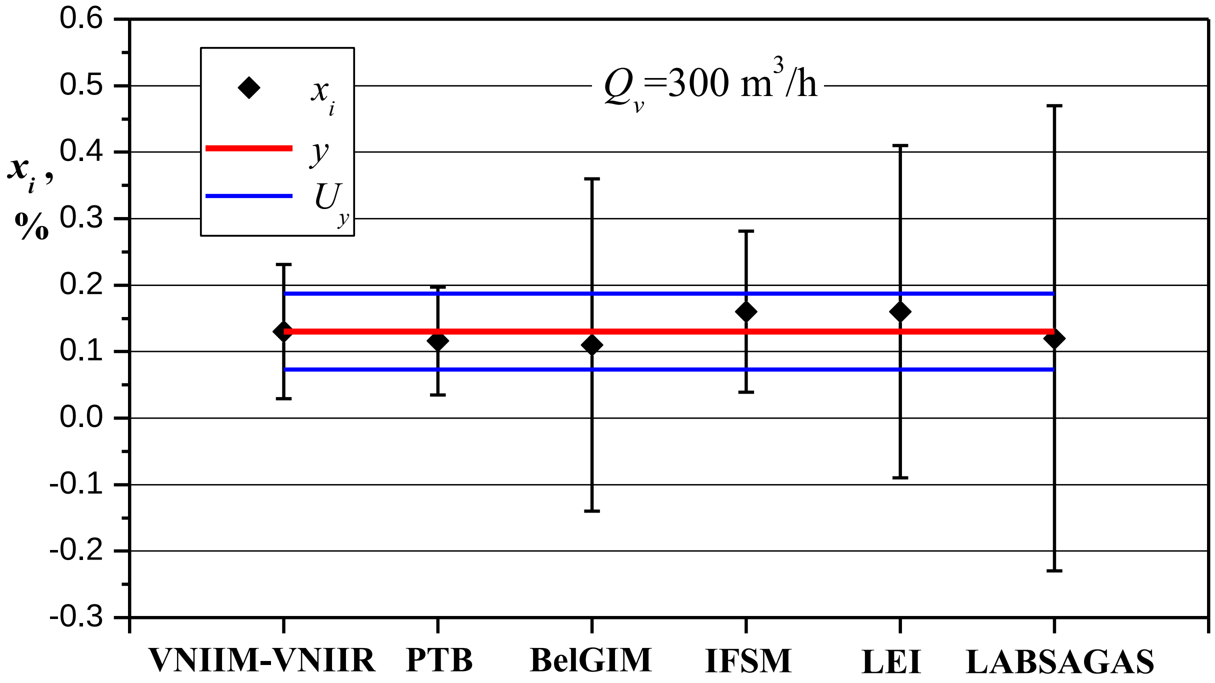


9.1.3 Flow rate 300 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.13	0.0513	0.0000
PTB	0.116	0.0415	0.1138
IFSM	0.16	0.0612	0.2403
LABSAGAS	0.12	0.1753	0.0033

y = 0.13 %
U_y = 0.057 %
χ^2_{obs} = 0.3574
CHIINV = 7.8147

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.13	0.101	0.0513	0.00	0.086	0.00
BelGIM	0.11	0.25	0.1254	-0.02	0.245	0.08
IFSM	0.16	0.121	0.0612	0.03	0.109	0.28
LEI	0.16	0.25	0.1254	0.03	0.245	0.12
PTB	0.116	0.081	0.0415	-0.01	0.061	0.23
LABSAGAS	0.12	0.35	0.1753	-0.01	0.346	0.03

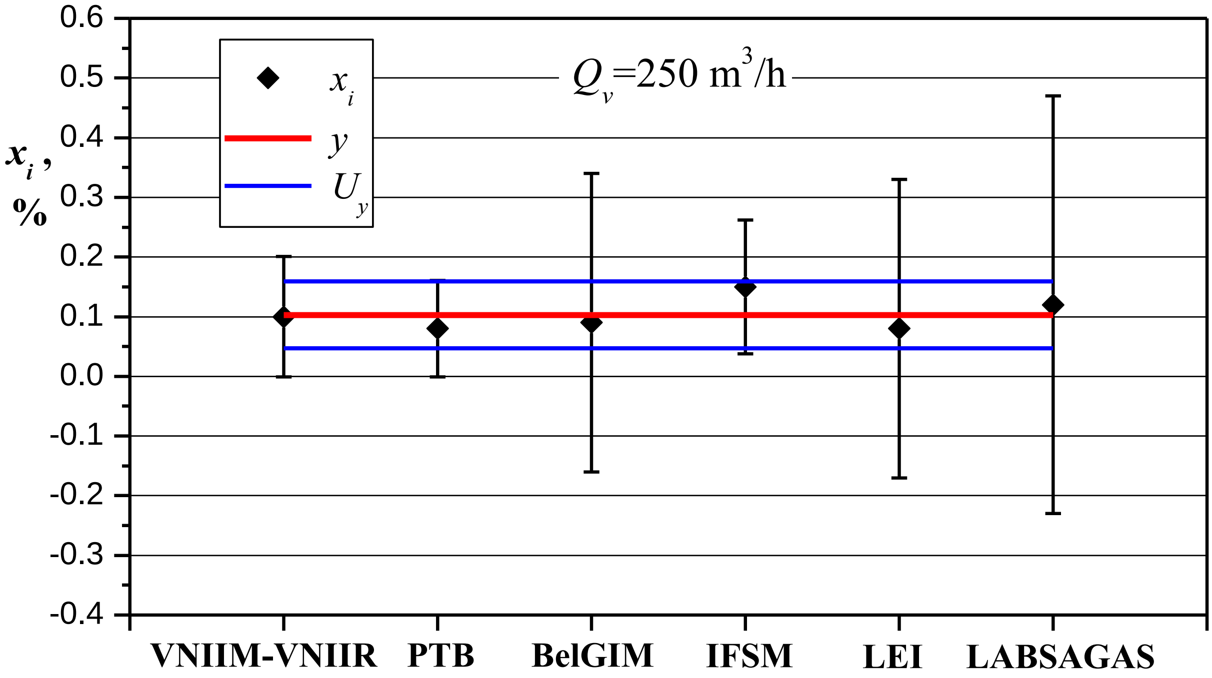


9.1.4 Flow rate 250 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.10	0.0513	0.0034
PTB	0.08	0.0415	0.3072
IFSM	0.15	0.0568	0.6847
LABSAGAS	0.12	0.1753	0.0094

y = 0.104 %
U_y = 0.056 %
χ^2_{obs} = 0.9968
CHIINV = 7.8147

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.10	0.101	0.0513	0.00	0.086	0.03
BelGIM	0.09	0.25004	0.1254	-0.01	0.245	0.05
IFSM	0.15	0.112	0.0568	0.05	0.099	0.48
LEI	0.08	0.25	0.1254	-0.02	0.245	0.09
PTB	0.08	0.081	0.0415	-0.02	0.062	0.38
LABSAGAS	0.12	0.35	0.1753	0.02	0.347	0.05

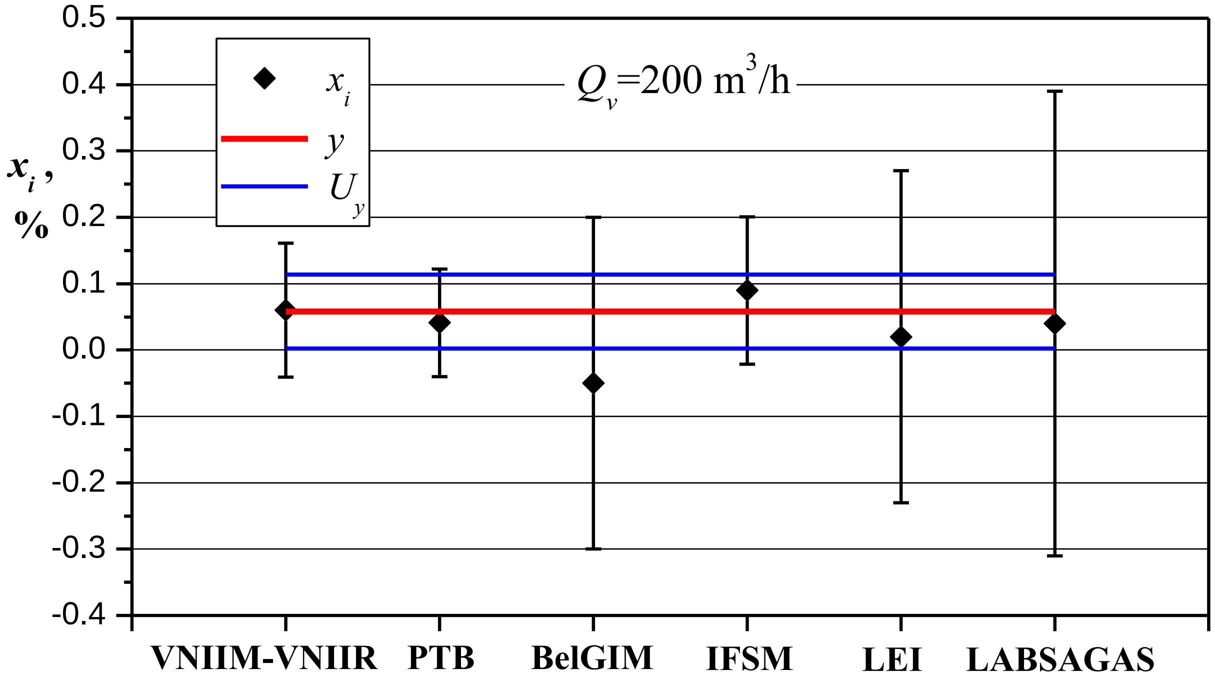


9.1.5 Flow rate 200 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.06	0.0513	0.0015
PTB	0.041	0.0415	0.1678
IFSM	0.09	0.0563	0.3231
LABSAGAS	0.04	0.1753	0.0105

y = 0.058 %
U_y = 0.056 %
χ^2_{obs} = 0.5029
CHIINV = 7.8147

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.06	0.101	0.0513	0.00	0.086	0.02
BelGIM	-0.05	0.25004	0.1254	-0.11	0.245	0.44
IFSM	0.09	0.111	0.0563	0.03	0.098	0.33
LEI	0.02	0.25	0.1254	-0.04	0.245	0.16
PTB	0.041	0.081	0.0415	-0.02	0.062	0.28
LABSAGAS	0.04	0.35	0.1753	-0.02	0.347	0.05

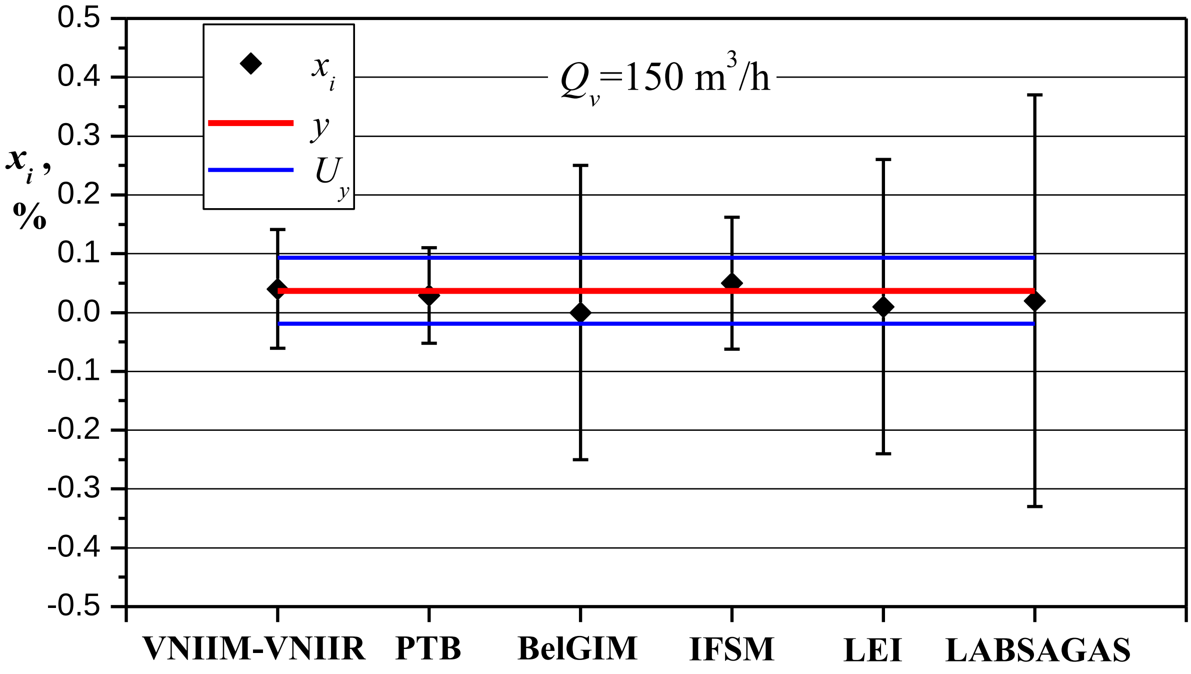


9.1.6 Flow rate 150 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.04	0.0513	0.0034
PTB	0.029	0.0415	0.0372
IFSM	0.05	0.0568	0.0524
LABSAGAS	0.02	0.1753	0.0094

y = 0.037 %
U_y = 0.056 %
χ^2_{obs} = 0.1024
CHIINV = 7.8147

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.04	0.101	0.0513	0.00	0.086	0.03
BelGIM	0.00	0.25031	0.1255	-0.04	0.245	0.15
IFSM	0.05	0.112	0.0568	0.01	0.099	0.13
LEI	0.01	0.25	0.1254	-0.03	0.245	0.11
PTB	0.029	0.081	0.0415	-0.01	0.062	0.13
LABSAGAS	0.02	0.35	0.1753	-0.02	0.347	0.05

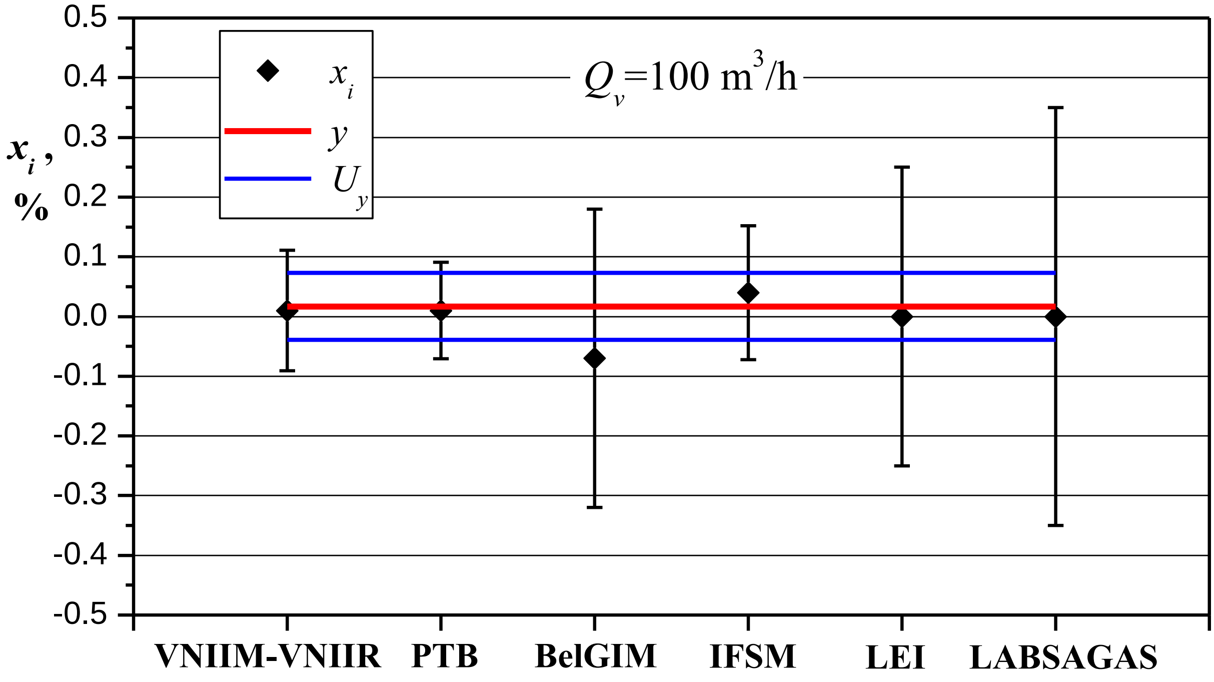


9.1.7 Flow rate 100 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.01	0.0513	0.0186
PTB	0.010	0.0415	0.0285
IFSM	0.04	0.0568	0.1640
LABSAGAS	0.00	0.1753	0.0094

y = 0.017 %
U_y = 0.056 %
χ^2_{obs} = 0.2204
CHIINV = 7.8147

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.01	0.101	0.0513	-0.01	0.086	0.08
BelGIM	-0.07	0.25	0.1254	-0.09	0.245	0.36
IFSM	0.04	0.112	0.0568	0.02	0.099	0.23
LEI	0.00	0.25	0.1254	-0.02	0.245	0.07
PTB	0.010	0.081	0.0415	-0.01	0.062	0.11
LABSAGAS	0.00	0.35	0.1753	-0.02	0.347	0.05

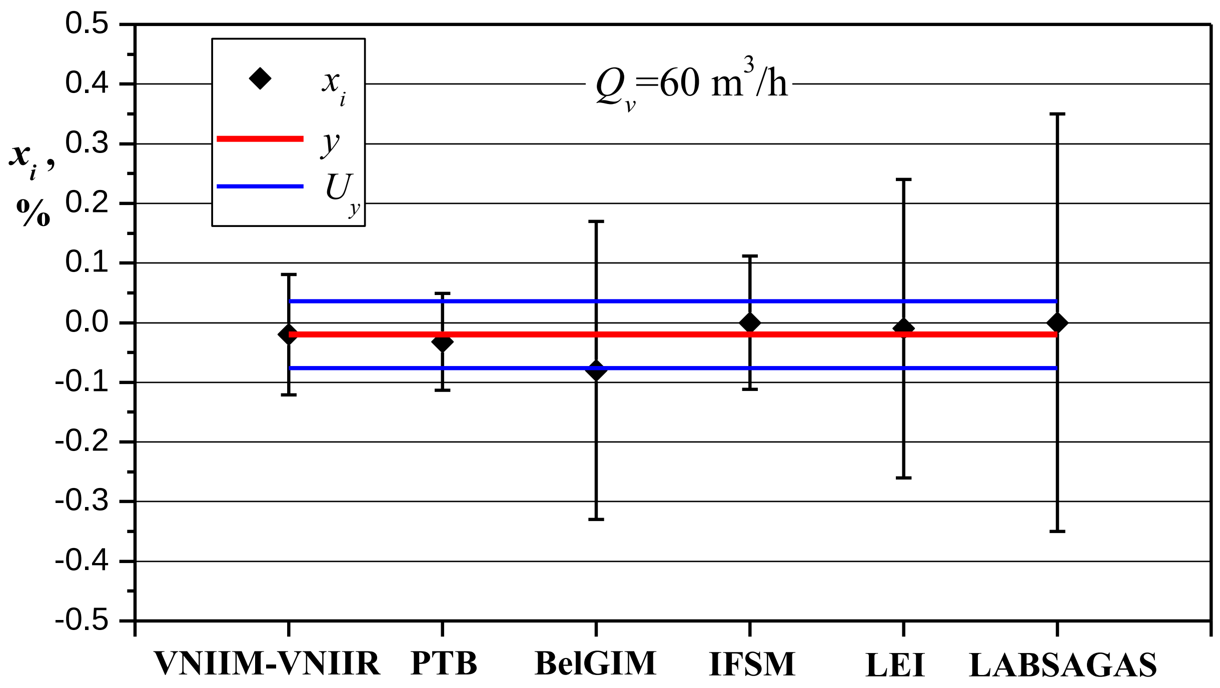


9.1.8 Flow rate 60 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	-0.02	0.0513	0.0000
PTB	-0.032	0.0415	0.0836
IFSM	0.00	0.0568	0.1240
LABSAGAS	0.00	0.1753	0.0130

y = -0.02 %
U_y = 0.056 %
χ^2_{obs} = 0.2206
CHIINV = 7.8147

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	-0.02	0.101	0.0513	0.00	0.086	0.00
BelGIM	-0.08	0.25004	0.1254	-0.06	0.245	0.25
IFSM	0.00	0.112	0.0568	0.02	0.099	0.20
LEI	-0.01	0.25	0.1254	0.01	0.245	0.04
PTB	-0.032	0.081	0.0415	-0.01	0.062	0.20
LABSAGAS	0.00	0.35	0.1753	0.02	0.347	0.06

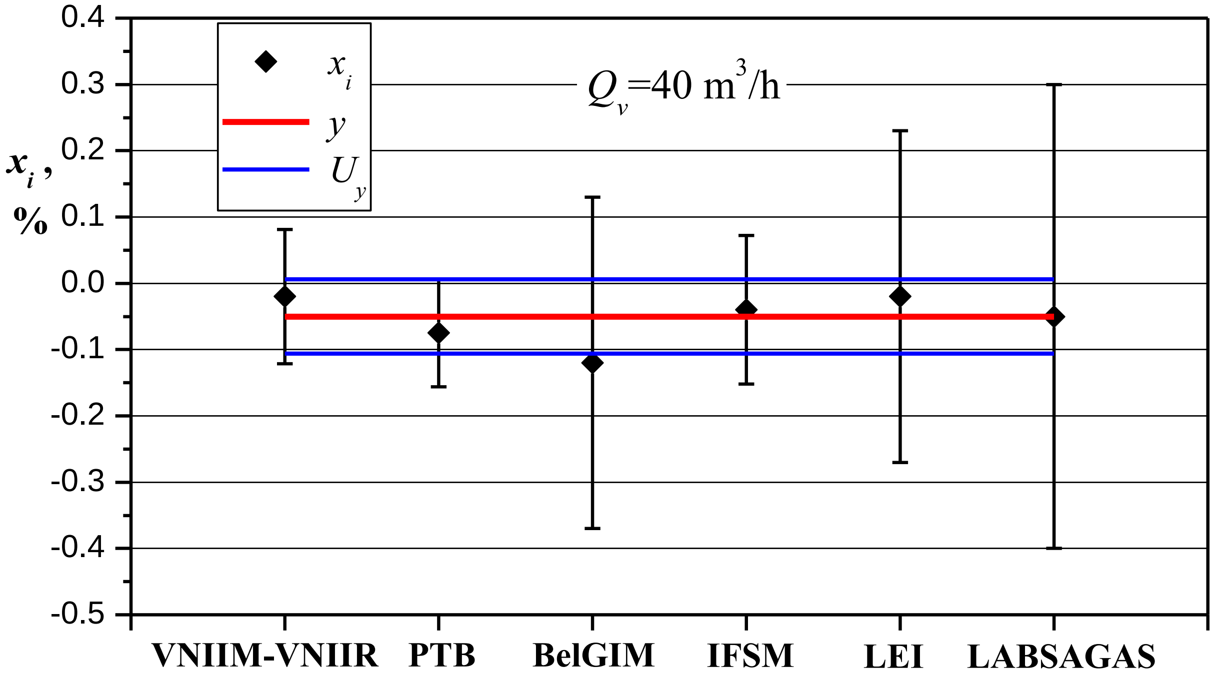


9.1.9 Flow rate 40 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	-0.02	0.0513	0.3420
PTB	-0.075	0.0415	0.3629
IFSM	-0.04	0.0568	0.0310
LABSAGAS	-0.05	0.1753	0.0000

y = -0.05 %
U_y = 0.056 %
χ^2_{obs} = 0.7359
CHIINV = 7.8147

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	-0.02	0.101	0.0513	0.03	0.086	0.35
BelGIM	-0.12	0.25	0.1254	-0.07	0.245	0.29
IFSM	-0.04	0.112	0.0568	0.01	0.099	0.10
LEI	-0.02	0.25	0.1254	0.03	0.245	0.12
PTB	-0.075	0.081	0.0415	-0.03	0.062	0.41
LABSAGAS	-0.05	0.35	0.1753	0.00	0.347	0.00

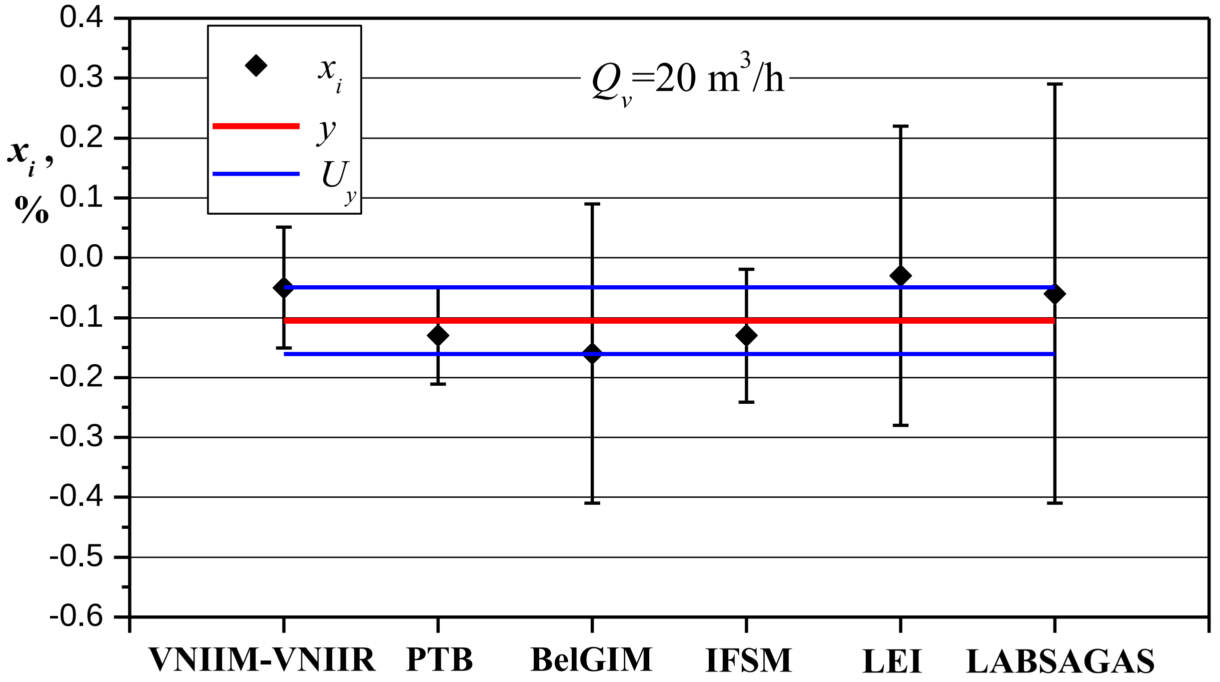


9.1.10 Flow rate 20 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	-0.05	0.0513	1.1495
PTB	-0.130	0.0415	0.3629
IFSM	-0.13	0.0563	0.1972
LABSAGAS	-0.06	0.1753	0.0659

y = -0.105 %
U_y = 0.056 %
χ^2_{obs} = 1.7754
CHIINV = 7.8147

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	-0.05	0.101	0.0513	0.06	0.086	0.64
BelGIM	-0.16	0.25004	0.1254	-0.06	0.245	0.22
IFSM	-0.13	0.111	0.0563	-0.03	0.098	0.26
LEI	-0.03	0.25	0.1254	0.08	0.245	0.31
PTB	-0.130	0.081	0.0415	-0.03	0.062	0.41
LABSAGAS	-0.06	0.35	0.1753	0.05	0.347	0.13



9.2 Turbine gas meter TRZ G4000

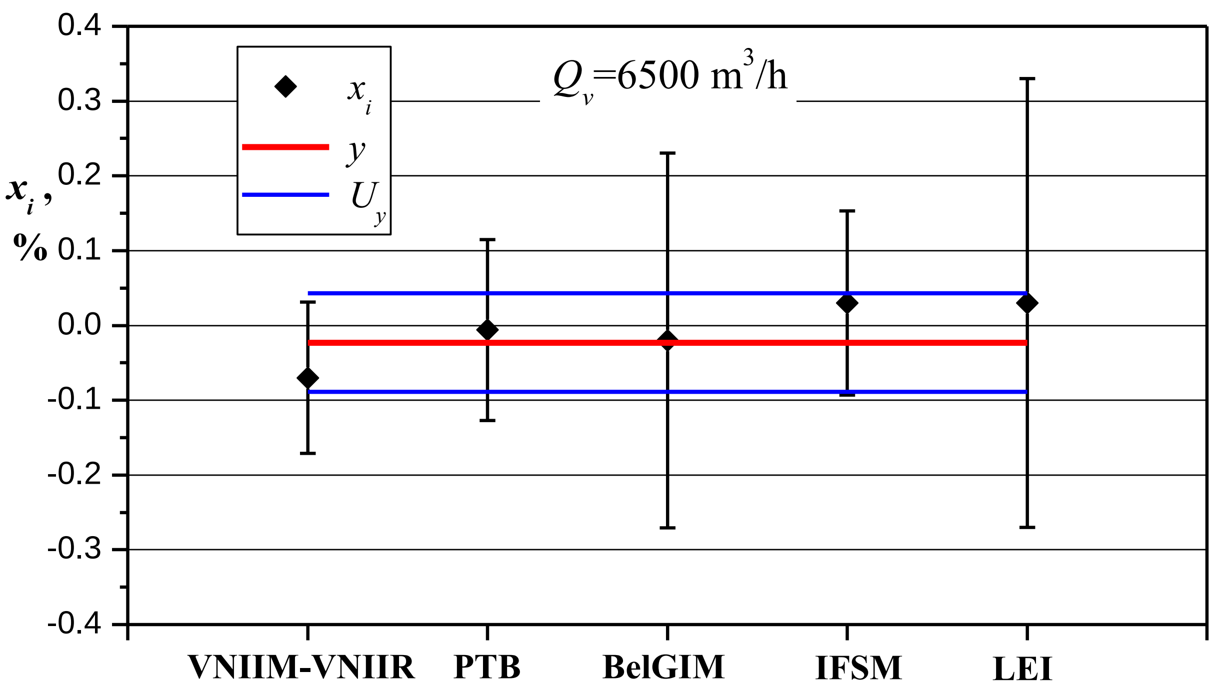
All results of the independent laboratories passed the chi-squared test.

9.2.1 Flow rate 6500 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	-0.07	0.0506	0.9069
PTB	-0.006	0.0606	0.0787
IFSM	0.03	0.0616	0.7403

y = -0.023 %
U_y = 0.066 %
χ^2_{obs} = 1.7259
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	-0.07	0.101	0.0506	-0.05	0.077	0.63
BelGIM	-0.02	0.25053	0.1254	0.00	0.242	0.01
IFSM	0.03	0.123	0.0616	0.05	0.105	0.51
LEI	0.03	0.3	0.1501	0.05	0.293	0.18
PTB	-0.006	0.121	0.0606	0.02	0.102	0.17

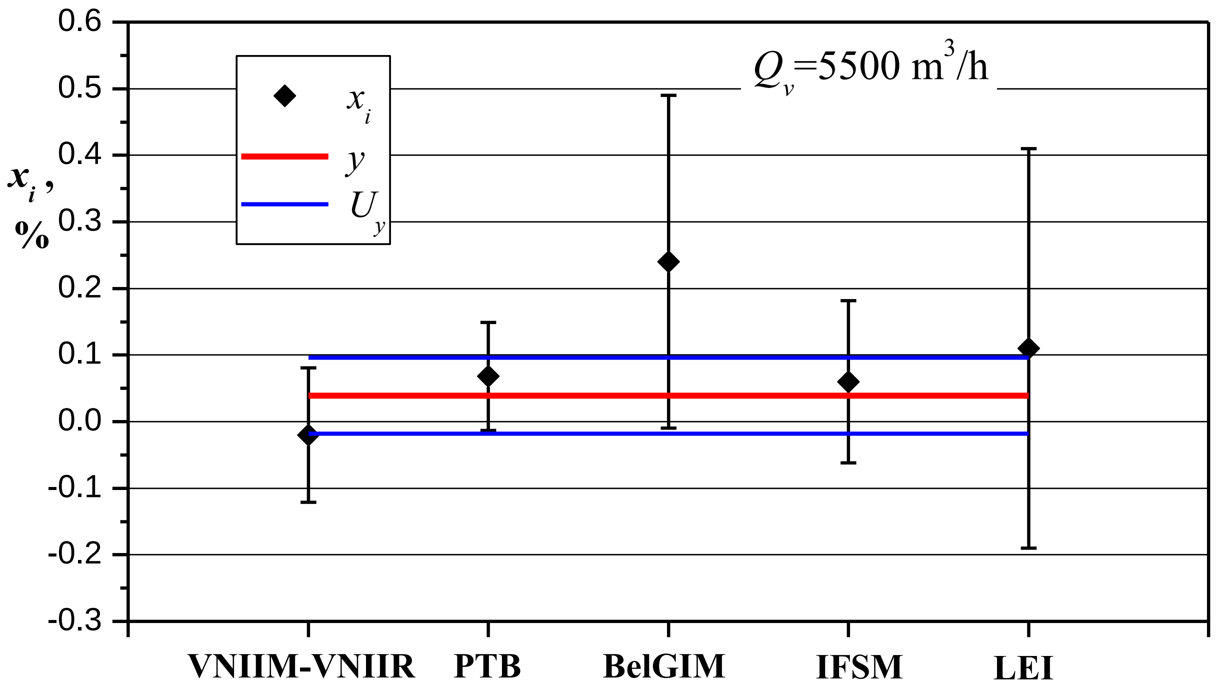


9.2.2 Flow rate 5500 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	-0.02	0.0506	1.3152
PTB	0.068	0.0407	0.5077
IFSM	0.06	0.0611	0.1181

y = 0.039 %
U_y = 0.057 %
χ^2_{obs} = 1.9410
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	-0.02	0.101	0.0506	-0.06	0.084	0.69
BelGIM	0.24	0.25004	0.1251	0.20	0.244	0.83
IFSM	0.06	0.122	0.0611	0.02	0.109	0.19
LEI	0.11	0.3	0.1501	0.07	0.295	0.24
PTB	0.068	0.081	0.0407	0.03	0.059	0.50

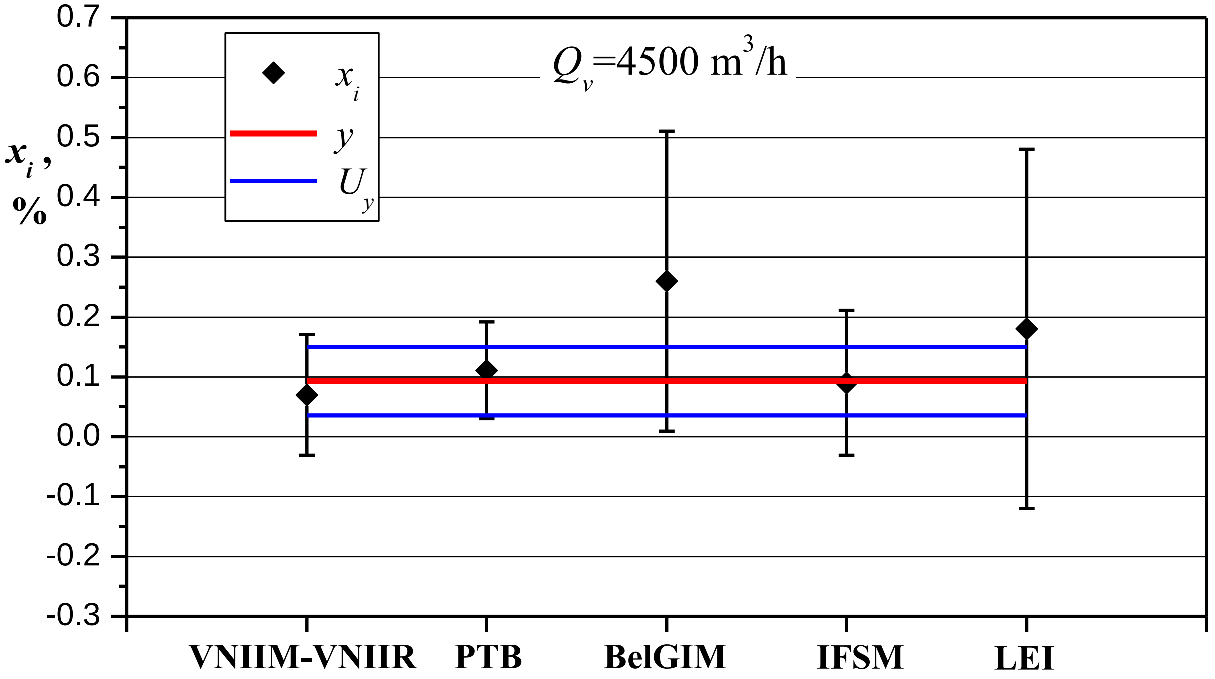


9.2.3 Flow rate 4500 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.07	0.0506	0.2370
PTB	0.111	0.0407	0.1956
IFSM	0.09	0.0606	0.0025

y = 0.093 %
U_y = 0.057 %
χ^2_{obs} = 0.4350
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.07	0.101	0.0506	-0.02	0.084	0.29
BelGIM	0.26	0.2504	0.1253	0.17	0.245	0.68
IFSM	0.09	0.121	0.0606	0.00	0.107	0.03
LEI	0.18	0.3	0.1501	0.09	0.295	0.30
PTB	0.111	0.081	0.0407	0.02	0.059	0.31

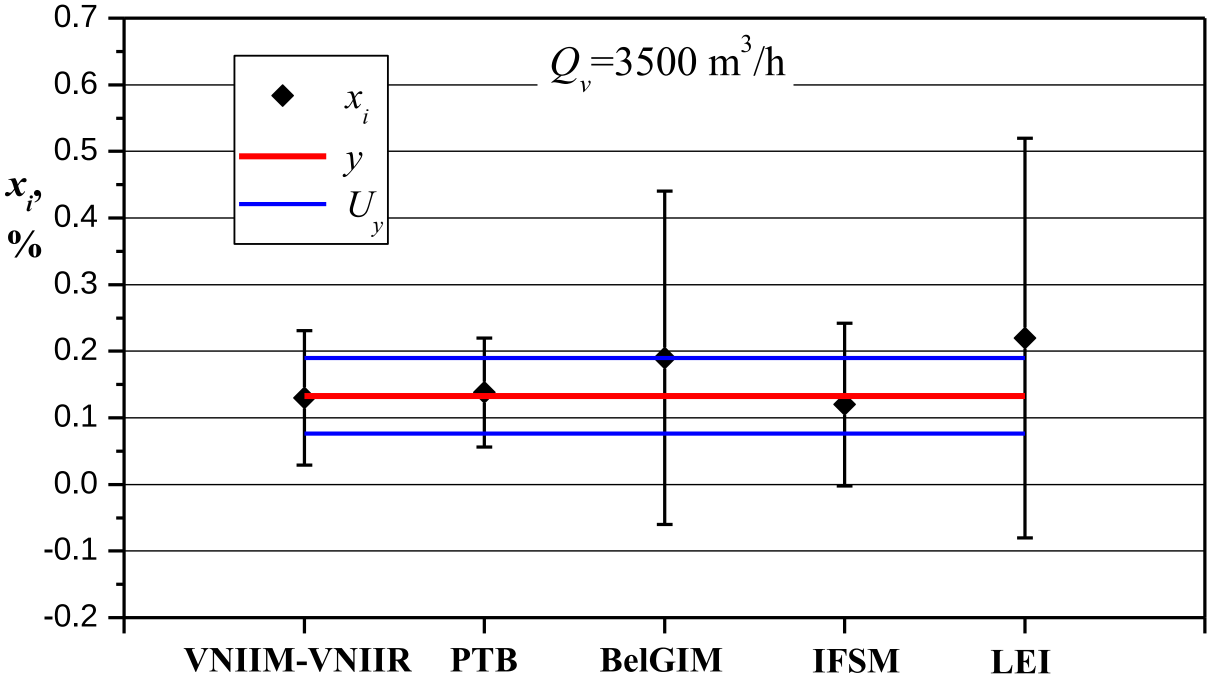


9.2.4 Flow rate 3500 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.13	0.0506	0.0000
PTB	0.138	0.0412	0.0147
IFSM	0.12	0.0611	0.0453

y = 0.133 %
U_y = 0.057 %
χ^2_{obs} = 0.06
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.13	0.101	0.0506	0.00	0.084	0.00
BelGIM	0.19	0.25013	0.1252	0.06	0.244	0.23
IFSM	0.12	0.122	0.0611	-0.01	0.109	0.12
LEI	0.22	0.3	0.1501	0.09	0.295	0.30
PTB	0.138	0.082	0.0412	0.01	0.060	0.08

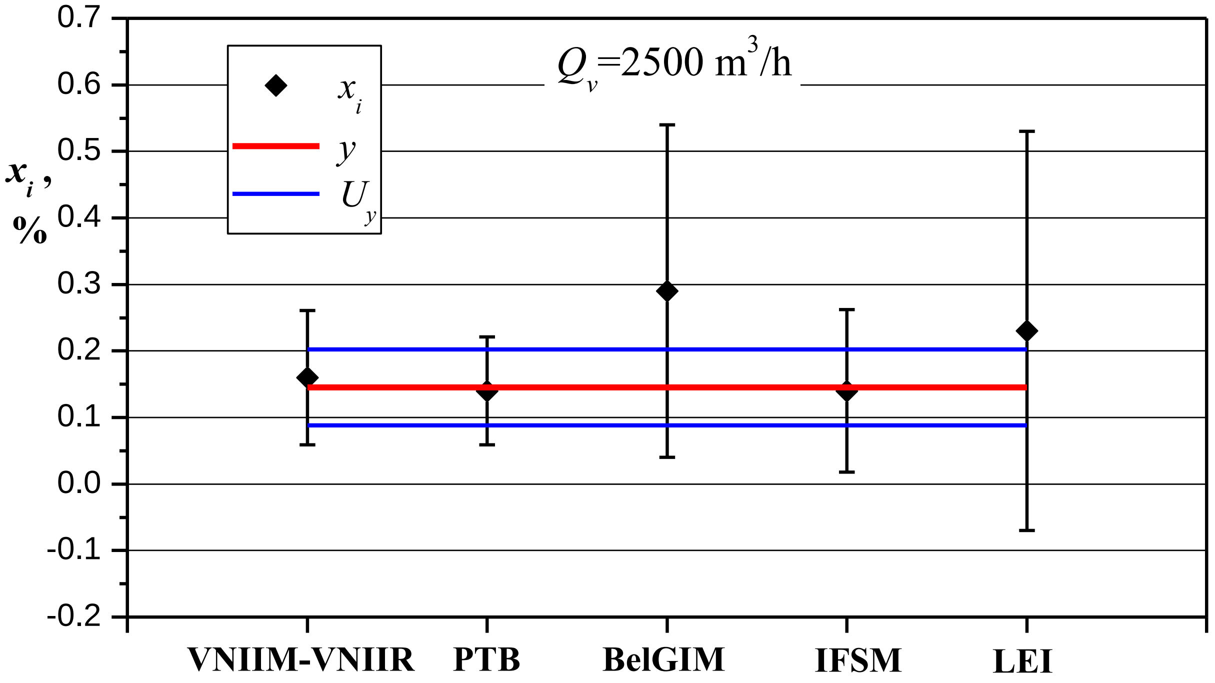


9.2.5 Flow rate 2500 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.16	0.0506	0.0560
PTB	0.14	0.0407	0.0151
IFSM	0.14	0.0611	0.0067

y = 0.145 %
U_y = 0.057 %
χ^2_{obs} = 0.0778
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.16	0.101	0.0506	0.01	0.084	0.14
BelGIM	0.29	0.25018	0.1252	0.15	0.244	0.59
IFSM	0.14	0.122	0.0611	0.00	0.109	0.05
LEI	0.23	0.3	0.1501	0.09	0.295	0.29
PTB	0.14	0.081	0.0407	0.00	0.059	0.09

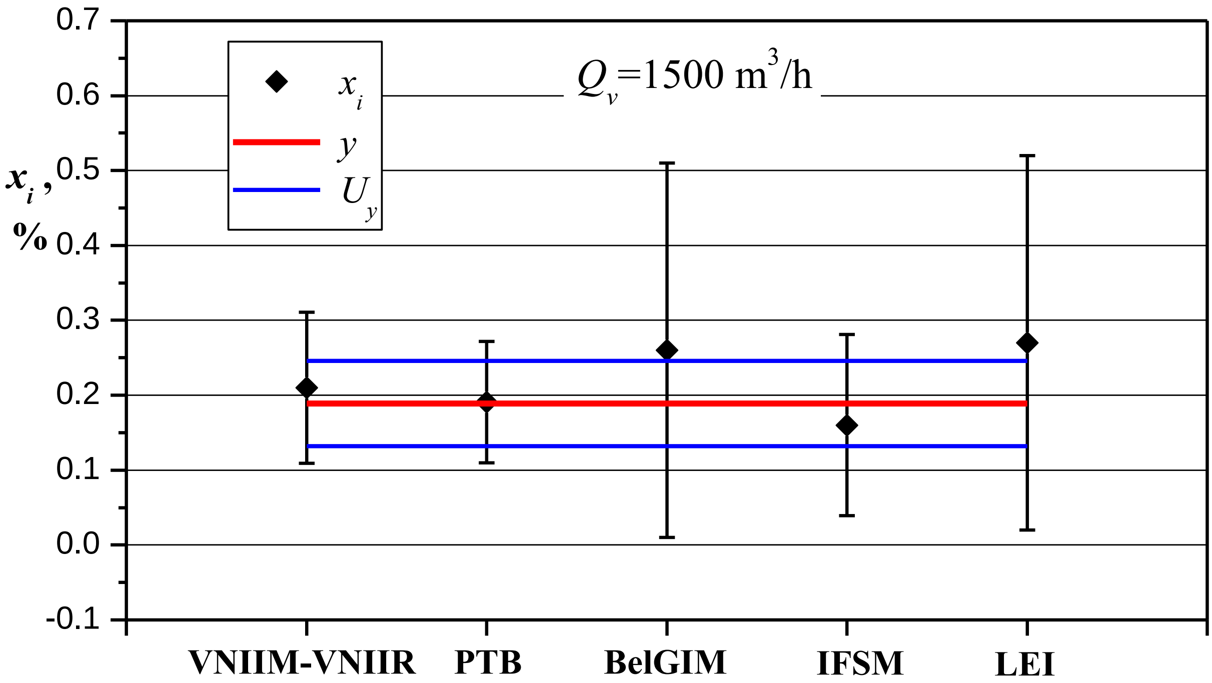


9.2.6 Flow rate 1500 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.21	0.0506	0.1227
PTB	0.191	0.0407	0.0024
IFSM	0.16	0.0606	0.2290

y = 0.189 %
U_y = 0.057 %
χ^2_{obs} = 0.3541
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.21	0.101	0.0506	0.02	0.084	0.21
BelGIM	0.26	0.25	0.1251	0.07	0.244	0.29
IFSM	0.16	0.121	0.0606	-0.03	0.107	0.27
LEI	0.27	0.25	0.1251	0.08	0.244	0.33
PTB	0.191	0.081	0.0407	0.00	0.059	0.03

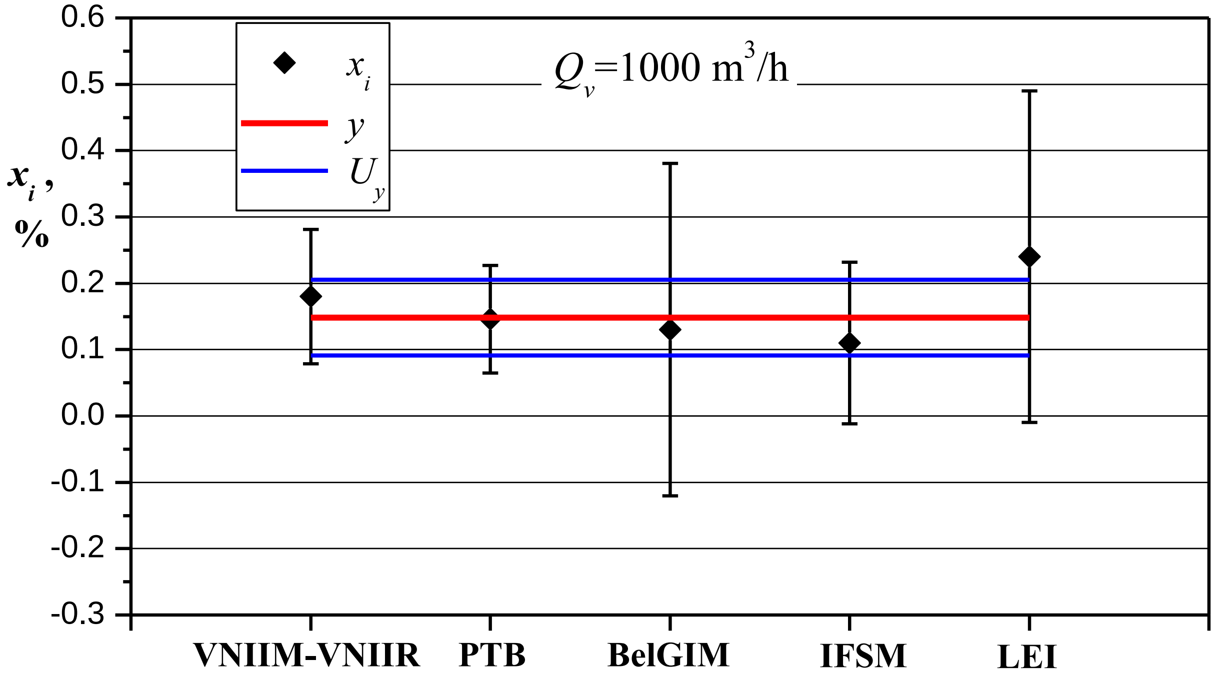


9.2.7 Flow rate 1000 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.18	0.0506	0.3287
PTB	0.146	0.0407	0.0024
IFSM	0.11	0.0611	0.3868

y = 0.148 %
U_y = 0.057 %
χ^2_{obs} = 0.7179
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.18	0.101	0.0506	0.03	0.084	0.35
BelGIM	0.13	0.25058	0.1254	-0.02	0.245	0.07
IFSM	0.11	0.122	0.0611	-0.04	0.109	0.35
LEI	0.24	0.25	0.1251	0.09	0.244	0.38
PTB	0.146	0.081	0.0407	0.00	0.059	0.03

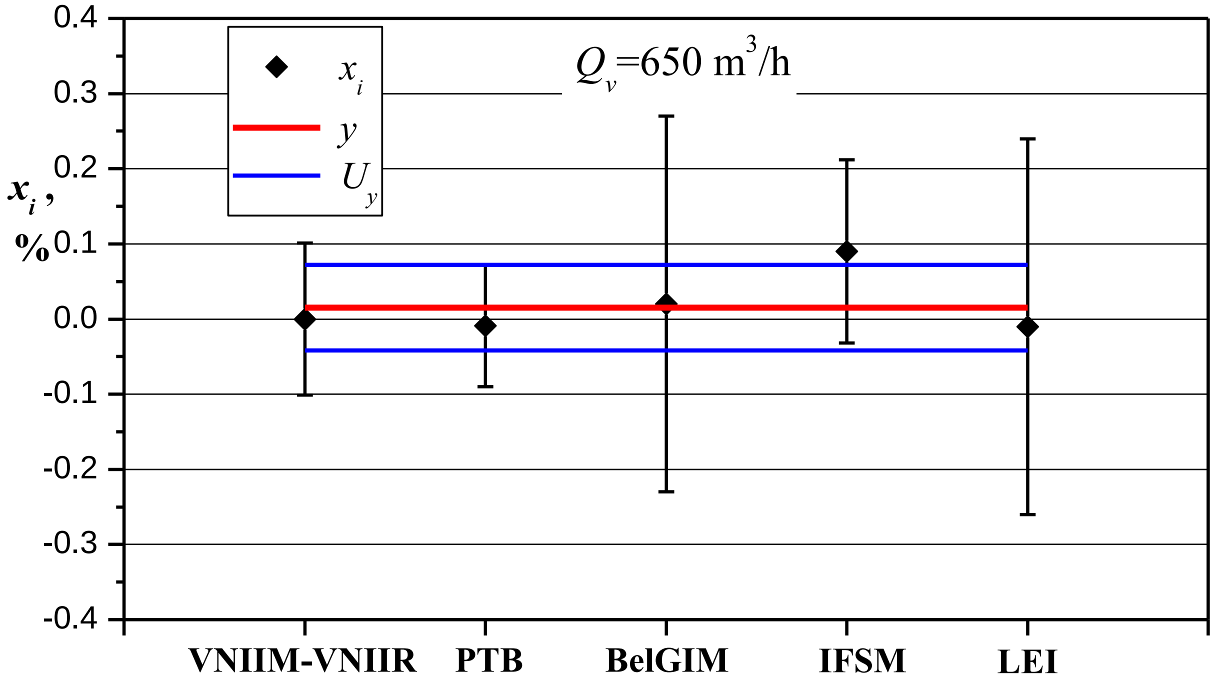


9.2.8 Flow rate 650 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	0.00	0.0506	0.0813
PTB	-0.009	0.0407	0.3477
IFSM	0.09	0.0611	1.5067

y = 0.015 %
U_y = 0.057 %
χ^2_{obs} = 1.9358
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	0.00	0.101	0.0506	-0.01	0.084	0.17
BelGIM	0.02	0.25004	0.1251	0.01	0.244	0.02
IFSM	0.09	0.122	0.0611	0.08	0.109	0.69
LEI	-0.009	0.25	0.1251	-0.03	0.244	0.10
PTB	-0.01	0.081	0.0407	-0.02	0.059	0.41

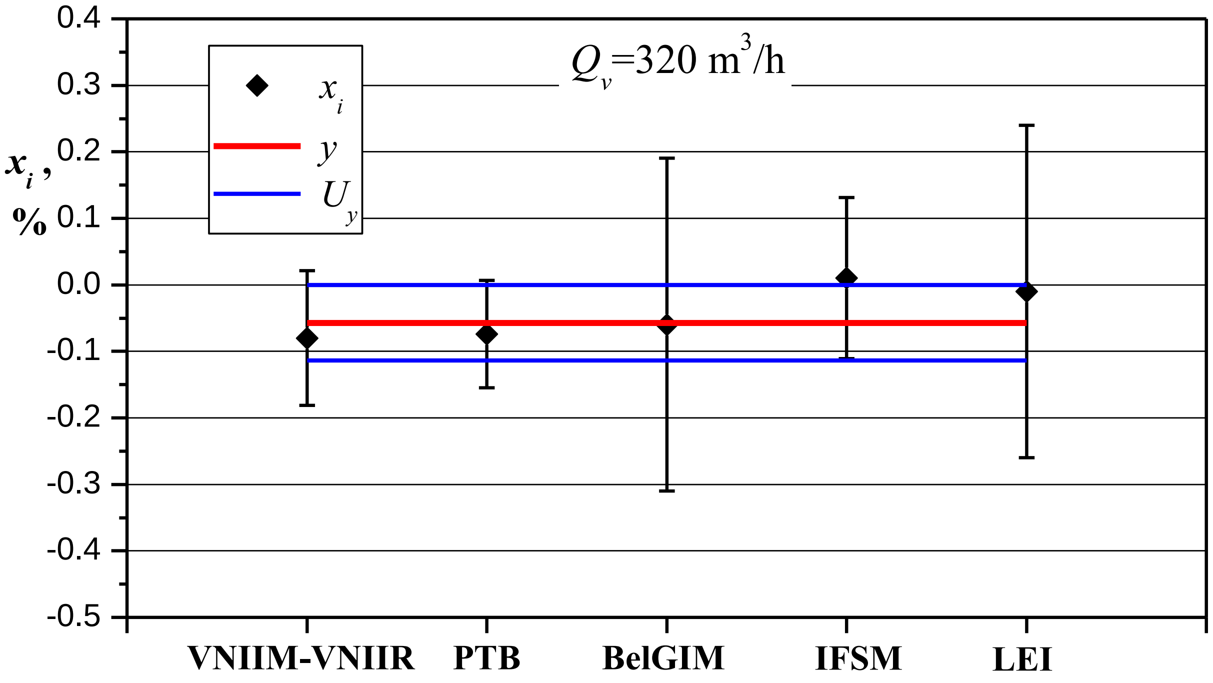


9.2.9 Flow rate 320 m³/h

Laboratory	x_i, %	u_{xi}, %	$(x_i - y)^2/u_{xi}^2$
VNIIM-VNIIR	-0.08	0.0506	0.1732
PTB	-0.074	0.0407	0.1545
IFSM	0.01	0.0606	1.2591

y = -0.058 %
U_y = 0.057 %
χ^2_{obs} = 1.5869
CHIINV = 5.9915

Laboratory	x_i, %	$U_{meas(i)}$	u_{xi}, %	d_i, %	$U(d_i)$, %	E_i
VNIIM-VNIIR	-0.08	0.101	0.0506	-0.02	0.084	0.25
BelGIM	-0.06	0.25018	0.1252	0.00	0.244	0.01
IFSM	0.01	0.121	0.0606	0.07	0.107	0.64
LEI	-0.01	0.25	0.1251	0.05	0.244	0.20
PTB	-0.074	0.081	0.0407	-0.02	0.059	0.28



10 Summary and conclusions

All test and summary results of comparison with turbine gas meter TRZ G4000 are shown in Figure 19 and Table 4.

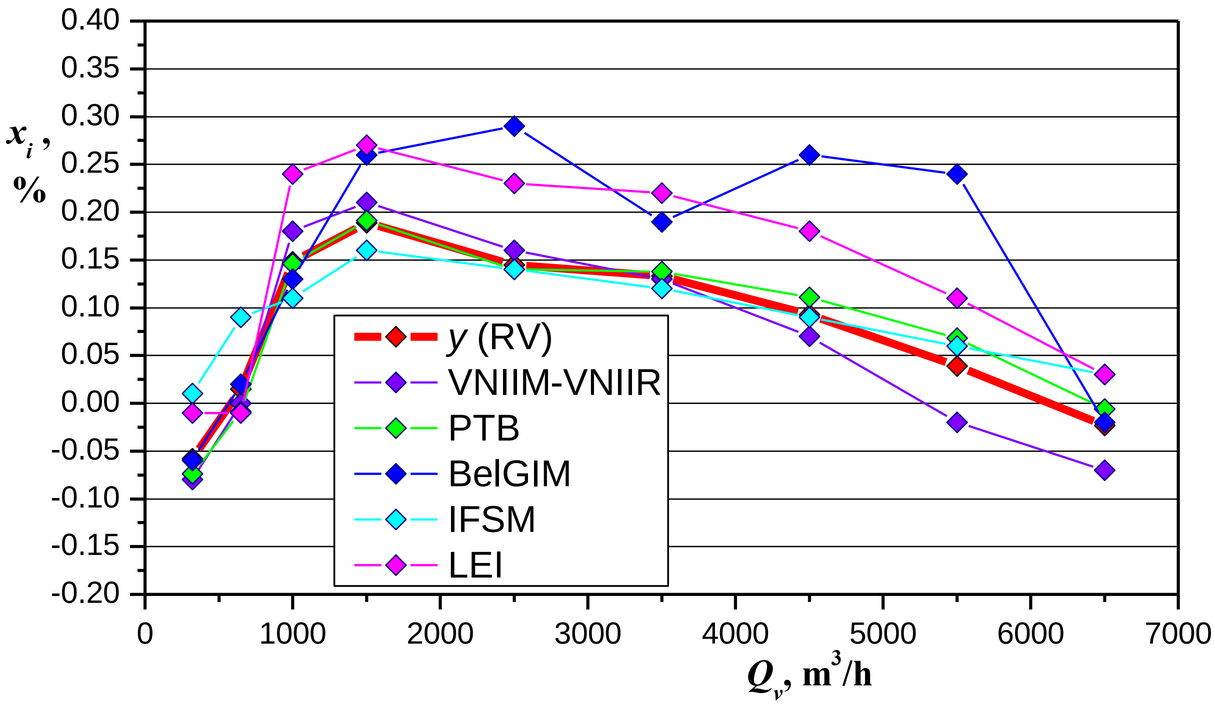


Figure 19 – All test results of comparison with turbine gas meter TRZ G4000

Table 4 – Summary results of comparison with turbine gas meter TRZ G4000

Flow, m³/h	**VNIIM-VNIIR**		**PTB**		**BelGIM**		**IFSM**		**LEI**	
	E_i	**Result**	E_i	**Result**	E_i	**Result**	E_i	**Result**	E_i	**Result**
6500	0.63	passed	0.17	passed	0.01	passed	0.51	passed	0.18	passed
5500	0.69	passed	0.50	passed	0.83	passed	0.19	passed	0.24	passed
4500	0.29	passed	0.31	passed	0.68	passed	0.03	passed	0.30	passed
3500	0.00	passed	0.08	passed	0.23	passed	0.12	passed	0.30	passed
2500	0.14	passed	0.09	passed	0.59	passed	0.05	passed	0.29	passed
1500	0.21	passed	0.03	passed	0.29	passed	0.27	passed	0.33	passed
1000	0.35	passed	0.03	passed	0.07	passed	0.35	passed	0.38	passed
650	0.17	passed	0.41	passed	0.02	passed	0.69	passed	0.10	passed
320	0.25	passed	0.28	passed	0.01	passed	0.64	passed	0.20	passed

All test and summary results of comparison with rotary gas meter IRM-A-DUO G250 are shown in Figure 20 and Table 5.

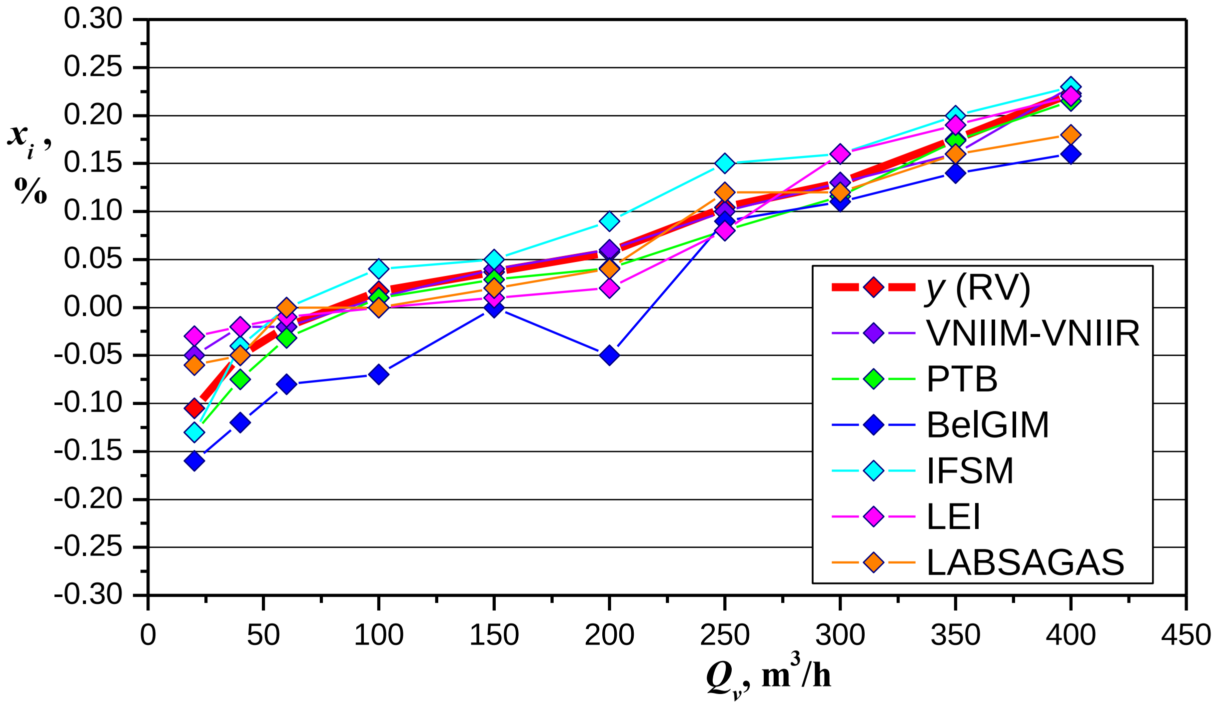


Figure 20 – All test results of comparison with rotary gas meter IRM-A-DUO G250

Table 5 – Summary results of comparison with rotary gas meter IRM-A-DUO G250

Flow, m³/h	**VNIIM-VNIIR**		**PTB**		**BelGIM**		**IFSM**		**LEI**		**LABSAGAS**	
	E_i	**Result**	E_i	**Result**	E_i	**Result**	E_i	**Result**	E_i	**Result**	E_i	**Result**
400	0.08	passed	0.13	passed	0.26	passed	0.06	passed	0.01	passed	0.12	passed
350	0.17	passed	0.02	passed	0.14	passed	0.23	passed	0.06	passed	0.04	passed
300	0.00	passed	0.23	passed	0.08	passed	0.28	passed	0.12	passed	0.03	passed
250	0.03	passed	0.38	passed	0.05	passed	0.48	passed	0.09	passed	0.05	passed
200	0.02	passed	0.28	passed	0.44	passed	0.33	passed	0.16	passed	0.05	passed
150	0.03	passed	0.13	passed	0.15	passed	0.13	passed	0.11	passed	0.05	passed
100	0.08	passed	0.11	passed	0.36	passed	0.23	passed	0.07	passed	0.05	passed
60	0.00	passed	0.20	passed	0.25	passed	0.20	passed	0.04	passed	0.06	passed
40	0.35	passed	0.41	passed	0.29	passed	0.10	passed	0.12	passed	0.00	passed
20	0.64	passed	0.41	passed	0.22	passed	0.26	passed	0.31	passed	0.13	passed

All results were consistent with Reference Value. If the country does not yet have CMC tables, the results will be used for support of a new database entry (Table 6).

Table 6 – Relationship to the CMC-tables

Institute	Flow rate range of facilities used in comparison	Declared CMC-uncertainty of the facilities	KCDB service identifier	Result
VNIIM-VNIIR	From 10 to 16000 m^3/h	0.1 %	No entry	For further support
PTB	From 0.1 to 5600 m^3/h	0.08 %	DE35	In accordance
	From 200 to 24000 m^3/h	0.12 %	DE36	In accordance
BelGIM	From 1.5 to 6500 m^3/h	0.25 %	No entry	For further support
IFSM	From 4 to 200 m^3/h	0.10 %	UA1	In accordance
	From 1 to 7800 m^3/h	0.12 %	No entry	For further support
LEI	From 2.5 to 9700 m^3/h	0.25 to 0.3%	LT3	In accordance
LABSAGAS	From 20 to 400 m^3/h	0.35%	No entry	For further support