FINAL REPORT

COOMET.M.FF-S10

Type of comparison - supplementary

Comparison of national standards in the field of flow and mass of liquid within the flow range of 0.1 to 45 t/h

Pilot

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2023

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1. Description of the project

The purpose of this project is to carry out a comparison in the field of liquid flow measurement between the laboratories - members of the Technical Committee TC 1.4 “Flow measurement” of the COOMET regional metrological organization with the participation of a laboratory - member of the Euramet regional metrological organization in order to establish the degree of equivalence of national standards and evaluate the calibration and measurement capabilities of the laboratories of national metrological institutes in the field of fluid flow. The comparison is carried out within the liquid mass flow range of 0.1 to 45 t/h. The comparison scheme is circular.

2. Comparison participants

The comparison participants and schedule are specified in table 1.

Table 1 – Comparison participants and comparison schedule for COOMET 760/RU-a/18

Country	NMI	Place comparison	Note	Date comparisons (taking into account transportation time)	Responsible person
Russia	VNIIM	Russian Federation, Kazan, Vtoraya Azinskaya str., 7A	full range of comparisons, independent laboratory	October –November 2019	Mr. Albert Tuhvatullin
Belarus	BelGIM	Belarus, Minsk, Starovilenskiy tract, 93	full range of comparisons, independent laboratory	November 2019	Mr. Bardanov Alexander
Lithuania	LEI	Breslaujos g. 3, LT-44403 Kaunas	full range of comparisons, independent laboratory	December 2019	Dr. Gediminas Zygmantas
Czechia	CMI	Okruzní 31 638 00 Brno	full range of comparisons, independent laboratory	January 2020	Ing. Miroslava Benková Ph.D
Moldova	MD	Str. Eugen Coca nr. 28 MD2064 Chisinau	full range of comparisons, independent laboratory	March – August 2020	Mr. Grushka Viktor
Ukraine	NSC «Institute of Metrology»	Ukraine, Kharkiv, myronosytska str 42	full range of comparisons, independent laboratory	September 2020 January 2021	Professor Gennady Narodnitsky
Russia	VNIIM	Russian Federation, Kazan, Vtoraya Azinskaya str., 7A	full range of comparisons, independent laboratory	February – April 2021	Mr. Albert Tuhvatullin
Kazakhstan	RSE «KazStandart»	Kazakhstan, Uralsk, St. 3rd Zavokzal stalled, house 59	partial range of comparisons, independent laboratory	May – August 2021	Mr. Nurlan Davletyarov
Russia	VNIIM	Russian Federation, Kazan, Vtoraya Azinskaya str., 7A	full range of comparisons, independent laboratory	August – September 2021	Mr. Albert Tuhvatullin

3. Transfer standards

The transfer standard includes 3 Micro Motion model CMF mass flow meters.

3.1. Micro Motion model CMF 025 mass flow meter

Name of the flow meter: Micro Motion model CMF 025 (Elite series) mass flow meter (hereinafter referred to as flow meter No. 1).

Manufacturer: Emerson Process Management Flow BV, Mexico.

Factory number: 14824301/09002075.

Mass flow range: 0.1 to 1.0 t/h.

Nominal diameter: DN 6.

Type of connection: flange.

Flange as per EN 1092-1/11, mounting holes 16 mm as per DIN 931.

Type of output signal: pulse-frequency (active).

The maximum frequency of the output signal at the highest flow rate of 2.1 t/h is 10,000 Hz.

Figure 1 – General view of flow meter No. 1

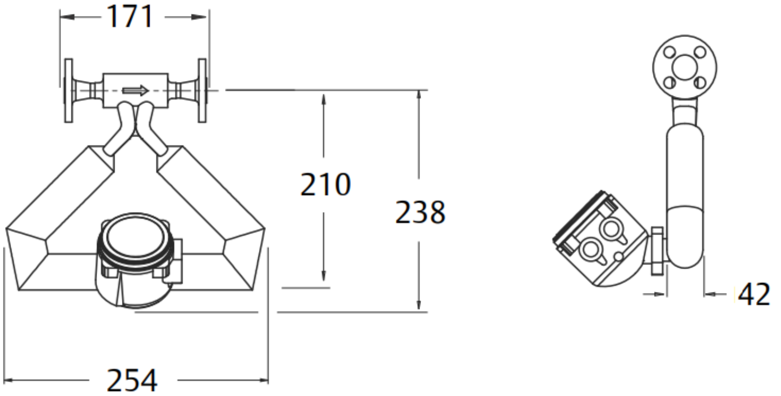


Figure 2 – Overall dimensions of flow meter No. 1

3.2. Micro Motion model CMF 050 mass flow meter

Name of the flow meter: Micro Motion model CMF 050 (Elite series) mass flow meter (hereinafter referred to as flow meter No. 2).

Manufacturer: Emerson Process Management Flow BV, Mexico.

Factory number: 14817177/25979230.

Mass flow range: 1 to 5 t/h.

Nominal diameter: DN 15.

Type of connection: flange.

Flange as per EN 1092-1/11, mounting holes 16 mm as per DIN 931.
Type of output signal: pulse-frequency (active).
The maximum frequency of the output signal at the highest flow rate of 6.8 t/h is 5000 Hz.

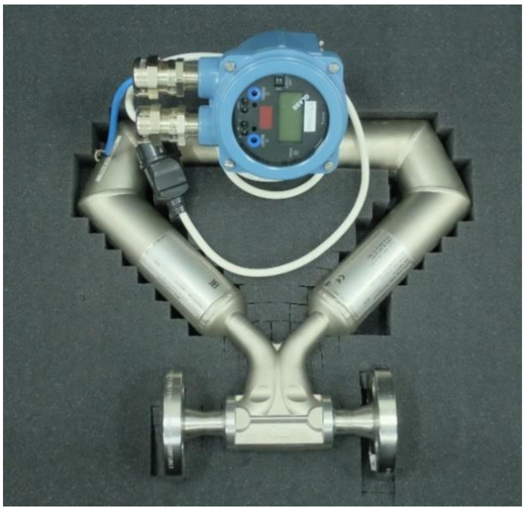


Figure 3 – General view of flow meter No. 2

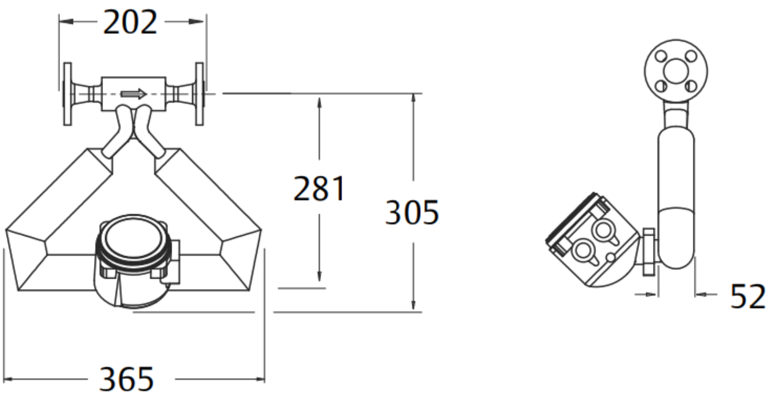


Figure 4 – Overall dimensions of flow meter No. 2

3.3. Micro Motion model CMF 200 mass flow meter

Name of the flow meter: Micro Motion model CMF 200 (Elite series) mass flow meter (hereinafter referred to as flow meter No. 3).
Manufacturer: Emerson Process Management Flow BV, Mexico.
Factory number: 14827932/25971507.
Mass flow range: 5 to 45 t/h.
Nominal diameter: DN 50.
Type of connection: flange.
Flange as per EN 1092-1/11, mounting holes 16 mm as per DIN 931.
Type of output signal: pulse-frequency (active).
The maximum frequency of the output signal at the highest flow rate of 87.1 t/h is 5000 Hz.

Figure 5 – General view of flow meter No. 3

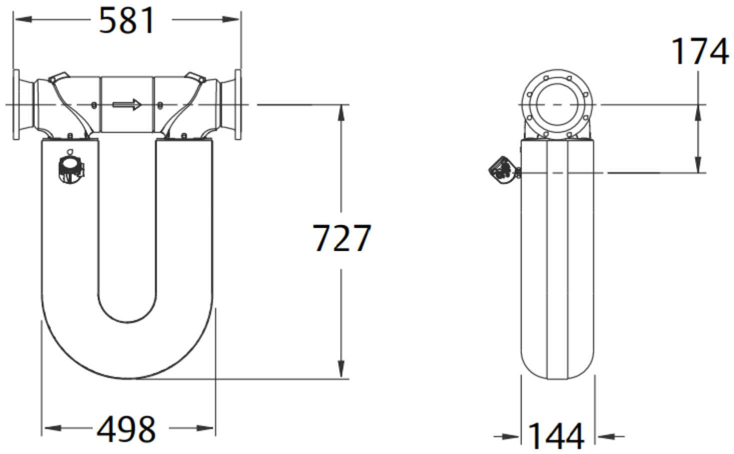


Figure 6 – Overall dimensions of flow meter No. 3

3.4. Unboxing and Packing

The transfer standard is transported in three containers.

Flow meter No. 1 is located in a container with dimensions 800 × 500 × 300 mm (length × width × height). The weight of the container with flow meter No. 1 is 22 kg.

Flow meter No. 2 c is located in a container with dimensions 800 × 500 × 300 mm (length × width × height). The weight of the container with flow meter No. 2 is 24 kg.

Flow meter No. 3 is located in a container with dimensions 1200 × 700 × 250 mm (length × width × height). The weight of the container with flow meter No. 3 is 51 kg.

In order to ensure the safety of the flow meter during transportation, the secondary converter of flow meter No. 3 is disconnected from the sensor. Disassembly and assembly of the transmitter is carried out in accordance with the operational documents of the flow meters. Figure 7 shows a scheme of connecting the transmitter to the sensor.

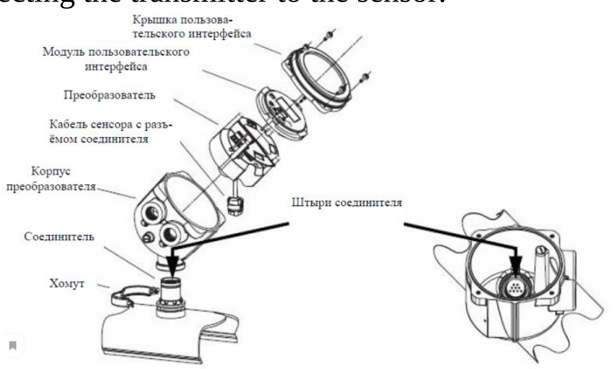


Figure 7 – Scheme of connecting the transmitter to the sensor

Handling of the comparison standard, including unpacking, storage, packaging, should be carried out in accordance with the procedures and rules for handling measuring instruments in force in the laboratory of the comparison participant.

A photo of the general view of the container is shown in Figure 8.

Figure 8 – Photo of the general view of the container

3.5. Additional errors of the transfer standards

In accordance with approved data from the manufacturer of the flow meters of the transfer standards and the results of the evaluation of metrological characteristics, flowmeters 1 – 3 have additional errors due to the change in the temperature and pressure of the measured medium.

Flow meter 1 has an additional error due to the change in the temperature of the measured medium equal to ±0.0001% of the maximum mass flow per 1 degree °C. There is no additional error due to the change in the pressure of the measured medium.

Flow meter 2 has an additional error due to the change in the temperature of the measured medium equal to ±0.0001% of the maximum mass flow per 1 degree °C. There is no additional error due to the change in the pressure of the measured medium.

Flow meter 3 has: an additional error due to the change in the temperature of the measured medium equal to ±0.0005% of the maximum mass flow per 1 degree °C; additional error from the change in the pressure of the measured medium equal to -0.008% of the flow rate per 1 bar.

The value of additional error due to the change in the temperature of the measured medium is determined using the temperature of the measured medium at the time of the zero setting procedure. The value of additional error due to the change in the temperature of the measured medium is a component of the uncertainty of the transfer standard and is calculated for each run's result for each flow point.

The additional error due to the pressure change has a known nature, and in accordance with the recommendations by the flow meter manufacturer, the measurement results are corrected for the value of this additional error taken from the nominal pressure of 0.15 MPa. Correction for the additional error due to the pressure change is carried out for each run's result for each flow point by the pilot laboratory.

4. Measurement method

4.1. Measurement conditions

When carrying out measurements, the participating laboratory ensures that the following conditions are met:

- working fluid: water;
- working fluid temperature: 20±5°C;
- ambient temperature: 20±5°C;
- ambient air humidity: 30% to 80%;
- atmospheric pressure: 86 to 106 kPa;
- absence of free air in the measuring line of the standard.

Before starting, the standard should be kept at the laboratory for at least 8 hours.

4.2. Installation requirements

Installation and connection of the transfer standard are carried out in accordance with the installation manual for the primary transducer (sensor) [1], installation manual for the secondary transducer [2], ProLink III setup and maintenance manual [3].

Installation of the transfer standard in the hydraulic circuit is carried out with the transfer standard in normal position (according to figure 9).

Figure 9 – Normal position of the transfer standard

4.3. "Zero setting" operation.

When performing the "zero setting" operation on the flow meters of the transfer standard, the following procedures should be carried out.

After installing the flow meter of the transfer standard into the measuring table of the standard, after connecting the grounding and signal cables and providing supplying voltage, it is necessary to circulate the flow through the flow meter at maximum flow for at least 15 minutes. Then the flow should be reduced to minimum, and flow circulation should be continued for 5 minutes, after which the flow should be stopped.

The zero setting procedure is carried out in accordance with section 2.6 of the installation manual for the secondary transducer [2].

The "zero setting" procedure is carried out using ProLink III software, which should be downloaded from the official manufacturer's website at: https://www.emerson.com/en-us/catalog/micro-motion-sku-plk.

The electrical connection is made using a RS-485 converter supplied together with the transfer standard.

4.4. Measurement procedure

According to the measurement procedure, the participating laboratories should use their own measurement methods, personnel, software and tools.

For each flow meter of the transfer standard, measurements are made at the following flow points:

– for flow meter No. 1, measurements are carried out at the following points: 0.1 t/h; 0.5 t/h; 1.0 t/h;

– for flow meter No. 2, measurements are carried out at the following points: 1.0 t/h; 2.5 t/h; 5.0 t/h;

– for flow meter No. 3, measurements are carried out at the following points: 5.0 t/h; 25.0 t/h; 45.0 t/h.

The deviation range of the required flow rate value is ±3%. A total of 11 measurements are made at each flow point. The flow points are selected from largest to smallest.

After the measurements were completed, the participating laboratories provided the following information:

– data obtained using their national standard (nominal mass flow, measurement time, measured liquid mass according to standard's readings, temperature and differential pressure of liquid in the hydraulic circuit downstream of the transfer standard, uncertainty of mass liquid flow measurement);

– data obtained from the transfer standard (number of pulses over the measurement period, mass according to the transfer standard's readings, flow meter's conversion factor).

5. National standards

5.1. Description of the national standard of Belarus

The national standard for units of mass and volume flow of liquid (water) NE RB 46-18 is a gravimetric system located in a specialized room. The main parts of the standard are located in the main laboratory room. The flow generators (pumps) and water storage tank are located in a specially created basement of the main room, below floor level, and a constant level pressure tank is fixed to the ceiling level in the room above the laboratory at a height of about 6 m.

The standard is a hydrodynamic research flow metering unit designed to reproduce a unit of mass and volume flow of liquid (water). Tap water is used as the working fluid. The standard was developed with the ability to test, verify and calibrate liquid flow meters in the ranges of mass and volume flow of the working medium (water) from 1 to 60,000 kg/h and from 0.001 to 60 m³/h, respectively.

The main parts of the standard are: flow generators with a water storage tank; constant level pressure tank; a work table with two test lines allowing the installation of primary transducers with a nominal diameter from 2 to 50 mm; three weighing devices with containers for collecting water located on them; four flow switching devices; three mass flow meters; flow regulators; frequency drives for pump control; one power ШС-1 and two automation cabinets ША-1 and ША-2; remote control; water treatment and water change system; compressed air supply system; microclimate maintenance system. Expanded uncertainty no more than 0.06%.

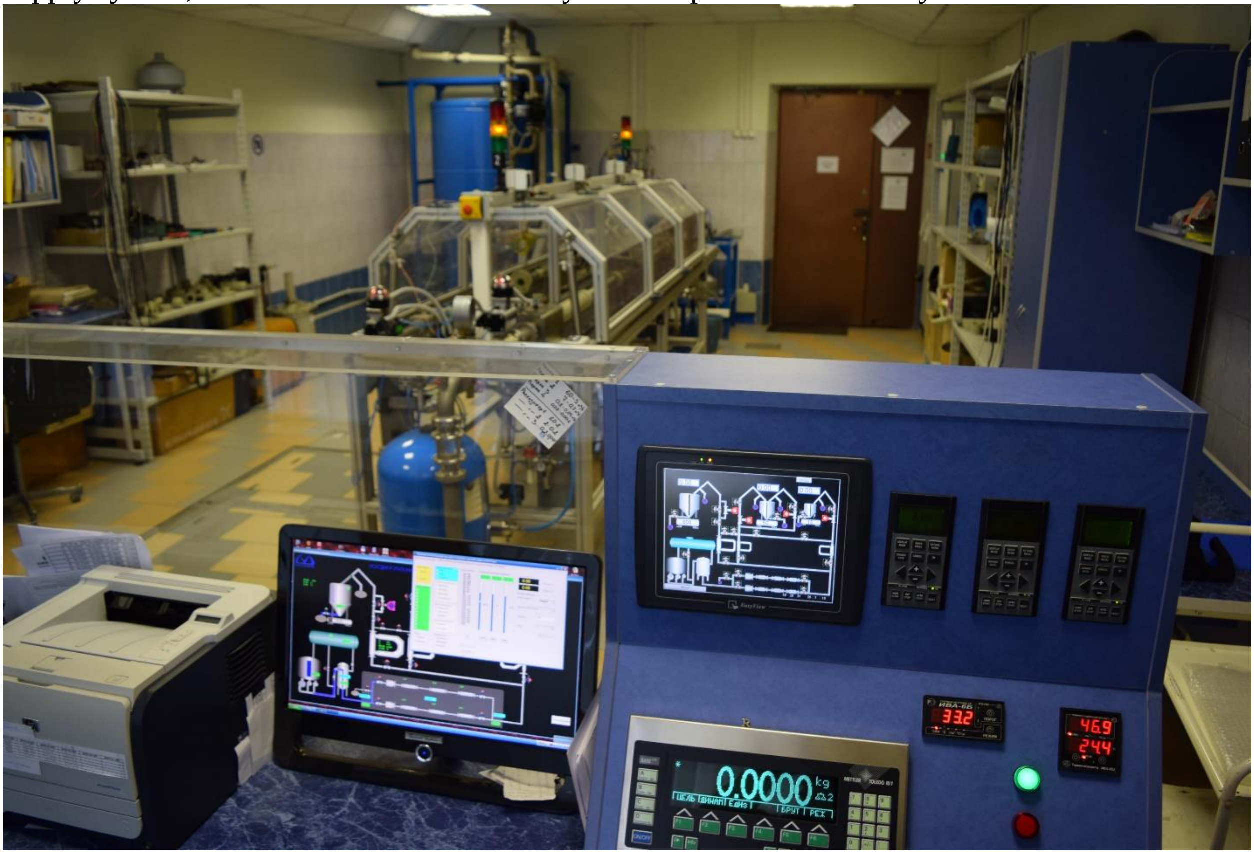


Figure 10 – General view of the national standard of Belarus

5.2. Description of the national standard of Lithuania

The Lithuanian national water flow (volume) standard is maintained by the Lithuanian Energy Institute (LEI), which is a Designated Institute (DI) for Air (gas) Velocity, Air (gas) Volume and Flow, Water Volume and Flow, Liquids (other than water) Volume and Flow and Pressure national standards.

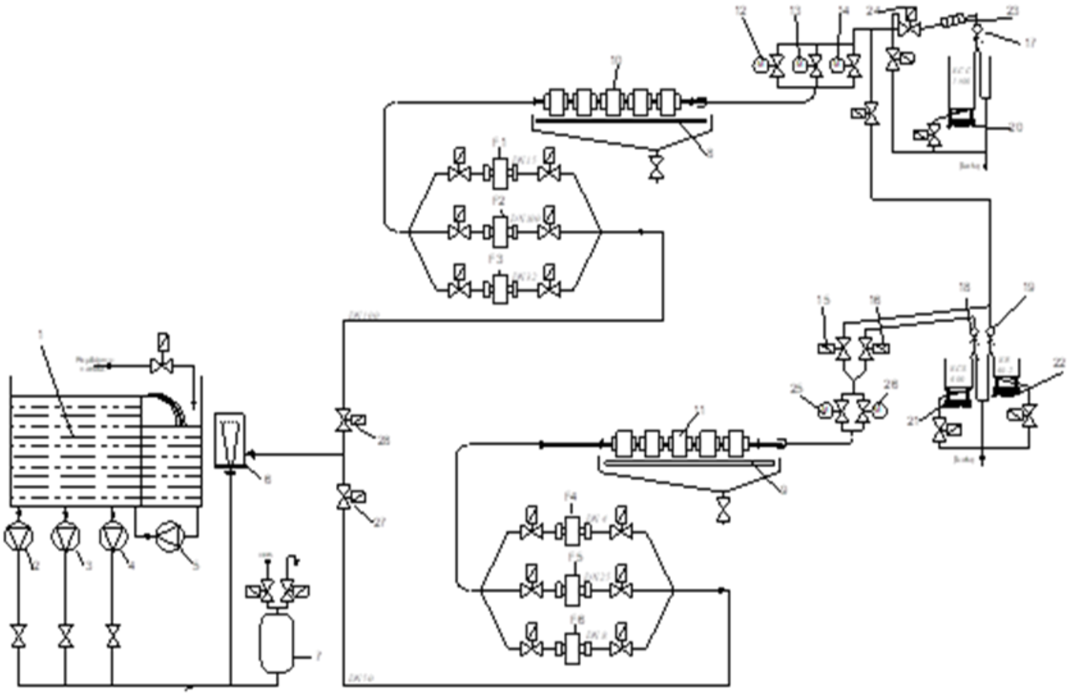


Figure 11 – Simplified hydraulic diagram of water flow reference facility 3E

The water flow reference unit consists of a water supply and stabilization system consisting of a 10 m3 main tank and 3 water supply pumps and one circulation pump that ensures a constant water level on the suction side of the tank, a pulsation damper and an air separator and two measuring lines (DN40 and DN100), each with 3 reference flow meters, and 3 scales with independent flow diverters. The measuring line DN100 with a flow rate of (0.1 to 100) m^3/h can operate with scales of 1500 kg and 60 kg capacity, and the line DN40 with a flow rate of (0.01 to 15) m^3/h with 600 kg and 60 kg. Each measuring line has a straight pipe section 60×DN upstream and 20×DN downstream the instrument to be calibrated. The facility can implement both - flying start-and-stop and standing start-and-stop mode. Water temperature range 20 to 55^{o}C. Pressure in front of the device to be calibrated ≤ 4 bar.

In the flying start-and-stop method, the pulse counter of the MUT and the measuring time counter are started at the moment when the blade of the flow diverter crosses the hydraulic axis of the nozzle to the balance tank at the beginning of the measurement and stop when the blade of the flow diverter crosses hydraulic axis of the nozzle at the end of the measurement. Three optical switches are installed in each flow diverter to measure the diverting time. The measurement is considered acceptable if the difference in flow diverting time between the beginning and the end of the measurement is less than 10%. The water pressure and temperature are measured at both the inlet and outlet of the work area throughout the measurement and the water density is determined from these parameters.

5.3. Description of the national standard of Czechia

CMI flow national standard uses a gravimetric method using scales together with the volumetric method using a piston prover. Temperature of water can be set from 10 ° C to 90 ° C. The standard consists of following main parts – a water source containing tanks for cold and hot water, a source of flow containing a piston prover standard or pumps (depending on method of measurement), a measuring part with measures for installation of tested meters and an evaluation device. The standard is equipped with temperature and pressure sensors for monitoring of conditions of measurement.

The gravimetric method of measurement can be performed in the flow range (0.7 to 60) m^3/h at a pressure of (0.3 to 2) bar using a 600 kg scale as a reference. The volumetric method uses piston prover of 30 L piston as reference standard, source of flow and flow regulator. This method of measurement allows to perform static as well as dynamic measurements and can be set in flow range (0.002 to 7) m^3/h and pressure (0.3 to 6) bar. The pressure is maintained using an expansion vessel. When the desired initial value is reached, the measurement starts. Subsequently, the device automatically sets required configuration of the valves for the next flow and the next flow is set. This processes are controlled automatically. Calculation of mass of water is based on density of water (evaluated from sample of water in laboratory) and actual measured water temperature.

The piston prover as well as scale are traceable to the CMI national standards. The expanded uncertainty of the standard value was determined as 0.10 % and better.

Figure 12 – General view of the national standard of the Czechia

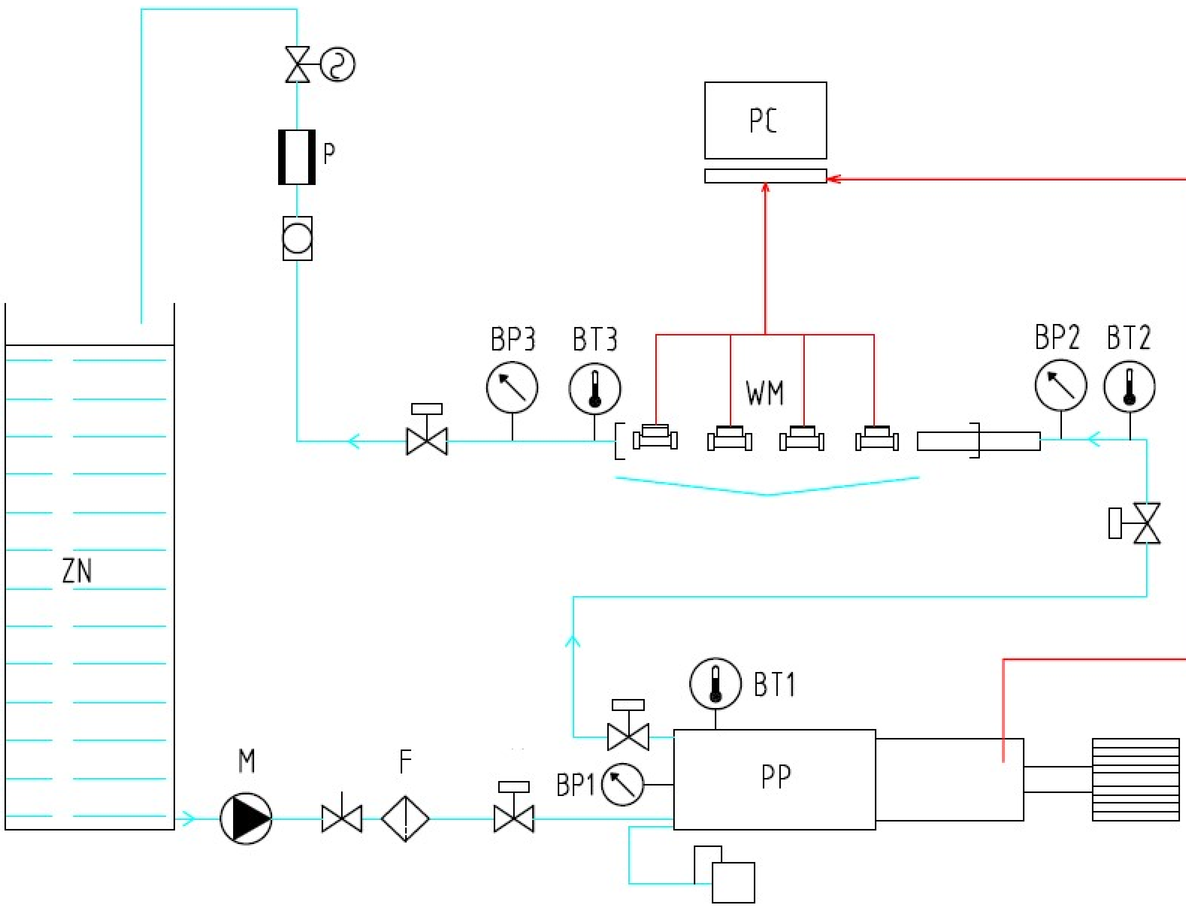


Figure 13 – Diagram of the national standard of the Czechia

5.4. Description of the national standard of Moldova

Table 2 – General information

Type of installation	MR-T-S 1020/2550
Made by	ENBRA, a.s
Serial number	Nº022013.076
Year of construction	2013, February
The number of test lines	2

Table 3 – Technical characteristics

Flow range, m^3/h	0.01 - 35
Pipe diameter, mm	15 - 50
The temperature of water, °C	10°C - 60°C
The uncertainty of installation in transmission of the unit of volume by comparison method	0.2%
The uncertainty of installation in transmission of the unit of volume by gravimetric method	0.05%
Tank capacity	For cold water – 1000 l For hot water – 1000 l

Table 4 – Components

Scales	
Scales 1: Made by Weighing range (kg)	KC 600, S/N 3345262 METTLER TOLEDO 600
Value of division (g)	2.0
Scales 2: Made by Weighing range (kg) Value of division (g)	KC 150, S/N 3345261 METTLER TOLEDO 150 1
Scales 3: Made by Weighing range (kg) Value of division (g)	KA 32s, S/N 3345260 METTLER TOLEDO 25 0.1
Display of scales – common to all weighing systems	IND 690 – S/N 3345263

Table 5 – Flowmeters

Flowmeters	
1. Electromagnetic flowmeter BQ1 Made by Serial number Flow: Qmax (m³/h) Qmin (m³/h)	DN 40; MAG 1100 SIEMENS 432912H492/7ME61102RA202AA1 35.00 4.000
2. Electromagnetic flowmeter BQ2 Made by Serial number Flow: Qmax (m³/h) Qmin (m³/h)	DN 15; MAG 1100 SIEMENS 404412H452/7ME61101VA202AA1 4.50 0.250
3. Electromagnetic flowmeter BQ3 Made by Serial number Flow: Qmax (m³/h) Qmin (m³/h)	DN 6; MAG 1100 SIEMENS 442612H205/7ME61101MA202AA1 0.300 0.80
4. Electromagnetic flowmeter BQ4 Made by Serial number Flow: Qmax (m³/h) Qmin (m³/h)	DN 2; MAG 1100 SIEMENS 225512H565/7ME61101DA202AA1 0.100 0.010

Table 6 – Temperature transducer

Temperature transducer	
Type	Pt 100
Error	0.1 ^{0}C

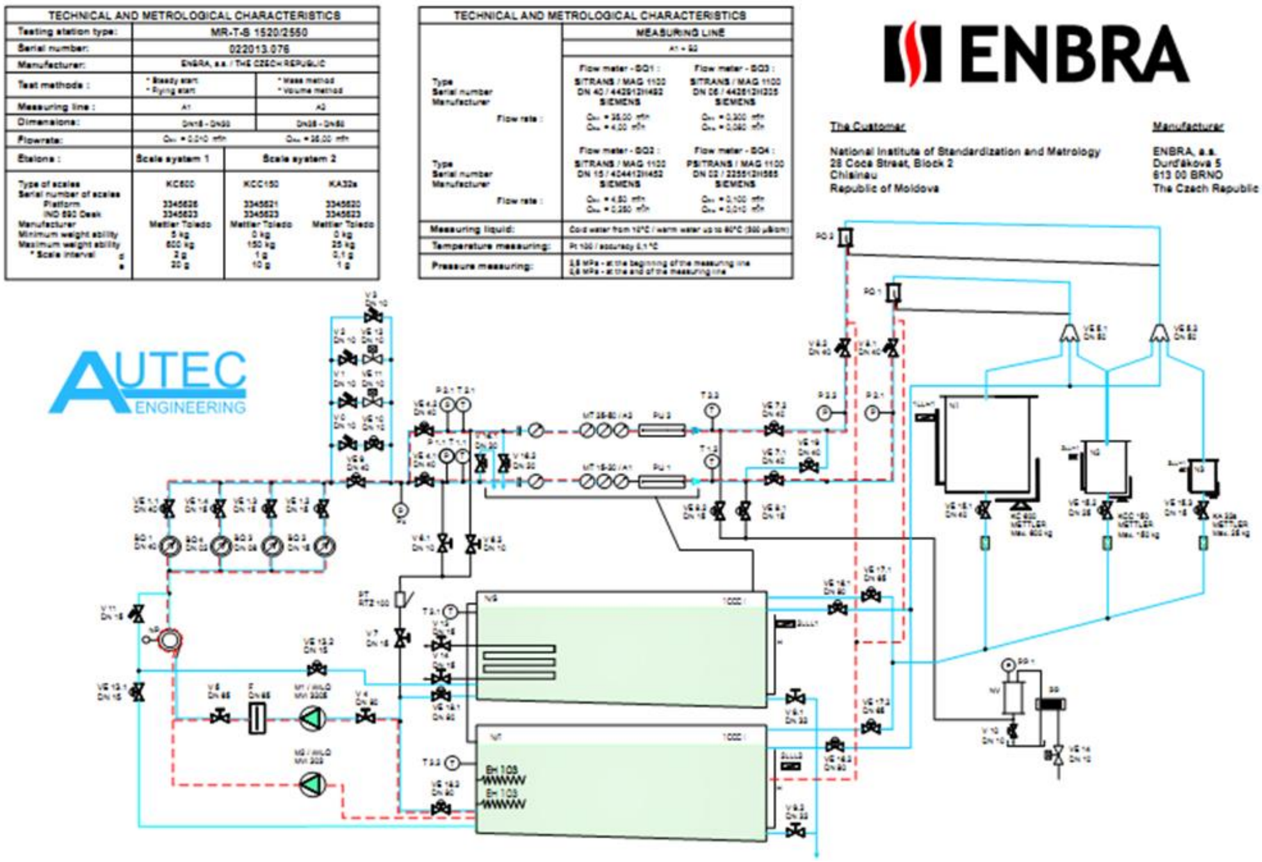


Figure 14 – Diagram of the national standard of the Moldova

5.5. Description of the national standard of Ukraine

The State Primary Measurement Standard of the unit of the volume and mass flow of liquid and the volume and mass of liquid flowing through a pipeline (DETU 03-04-04) is designed for reproduction, maintenance and dissemination of the unit of the liquid volume flow in the range from 2.8·10–4 to 2.8·10–2 m3/s, the liquid mass flow in the range from 2.8·10–1 to 28 kg/s, the liquid volume in the range from 0.1 to 3.0 m3, and the liquid mass in the range from 100.0 to 3000 kg of mass.

The state primary measurement standard uses the weight measurement method.

The main components of the measurement standard are: two precision floor balances manufactured by Mettler Toledo with a measurement range from 0 to 150 kg and from 0 to 3000 kg; a diverting device that redirects the liquid flow alternately into the liquid storage tank or into the liquid weighing tank; and electromagnetic flow meters to set and maintain the required liquid flow.

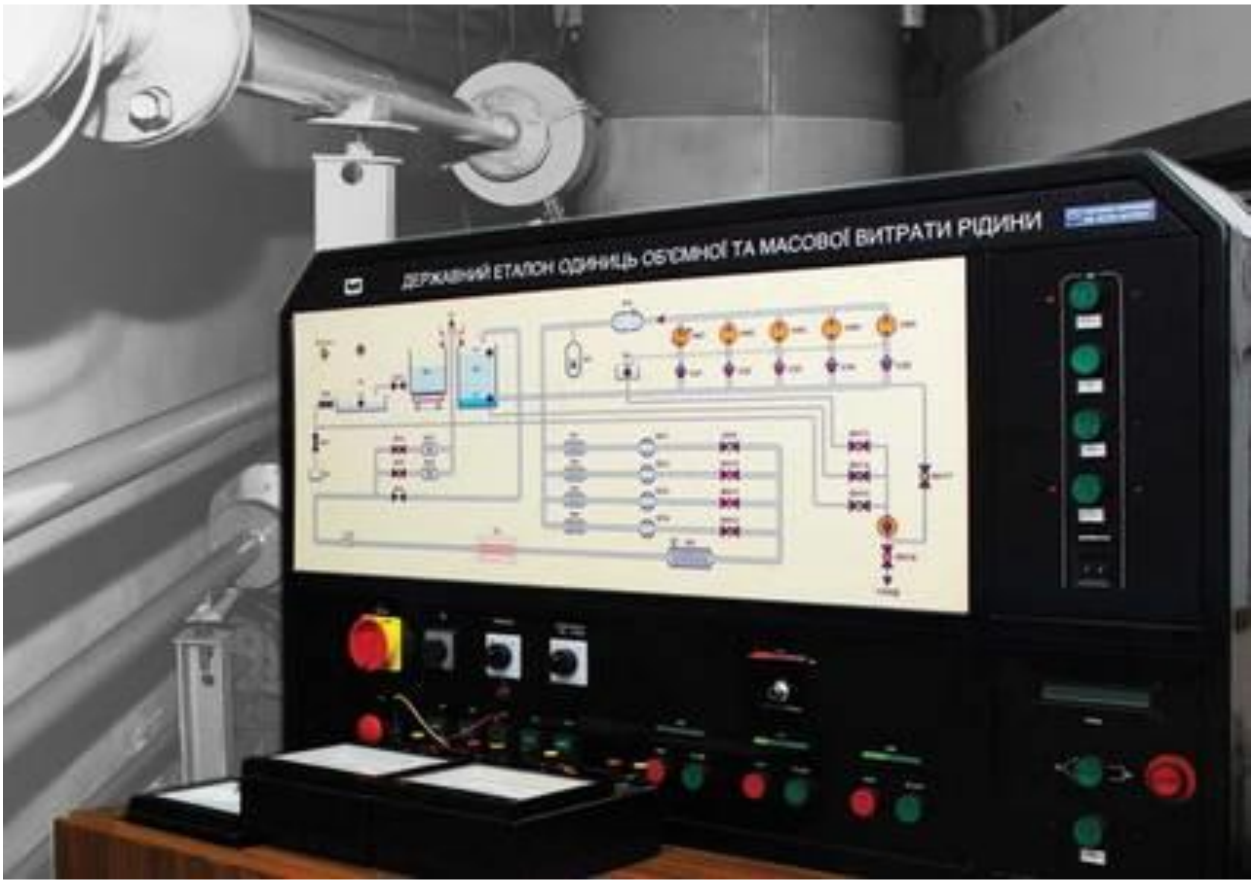


Figure 15 – General view of the national standard of Ukraine

5.6. Description of the national standard of Russia

The state primary special standard of units of mass and volume of liquid in a flow, mass and volumetric flow rates of liquid GET 63, consists of three standard installations EU-1, EU-2 and EU-3.

The reference installations provide a hydrostatic measurement method. Reference installations include storage and drainage systems for working fluid, systems for creating and stabilizing the flow of working fluid, systems for regulating the flow of working fluid, flow switching systems, weighing units for working fluid, temperature stabilization systems for working fluid, chemical water treatment systems, systems for maintaining environmental parameters, sets of comparison standards. Water is used as a working fluid at temperatures from +15 °C to +25 °C.

EU-1 provides reproduction of units of mass and volume of liquid in a flow, mass and volumetric flow rates of liquid in the range of mass and volume flow rates of liquid from 2.5 to 500 t/h (m^3/h). EU-2 provides reproduction in the range of liquid flow rates from 0.01 to 50 t/h (m^3/h). EU-3 provides reproduction in the range of liquid flow rates from 5 to 2000 t/h (m^3/h).

The studies were carried out on EU-2, which includes two scales with measurement ranges of up to 62 kg and up to 1500 kg. Pressure in the hydraulic path of the standard is no more than 6 bar. Expanded uncertainty no more than 0.04%.

Figure 16 – General view of the national standard GET 63 EU-1 of Russia

Figure 17 – General view of the national standard GET 63 EU-2 of Russia

Figure 18 – General view of the national standard GET 63 EU-3 of Russia

Figure 19 – General view of the national standard GET 63 EU-3 of Russia

5.7. Description of the national standard of Kazakhstan

The state standard for liquid flow measuring instruments in the range from 2.2 · 10^{-4} to 2.2 · 10-1 m^3/s (0.794 - 794 m^3/h) is a verification unit compact prover VSR manufactured by Fisher-Rosemount, USA.

The reference unit as part of the unit for liquid flow provides a pouring measurement method. The calibration facility and unit for fluid flow includes a system for storing and draining fluid, a system for creating and stabilizing flow of systems for regulating flow of fluid, a flow switching system, and a system for maintaining environmental parameters. Water is used as fluid at a temperature from +15 °C to +25 °C.

The reference unit provides reproduction of the unit of volume and mass of liquid in the flow, the volumetric flow rate of the liquid in the range of volumetric flow rates from 0.794 m^3/h to 794 m^3/h. The mass of a liquid is determined by an indirect method depending on the density of the liquid.

The reference unit includes a «BROOKS-Compact Prover», a «Solartron-7835» in-line liquid density transducer, a pressure transducer, a platinum resistance thermal transducer, a temperature transducer, a «Parity» turbine flow transducer, an «OMNI 3000» in-line computer, a stand for fluid flow.

Relative accuracy no more than ± 0.05 %. Expanded uncertainty 0.04 %.

Figure 20 – General view of the national standard of Kazakhstan

5.8. Declared uncertainties of the national standards of comparison participants

The declared uncertainties of the national standards of comparison participants are listed in table 2.

Table 7 – Declared uncertainties of the national standards of comparison participants

Country	Flow point t/h (m³/h)	Declared expanded uncertainties of comparison participants (at k = 2), %	Declared standard uncertainties of comparison participants, %
Belarus	0.1	0.04	0.02
	0.5	0.04	0.02
	1	0.04	0.02
	2.5	0.04	0.02
	5	0.04	0.02
	25	0.04	0.02
	45	0.04	0.02
Lithuania	0.1	0.06	0.030
	0.5	0.06	0.030
	1	0.05	0.025
	2.5	0.06	0.030
	5	0.06	0.030
	25	0.05	0.025
	45	0.05	0.025
Czech Republic	0.1	0.06	0.03
	0.5	0.06	0.03
	1	0.10	0.05
	2.5	0.10	0.05
	5	0.10	0.05
	25	0.10	0.05
	45	0.10	0.05
Moldova	0.1	0.05	0.025
	0.5	0.05	0.025
	1	0.05	0.025
	2.5	0.05	0.025
	5	0.05	0.025
	25	0.05	0.025
	45	0.05	0.025
Ukraine	0.1	0.04	0.02
	0.5	0.04	0.02
	1	0.04	0.02
	2.5	0.04	0.02
	5	0.04	0.02
	25	0.04	0.02
	45	0.04	0.02
Kazakhstan	5	0.04	0.02
	25	0.04	0.02
	45	0.04	0.02
Russia	0.1	0.04	0.02
	0.5	0.04	0.02
	1	0.04	0.02
	2.5	0.04	0.02

Country	Flow point t/h (m^3/h)	Declared expanded uncertainties of comparison participants (at k = 2), %	Declared standard uncertainties of comparison participants, %
	5	0.04	0.02
	25	0.04	0.02
	45	0.04	0.02

5.9. Stability of comparison standards

In order to determine the stability of the comparison standard, multiple studies were carried out in the pilot laboratory on the reference installation EU-2 GET 63 before and after the comparison procedure, in which at least 11 measurements were carried out at each flow point. Standard uncertainty (not expanded) due to the stability of the comparison standard, $u_{rs\ j}$, %, is determined by the formula:

$$u_{rs\ j} = \frac{k_{j,max} - k_{j,min}}{k_{nom}} \cdot \frac{100}{2 \cdot \sqrt{3}}. \quad (1)$$

where $k_{j,max}$ – maximum (largest) value of the arithmetic mean value of the conversion factor (k-factor) obtained in one series of measurements from the comparison standard, imp/kg;

$k_{j,min}$ – minimum (smallest) value of the arithmetic mean value of the conversion factor (k-factor) obtained in one series of measurements from the comparison standard, imp/kg;

k_{nom} – nominal value of the flowmeter conversion coefficient, imp/kg.

Standard uncertainties u_{rs} do not exceed 0.015%. Distributions of the relative deviation from the average value of the conversion factors of comparison standards are presented in tables (3)-(12) and in the figures (19)-(21).

Table 8 – distribution of conversion coefficients for the Micro Motion mass flow meter model CMF 025 (Elite series), flow meter No. 1

Date	08.11.2018	28.11.2018	20.12.2018	17.01.2019	20.03.2019
Point number	1	2	3	4	5
Q = 100 kg/h	0.007	0.007	0.006	-0.011	-0.009
Q = 500 kg/h	0.005	-0.006	-0.013	-0.010	0.002
Q = 1000 kg/h	0.008	0.006	-0.010	-0.009	-0.001

Table 9 – distribution of conversion coefficients for the Micro Motion mass flow meter model CMF 025 (Elite series), flow meter No. 1

Date	30.05.2019	20.06.2019	18.07.2019	08.08.2019	16.05.2019
Point number	6	7	8	9	10
Q = 100 kg/h	-0.020	-0.011	-0.012	0.028	0.009
Q = 500 kg/h	-0.009	0.002	0.008	0.015	0.008
Q = 1000 kg/h	-0.007	-0.004	0.006	0.013	-0.002

Table 10 – distribution of conversion coefficients of the Micro Motion mass flow meter model CMF 025 (Elite series), flow meter No. 1

Date	20.08.2019	12.09.2019	19.09.2019	10.10.2019	20.08.2021
Point number	11	12	13	14	15
Q = 100 kg/h	0.002	0.001	-0.007	0.003	0.011
Q = 500 kg/h	-0.012	0.001	0.007	0.013	0.002
Q = 1000 kg/h	-0.007	0.004	-0.002	0.016	0.006

Table 11 – distribution of conversion coefficients of the Micro Motion mass flow meter model CMF 025 (Elite series), flow meter No. 1

Date	25.08.2021	02.09.2021	16.09.2021	12.01.2022	27.01.2022
Point number	16	17	18	19	20
Q = 100 kg/h	0.011	-0.014	0.013	0.000	-0.015
Q = 500 kg/h	0.013	-0.016	0.004	-0.005	-0.009
Q = 1000 kg/h	-0.004	-0.003	0.007	-0.003	-0.013

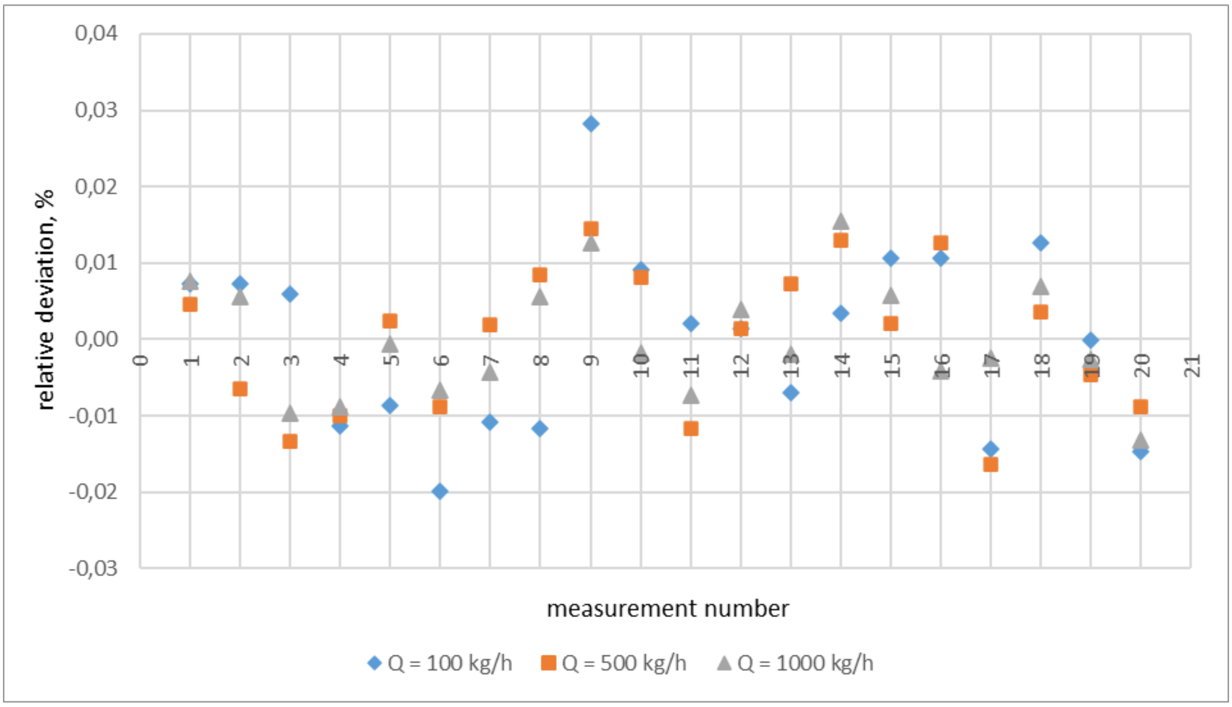


Figure 21 – distribution of the relative deviation
from the average value of the conversion coefficients of the Micro Motion
mass flow meter model CMF 025 (Elite series), flow meter No. 1

Table 12 – distribution of conversion coefficients for the Micro Motion mass flow meter model CMF 050 (Elite series), flow meter No. 2

Date	16.11.2018	14.12.2018	30.01.2019	13.02.2019	04.03.2019
Point number	1	2	3	4	5
Q = 1000 kg/h	0.018	-0.009	-0.026	0.004	0.011
Q = 2500 kg/h	-0.016	0.000	-0.005	-0.013	0.010
Q = 5000 kg/h	0.000	0.020	-0.002	-0.007	0.011

Table 13 – distribution of conversion coefficients for the Micro Motion mass flow meter model CMF 050 (Elite series), flow meter No. 2

Date	11.04.2019	22.04.2019	27.05.2019	19.06.2019	02.06.2019
Point number	6	7	8	9	10
Q = 1000 kg/h	-0.002	0.001	-0.006	0.008	-0.003
Q = 2500 kg/h	0.003	-0.002	0.014	0.002	0.001
Q = 5000 kg/h	-0.011	-0.016	-0.015	0.003	-0.010

Table 14 – distribution of conversion coefficients for the Micro Motion mass flow meter model CMF 050 (Elite series), flow meter No. 2

Date	12.06.2019	22.06.2019	15.08.2019	09.09.2019	26.08.2021
Point number	11	12	13	14	15
Q = 1000 kg/h	-0.001	0.019	-0.009	0.008	-0.007
Q = 2500 kg/h	-0.003	0.010	-0.005	-0.010	0.001
Q = 5000 kg/h	0.013	-0.001	-0.007	0.004	0.012

Table 15 – distribution of conversion coefficients for the Micro Motion mass flow meter model CMF 050 (Elite series), flow meter No. 2

Date	01.09.2021	13.09.2021	20.09.2021	14.01.2022	02.02.2022
Point number	16	17	18	19	20
Q = 1000 kg/h	0.004	-0.006	0.015	-0.006	-0.012
Q = 2500 kg/h	0.004	0.008	0.006	-0.009	0.004
Q = 5000 kg/h	-0.008	-0.001	0.008	0.008	-0.002

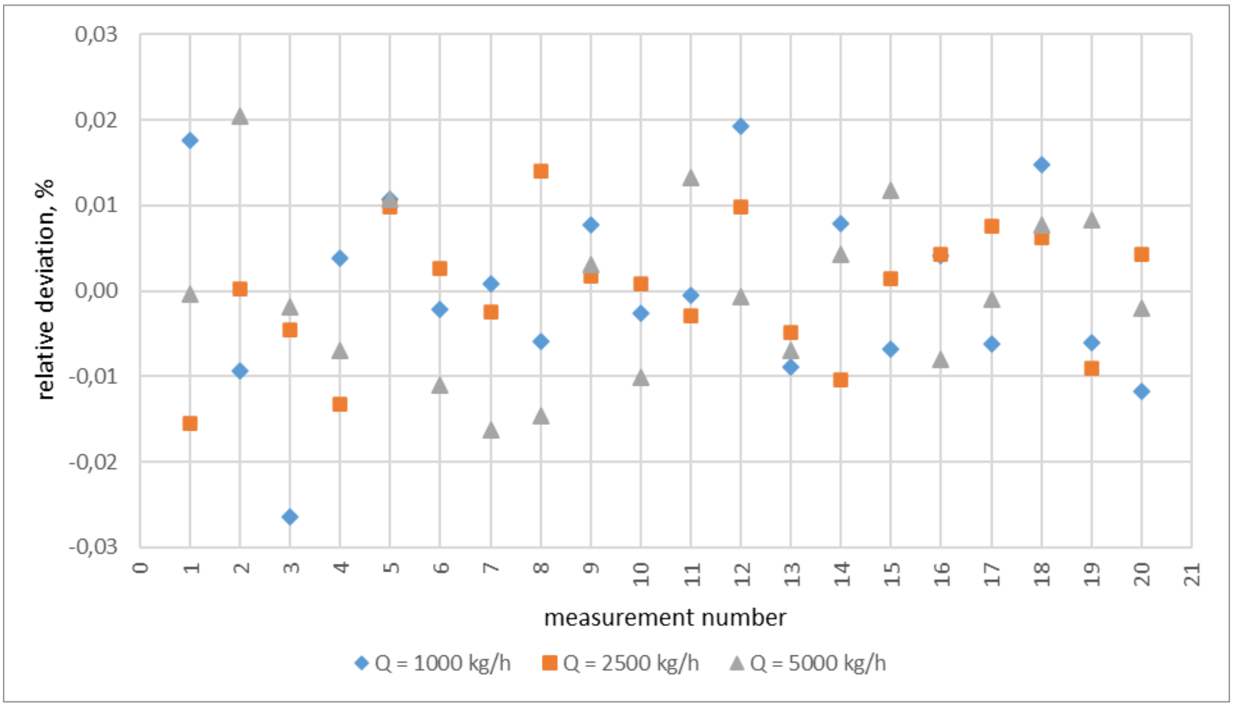


Figure 22 – distribution of the relative deviation from the average value of the conversion coefficients of the Micro Motion mass flow meter model CMF 050 (Elite series), flow meter No. 2

Table 16 – distribution of conversion coefficients for the Micro Motion mass flow meter model CMF 200 (Elite series), flow meter No. 3

Date	16.01.2019	12.02.2019	05.03.2019	28.05.2019	17.06.2019	21.08.2019	25.08.2021
Point number	1	2	3	4	5	6	7
Q = 5000 kg/h	0.004	0.012	0.009	0.004	-0.001	-0.013	-0.008
Q = 2500 kg/h	0.008	-0.016	0.012	-0.011	-0.010	-0.012	-0.001
Q = 45000 kg/h	0.006	0.002	0.001	-0.017	-0.018	-0.012	-0.001

Table 17 – distribution of conversion coefficients for the Micro Motion mass flow meter model CMF 200 (Elite series), flow meter No. 3

Date	03.09.2021	22.09.2021	24.09.2021	05.10.2021	07.10.2021	11.01.2022	04.02.2022
Point number	8	9	10	11	12	13	14
Q = 5000 kg/h	-0.013	0.011	0.004	0.018	-0.014	0.000	-0.012
Q = 2500 kg/h	-0.007	-0.007	-0.004	0.028	0.029	0.011	-0.019
Q = 45000 kg/h	0.001	0.004	0.005	0.007	0.011	0.019	-0.009

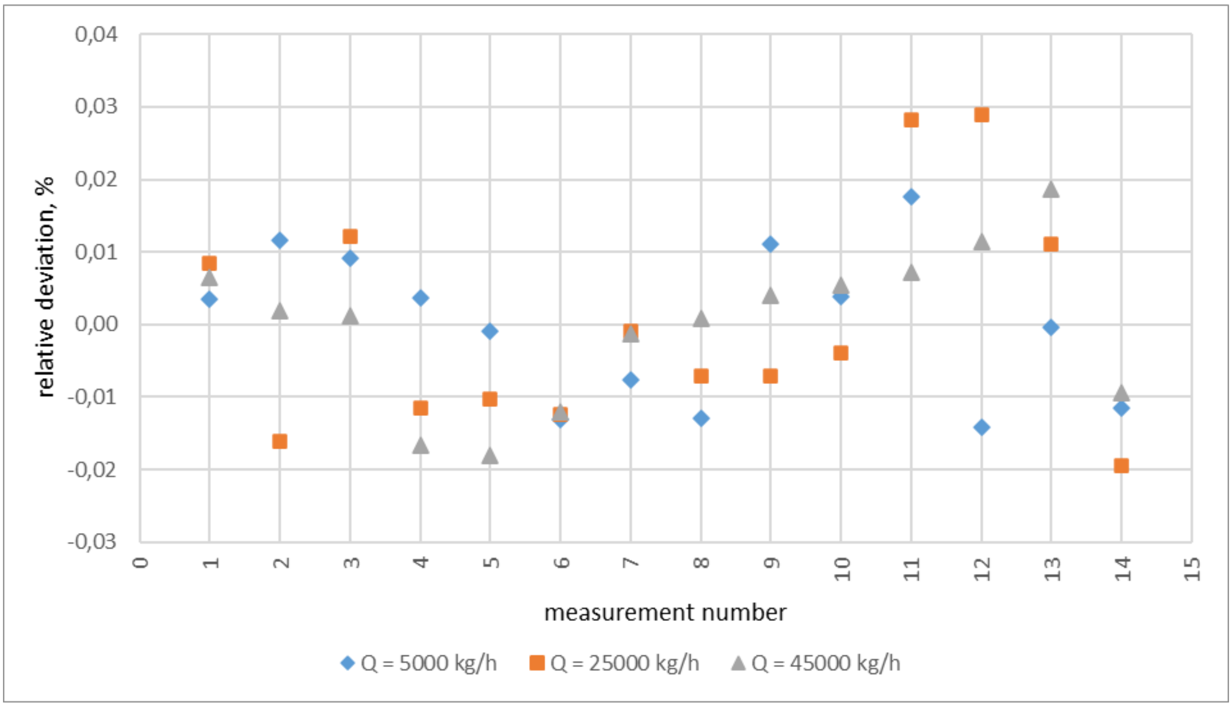


Figure 23 – distribution of the relative deviation
from the average value of the conversion coefficients of the Micro Motion
mass flow meter model CMF 200 (Elite series), flow meter No. 3

6. Dependence of national standards

All laboratories participating in this comparison are independent laboratories.

7. Processing of results

The data evaluation procedure was performed by the pilot laboratory in accordance with the publication by M.G. Cox [4] and COOMET recommendations [5]. The “*Chi* - square” test method was used to determine the allowable variation in the results of the participating laboratories when establishing the initial value of KCRV.

7.1. Evaluation of data from participating laboratories

The conversion factor (k-factor) at each measurement, k_{ij}, pulses/kg, is determined using the formula:

$$k_{mji} = \frac{N_{mji}}{M_{Ref\,mji}}, \tag{2}$$

where N – number of pulses received from the transfer standard over the measurement period, pulses;
M_{Ref} – mass of liquid measured by the standard over the measurement period τ_{Ref}, kg;
m – serial number of the evaluated laboratory;
j, i – flow point number and measurement number, respectively.

Expanded measurement uncertainty (at k = 2), U_CMC, %, is estimated in accordance with WGFF recommendations [4]:

$$U_{CMC\,mj} = \sqrt{U^2_{base\,mj} + 2 \cdot u^2_{repeat\,mj}}, \tag{3}$$

where U_{base} – expanded uncertainty (k = 2) declared by the laboratory, %;
u_{repeat} – repeatability of k value (type A uncertainty), %.

$$u_{repeat\ mj} = \frac{100}{k_{mj}} \cdot \sqrt{\frac{\sum_{i=1}^{n}(k_{mji}-k_{mj})^2}{n\cdot(n-1)}}, \quad (4)$$

where k_j – arithmetic mean of the conversion factor (k-factor) at the flow point, imp/kg;

n – number of measurements at the flow point.

$$k_{mj} = \frac{\sum_{i=1}^{n} k_{mji}}{n}. \quad (5)$$

In order to bring the measurement results to a relative form, the relative deviation of the conversion factor from the nominal value of the conversion factor during each measurement, %, is determined according to the formula:

$$e_{mji} = \frac{k_{mji}-k_{j\ nom}}{k_{j\ nom}} \cdot 100, \quad (6)$$

where e_{mji} – relative deviation of the conversion factor from the nominal value of the conversion factor during each measurement , %;

$k_{j\ nom}$ – nominal value of the conversion factor, pulses/kg (equal to 18000 pulses/kg for flow meter No. 1, 3600 pulses/kg for flow meter No. 2 and 300 pulses/kg for flow meter No. 3).

The arithmetic mean of the relative deviation of the conversion factors from the nominal value of the conversion factor during each measurement for the jth flow point is determined by the formula:

$$e_{mj} = \frac{\sum_{i=1}^{n} e_{mji}}{n}, \quad (7)$$

where e_{mj} – arithmetic mean of the relative deviation of the conversion factors during each measurement from the nominal value of the conversion factor for laboratory number m at the jth flow point, %.

7.2. Establishing the initial value of KCRV and its uncertainty

The reference value of the supplementary comparison is calculated for each flow point using the formula:

$$e_{ref\ j} = \frac{\sum_1^m \frac{e_{mj}}{u_{e(mj)}^2}}{\sum_1^m \frac{1}{u_{e\ (mj)}^2}}, \quad (8)$$

where $e_{ref\ j}$ – reference value of the supplementary comparison for the jth flow point, %;

$u_{e\ (mj)}$ – standard uncertainty of the reference value of supplementary comparisons of the evaluated laboratory m at the jth flow point, %.

The standard uncertainty of the reference value of the supplementary comparison evaluated for laboratory number m at the jth flow point is determined by the formula:

$$u_{e\ (mj)} = \sqrt{\left(\frac{U_{CMC\ mj}}{2}\right)^2 + u_{te}^2 + u_{rs}^2}, \quad (9)$$

where $U_{CMC\ mj}$ – expanded measurement uncertainty (k = 2) for laboratory number m, %;

u_{te} – standard (not extended) uncertainty due to the influence of the temperature of the measured medium on the flow meter of the transfer standards, %;

u_{rs} – standard (not expanded) uncertainty due to the stability of the transfer standard, %.

The standard (not extended) uncertainty due to the influence of the temperature of the measured medium on the flow meter of the transfer standards is determined by the formula:

$$u_{te} = \delta_{te} \cdot \frac{|t_{mji} - t_0| \cdot Q_{max}}{Q_j}, \tag{10}$$

where u_{te} – standard uncertainty due to the influence of the temperature of the measured medium on the flow meter of the transfer standards, %;

δ_{te} – additional error due to the change in the temperature of the measured medium relative to the maximum mass flow per 1 degree °C (equal to ±0.0001% for flow meters No. 1 and No. 2, and ±0.0005% for flow meter No. 3), %;

t_{mji} – temperature of the measured medium for flow meter number m at the jth flow point during the ith measurement, °C;

t_0 – temperature of the measured medium during the zero setting procedure, °C;

Q_j – mass flow value at the jth flow point, kg/h;

Q_{max} – maximum mass flow rate for the flow meter, kg/h (equal to 2100 kg/h for flow meter No. 1, 6800 kg/h for flow meter No. 2 and 87100 kg/h for flow meter No. 3).

The standard uncertainty associated with the initial value of KCRV is calculated using the formula:

$$u^2_{e_{ref\ j}} = \frac{1}{\sum_1^m \frac{1}{u^2_{e\,(mj)}}}. \tag{11}$$

The expanded uncertainty associated with the initial value is determined using the formula:

$$U_{e_{ref\ j}} = 2 \cdot u_{e_{ref\ j}}. \tag{12}$$

7.3. Verifying the consistency of comparison data

The “*Chi* - square” test method was used to determine the allowable variation in the results of the participating laboratories when establishing the initial value of *KCRV*. Individual independent laboratories contribute to the establishment of the value χ^2_j using their measured values of measurement error and uncertainty. The square of the *Chi* value is calculated for each flow point using the formula:

$$\chi^2_j = \sum_1^m \frac{\left(e_{mj} - e_{ref\ j}\right)^2}{u^2_{e\,(mj)}}. \tag{13}$$

The degree of freedom was established in accordance with the equation:

$$\nu = m - 1. \tag{14}$$

In order to achieve the initial value, the comparison participant’s laboratories should meet the following conditions:

$$CHIINV(0{,}05;\ \nu) > \chi^2_j\ . \tag{15}$$

The $CHIINV(0{,}05;\ \nu)$ function is calculated using a standard method in MS Excel software.

If the condition (15) is met, the data of comparison participants is considered to be consistent.

If the condition (15) is not met, then inconsistent data is identified, and a set of consistent comparison data is generated.

7.4. Identification of inconsistent data and generation of a set of consistent comparison data

In order to identify inconsistent data, a participating laboratory is determined. Which provides the maximum value of the E_{mj} criterion at a given flow point according to the formula:

$$E_{mj} = \frac{|e_{mj} - e_{ref\,j}|}{2 \cdot \sqrt{u^2_{e(mj)} - u^2_{e_{ref\,j}}}}, \tag{16}$$

Then the data obtained by the participant's laboratory at the jth flow point, for which the highest value of the E_{mj} criterion was determined, is excluded, and the comparison data consistency verification procedure is repeated. Sequential data exclusion is repeated until the condition of comparison data consistency according to the "*Chi* - square" method is met for the group of remaining data (a set of consistent data).

After identifying consistent data, the obtained value $e_{ref\,j}$ is accepted as the initial value of KCRV, and the value $U_{e_{ref\,j}}$ is recognized as the expanded measurement uncertainty associated with KCRV.

7.5. Confirmation of CMC data

For measurement results included in the set of consistent data and used to calculate the reference value, the following CMC data confirmation procedure is applied.

If the measurement result meets the following condition:

$$E_{mj} = \frac{|e_{mj} - e_{ref\,j}|}{2 \cdot \sqrt{u^2_{e(mj)} - u^2_{e_{ref\,j}}}} < 1, \tag{17}$$

Then the participating laboratory's results are acceptable (satisfactory) and the minimum standard uncertainty of the participating laboratory at the jth flow point that can be declared as a CMC corresponds to $U_{CMC\,mj}$.

If the measurement result does not meet the condition (17), then the minimum standard uncertainty that can be declared as a result of measurements/calibrations (CMC) for the participant's laboratory is calculated using the formula:

$$u^2_{CMC\,mj} = \frac{(e_{mj} - e_{ref\,j})^2}{4} + u^2_{e_{ref\,j}}, \tag{18}$$

Accordingly, the expanded uncertainty is as follows:

$$U_{0.95\,CMC\,mj} = 2 \cdot u_{CMC\,mj}, \tag{19}$$

8. Comparison results

8.1. Initial results

Table 18 – Evaluation of data from comparison participants

	j	3	2	1	6	5	4	9	8	7
	Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
Belarus	e_{mj}, %	0.004	-0.030	-0.030	-0.019	-0.018	-0.100	-0.019	-0.022	-0.014
	$u_{e\,(mj)}$, %	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Lithuania	e_{mj}, %	0.054	0.016	0.021	0.003	-0.006	-0.056	-0.014	-0.003	0.002
	$u_{e\,(mj)}$, %	0.035	0.034	0.029	0.029	0.034	0.034	0.034	0.029	0.029
Czechia	e_{mj}, %	-0.025	-0.018	-0.005	-0.018	0.002	-0.074	0.061	0.071	0.071
	$u_{e\,(mj)}$, %	0.034	0.034	0.052	0.052	0.052	0.052	0.053	0.052	0.052
Moldova	e_{mj}, %	0.003	-0.003	0.051	0.025	0.066	-0.063	0.051	0.089	–
	$u_{e\,(mj)}$, %	0.030	0.030	0.029	0.029	0.029	0.029	0.036	0.029	–
Ukraine	e_{mj}, %	-0.025	0.098	0.120	0.149	0.154	0.193	0.042	0.154	0.119
	$u_{e\,(mj)}$, %	0.025	0.025	0.026	0.026	0.025	0.025	0.026	0.026	0.027
Kazakhstan	e_{mj}, %	–	–	–	–	–	–	-0.024	-0.046	-0.036
	$u_{e\,(mj)}$, %	–	–	–	–	–	–	0.025	0.025	0.025
Russia	e_{mj}, %	0.023	0.046	0.024	0.029	0.035	-0.055	0.008	-0.034	-0.030
	$u_{e\,(mj)}$, %	0.025	0.025	0.026	0.025	0.027	0.025	0.026	0.025	0.025

Table 19 – Establishing the baseline value of KCRV and its uncertainty

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
$e_{ref\ j}$	0.004	0.022	0.034	0.036	0.048	-0.014	0.014	0.037	0.021
$u_{e_{ref\ j}}$	0.011	0.011	0.012	0.012	0.012	0.012	0.011	0.011	0.011
$U_{e_{ref\ j}}$	0.023	0.023	0.023	0.023	0.024	0.024	0.022	0.021	0.023

Table 20 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
ν	5.00	5.00	5.00	5.00	5.00	5.00	6.00	6.00	5.00
χ_j^2	4.72	**16.39**	**18.83**	**26.57**	**28.88**	**86.99**	7.69	**51.00**	**26.22**
$CHIINV$	11.07	11.07	11.07	11.07	11.07	11.07	12.59	12.59	11.07
Flag	∨	–	–	–	–	–	∨	–	–

The graph of the deviation of e_{mj} values from $e_{ref\ j}$ (d_{mj}, formula No.21) for all points and for all participants before the formation of a set of agreed comparison data is shown in the figure:

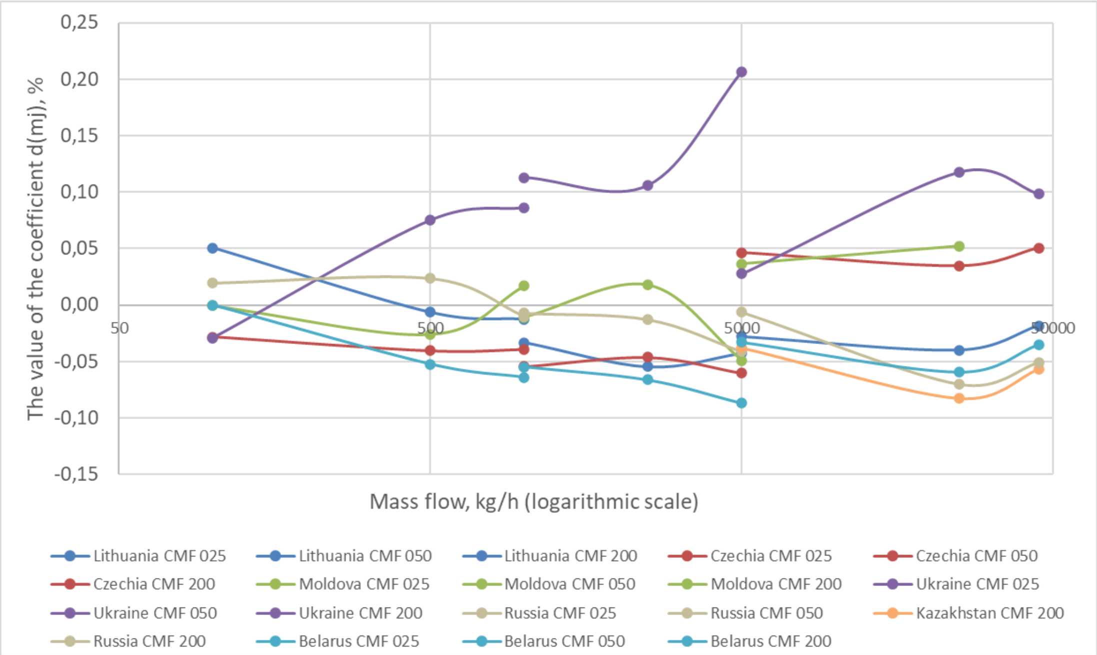
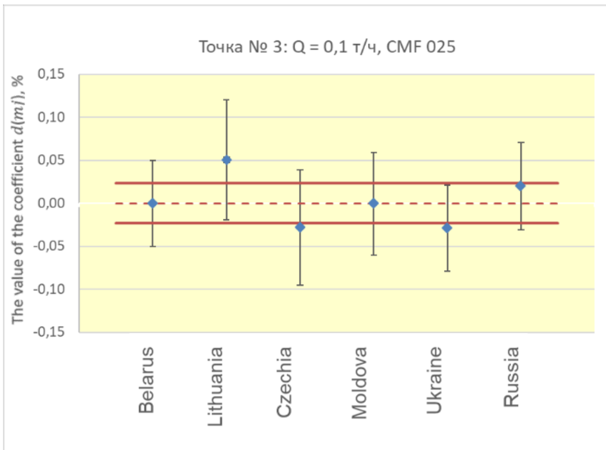


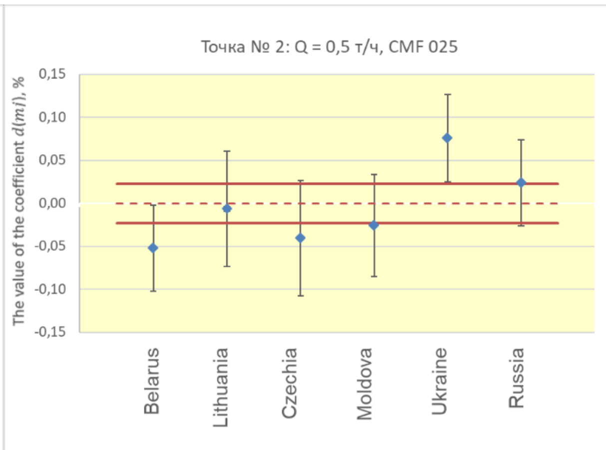
Figure 24 – the graph of the deviation of e_{mj} values from $e_{ref\ j}$ for all points and for all participants before the formation of a set of agreed comparison data

Table 21 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.00	**1.18**	**1.46**	**1.24**	**1.51**	**1.97**	0.73	**1.30**	0.78
Lithuania	0.76	0.10	0.23	0.62	0.87	0.68	0.43	0.73	0.34
Czechia	0.45	0.64	0.39	0.53	0.45	0.59	0.45	0.34	0.50
Moldova	0.01	0.47	0.31	0.20	0.33	0.92	0.53	0.95	–
Ukraine	0.65	**1.67**	**1.86**	**2.46**	**2.40**	**4.61**	0.58	**2.53**	**2.05**
Kazakhstan	–	–	–	–	–	–	0.85	**1.82**	**1.27**
Russia	0.43	0.53	0.22	0.16	0.26	0.93	0.13	**1.55**	**1.13**

Graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\ (mj)}$ and $U_{e_{ref\ j}}$ are shown in the figure:





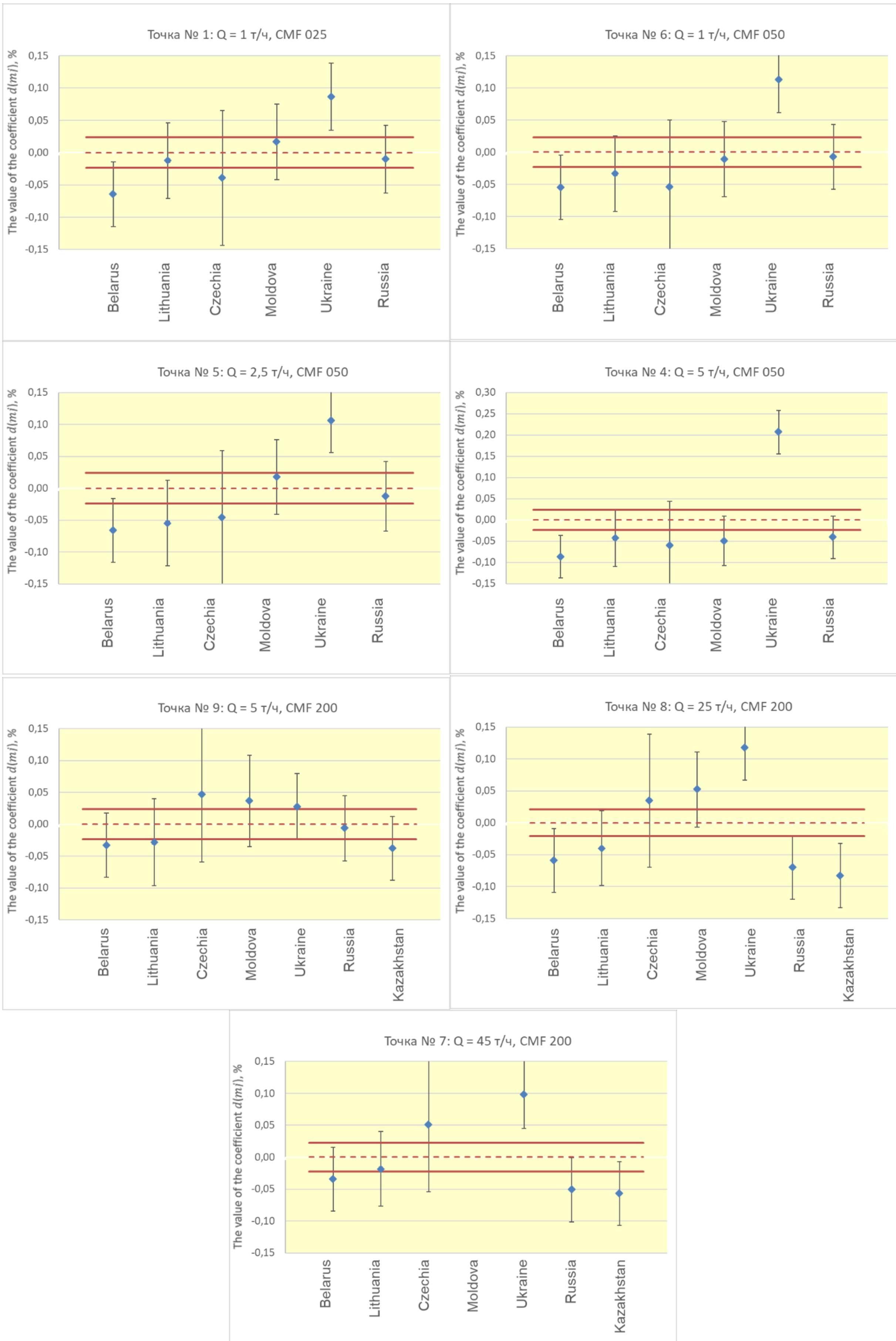


Figure 25 – graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\ (mj)}$ and $U_{e_{ref\ j}}$

8.2. Generating a set of consistent comparison data. Stage No. 1

In order to form a set of consistent comparison data, the point with the highest value of E_{mj} (Table No. 21) equal to 4.61 (country Ukraine, j = 4) was removed.

Table 22 – Evaluation of participant laboratory data after removal of non-consensus value

	j	3	2	1	6	5	4	9	8	7
	Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
Ukraine	e_{mj}, %	-0.025	0.098	0.120	0.149	0.154	–	0.042	0.154	0.119
	$u_{e\,(mj)}$, %	0.025	0.025	0.026	0.026	0.025	–	0.026	0.026	0.027

Table 23 – Establishing the baseline value of KCRV and its uncertainty

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
$e_{ref\ j}$	0.004	0.022	0.034	0.036	0.048	-0.071	0.014	0.037	0.021
$u_{e_{ref\ j}}$	0.011	0.011	0.012	0.012	0.012	0.013	0.011	0.011	0.011
$U_{e_{ref\ j}}$	0.023	0.023	0.023	0.023	0.024	0.027	0.022	0.021	0.023

Table 24 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
ν	5.00	5.00	5.00	5.00	5.00	4.00	6.00	6.00	5.00
χ_j^2	4.72	**16.39**	**18.83**	**26.57**	**28.88**	2.07	7.69	**51.00**	**26.22**
CHIINV	11.07	11.07	11.07	11.07	11.07	9.49	12.59	12.59	11.07
Flag	∨	–	–	–	–	∨	∨	–	–

Table 25 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.00	**1.18**	**1.46**	**1.24**	**1.51**	0.70	0.73	**1.30**	0.78
Lithuania	0.76	0.10	0.23	0.62	0.87	0.23	0.43	0.73	0.34
Czechia	0.45	0.64	0.39	0.53	0.45	0.03	0.45	0.34	0.50
Moldova	0.01	0.47	0.31	0.20	0.33	0.16	0.53	0.95	–
Ukraine	0.65	**1.67**	**1.86**	**2.46**	**2.40**	–	0.58	**2.53**	**2.05**
Kazakhstan	–	–	–	–	–	–	0.85	**1.82**	**1.27**
Russia	0.43	0.53	0.22	0.16	0.26	0.38	0.13	**1.55**	**1.13**

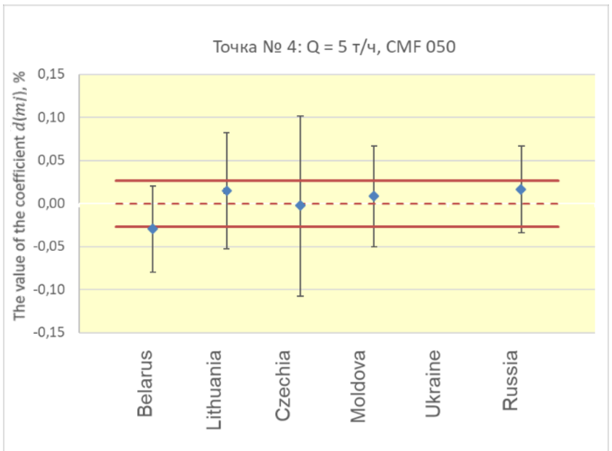


Figure 26 – graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\,(mj)}$ and $U_{e_{ref\ j}}$

8.3. Generating a set of consistent comparison data. Stage No. 2

In order to form a set of consistent comparison data, the point with the highest value of E_{mj} (Table No. 25) equal to 2.53 (country Ukraine, j = 8) was removed.

Table 26 – Evaluation of participant laboratory data after removal of non-consensus value

	j	3	2	1	6	5	4	9	8	7
	Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
Ukraine	e_{mj}, %	-0.025	0.098	0.120	0.149	0.154	–	0.042	–	0.119
	$u_{e\,(mj)}$, %	0.025	0.025	0.026	0.026	0.025	–	0.026	–	0.027

Table 27 – Establishing the baseline value of KCRV and its uncertainty

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
$e_{ref\ j}$	0.004	0.022	0.034	0.036	0.048	-0.071	0.014	0.006	0.021
$u_{e_{ref\ j}}$	0.011	0.011	0.012	0.012	0.012	0.013	0.011	0.012	0.011
$U_{e_{ref\ j}}$	0.023	0.023	0.023	0.023	0.024	0.027	0.022	0.023	0.023

Table 28 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
ν	5.00	5.00	5.00	5.00	5.00	4.00	6.00	5.00	5.00
χ_j^2	4.72	**16.39**	**18.83**	**26.57**	**28.88**	2.07	7.69	**17.70**	**26.22**
CHIINV	11.07	11.07	11.07	11.07	11.07	9.49	12.59	11.07	11.07
Flag	∨	–	–	–	–	∨	∨	–	–

Table 29 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.00	**1.18**	**1.46**	**1.24**	**1.51**	0.70	0.73	0.64	0.78
Lithuania	0.76	0.10	0.23	0.62	0.87	0.23	0.43	0.17	0.34
Czechia	0.45	0.64	0.39	0.53	0.45	0.03	0.45	0.64	0.50
Moldova	0.01	0.47	0.31	0.20	0.33	0.16	0.53	**1.53**	–
Ukraine	0.65	**1.67**	**1.86**	**2.46**	**2.40**	–	0.58	–	**2.05**
Kazakhstan	–	–	–	–	–	–	0.85	**1.17**	**1.27**
Russia	0.43	0.53	0.22	0.16	0.26	0.38	0.13	0.89	**1.13**

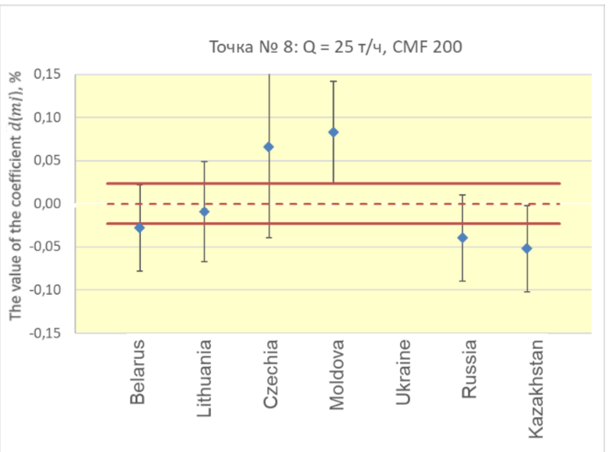


Figure 27 – graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\,(mj)}$ and $U_{e_{ref\ j}}$

8.4. Generating a set of consistent comparison data. Stage No. 3

In order to form a set of consistent comparison data, the point with the highest value of E_{mj} (Table No. 29) equal to 1.53 (country Moldova, j = 8) was removed.

Table 30 – Evaluation of participant laboratory data after removal of non-consensus value

	j	3	2	1	6	5	4	9	8	7
	Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
Moldova	e_{mj}, %	0.003	-0.003	0.051	0.025	0.066	-0.063	0.051	–	–
	$u_{e\,(mj)}$, %	0.030	0.030	0.029	0.029	0.029	0.029	0.036	–	–

Table 31 – Establishing the baseline value of KCRV and its uncertainty

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
$e_{ref\ j}$	0.004	0.022	0.034	0.036	0.048	-0.071	0.014	-0.014	0.021
$u_{e_{ref\ j}}$	0.011	0.011	0.012	0.012	0.012	0.013	0.011	0.013	0.011
$U_{e_{ref\ j}}$	0.023	0.023	0.023	0.023	0.024	0.027	0.022	0.025	0.023

Table 32 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
ν	5.00	5.00	5.00	5.00	5.00	4.00	6.00	4.00	5.00
χ_j^2	4.72	**16.39**	**18.83**	**26.57**	**28.88**	2.07	7.69	5.15	**26.22**
CHIINV	11.07	11.07	11.07	11.07	11.07	9.49	12.59	9.49	11.07
Flag	∨	–	–	–	–	∨	∨	∨	–

Table 33 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.00	**1.18**	**1.46**	**1.24**	**1.51**	0.70	0.73	0.19	0.78
Lithuania	0.76	0.10	0.23	0.62	0.87	0.23	0.43	0.21	0.34
Czechia	0.45	0.64	0.39	0.53	0.45	0.03	0.45	0.84	0.50
Moldova	0.01	0.47	0.31	0.20	0.33	0.16	0.53	–	–
Ukraine	0.65	**1.67**	**1.86**	**2.46**	**2.40**	–	0.58	–	**2.05**
Kazakhstan	–	–	–	–	–	–	0.85	0.74	**1.27**
Russia	0.43	0.53	0.22	0.16	0.26	0.38	0.13	0.45	**1.13**

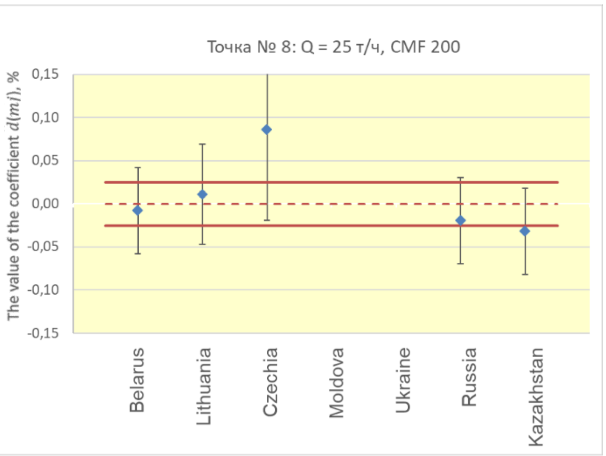


Figure 28 – graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\,(mj)}$ and $U_{e_{ref\ j}}$

8.5. Generating a set of consistent comparison data. Stage No. 4

In order to form a set of consistent comparison data, the point with the highest value of E_{mj} (Table No. 33) equal to 2.4 (country Ukraine, j = 5) was removed.

Table 34 – Evaluation of participant laboratory data after removal of non-consensus value

	j	3	2	1	6	5	4	9	8	7
	Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
Ukraine	e_{mj}, %	-0.025	0.098	0.120	0.149	–	–	0.042	–	0.119
	$u_{e\,(mj)}$, %	0.025	0.025	0.026	0.026	–	–	0.026	–	0.027

Table 35 – Establishing the baseline value of KCRV and its uncertainty

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
$e_{ref\ j}$	0.004	0.022	0.034	0.036	0.017	-0.071	0.014	-0.014	0.021
$u_{e_{ref\ j}}$	0.011	0.011	0.012	0.012	0.014	0.013	0.011	0.013	0.011
$U_{e_{ref\ j}}$	0.023	0.023	0.023	0.023	0.027	0.027	0.022	0.025	0.023

Table 36 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
ν	5,00	5,00	5,00	5,00	4,00	4,00	6,00	4,00	5,00
χ_j^2	4.72	**16.39**	**18.83**	**26.57**	5.76	2.07	7.69	5.15	**26.22**
$CHIINV$	11.07	11.07	11.07	11.07	9.49	9.49	12.59	9.49	11.07
Flag	∨	–	–	–	∨	∨	∨	∨	–

Table 37 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.00	**1.18**	**1.46**	**1.24**	0.83	0.70	0.73	0.19	0.78
Lithuania	0.76	0.10	0.23	0.62	0.38	0.23	0.43	0.21	0.34
Czechia	0.45	0.64	0.39	0.53	0.15	0.03	0.45	0.84	0.50
Moldova	0.01	0.47	0.31	0.20	0.94	0.16	0.53	–	–
Ukraine	0.65	**1.67**	**1.86**	**2.46**	–	–	0.58	–	**2.05**
Kazakhstan	–	–	–	–	–	–	0.85	0.74	**1.27**
Russia	0.43	0.53	0.22	0.16	0.39	0.38	0.13	0.45	**1.13**

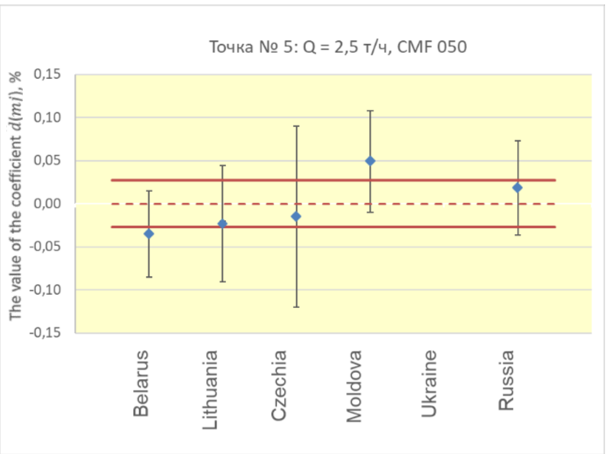


Figure 29 – graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\,(mj)}$ and $U_{e_{ref\ j}}$

8.6. Generating a set of consistent comparison data. Stage No. 5

In order to form a set of consistent comparison data, the point with the highest value of E_{mj} (Table No. 37) equal to 2.05 (country Ukraine, j = 7) was removed.

Table 38 – Evaluation of participant laboratory data after removal of non-consensus value

	j	3	2	1	6	5	4	9	8	7
	Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
Ukraine	e_{mj}, %	-0.025	0.098	0.120	0.149	–	–	0.042	–	–
	$u_{e\,(mj)}$, %	0.025	0.025	0.026	0.026	–	–	0.026	–	–

Table 39 – Establishing the baseline value of KCRV and its uncertainty

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
$e_{ref\,j}$	0.004	0.022	0.034	0.036	0.017	-0.071	0.014	-0.014	-0.009
$u_{e_{ref\,j}}$	0.011	0.011	0.012	0.012	0.014	0.013	0.011	0.013	0.013
$U_{e_{ref\,j}}$	0.023	0.023	0.023	0.023	0.027	0.027	0.022	0.025	0.025

Table 40 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
v	5.00	5.00	5.00	5.00	4.00	4.00	6.00	4.00	4.00
χ_j^2	4.72	**16.39**	**18.83**	**26.57**	5.76	2.07	7.69	5.15	4.45
$CHIINV$	11.07	11.07	11.07	11.07	9.49	9.49	12.59	9.49	9.49
Flag	∨	–	–	–	∨	∨	∨	∨	∨

Table 41 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.00	**1.18**	**1.46**	**1.24**	0.83	0.70	0.73	0.19	0.12
Lithuania	0.76	0.10	0.23	0.62	0.38	0.23	0.43	0.21	0.21
Czechia	0.45	0.64	0.39	0.53	0.15	0.03	0.45	0.84	0.79
Moldova	0.01	0.47	0.31	0.20	0.94	0.16	0.53	–	–
Ukraine	0.65	**1.67**	**1.86**	**2.46**	–	–	0.58	–	–
Kazakhstan	–	–	–	–	–	–	0.85	0.74	0.63
Russia	0.43	0.53	0.22	0.16	0.39	0.38	0.13	0.45	0.49

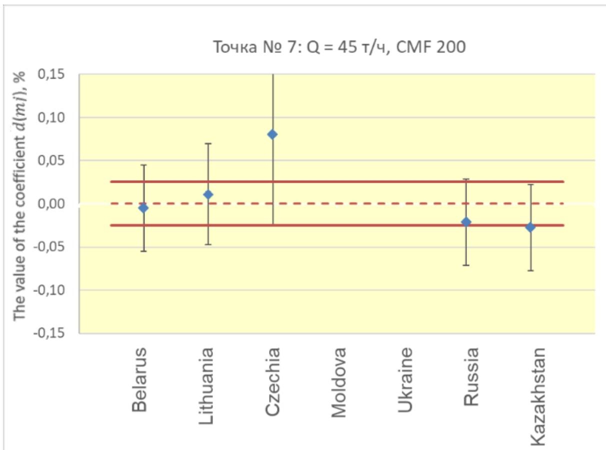


Figure 30 – graphs of the absolute deviation of e_{mj} values from $e_{ref\,j}$ with indication of the boundaries $U_{e\,(mj)}$ and $U_{e_{ref\,j}}$

8.7. Generating a set of consistent comparison data. Stage No. 6

In order to form a set of consistent comparison data, the point with the highest value of E_{mj} (Table No. 41) equal to 2.46 (country Ukraine, j = 6) was removed.

Table 42 – Evaluation of participant laboratory data after removal of non-consensus value

	j	3	2	1	6	5	4	9	8	7
	Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
Ukraine	e_{mj}, %	-0.025	0.098	0.120	–	–	–	0.042	–	–
	$u_{e\,(mj)}$, %	0.025	0.025	0.026	–	–	–	0.026	–	–

Table 43 – Establishing the baseline value of KCRV and its uncertainty

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
$e_{ref\ j}$	0.004	0.022	0.034	0.007	0.017	-0.071	0.014	-0.014	-0.009
$u_{e_{ref\ j}}$	0.011	0.011	0.012	0.013	0.014	0.013	0.011	0.013	0.013
$U_{e_{ref\ j}}$	0.023	0.023	0.023	0.026	0.027	0.027	0.022	0.025	0.025

Table 44 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
ν	5.00	5.00	5.00	4.00	4.00	4.00	6.00	4.00	4.00
χ_j^2	4.72	**16.39**	**18.83**	2.45	5.76	2.07	7.69	5.15	4.45
$CHIINV$	11.07	11.07	11.07	9.49	9.49	9.49	12.59	9.49	9.49
Flag	∨	–	–	∨	∨	∨	∨	∨	∨

Table 45 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.00	**1.18**	**1.46**	0.60	0.83	0.70	0.73	0.19	0.12
Lithuania	0.76	0.10	0.23	0.08	0.38	0.23	0.43	0.21	0.21
Czechia	0.45	0.64	0.39	0.25	0.15	0.03	0.45	0.84	0.79
Moldova	0.01	0.47	0.31	0.35	0.94	0.16	0.53	–	–
Ukraine	0.65	**1.67**	**1.86**	–	–	–	0.58	–	–
Kazakhstan	–	–	–	–	–	–	0.85	0.74	0.63
Russia	0.43	0.53	0.22	0.51	0.39	0.38	0.13	0.45	0.49

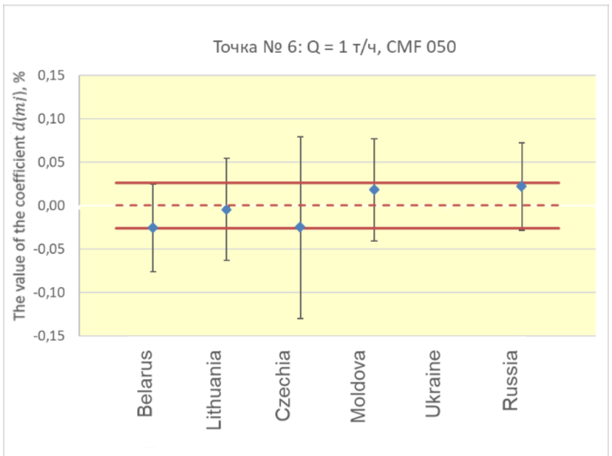


Figure 31 – graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\,(mj)}$ and $U_{e_{ref\ j}}$

8.8. Generating a set of consistent comparison data. Stage No. 7

In order to form a set of consistent comparison data, the point with the highest value of E_{mj} (Table No. 45) equal to 1.86 (country Ukraine, j = 1) was removed.

Table 46 – Evaluation of participant laboratory data after removal of non-consensus value

	j	3	2	1	6	5	4	9	8	7
	Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
Ukraine	e_{mj}, %	-0.025	0.098	–	–	–	–	0.042	–	–
	$u_{e\,(mj)}$, %	0.025	0.025	–	–	–	–	0.026	–	–

Table 47 – Establishing the baseline value of KCRV and its uncertainty

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
$e_{ref\ j}$	0.004	0.022	0.012	0.007	0.017	-0.071	0.014	-0.014	-0.009
$u_{e_{ref\ j}}$	0.011	0.011	0.013	0.013	0.014	0.013	0.011	0.013	0.013
$U_{e_{ref\ j}}$	0.023	0.023	0.026	0.026	0.027	0.027	0.022	0.025	0.025

Table 48 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
ν	5.00	5.00	4.00	4.00	4.00	4.00	6.00	4.00	4.00
χ_j^2	4.72	**16.39**	5.04	2.45	5.76	2.07	7.69	5.15	4.45
$CHIINV$	11.07	11.07	9.49	9.49	9.49	9.49	12.59	9.49	9.49
Flag	∨	–	∨	∨	∨	∨	∨	∨	∨

Table 49 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.00	**1.18**	0.99	0.60	0.83	0.70	0.73	0.19	0.12
Lithuania	0.76	0.10	0.18	0.08	0.38	0.23	0.43	0.21	0.21
Czechia	0.45	0.64	0.17	0.25	0.15	0.03	0.45	0.84	0.79
Moldova	0.01	0.47	0.74	0.35	0.94	0.16	0.53	–	–
Ukraine	0.65	**1.67**	–	–	–	–	0.58	–	–
Kazakhstan	–	–	–	–	–	–	0.85	0.74	0.63
Russia	0.43	0.53	0.26	0.51	0.39	0.38	0.13	0.45	0.49

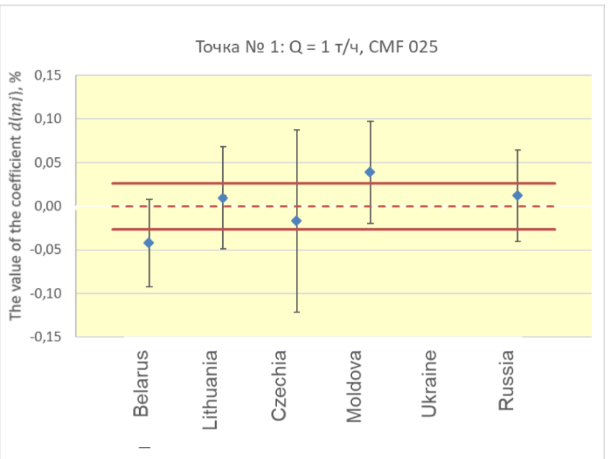


Figure 32 – graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\,(mj)}$ and $U_{e_{ref\ j}}$

8.9. Generating a set of consistent comparison data. Stage No. 8

In order to form a set of consistent comparison data, the point with the highest value of E_{mj} (Table No. 49) equal to 1.67 (country Ukraine, j = 2) was removed.

Table 50 – Evaluation of participant laboratory data after removal of non-consensus value

	j	3	2	1	6	5	4	9	8	7
	Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
Ukraine	e_{mj}, %	-0.025	–	–	–	–	–	0.042	–	–
	$u_{e\,(mj)}$, %	0.025	–	–	–	–	–	0.026	–	–

Table 51 – Establishing the baseline value of KCRV and its uncertainty

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
$e_{ref\ j}$	0.004	0.003	0.012	0.007	0.017	-0.071	0.014	-0.014	-0.009
$u_{e_{ref\ j}}$	0.011	0.013	0.013	0.013	0.014	0.013	0.011	0.013	0.013
$U_{e_{ref\ j}}$	0.023	0.026	0.026	0.026	0.027	0.027	0.022	0.025	0.025

Table 52 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
ν	5.00	4.00	4.00	4.00	4.00	4.00	6.00	4.00	4.00
χ_j^2	4.72	5.29	5.04	2.45	5.76	2.07	7.69	5.15	4.45
$CHIINV$	11.07	9.49	9.49	9.49	9.49	9.49	12.59	9.49	9.49
Flag	∨	∨	∨	∨	∨	∨	∨	∨	∨

Table 53 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.000	0.776	0.993	0.604	0.834	0.696	0.730	0.191	0.123
Lithuania	0.763	0.206	0.182	0.083	0.379	0.235	0.435	0.208	0.211
Czechia	0.449	0.342	0.171	0.251	0.146	0.028	0.451	0.843	0.789
Moldova	0.010	0.122	0.743	0.347	0.944	0.155	0.534	–	–
Ukraine	0.649	–	–	–	–	–	0.585	–	–
Kazakhstan	–	–	–	–	–	–	0.846	0.737	0.632
Russia	0.433	0.994	0.262	0.506	0.392	0.383	0.135	0.448	0.491

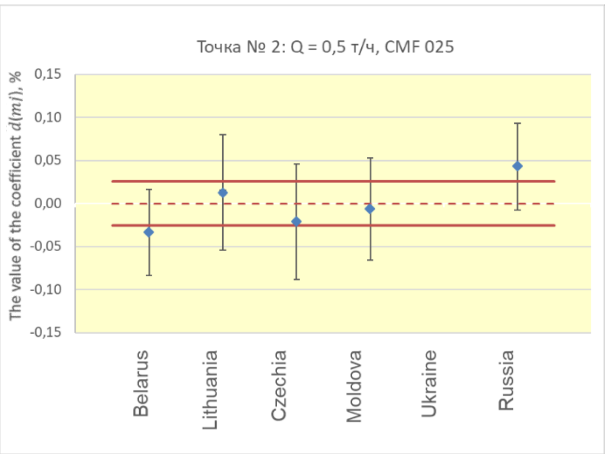


Figure 33 – graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\,(mj)}$ and $U_{e_{ref\ j}}$

9. Summary and conclusions

After carrying out 8 stages of the procedure for generating a set of consistent comparison data, the consistency of comparison data was achieved (Table No. 54).

Table 54 – Checking the consistency of comparison data

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
ν	5.00	4.00	4.00	4.00	4.00	4.00	6.00	4.00	4.00
χ_j^2	4.72	5.29	5.04	2.45	5.76	2.07	7.69	5.15	4.45
CHIINV	11.07	9.49	9.49	9.49	9.49	9.49	12.59	9.49	9.49
Flag	∨	∨	∨	∨	∨	∨	∨	∨	∨

The graph of the deviation of e_{mj} values from $e_{ref\ j}$ for all points and for all participants after the formation of a set of agreed comparison data is shown in the figure:

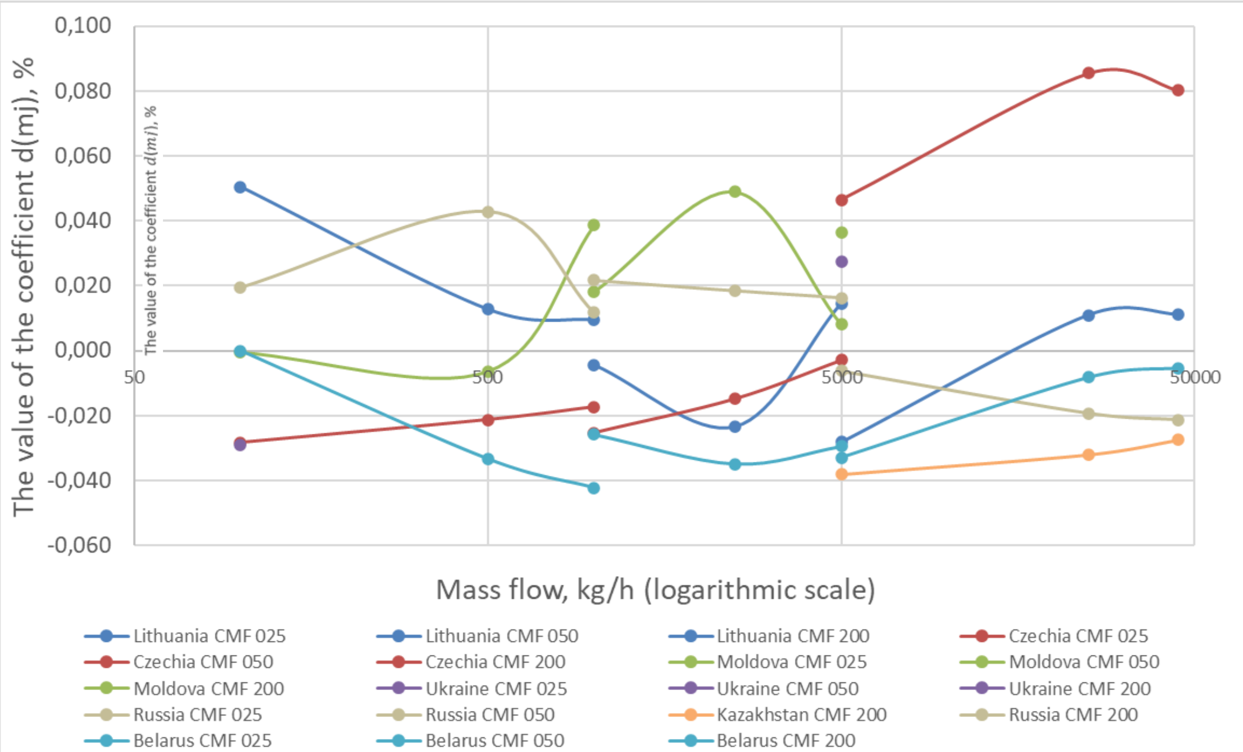


Figure 34 – the graph of the deviation of e_{mj} values from $e_{ref\ j}$ for all points and for all participants after the formation of a set of agreed comparison data

All values included in the set of consistent comparison data satisfy the condition:

$$E_{mj} = \frac{|e_{mj} - e_{ref\ j}|}{2 \cdot \sqrt{u^2_{e(mj)} - u^2_{e_{ref\ j}}}} < 1. \qquad (20)$$

Table 55 – Identification of inconsistent data

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Belarus	0.000	0.776	0.993	0.604	0.834	0.696	0.730	0.191	0.123
Lithuania	0.763	0.206	0.182	0.083	0.379	0.235	0.435	0.208	0.211
Czechia	0.449	0.342	0.171	0.251	0.146	0.028	0.451	0.843	0.789
Moldova	0.010	0.122	0.743	0.347	0.944	0.155	0.534	–	–
Ukraine	0.649	–	–	–	–	–	0.585	–	–

j	3	2	1	6	5	4	9	8	7
Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	E_{mj}								
Kazakhstan	–	–	–	–	–	–	0.846	0.737	0.632
Russia	0.433	0.994	0.262	0.506	0.392	0.383	0.135	0.448	0.491

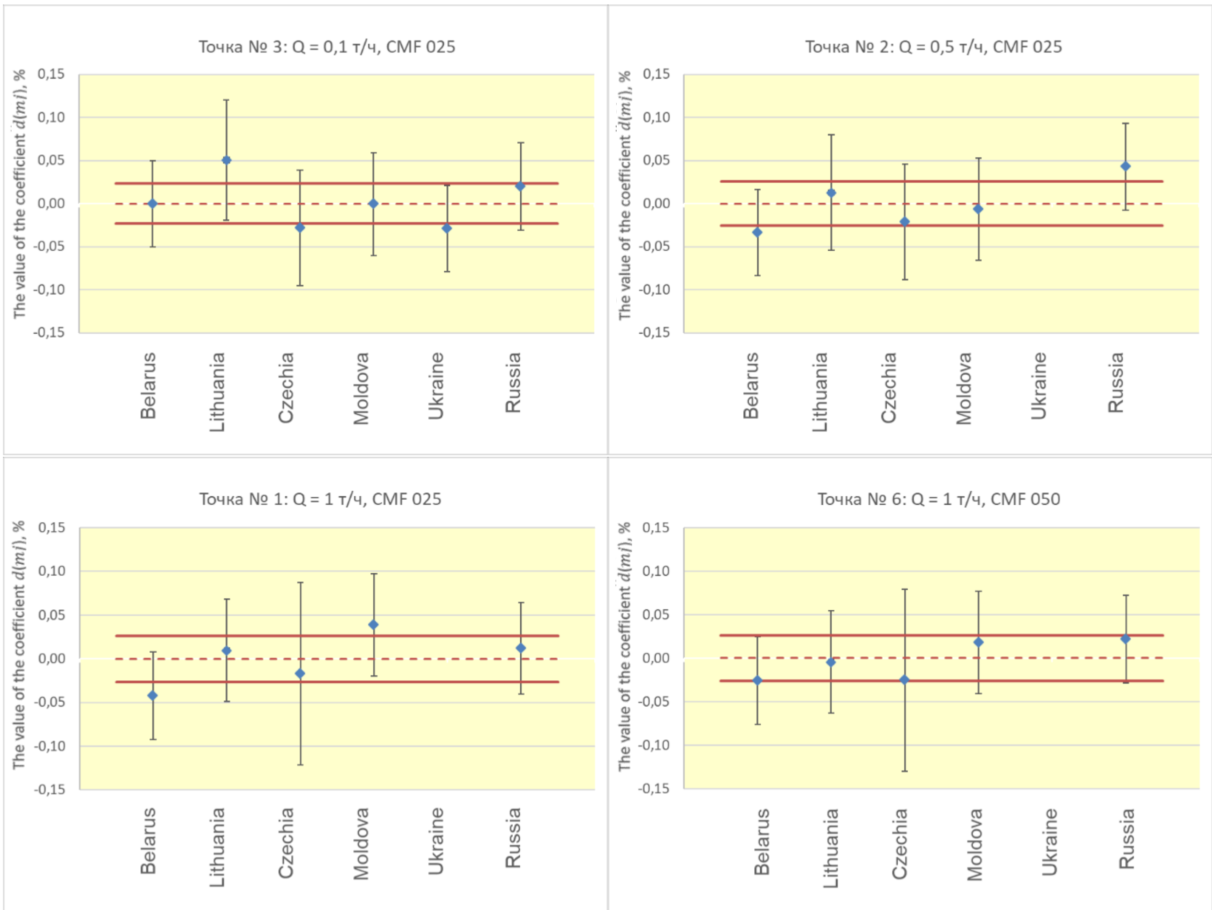
The value of the coefficient d_{mj}, showing the difference in the values of the laboratory of the participant from the reference value of additional comparisons for the j-th flow point, for the laboratories of the participants that confirmed the consistency of these comparisons, is given in Table No. 56.

$$d_{mj} = e_{mj} - e_{ref\ j}. \tag{21}$$

Table 56 – Coefficient values d_{mj}

Q, kg/h	100	500	1000	1000	2500	5000	5000	25000	45000
–	d_{mj}, %								
Belarus	0.000	-0.033	-0.042	-0.026	-0.035	-0.029	-0.033	-0.008	-0.005
Lithuania	0.050	0.013	0.009	-0.004	-0.023	0.015	-0.028	0.011	0.011
Czechia	-0.028	-0.021	-0.017	-0.025	-0.015	-0.003	0.046	0.085	0.080
Moldova	-0.001	-0.007	0.039	0.018	0.049	0.008	0.036	–	–
Ukraine	-0.029	–	–	–	–	–	0.028	–	–
Kazakhstan	–	–	–	–	–	–	-0.038	-0.032	-0.027
Russia	0.020	0.043	0.012	0.022	0.019	0.016	-0.006	-0.019	-0.021

Graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ (d_{mj}) with indication of the boundaries $U_{e\ (mj)}$ and $U_{e_{ref\ j}}$ are shown in the figure:



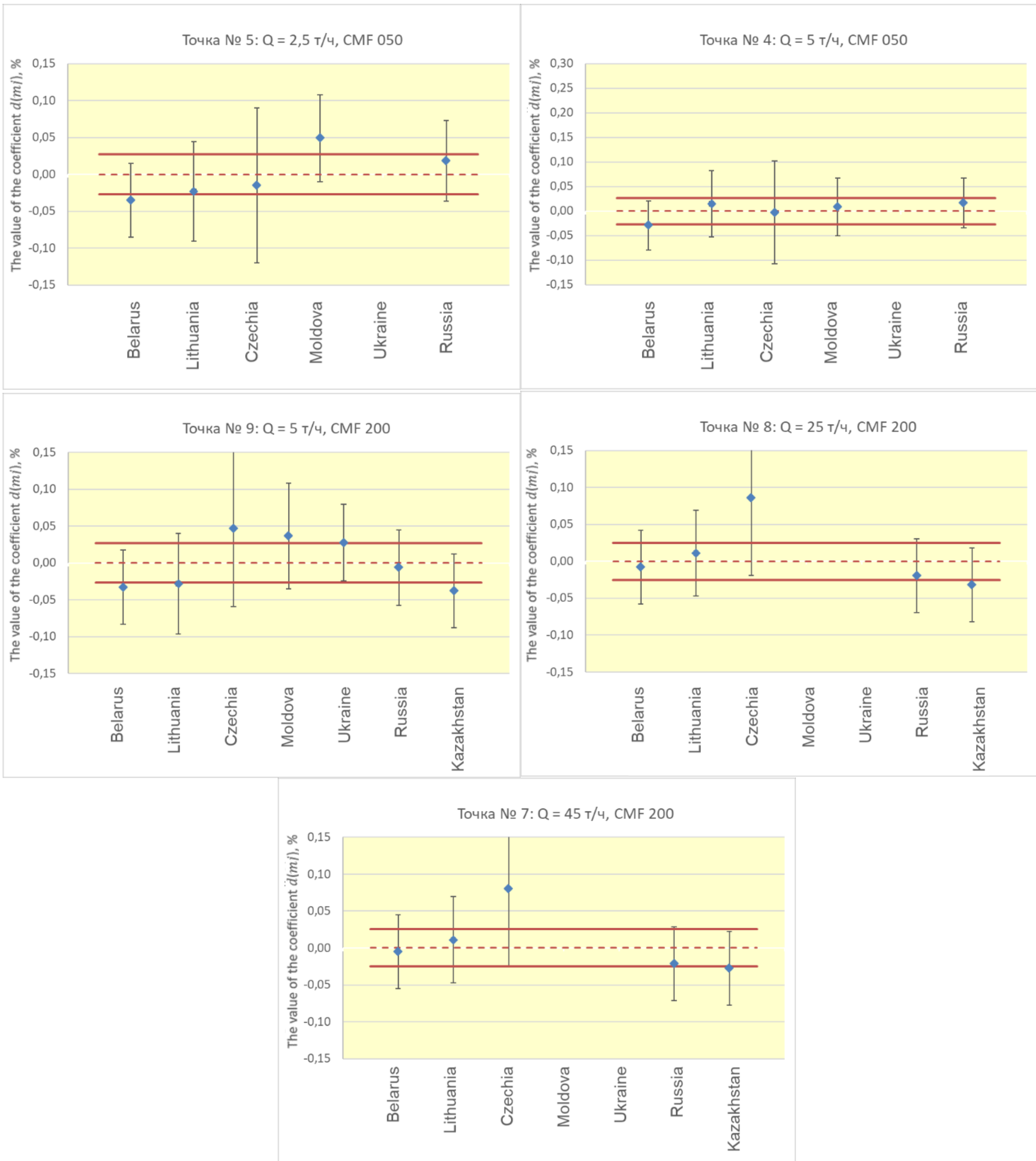


Figure 35 – graphs of the absolute deviation of e_{mj} values from $e_{ref\ j}$ with indication of the boundaries $U_{e\ (mj)}$ and $U_{e_{ref\ j}}$

10. References

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