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Ensuring metrological traceability of volume units and gas flow rate to the National Measurement Standard Base of Ukraine

A. Barchuk, D. Serediuk, T. Kepeshchuk, V. Lemishka, Yu. Pelikan

SE "IVANO-FRANKIVSKSTANDARDMETROLOGY", Vovchynetska Str., 127, 76007, Ivano-Frankivsk, Ukraine
evilkefir@gmail.com; denys.serediuk@ifdcsms.com.ua; ktv.metr77@gmail.com; vova.lemishka@ukr.net; yura.pelikan@gmail.com

Abstract

The processes of globalization in the world economy demand the elimination of technical barriers in international trade, particularly in the energy sector. To resolve conflicts between gas suppliers and consumers, the implementation of the concept of metrological traceability of measuring instruments to the base units of the SI system through a continuous calibration chain becomes relevant. Simultaneously, it is necessary to apply the concept of measurement uncertainty to assess the accuracy of measurements.

An important aspect of measurements is measurement traceability insurance, as one of the most effective ways to determine the measurement uncertainty is to assess the accuracy of the instrument. This concept plays a key role in the processes of calibration, conformity assessment, and verification of measuring instruments, and it is also essential for participation in international trade. Metrological traceability ensures the reliability of measurement results through the establishment of a continuous calibration chain.

The paper focuses on improving the methods, development of relevant devices, and on the creation of a regulatory framework that would ensure the linkage of working measuring instruments used for natural gas accounting with national primary state measurement standards. A traceability chain has been established for measurements from the national primary measurement standard of the unit of volume and volumetric gas flow rate to working measuring instruments, with normalized uncertainty values throughout the entire hierarchy of gas flow rate unit transfer. To ensure measurement traceability, regulatory documents, which establish calibration procedures, have been implemented in Ukraine's metrological practice. Theoretical and experimental studies of meters have been conducted to use them as transfer measurement standards. Particular attention has been paid to the stability and reproducibility of results, as well as the adaptation of methods to international measurement standards.

Keywords: metrology; metrological traceability; calibration; measurement uncertainty; measurement standards; unit of measurement.

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Introduction

Metrological traceability is a property of measurement results that ensures the possibility of linking them to a measurement standard through an unbroken chain of calibrations, each of which is documented and contributes to the measurement uncertainty [1].

National metrology institutes maintain units of measurement with detailed and analysed uncertainties and transfer them to secondary and working measurement standards (e.g., standards used in accredited laboratories) for use during calibrations.

Consumers aim to reduce their costs, meaning they want to be confident in the accuracy of measurements performed by commercial gas metering skids [2]. The calculation of consumed energy is usually based on the aggregated volumes of natural gas at the metering skids of both the supplier and the consumer. Accordingly, the consumer is confident that the gas meter, after periodic verifications, remains within the established confidence limits of the measurement error. At the State Enterprise "IVANO-FRANKIVSKSTANDARDMETROLOGY", efforts are being made to meet these requirements and support the energy independence of this country. First and foremost, this involves maintaining and ensuring the sustainable functioning of the national measurement standard base, which is a state-owned one and, in turn, ensures the preservation, reproduction, and transmission of the unit of volume and gas flow rate in Ukraine.

The issue of ensuring the metrological traceability through the improvement of methods and devices, as well as the establishment, preservation, and stable functioning of Ukraine's national measurement standard base, is particularly relevant today.

The purpose of this paper is to solve the scientific and applied problem of ensuring the accuracy of measurements of volume and gas flow rate. This is achieved through the improvement of methods and devices that ensure the linkage of working measuring instruments used for natural gas accounting with the national measurement standard base of Ukraine.

Main material of the paper

Metrological traceability of measurements of volume and gas flow rate, which is ensured at the State Enterprise "IVANO-FRANKIVSKSTANDARDMETROLOGY", is shown in Fig. 1.

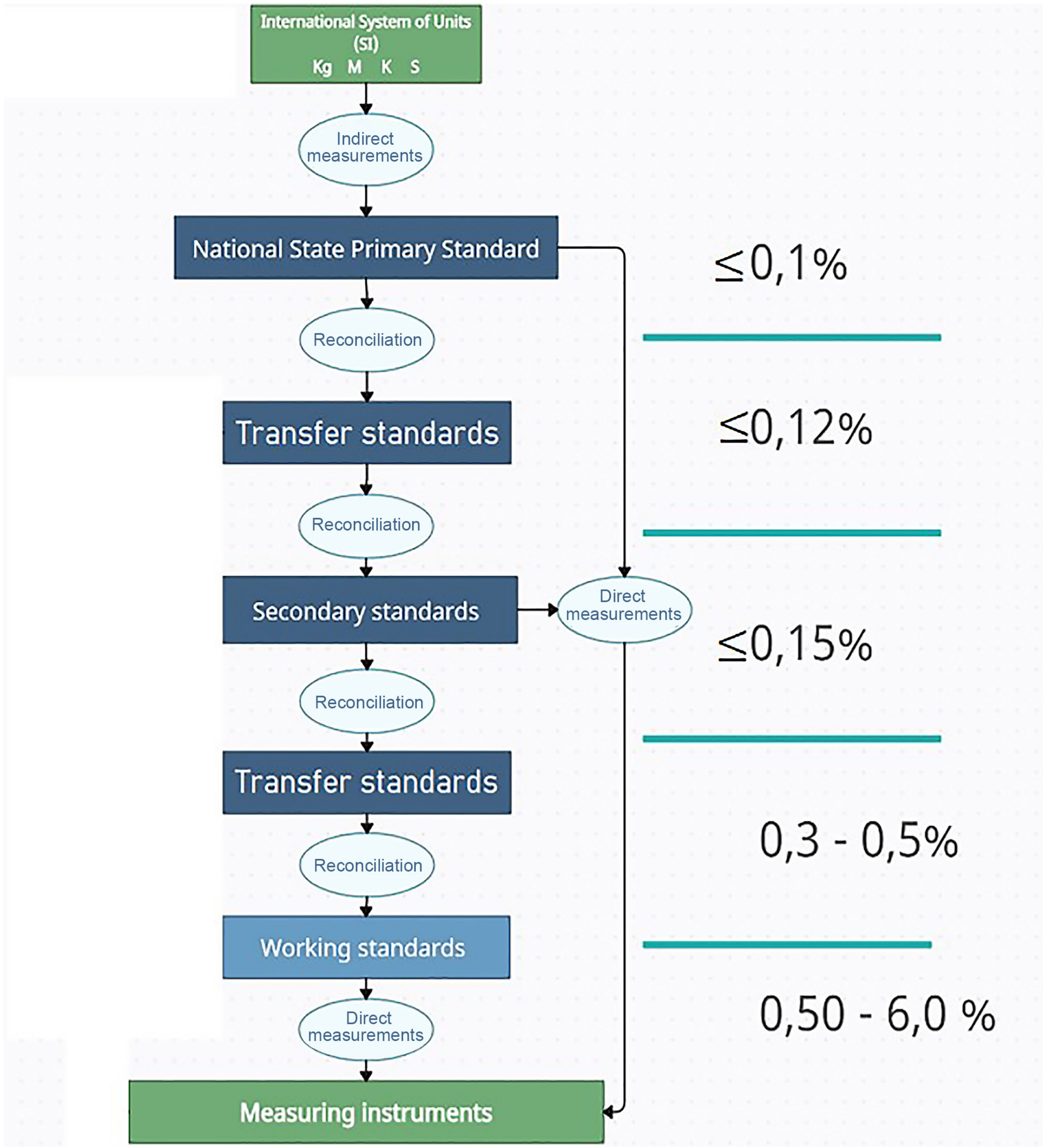

Fig. 1. Structural diagram of the transfer of the unit of volume and volumetric gas flow rate provided by the SE "IVANO-FRANKIVSKSTANDARDMETROLOGY"

Fig. 2. State primary measurement standard of units of gas volume and volumetric flow rate (CMC-entry – UA1) – DETU 03-01-15

At the "National State Primary Standard" level, there is the state primary measurement standard of volume and gas flow rate units (CMC-entry – UA1) – DETU 03-01-15 (Fig. 2), designed for the preservation, reproduction, and transmission of the unit of volume and gas flow rate. This standard has the highest metrological characteristics in this measurement field in Ukraine, with a combined standard uncertainty of 0.1%.

The State Primary Measurement Standard and most secondary measurement standards are complex, dynamic systems that cannot be dismantled or transported. Therefore, to ensure the transfer of the size of volume and gas flow rate units from the primary measurement standard to secondary and working standards (calibration installations), as well as to conduct their mutual comparisons, the traceability chain includes transfer measurement standards, which are at the "Transfer standards" level.

Comparisons using transfer measurement standards are advisable, since the metrological analysis of working measurement standards (calibration installations) may not fully identify all sources of measurement uncertainty, particularly Type A uncertainties. Therefore, comparisons against the primary measurement standard shall be the best method for identifying these components [2].

First of all, each transfer measurement standard is subject to individual calibration to ensure a higher level of accuracy. The reproducibility of the calibration characteristic of the transfer measurement standard, which indicates its stability over time (at least during the calibration interval), shall not be worse than ± 0.05%. The calibration characteristic shall be periodically verified, especially as soon as the transfer measurement standard has been transported, or if it has been preserved for a long period. The calibration characteristic of transfer measurement standards shall be approximated by a polynomial of no higher than the second order as follows [2]:

$$\delta(q) = a_{-2}q^{-2} + a_{-1}q^{-1} + a_0 + a_1q^1 + a_2q^2, \qquad (1)$$

where a are the coefficients of the approximation polynomial, which are determined from the calibration results; q is a volumetric flow rate.

A transfer measurement standard shall have a well-understood physical model and clear external influences on it. If the characteristics of the standard can be affected by temperature changes, installation conditions, or the parameters of the ambient conditions, these influences shall be eliminated, or they shall be predictable so that they can be accounted for, and all the necessary corrections can be made [3].

A transfer measurement standard shall be resistant to any mechanical damage during transportation and operation. It is desirable for such standards to be made and used in the form of a modular design, which shall be stable and uniform for different types of installations [4].

A special requirement for transfer measurement standards is their compatibility (electrical, mechanical, hydrodynamic, etc.) with primary, secondary, and working standards. To meet this requirement, transfer standards shall be equipped with high-frequency and low-frequency pulse volume and gas flow rate converters, and their calibration (grading) and operation shall be carried out with straight sections of pipelines, which shall be an integral part of the transfer measurement standards and ensure the same installation position [2].

It is desirable for transfer measurement standards to have a self-diagnosing component. For this purpose, such standards are equipped with redundant pulse converters and a system for data collection and processing.

In addition, transfer standards shall not disturb the flow of the working environment (i.e., they shall not create flow pulsations, resonance phenomena, etc.) not to influence the metrological characteristics of the standards being compared [4].

For example, the following are used as transfer standards: the IGTM-CT turbine meter, equipped with high- and low-frequency pulse converters for volume and gas flow rate (Fig. 3), the non-resonant IRM3-DUO rotary gas meter (Fig. 4), and the Ritter drum gas meter (Fig. 5).

The transfer measurement standards used at the State Enterprise "IVANO-FRANKIVSK-STANDARDMETROLOGY" operate in the measurement range from 0.016 m³/hour to 6500 m³/hour. The expanded measurement uncertainty of gas volume measurements does not exceed 0.15%.

Experts from the State Enterprise "IVANO-FRANKIVSKSTANDARDMETROLOGY" have already conducted comprehensive studies of the transfer measurement standards, the results of which are presented in Table 1.

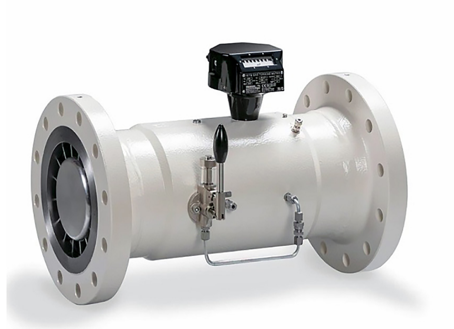

Fig. 3. IGTM-CT turbine type transfer standard

Fig. 4. IRM3-DUO rotary transfer standard

Fig. 5. Ritter drum-type transfer standard

Table 1

Characteristics of Transfer Measurement Standards

№	Metrological characteristics	Ritter	IRM3-DUO G650	IGTM-CT G1600
1	Flow range, m³/hour	0.016 ÷ 2	2 ÷ 1000	160 ÷ 2500
2	Expanded measurement uncertainty	± 0.15%	± 0.12%	± 0.14%
3	Deviation from the approximated characteristic over the entire flow range, not more than	± 0.04%	± 0.03%	± 0.03%
4	Reproducibility	± 0.05%	± 0.05%	± 0.05%

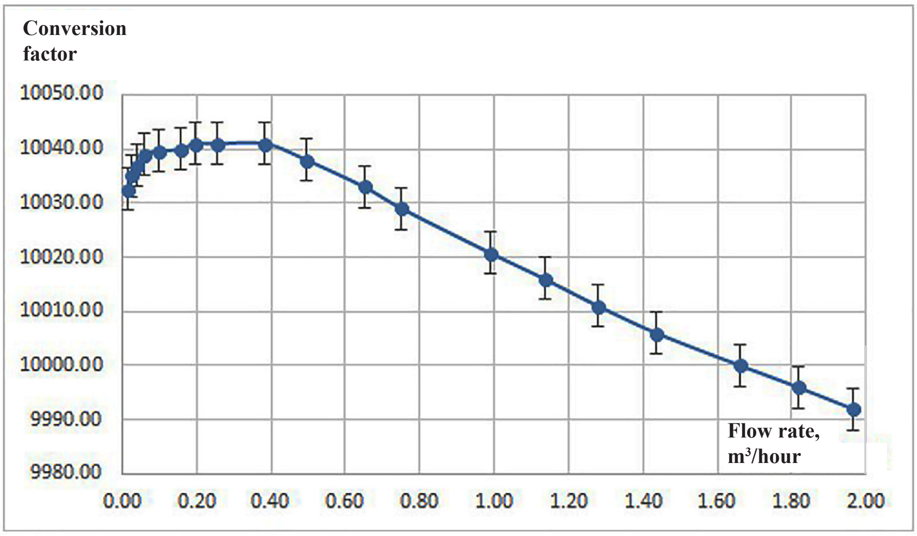

Fig. 6. Conversion factor of the transfer standard based on the Ritter drum meter

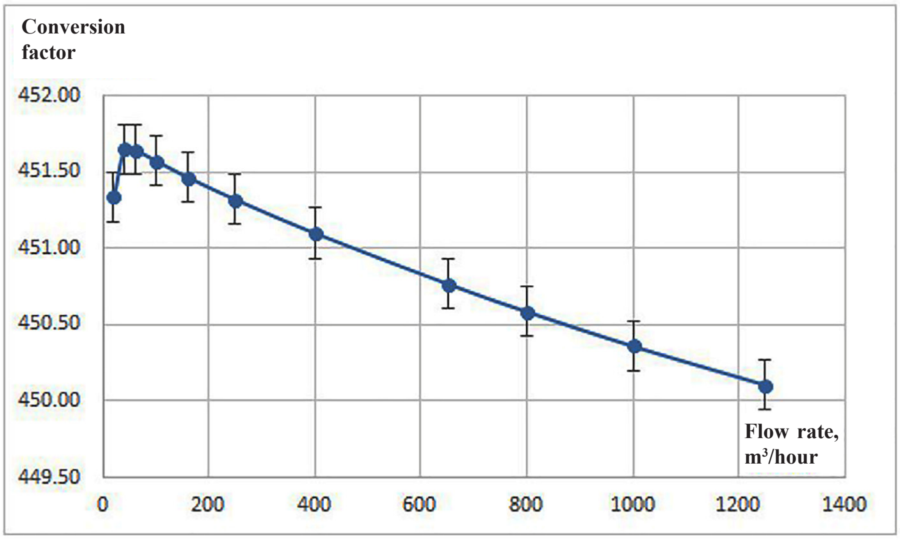

Fig. 7. Conversion factor of the transfer standard based on the IRM3-DUO rotary meter

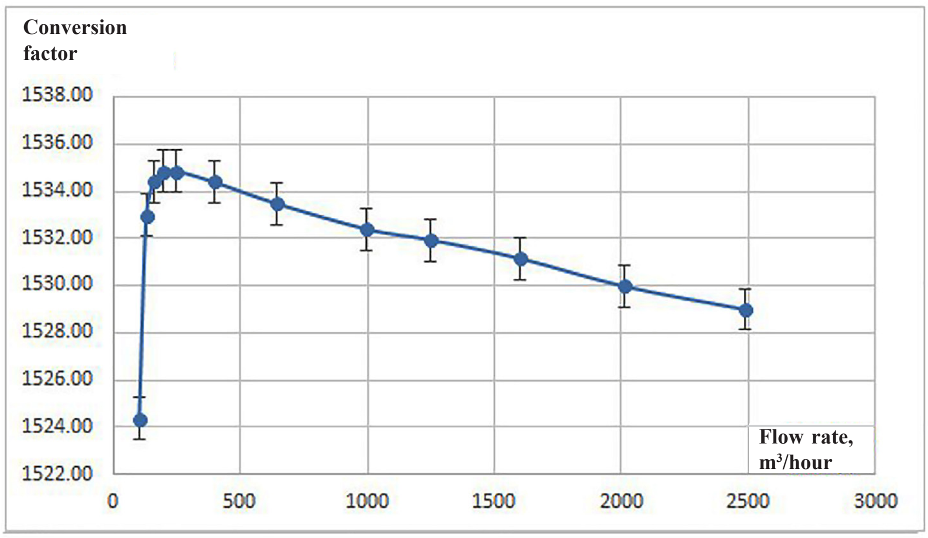

Fig. 8. Conversion factor of the transfer standard based on the IGTM-CT turbine type meter

Figures 6–8 show the conversion coefficients of transfer measurement standards based on the Ritter drum meter, the IRM3-DUO rotary gas meter, and the IGTM CT turbine meter, respectively.

At the "Secondary standards" level, there are national (secondary) measurement standards of volume and gas flow rate units (CMC-entry – UA2) – NDETUM-04-2019 (Fig. 9),

Fig. 9. NDETUM-04-2019

Fig. 10. NDETUM-05-2019

Fig. 11. VETU 03-01-03-11

Fig. 12. VETU 03-01-04-12

NDETUM-05-2019 (Fig. 10), and (CMC-entry – UA4) – VETU 03-01-03-11 (Fig. 11) / VETU 03-01-04-12 (Fig. 12), which receive the unit and are compared with the primary measurement standard using methods and tools that vary depending on the gas flow rate. The expanded measurement uncertainty of gas volume measurements does not exceed 0.15%, with a flow range of 0.001 m^3/hour – 7800 m^3/hour.

It shall be noted that the secondary standards, maintained by the State Enterprise "IVANO-FRANKIVSKSTANDARDMETROLOGY", operate in an "air" working environment. Accordingly, when the working environment and its parameters change, the metrological characteristics of the standards will also change.

Existing national measurement standards require the measurement uncertainty of the standards used

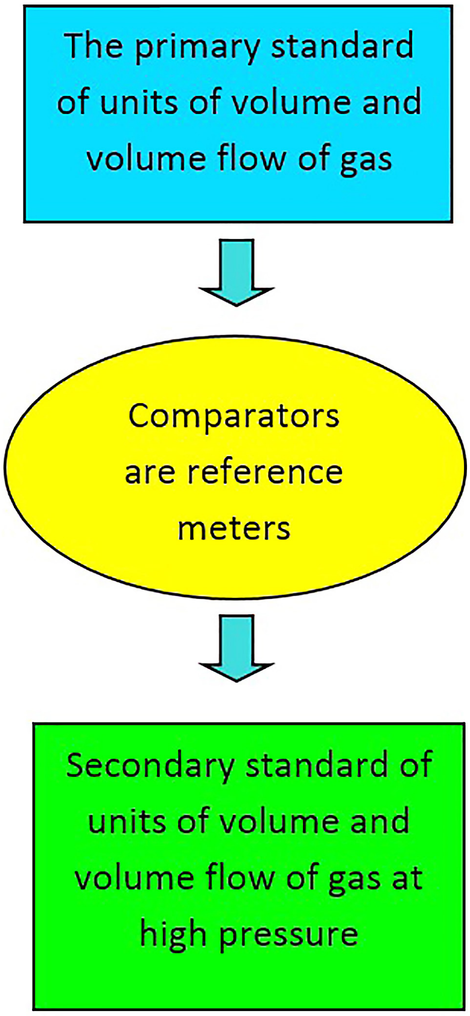

Fig. 13. Accumulation of uncertainty when transferring units from the primary standard

to be specified. Fig. 13 shows the scheme for the accumulation of uncertainty when transferring units from a primary standard to a secondary one.

Thus, the expanded measurement uncertainty of the primary standard $U(U_{PS})$ includes uncertainties of Type A(U_A) and Type B(U_B):

$$U_{PS} = \sqrt{U_A^2 + U_B^2}. \quad (2)$$

As for the expanded uncertainty of the unit transfer by the comparator, it includes the expanded uncertainty of the transfer measurement standard of Type A ($U_{A.PS}$) and the expanded uncertainty of the primary measurement standard U_{PS}.

$$U_{com} = \sqrt{U_{PS}^2 + U_{A.TS}^2}. \quad (3)$$

Thus, the uncertainty of the secondary standard U_{SS} shall account for the root mean square deviation of the measurement result when comparing it with the primary measurement standard, U_{PS}, and the root mean square deviation of the systematic component of the uncertainty of the transfer measurement standard, which includes the uncertainty of transferring the unit from the primary standard using transfer standards accordingly [4].

The expanded uncertainty of the secondary standard U_{SS} actually includes the expanded uncertainty of the unit transfer method U_{TS} using the comparator and the expanded uncertainty of Type A of the secondary standard $U_{A.SS}$:

$$U_{SS} = \sqrt{U_{PS}^2 + U_{A.TS}^2 + U_{A.SS}^2}. \quad (4)$$

In practice, a lot of working measurement standards are used at enterprises for the calibration of gas accounting measuring instruments, which cannot be directly compared with the “Secondary standards” [4].

Therefore, such enterprises need to have own standards to be used for the calibration of working measuring instruments. These standards are included in the traceability chain and shall therefore be calibrated using “Transfer standards”.

At the “Working standards” level, there are working measurement standards, which are calibrated with the “Transfer standard” according to the established calibration intervals. This calibration is carried out to calculate the metrological uncertainty of the working measurement standards, while checking the completeness, labelling, external inspection, and functionality. The uncertainty of pressure and temperature sensors shall be evaluated, and the tightness of the experimental and measurement lines shall be checked [5]. All measurement results shall be recorded in reports and confirmed by the appropriate document – a calibration certificate.

In the final result, gas volumetric flow meters are tested on “Working standards” according to accuracy classes and are then handed over to the consumer [6].

Conclusion

The National Measurement Standard Base of Ukraine, maintained and operated by the State Enterprise “IVANO-FRANKIVSKSTANDARD-METROLOGY”, undergoes regular international comparisons and is included in the BIPM database, which positively impacts the consistency and reliability of measurements in natural gas accounting and ensures the metrological and energy independence of this country.

The activities of specialists at State Enterprise “IVANO-FRANKIVSKSTANDARDMETROLOGY” are focused on ensuring the transfer of the unit of volume and gas flow rate from the national primary measurement standard to the gas meters used by consumers with a declared accuracy.

Забезпечення простежуваності одиниць об'єму та об'ємної витрати газу до Національної еталонної бази України

А. М. Барчук, Д. О. Середюк, Т. В. Кепещук, В. І. Лемішка, Ю. Т. Пелікан

ДП "ІВАНО-ФРАНКІВСЬКСТАНДАРТМЕТРОЛОГІЯ", вул. Вовчинецька, 127, 76007, Івано-Франківськ, Україна
evilkefir@gmail.com; denys.serediuk@ifdcsms.com.ua; ktv.metr77@gmail.com; vova.lemishka@ukr.net; yura.pelikan@gmail.com

Анотація

Процеси глобалізації світової економіки вимагають усунення технічних бар'єрів у міжнародній торгівлі, зокрема у сфері енергоносіїв. Для врегулювання суперечностей між постачальниками та споживачами газу актуальним стає впровадження концепції метрологічної простежуваності засобів вимірювання до основних одиниць системи SI через безперервний ланцюг калібрування. Одночасно необхідно застосовувати концепцію невизначеності для оцінювання точності вимірювань.

Важливим аспектом вимірювань є забезпечення простежуваності, адже одним із найефективніших способів визначення невизначеності є оцінка точності засобу. Це поняття відіграє ключову роль у процесах калібрування, оцінювання відповідності та повірки засобів вимірювання, а також є необхідним для участі в міжнародній торгівлі. Завдяки простежуваності досягається надійність результатів вимірювань через створення безперервного ланцюга калібрувань.

Роботу спрямовано на вдосконалення методів, розробку засобів і створення нормативно-документальної бази, яка забезпечує зв'язок робочих засобів вимірювання, що використовуються для обліку природного газу, з національним державним первинним еталоном. Розроблено ланцюг простежуваності вимірювань від національного первинного еталона одиниці об'єму та об'ємної витрати газу до робочих засобів вимірювань із нормованими значеннями невизначеностей по всій ієрархії передавання розміру одиниці витрати газу. Впроваджено у метрологічну практику України нормативні документи, які регламентують методики проведення калібрування для забезпечення простежуваності вимірювань. Здійснено теоретичні та експериментальні дослідження лічильників для використання їх як еталонів передавання. Особливу увагу приділено стабільності, відтворюваності результатів і адаптації методів до міжнародних стандартів.

Ключові слова: метрологія; простежуваність; калібрування; невизначеність вимірювань; еталони; одиниця вимірювання.

References

1. Law of Ukraine "On metrology and metrological activity" dated June 5, 2014, No. 1314–VII (in Ukrainian). Available at: https://zakon.rada.gov.ua/laws/show/1314-18#Text
2. Seredyuk D.O. Udoskonalennia metodiv ta prystroiv zabezpechennia otsiniuvannia vidpovidnosti zasobiv dlia obliku pryrodnoho hazu: diss. kand. tekhn. nauk [Improvement of methods and devices for ensuring conformity assessment of means for accounting for natural gas: Cand. tech. sci. diss.]. Ivano-Frankivsk National Technical University of Oil and Gas, 2012. 195 p. (in Ukrainian).
3. Lukasheva T., Postnikova V., Strilets V. Skladovi systemy yakosti u zabezpechenni prostezhuvanosti vymiriuvan v Ukraini do mizhnarodnykh etaloniv [Components of the quality system in ensuring the traceability of measurements in Ukraine to international standards]. *Metrology and Instruments*, 2016, no. 5, pp. 7–10 (in Ukrainian). Available at: http://nbuv.gov.ua/UJRN/mettpr_2016_5_6
4. ILAC P10:07/2020. ILAC Policy on Metrological Traceability of Measurement Results. 11 p.
5. Montuori A. Systems Approach. Encyclopedia of Creativity (Second Edition). 2011, pp. 414–421. doi: https://doi.org/10.1016/B978-0-12-375038-9.00212-0
6. OIML TC 4/N 5. ORGANISATION INTERNATIONALE DE METROLOGIE LEGALE. 2006. 17 p. Available at: https://www.oiml.org/en/tc-sc-pg/committee-drafts/files/tc4-d5-2cd.pdf