	COOMET Recommendation	COOMET
	Flow Transducers, Flow Meters, Volumetric and Mass Liquid Meters. Calibration Method	____________
Approved at the ___ meeting of the COOMET Committee (___________________________)		

1 APPLICATION AREA

The recommendation applies to flow transducers, flow meters, volumetric and mass liquid meters, and establishes their calibration method by direct comparison using national standards of units of quantities. The recommendation was developed in accordance with the requirements of the ISO/IEC 17025:2017 and COOMET R/GM/31:2016.

The metrological characteristics of flow transducers, flow meters and volumetric and mass liquid meters, the actual values of which should be determined during the calibration process, are: relative deviation when measuring the mass of liquid in a flow, relative deviation when measuring the volume of liquid in a flow, relative deviation when measuring mass flow of liquid, relative deviation when measuring the volume of liquid in a flow, and relative deviation when measuring the volumetric flow rate of a liquid.

2 REFERENCES

References to the following documents and COOMET publications [1] are used in this Recommendation:

ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories;

COOMET Recommendation R/GM/15:2020 Procedure for issuing calibration certificates of national metrology institutes within the CIPM MRA;

COOMET Recommendation R/GM/21:2011 Use of concepts “error of measurement” and “uncertainty of measurement”. General principles materials;

COOMET Recommendation R/GM/31:2016 Calibration techniques. General requirements;

JCGM 200:2012 «International vocabulary of metrology - Basic and general concepts and associated terms (VIM3).

3 TERMS AND DEFINITIONS, ABBREVIATIONS AND SYMBOLS

3.1 The terms and definitions of JCGM 200:2012 and the following are used in this recommendation.

The Mutual Recognition Arrangement of national measurement standards and of calibration and measurement certificates issued by national metrology institutes (hereinafter referred to as the

[1] Using this recommendation, it is advisable to check the year of approval of referenced publications on the site www.coomet.org (section "COOMET Publications") or portal www.coomet.net (section "Publications").

CIPM MRA) is a technical agreement signed by the directors of national metrology institutes in order to establish the degree of equivalence of national measurement standards and ensure mutual recognition of calibration and measurement certificates.

3.2 The following abbreviations are used in this Recommendation:

CF - calibrated flow transducer, flow meter, volumetric or mass liquid meter;

NMS - national measurement standard;

CM - calibration method;

MI - measuring instrument.

3.3 The following symbols are used in this Recommendation:

$\delta(M)$ – relative deviation of the CF reading from NMS reading when transferring a liquid mass unit, %;

i – measurement index;

j – flow rate point index;

M – mass of liquid in a flow according to CF readings, kg;

M_{NMS} – mass of liquid in a flow according to NMS readings, kg;

$\overline{\delta(M)}$ – arithmetic mean deviation of CF readings from NMS readings when transferring a unit of mass of liquid in a flow, %;

n – index of the number of measurements;

$u_A\big(\delta(M)\big)$– standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass of liquid in a flow, estimated by type A, %;

$u_B\big(\delta(M_{cal})\big)$ – standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of mass of liquid in a flow, estimated by type B, %;

$u_c(M)_{NMS}$ – combined standard uncertainty of reproduction of a unit of mass of liquid in a flow by NMS, %;

$u_B(M_{NMS\,PRI})$ – standard uncertainty of transferring a unit of mass of liquid in a flow from NMS, %;

$u_C\big(\delta(M)\big)$ – combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass of liquid in a flow, %;

$u_A\big(\delta(M)\big)_{jmax}$ – largest value of the standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass of liquid in a flow, estimated by type A, across all flow rate points, %;

$u_B\big(\delta(M)\big)_{jmax}$ - largest value of the standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of mass of liquid in a flow, estimated by type B, across all flow rate points, %;

$U\big(\delta(M)\big)$ – expanded uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass of liquid in a flow for a confidence level of 0.95, %;

$\delta(V)$ – relative deviation of the CF reading from NMS reading when transferring a unit of volume of liquid in a flow, %;

V – volume of liquid in a flow according to CF readings, dm^3;

V_{NMS} – volume of liquid in a flow according to NMS readings, dm^3;

$\overline{\delta(V)}$ – arithmetic mean deviation of CF readings from NMS readings when transferring a unit of volume of liquid in a flow, %;

$u_A\big(\delta(V)\big)$– standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volume of liquid in a flow, estimated by type A, %;

$u_B\left(\delta(V_{cal})\right)$ – standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of volume of liquid in a flow, estimated by type B, %;

$u_c(V)_{NMS}$ – combined standard uncertainty of reproduction of a unit of volume of liquid in a flow by NMS, %;

$u_B(V_{NMS\,PRI})$ – standard uncertainty of transferring a unit of volume of liquid in a flow from NMS, %;

$u_C\left(\delta(V)\right)$ – combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volume of liquid in a flow, %;

$u_A\left(\delta(V)\right)_{jmax}$ – largest value of the standard uncertainty of estimating of deviations of CF readings from NMS readings when transferring a unit of volume of liquid in a flow, estimated by type A, across all flow rate points, %;

$u_B\left(\delta(V)\right)_{jmax}$ - largest value of the standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of volume of liquid in a flow, estimated by type B, across all flow rate points, %;

$U\left(\delta(V)\right)$ – expanded uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volume of liquid in a flow for a confidence level of 0.95, %;

$\delta(Q_M)$ – relative deviation of the CF reading from NMS reading when transferring a unit of liquid mass flow rate, %;

Q_M – liquid mass flow rate according to CF readings, t/h;

Q_{MNMS} – liquid mass flow rate according to NMS readings, t/h;

$\overline{\delta(Q_M)}$ – arithmetic mean deviation of CF readings from NMS readings when transferring a unit of liquid mass flow rate, %;

$u_A\left(\delta(Q_M)\right)$– standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass flow rate of liquid, estimated by type A, %;

$u_B\left(\delta\left(Q_{M_{cal}}\right)\right)$ – standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of mass flow rate of liquid, estimated by type B, %;

$u_c(Q_M)_{NMS}$ – combined standard uncertainty of reproduction of a unit of mass flow rate of liquid by NMS, %;

$u_B\left(Q_{M_{NMS\,PRI}}\right)$ – standard uncertainty of transferring of a unit of mass flow rate of liquid in a flow from NMS, %;

$u_C\left(\delta(Q_M)\right)$ – combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass flow rate of liquid, %;

$u_A\left(\delta(Q_M)\right)_{jmax}$ – largest value of the standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass flow rate of liquid, estimated by type A, across all flow rate points, %;

$u_B\left(\delta(Q_M)\right)_{jmax}$ - largest value of the standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of mass flow rate of liquid, estimated by type B, across all flow rate points, %;

$U\left(\delta(Q_M)\right)$ – expanded uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass flow rate of liquid for a confidence level of 0.95, %;

$\delta(Q_V)$ – relative deviation of CF readings from NMS readings when transferring a unit of liquid volumetric flow rate, %;

Q_V – liquid volumetric flow rate according to CF readings, m³/h;

Q_{VNMS} – liquid volumetric flow rate according to NMS readings, m³/h;

$\overline{\delta(Q_V)}$ – arithmetic mean deviation of CF readings from NMS readings when transferring a unit of liquid volumetric flow rate, %;

$u_A(\delta(Q_V))$– standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid, estimated by type A, %;

$u_B\left(\delta(Q_{V_{cal}})\right)$ – standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of volumetric flow rate of liquid, estimated by type B, %;

$u_c(Q_V)_{NMS}$ – combined standard uncertainty of reproduction of a unit of volumetric flow rate of liquid by NMS, %;

$u_B(Q_{V_{NMS\ PRI}})$ – standard uncertainty of transferring of a unit of volumetric flow rate of liquid in a flow from NMS, %;

$u_C(\delta(Q_V))$ – combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid, %;

$u_A(\delta(Q_V))_{jmax}$ – largest value of the standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid, estimated by type A, across all flow rate points, %;

$u_B(\delta(Q_V))_{jmax}$ - largest value of the standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of volumetric flow rate of liquid, estimated by type B, across all flow rate points, %;

$U(\delta(Q_V))$ – expanded uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid for a confidence level of 0.95, %.

4 CALIBRATION OPERATIONS

The following operations are performed during calibration:

- preparation for calibration (section 10);
- calibration (section 11);
- processing of measurement results (section 12);
- registration of calibration results (section 13).

5 CALIBRATION INSTRUMENTS

When performing calibration, NMS is used, as well as measuring instruments of ambient temperature and humidity, atmospheric pressure and process temperature, used during the operation of NMS.

6 SPECIALIST QUALIFICATION REQUIREMENTS

The specialists performing calibration should meet the following requirements:

- possess NMS operation skills;
- be familiar with the requirements of this Recommendation;
- be familiar with the operating documents for NMS;
- undergo a safety briefing according to the established procedure.

7 SAFETY REQUIREMENTS

The following safety requirements are followed during calibration:

- safety rules for the operation of NMS and CF specified in their operating documents;
- labor protection regulations in force at the calibration site.

8 CALIBRATION CONDITIONS

The following conditions are provided during calibration:

Measured medium - water with the following parameters:

– temperature, °C from plus 15 to plus 25;

No undissolved air or cavitation effects are allowed in the hydraulic channel during measurements.

Environment - air with the following parameters:

– temperature, °C from plus 15 to plus 25;
– relative humidity, % from 30 to 80;
– atmospheric pressure, kPa from 96 to 104.

9 HANDLING THE CALIBRATION ITEM

The CF handling procedures are carried out in accordance with the operating documents for the CF.

10 PREPARING FOR CALIBRATION

The following operations are performed when preparing for calibration:

– verification of compliance with the requirements of sections 5-9 of this Recommendation;

– The NMS and CF are kept at the ambient air temperature specified in Section 8 for at least two hours, unless anther time period is specified in the operating documents for NMS and CF;

– preparation of NMS and CF for operation in accordance with their operating documents;

– installation of the CF in the measuring line of NMS in accordance with the operating documents of the CF and NMS;

– checking the airtightness of connections in accordance with the operating documents of the CF and NMS;

– keeping the CF switched on for at least 30 minutes, unless another time period is indicated in the operating documents for the CF.

11 CALIBRATION

11.1 Visual inspection

Compliance with the following requirements is determined during the external examination:

– inscriptions and designations (markings) on the CF should comply with operating documents;

– completeness of the CF should comply with the operating documents;

– the CR should not have mechanical damage or defects preventing its use.

The external examination result is considered positive if the inscriptions and designations (markings) applied to the CF, as well as the completeness of the CF, correspond to the data of the operating documents of the CF, and there is no mechanical damage or defects preventing the use of the CF.

The external examination result is considered negative if the inscriptions or designations (markings) applied to the CF, or the completeness of the CF do not correspond to the data of the operating documents, or if the presence of mechanical damage or defects preventing the use of the CF is determined.

If the result of the external examination is negative, in case of discrepancy between the inscriptions and designations (markings) on the CF and the operating documents of the CF and (or) in the event that the CF has mechanical damage or defects preventing its use, further calibration of the CF is terminated.

If the result of the external examination is negative, in the event of a discrepancy between the completeness of the CF and the data specified in the operating documents of the CF, in agreement with the Customer (owner), further calibration of the CF is continued or terminated. If further calibration of the CF is continued, a record of the negative external examination result is made in the calibration protocol or calibration certificate, indicating the reason.

11.2 Trialing

During trialing, the flow rate of the measured medium is reproduced by NMS. The measured medium flow rate value of NMS is increased to the highest declared value of CF flow rate, which is then recorded, and then reduced to the smallest declared value of CF flow rate, which is then recorded.

The trialing result is considered positive, if when the flow rate is increased and decreased, the readings on the CF change accordingly (increase and decrease).

The trialing result is considered negative, if when the flow rate is increased and decreased, the readings on the CF do not change accordingly (increase and decrease).

If the trialing result is negative, further calibration of the CF is terminated.

11.3 Software conformity assessment

Software is subject to conformity assessment, if software is available for the CF.

During software conformity assessment, the CF identification data is determined in accordance with the operating documents of the CF.

The software conformity assessment result is considered positive if the obtained identification data of CF software (identification name of the software (if available), version number (software identification number) (if available), digital software identifier (if available)) correspond to the identification data specified in the relevant section of the operating documents for the CF.

The software conformity assessment result is considered negative if the obtained identification data of CF software (identification name of the software (if available), version number (software identification number) (if available), digital software identifier (if available)) do not correspond to the identification data specified in the relevant section of the operating documents for the CF.

In case of a negative result of software conformity assessment, in agreement with the Customer (owner), further calibration of the CF is continued or terminated. If further calibration of the CF is continued, a negative result of software conformity assessment is recorded in the calibration protocol or calibration certificate.

11.4 Determining metrological characteristics

Calibration is carried out at no less than equidistant flow rate points of the CF operating range, including the smallest and largest values of the declared CF operating range. The flow rate values are set with a tolerance of plus 5% of the smallest value of the CF operating range, with a tolerance of minus 5% of the largest value of the CF operating range, and with a tolerance of ±5 % in other flow rate points.

The operating range of the CF is determined by the Customer (owner) of the CF in accordance with its application or in accordance with the operating documents of the CF.

It is allowed to increase the number of flow rate points in the CF operating range at the written request of the Customer (owner).

At each flow rate point, at least 5 measurements are made (the recommended number of measurements is at least 11) with simultaneous recording of the mass and (or) volume of liquid in a flow, measurement time, temperature and pressure of the measured medium, number of pulses or frequency of the sequence of pulses from CF (if a frequency-pulse output signal is available) or the average value of the current during the measurement (if a current output signal is available).

The measurement time is determined in accordance with the operating documents of NMS.

12 PROCESSING MEASUREMENT RESULTS

12.1 Processing of measurement results and calculation of the expanded measurement uncertainty of a unit of mass of liquid in a flow of CF

Deviation of CF readings from NMS readings when transferring a unit of mass of liquid in a flow at the j-th point during the *i*-th measurement, $\delta(M)_{ji}$, %, is calculated using the formula

$$\delta(M)_{ji} = \left(\frac{M_{ji} - M_{NMSji}}{M_{NMSji}}\right) \cdot 100. \quad (1)$$

The arithmetic mean deviation of CF readings from NMS readings when transferring a unit of mass of liquid in a flow at the *j*-th point, $\overline{\delta(M)_j}$, %, is calculated using the formula

$$\overline{\delta(M)_j} = \frac{1}{n} \cdot \sum_{i=1}^{n} \delta(M)_{ji}. \quad (2)$$

The standard estimation uncertainty of deviations of CF readings from NMS readings when transferring a mass of liquid in a flow at the j-th flow rate point, estimated by type *A*, $u_A(\delta(M))_j$, %, is calculated using the formula

$$u_A(\delta(M))_j = \sqrt{\frac{\sum_{i=1}^{n}(\delta(M)_{ji} - \overline{\delta(M)_j})^2}{n \cdot (n-1)}}. \quad (3)$$

Note:

The calibration result is an estimation of the relative deviation of CF readings from NMS readings when transferring a unit of mass of liquid in a flow at the j-th flow rate point, and the corresponding uncertainty of this deviation. The relative deviation of CF readings from NMS readings when transferring a unit of mass of liquid in a flow can be taken into account as a correction coefficient when using this CF or included in the measurement budget when using this CF.

The standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of mass of liquid in a flow in the *j* flow at the *j*-th flow rate point $u_B(\delta(M_{cal}))_j$, estimated by type B, is determined using the formula (4) if combined standard uncertainty of reproduction of a unit of mass of liquid in a flow of NMS includes the standard transfer uncertainty of a unit of mass of liquid in a flow from NMS or according to formula (5) if the combined standard uncertainty of reproduction of a unit of mass of liquid in a flow of NMS does not include the standard transfer uncertainty of a unit of mass of liquid in a flow from NMS:

$$u_B(\delta(M_{cal}))_j = u_c(M_{NMS})_j, \quad (4)$$

$$u_B(\delta(M_{cal}))_j = \sqrt{u_c(M_{NMS})_j^2 + u_B(M_{NMS\,PRI})_j^2}\,. \quad (5)$$

The combined standard uncertainty of estimating deviations of CF readings from NMS when transferring a unit of mass of liquid in a flow at the j-th flow rate point, $u_C(\delta(\mathrm{M}))_j$, %, is calculated using the formula

$$u_C(\delta(M))_j = \sqrt{u_A(\delta(M))_j^2 + u_B(\delta(M_{cal}))_j^2}. \quad (6)$$

Expanded uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass of liquid in a flow for a confidence level of 0.95 %, $U(\delta(\mathrm{M}))_j$, is calculated using the formula

$$U(\delta(M))_j = 2 \cdot u_C(\delta(M))_j. \quad (7)$$

Upon agreement with the owner of CF, it is allowed to calculate the combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass of liquid, $u_C(\delta(\mathrm{M}))$, %, and the expanded measurement uncertainty of a unit of mass of liquid in a flow of CF for a confidence level of 0.95, $U(\delta(\mathrm{M}))$, %, in the entire CF measurement range using the following formulas:

$$u_C(\delta(M)) = \sqrt{u_A(\delta(M))_{jmax}^2 + u_B(\delta(M_{cal}))_{jmax}^2}, \quad (8)$$

$$U(\delta(M)) = 2 \cdot u_C(\delta(M)). \quad (9)$$

12.2 Processing measurement results and calculating the expanded measurement uncertainty of a unit of volume of liquid in a flow of CF

Deviation of CF reading from NMS reading when transferring a unit of volume of liquid in a flow at the *j*-th point during the *i*-th measurement, $\delta(V)_{ji}$, %, is calculated using the formula

$$\delta(V)_{ji} = \left(\frac{V_{ji} - V_{NMSji}}{V_{NMSji}}\right) \cdot 100. \quad (10)$$

The volume of liquid in a flow according to NMS readings is determined for the measurement conditions corresponding to the measurement conditions of CF.

The arithmetic mean deviation of CF readings from NMS readings when transferring a unit of volume of liquid in a flow at the *j*-th point, $\overline{\delta(V)_j}$, %, is calculated using the formula

$$\overline{\delta(V)_j} = \frac{1}{n} \cdot \sum_{i=1}^{n} \delta(V)_{ji}. \quad (11)$$

The standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volume of liquid in a flow at the j-th flow rate point, estimated by type *A*, $u_A(\delta(M))_j$, %, is calculated using the formula

$$u_A(\delta(V))_j = \sqrt{\frac{\sum_{i=1}^{n}\left(\delta(V)_{ji} - \overline{\delta(V)_j}\right)^2}{n \cdot (n-1)}}. \quad (12)$$

Note:

The calibration result is an estimation of the relative deviation of CF readings from NMS readings when transferring a unit of volume of liquid in a flow at the j-th flow rate point, and the corresponding uncertainty of this deviation. The relative deviation of CF readings from NMS readings when transferring a unit of volume of liquid in a flow can be taken into account as a correction coefficient when using this CF or included in the measurement budget when using this CF.

The standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of volume of liquid in a flow at the *j*-th flow rate point $u_B(\delta(V_{cal}))_j$, estimated by type B, is determined using the formula (13) if combined standard uncertainty of reproduction of a unit of volume of liquid in a flow of NMS includes the standard transfer uncertainty of a unit of volume of liquid in a flow from NMS or according to formula (14) if the combined standard uncertainty of reproduction of a unit of volume of liquid in a flow of NMS does not include the standard transfer uncertainty of a unit of volume of liquid in a flow from NMS:

$$u_B(\delta(V_{cal}))_j = u_{\mathrm{c}}(V_{NMS})_j, \quad (13)$$

$$u_B(\delta(V_{cal}))_j = \sqrt{u_{\mathrm{c}}(V_{NMS})_j^2 + u_B(V_{NMS\,PRI})_j^2}\,. \quad (14)$$

The combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volume of liquid in a flow at the j-th flow rate point, $u_C\big(\delta(V)\big)_j$, %, is calculated using the formula

$$u_C\big(\delta(V)\big)_j = \sqrt{u_A\big(\delta(V)\big)_j^2 + u_B\big(\delta(V_{cal})\big)_j^2}. \tag{15}$$

Expanded uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volume of liquid in a flow for a confidence level of 0.95 %, $U\big(\delta(V)\big)_j$,is calculated using the formula

$$U\big(\delta(V)\big)_j = 2 \cdot u_C\big(\delta(V)\big)_j. \tag{16}$$

Upon agreement with the owner of CF, it is allowed to calculate the combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volume of liquid in a flow, $u_C\big(\delta(V)\big)$, %, and the expanded measurement uncertainty of a unit of volume of liquid in a flow of CF for a confidence level of 0.95, $U\big(\delta(V)\big)$, %, in the entire CF measurement range using the following formulas:

$$u_C\big(\delta(V)\big) = \sqrt{u_A\big(\delta(V)\big)_{jmax}^2 + u_B\big(\delta(V_{cal})\big)_{jmax}^2}, \tag{17}$$

$$U\big(\delta(V)\big) = 2 \cdot u_C\big(\delta(V)\big). \tag{18}$$

12.3 Processing measurement results and calculating the expanded measurement uncertainty of a unit of mass flow rate of liquid of CF

The deviation of CF readings from NMS readings when transferring a unit of mass flow rate of liquid at the j-th point during the *i*-th measurement, $\delta(Q_M)_{ji}$, %, is calculated by the formula

$$\delta(Q_M)_{ji} = \left(\frac{Q_{Mji} - Q_{MNMSji}}{Q_{MNMSji}}\right) \cdot 100. \tag{19}$$

The arithmetic mean deviation of CF readings from NMS readings when transferring a unit of mass flow rate of liquid at the *j*-th point, $\overline{\delta(Q_M)_j}$, %, is calculated using the formula

$$\overline{\delta(Q_M)_j} = \frac{1}{n} \cdot \sum_{i=1}^{n} \delta(Q_M)_{ji}. \tag{20}$$

The standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass flow rate of liquid at the *j*-th flow rate point, estimated by type *A*, $\overline{\delta(Q_M)_j}$, %, is calculated using the formula

$$u_A\big(\delta(Q_M)\big)_j = \sqrt{\frac{\sum_{i=1}^{n}\big(\delta(Q_M)_{ji} - \overline{\delta(Q_M)_j}\big)^2}{n \cdot (n-1)}}. \tag{21}$$

Note:

The calibration result is an estimation of the relative deviation of CF readings from NMS readings when transferring a unit of mass flow rate of liquid at the *j*-th flow rate point, and the corresponding uncertainty of this deviation. The relative deviation of CF readings from NMS readings when transferring a unit of mass flow rate of liquid can be taken into account as a correction coefficient when using this CF or included in the measurement budget when using this CF.

The standard calibration uncertainty due to the nature of NMS operation when reproducing unit of mass flow rate of liquid at the *j*-th flow rate point $u_B\left(\delta\big(Q_{M\,cal}\big)\right)_j$, estimated by type B, is determined using the formula (22) if combined standard uncertainty of reproduction of a unit of mass flow rate of liquid of NMS includes the standard transfer uncertainty of a unit of mass flow rate of liquid from NMS or according to formula (23) if the combined standard uncertainty of reproduction of a unit of mass flow rate of liquid of NMS does not include the standard transfer uncertainty of a unit of mass flow rate of liquid from NMS:

$$u_B\left(\delta\left(Q_{M\,cal}\right)\right)_j = u_c\left(Q_{M\,NMS}\right)_j, \tag{22}$$

$$u_B\left(\delta\left(Q_{M\,cal}\right)\right)_j = \sqrt{u_c\left(Q_{M\,NMS}\right)_j^2 + u_B\left(Q_{M\,NMS\,PRI}\right)_j^2}\,. \tag{23}$$

The combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass flow rate of liquid at the *j*-th flow rate point, $u_C\left(\delta(Q_M)\right)_j$, %, is calculated using the formula

$$u_C\left(\delta(Q_M)\right)_j = \sqrt{u_A\left(\delta(Q_M)\right)_j^2 + u_B\left(\delta\left(Q_{M\,cal}\right)\right)_j^2}. \tag{24}$$

Expanded uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass flow rate of liquid for a confidence level of 0.95 %, $U\left(\delta(V)\right)_j$,is calculated using the formula

$$U\left(\delta(Q_M)\right)_j = 2 \cdot u_C\left(\delta(Q_M)\right)_j. \tag{25}$$

Upon agreement with the owner of CF, it is allowed to calculate the combined standard uncertainty of estimating deviations of CF readings from NMS when transferring a unit of mass flow rate of liquid, $u_C\left(\delta(Q_M)\right)$, %, and the expanded measurement uncertainty of a unit of mass flow rate of liquid of CF for a confidence level of 0.95, $\left(\delta(Q_M)\right)$, %, in the entire CF measurement range using the following formulas:

$$u_C\left(\delta(Q_M)\right) = \sqrt{u_A\left(\delta(Q_M)\right)_{jmax}^2 + u_B\left(\delta\left(Q_{M\,cal}\right)\right)_{jmax}^2}, \tag{26}$$

$$U\left(\delta(Q_M)\right) = 2 \cdot u_C\left(\delta(Q_M)\right). \tag{27}$$

12.4 Processing measurement results and calculating the expanded uncertainty of a unit of volumetric flow rate of liquid measurement of CF

Deviation of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid at the j-th point during the *i*-th measurement, $\delta(Q_V)_{ji}$, %, is calculated using the formula

$$\delta(Q_V)_{ji} = \left(\frac{Q_{V\,ji} - Q_{V\,NMS\,ji}}{Q_{V\,NMS\,ji}}\right) \cdot 100. \tag{28}$$

The liquid volumetric flow rate according to NMS readings is determined for the measurement conditions corresponding to the measurement conditions of CF.

The arithmetic mean deviation of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid at the *j*-th point, $\overline{\delta(Q_V)_j}$, %, is calculated using the formula

$$\overline{\delta(Q_V)_j} = \frac{1}{n} \cdot \sum_{i=1}^{n} \delta(Q_V)_{ji}. \tag{29}$$

The standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid at the *j*-th flow rate point, estimated by type *A*, $\overline{\delta(Q_V)_j}$, %, is calculated using the formula

$$u_A\left(\delta(Q_V)\right)_j = \sqrt{\frac{\sum_{i=1}^{n}\left(\delta(Q_V)_{ji} - \overline{\delta(Q_V)_j}\right)^2}{n \cdot (n-1)}}. \tag{30}$$

Note:

The calibration result is an estimation of the relative deviation of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid at the *j*-th flow rate point, and the corresponding uncertainty of this deviation. The relative deviation of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid can be taken into account as a correction coefficient when using this CF or included in the measurement budget when using this CF.

The standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of volumetric flow rate of liquid at the *j*-th flow rate point $u_B\left(\delta\left(Q_{V\,cal}\right)\right)_j$, estimated by type B, is determined using the formula (31) if combined standard uncertainty of reproduction of a unit of volumetric flow rate of liquid of NMS includes the standard transfer uncertainty of a unit of volumetric flow rate of liquid from NMS or according to formula (32) if the combined standard uncertainty of reproduction of a unit of volumetric flow rate of liquid of NMS does not include the standard transfer uncertainty of a unit of volumetric flow rate of liquid from NMS:

$$u_B\left(\delta\left(Q_{V\,cal}\right)\right)_j = u_c\left(Q_{V\,NMS}\right)_j, \tag{31}$$

$$u_B\left(\delta\left(Q_{V\,cal}\right)\right)_j = \sqrt{u_c\left(Q_{V\,NMS}\right)_j^2 + u_B\left(Q_{V\,NMS\,PRI}\right)_j^2}\,. \tag{32}$$

The combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid at the *j*-th flow rate point, $u_C\left(\delta(Q_V)\right)_j$, %, is calculated using the formula

$$u_C\left(\delta(Q_V)\right)_j = \sqrt{u_A\left(\delta(Q_V)\right)_j^2 + u_B\left(\delta\left(Q_{V\,cal}\right)\right)_j^2}. \tag{33}$$

Expanded uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid for a confidence level of 0.95 %, $U\left(\delta(V)\right)_j$,is calculated using the formula

$$U\left(\delta(Q_V)\right)_j = 2\cdot u_C\left(\delta(Q_V)\right)_j. \tag{34}$$

Upon agreement with the owner of CF it is allowed to calculate the combined standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of volumetric flow rate of liquid, $u_C\left(\delta(Q_V)\right)$, %, and the expanded measurement uncertainty of a unit of volumetric flow rate of liquid of CF for a confidence level of 0.95, $\left(\delta(Q_V)\right)$, %, in the entire CF measurement range using the following formulas:

$$u_C\left(\delta(Q_V)\right) = \sqrt{u_A\left(\delta(Q_V)\right)_{jmax}^2 + u_B\left(\delta\left(Q_{V\,cal}\right)\right)_{jmax}^2}, \tag{35}$$

$$U\left(\delta(Q_V)\right) = 2\cdot u_C\left(\delta(Q_V)\right). \tag{36}$$

13 REGISTERING CALIBRATION RESULTS

Calibration results are recorded in the calibration protocol, which is an appendix to the calibration certificate, or in the calibration certificate. The recommended calibration protocol form is provided in Appendix A.

The CF calibration results are as follows: the values of flow rates at which the calibration was carried out, the values of the arithmetic mean deviation of CF readings from NMS readings at each flow rate, and the expanded uncertainty at each flow rate or across the entire flow rate range.

A calibration certificate issued by the national metrology institutes that have signed the CIPM MRA is issued in accordance with the COOMET Recommendation R/GM/15:2020.

Appendix A

(recommended)

Calibration protocol form

Calibration protocol No. ____________ Sheet _ of _ Sheets

Calibration site: ____.
Calibration date: _______________.
Name of the measuring instrument: ______________________________________.
Serial number of the measuring instrument: ________________________________.
Name of the calibration method: ____.
Name of the Customer: ____.
Address of the Customer: ____.
Name of laboratory: ____.
Address of laboratory: ____.
Calibration site: ____.
Calibration instruments: ____.

Calibration conditions:
– measured medium: water;
– ambient (air) temperature: _________________;
– relative humidity of the environment (air): _________________;
– atmospheric pressure: _________________.

Calibration results:
1. Visual inspection: ____.
2. Trialing: ____.
3. Software conformity assessment: _______________
____.
4. Determination of metrological characteristics:

Abbreviations applied:

CF	–	calibrated flow transducer, flow meter, volumetric or mass liquid meter;
NMS	–	national measurement standard of a unit;
i	–	measurement index;
j	–	flow rate point index;
n	–	index of the number of measurements;
T	–	measurement time, s;
$t_{liq.}$	–	measured medium temperature, °C;
$P_{liq.}$	–	measured medium pressure, kPa;
M	–	mass of liquid in a flow according to CF readings, kg;
M_{NMS}	–	mass of liquid in a flow according to NMS readings, kg;
$\delta(M), \delta(V),$ $\delta(Q_M), \delta(Q_V)$	–	relative deviation of CF readings from NMS readings when transferring a unit of mass of liquid in a flow, unit of volume of liquid in a flow, liquid mass flow rate and liquid volumetric flow rate, respectively, %;

$\overline{\delta(M)}, \overline{\delta(V)}$ $\overline{\delta(Q_M)}, \overline{\delta(Q_V)}$	–	arithmetic mean deviation of CF readings from NMS readings when transferring a unit of mass of liquid in a flow, unit of volume of liquid in a flow, liquid mass flow rate and liquid volumetric flow rate, respectively, %;
$u_A\big(\delta(M)\big), u_A\big(\delta(V)\big),$ $u_A\big(\delta(Q_M)\big), u_A\big(\delta(Q_V)\big)$	–	standard uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass of liquid in a flow, unit of volume of liquid in a flow, unit of mass flow rate of liquid and unit of volumetric flow rate of liquid, respectively, estimated by type A, by CF, %;
$u_B\big(\delta(M_{cal})\big), u_B\big(\delta(V_{cal})\big)$ $u_B\big(\delta(Q_{M\,cal})\big), u_B(\delta(Q_{V\,cal}))$	–	standard calibration uncertainty due to the nature of NMS operation when reproducing a unit of mass of liquid in a flow, unit of volume of liquid in a flow, unit of mass flow rate of liquid and unit of volumetric flow rate of liquid, respectively, estimated by type B, by CF, %;
$U\big(\delta(M)\big), U\big(\delta(V)\big),$ $U\big(\delta(M)\big), U\big(\delta(Q_V)\big)$	–	expanded uncertainty of estimating deviations of CF readings from NMS readings when transferring a unit of mass of liquid in a flow, unit of volume of liquid in a flow, unit of mass flow rate of liquid and unit of volumetric flow rate of liquid, respectively, by CF, for a confidence level of 0.95, %;
V	–	volume of liquid in a flow according to CF readings, dm³;
V_{NMS}	–	volume of liquid in a flow according to NMS readings, dm³;
Q_M	–	liquid mass flow rate according to CF readings, t/h;
Q_{MNMS}	–	liquid mass flow rate according to NMS readings, t/h;
Q_V	–	liquid volumetric flow rate according to CF readings, m³/h;
Q_{VNMS}	–	liquid volumetric flow rate according to NMS readings, m³/h.

Table 1 - Processing measurement results and calculating the expanded measurement uncertainty of a unit of mass of liquid in a flow of CF

Meas. No.	Flow rate point, t/h	T_{ji}, s	$t_{liq.ji}$, °C	$P_{liq.ji}$, kPa	M_{ji}, kg	$M_{NMS\ ji}$, kg	$\delta(M)_{ji}$, %	$\overline{\delta(M)_j}$, %	$u_A(\delta(M))_j$, %	$u_B(\delta(M_{cal})_j)$, %	$U(\delta(M)_j)$, %
1											
:											
n											
…	…	…	…	…	…	…	…	…	…	…	…
1											
:											
n											

Table 2 - Processing measurement results and calculating the expanded measurement uncertainty of a unit of volume of liquid in a flow of CF

Meas. No.	Flow rate point, m³/h	T_{ji}, s	$t_{liq.ji}$, °C	$P_{liq.ji}$, kPa	V_{ji}, dm³	$V_{NMS\ ji}$, dm³	$\delta(V)_{ji}$, %	$\overline{\delta(V)_j}$, %	$u_A(\delta(V))_j$, %	$u_B(\delta(V_{cal}))_j$, %	$U(\delta(V))_j$, %
1											
:											
n											
…	…	…	…	…	…	…	…	…	…	…	…
1											
:											
n											

Table 3 - Processing measurement results and calculating the expanded measurement uncertainty of a unit of volumetric flow rate of liquid of CF

Meas. No.	Flow rate point, t/h	T_{ji}, s	$t_{liq.ji}$, °C	$P_{жид.ji}$, kPa	$Q_{M\,ji}$, t/h	$Q_{M\,НЭТ\,ji}$, t/h	$\delta(Q_M)_{ji}$, %	$\overline{\delta(Q_M)_j}$, %	$u_A(\delta(Q_M))_j$, %	$u_B(\delta(Q_{M\,cal}))_j$, %	$U(\delta(Q_M))_j$, %
1											
:											
n											
…	…	…	…	…	…	…	…	…	…	…	…
1											
:											
n											

Table 4 - Processing measurement results and calculating the expanded measurement uncertainty of a unit of volumetric flow rate of liquid of CF

Meas. No.	Flow rate point, m³/h	T_{ji}, s	$t_{liq.ji}$, °C	$P_{liq.ji}$, kPa	$Q_{V\,ji}$, m³/h	$Q_{V\,NMS\,ji}$, m³/h	$\delta(Q_V)_{ji}$, %	$\overline{\delta(Q_V)_j}$, %	$u_A(\delta(Q_V))_j$, %	$u_B(\delta(Q_{V\,cal}))_j$, %	$U(\delta(Q_V))_j$, %
1											
:											
n											
…	…	…	…	…	…	…	…	…	…	…	
1											
:											
n											

Note. Columns can be added to Tables 1-4 of this Appendix, containing the values of the number of pulses or the frequency of the sequence of pulses from CF (if a frequency-pulse output signal is available) or the average value of the current during the measurement (if a current output signal is available).

______________________________	______________________________	______________________________
Signature of the person who performed the calibration	Full name	Position

Information data

Recommendation ______________________

1. Development coordinator: Federal State Unitary Enterprise “All-Russian Research Institute of Metrology named after D.I. Mendeleev”;
2. COOMET topic: did not open;
3. The Recommendation was approved at the __ meeting of the COOMET Committee;
4. Information about the use of the publication by COOMET member countries:

Russian Federation