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EVOLUTION OF METHODS FOR ENSURING THE QUALITY OF TECHNICAL ACCOUNTING OF THERMAL ENERGY IN OPEN ENERGY SYSTEMS OF THE REPUBLIC OF KAZAKHSTAN

The article is devoted to the study of the evolution of heat meter verification methods as a key element in the system of technical accounting of thermal energy, considered in the context of open technical systems. A comparative analysis of the regulatory approaches to verification operating in the Republic of Kazakhstan has been carried out, their distinctive features and impact on metrological reliability and measurement accuracy have been identified. The necessity of adapting existing methods to changing operating conditions and technology development is substantiated, including through the introduction of artificial intelligence elements for processing and interpreting verification results. Approaches to the modernization of the verification system aimed at improving the efficiency of measuring systems integrated into open power systems are proposed. The results obtained can be used both in verification laboratories and in the development of new regulatory documents, contributing to an increase in accounting accuracy, energy efficiency and sustainability of open energy systems.

Keywords: heat meters, verification, methodology, regulatory document, verification laboratory, measuring instruments.

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Қазақстан Республикасының ашық энергетикалық жүйелеріндегі жылу энергиясын техникалық есепке алу сапасын қамтамасыз ету әдістерінің эволюциясы

Мақала ашық техникалық жүйелер контекстінде қарастырылатын жылу энергиясын техникалық есепке алу жүйесіндегі негізгі элемент ретінде жылу есептегіштерін тексеру әдістерінің эволюциясын зерттеуге арналған. Қазақстан Республикасында қолданыстағы салыстырып тексерудің нормативтік тәсілдеріне салыстырмалы талдау жүргізілді, олардың айрықша ерекшеліктері мен метрологиялық сенімділігі мен өлшеу дәлдігіне әсері анықталды. Қолданыстағы әдістемелерді технологияларды пайдалану мен дамытудың өзгеретін жағдайларына бейімдеу қажеттілігі, оның ішінде тексеру нәтижелерін өңдеу және түсіндіру үшін жасанды интеллект элементтерін енгізу есебінен негізделген. Ашық энергия жүйелеріне біріктірілген өлшеу жүйелері жұмысының тиімділігін арттыруға бағытталған тексеру жүйесін жаңғырту тәсілдері ұсынылды. Алынған нәтижелер тексеру зертханаларында да, жаңа нормативтік құжаттарды әзірлеу кезінде де пайдаланылуы мүмкін, бұл есепке алу дәлдігін, энергия тиімділігін және ашық энергетикалық жүйелердің тұрақтылығын арттыруға ықпал етеді.

Түйін сөздер: жылу есептегіштері, тексеру, әдістеме, нормативтік құжат, тексеру зертханасы, өлшеу құралдары.

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Эволюция методов обеспечения качества технического учёта тепловой энергии в открытых энергетических системах Республики Казахстан

Статья посвящена исследованию эволюции методов поверки теплосчётчиков как ключевого элемента в системе технического учёта тепловой энергии, рассматриваемой в контексте открытых технических систем. Проведён сравнительный анализ нормативных подходов к поверке, действующих в Республике Казахстан, выявлены их отличительные особенности и влияние на метрологическую надёжность и точность измерений. Обоснована необходимость адаптации существующих методик к изменяющимся условиям эксплуатации и развития технологий, в том числе за счёт внедрения элементов искусственного интеллекта для обработки и интерпретации результатов поверки. Предложены подходы к модернизации системы поверки, направленные на повышение эффективности работы измерительных систем, интегрированных в открытые энергосистемы. Полученные результаты могут быть использованы как в поверочных лабораториях, так и при разработке новых нормативных документов, способствуя повышению точности учёта, энергоэффективности и устойчивости открытых энергетических систем.

Ключевые слова: счетчики тепла, поверка, методика, нормативный документ, поверочная лаборатория, средства измерений.

Introduction

The modern development of Kazakhstan's energy sector is accompanied by the active implementation of technologies for monitoring and accounting of energy resources. This necessity arises from the growing demand to improve energy efficiency, reduce operational costs, and maintain transparent settlement processes between heat suppliers and consumers. A central element in achieving this is the heat meter, a device that enables precise monitoring of thermal energy usage.

The main types of heat meters include the following: mechanical, electromagnetic, and ultrasonic heat meters. Each type of heat meter has its own advantages and disadvantages, and the choice of a heat meter depends on the specific operating conditions (installation location) and heat metering requirements in each country. In Europe, ultrasonic heat meters are used, for example, in the work of G Ficco et al. The analysis of key metrological problems associated with clamping reference meters in the field verification of ultrasonic heat meters is shown. The authors further emphasize that, considering the allowable error and measurement uncertainty, field meters often struggle to fully meet metrological standards [1]. In a research paper on the evaluation of heat metering flowmeters, Choir et al. [2] investigated the metrological characteristics of all three types of thermal flowmeters in the field, showing the deviation of the mechanical and ultrasonic flowmeters in the range of ±2.5%, and electromagnetic in the range of 6.9%. If we are talking about the study of systematic errors in heat accounting, Weissenbrunner et al. employed computational fluid dynamics (CFD) modeling [3] to investigate systematic deviations in ultrasonic flow meters caused by uncertain inlet profiles generated by upstream disturbances, such as double elbows. Their results showed that when the meter is installed less than 40 pipe diameters downstream of a double bend, the systematic measurement error can range from 1.5% to 4.5%.

A. G. Lupey et al. considers the problems of accounting for heat energy from heat sources. The author claims that the statistical data obtained for the results of average hourly flow measurements at the entrance and exit of the heat supply system allow us to conclude that the quality of calibration of these flow meters cannot be considered satisfactory and the actual discrepancy in the calibration characteristics for this pair of flow meters is very noticeable. As a method of solving the problem, the author suggests entering measurement regulations in the state register and submitting a resolution stating that the production of flow meters should be preceded not only by laboratory tests, but also by adequate long-term commercial tests in closed heat supply systems or at the inlet and outlet of a hot water furnace (boiler, plate heat exchanger) [4].

In the EU, the use of heat meters is regulated by the Energy Efficiency Directive 2012/27/EU (EED) [5], which highlights individual heat consumption measurement as an essential means of boosting efficiency and fostering energy conservation.

A precise and equitable determination of thermal energy consumption in individual residential buildings remains a highly relevant issue, as it encompasses a wide range of technical, metrological, and consumer-related challenges [6], [7], [8]. In this context, the use of heat meters within the EU is governed by the Measuring Instruments Directive (MID) [9], which mandates that legally used measuring devices must satisfy essential metrological criteria. This implies that both the measurement error and its associated uncertainty must stay within the permissible limits defined for the corresponding measurement category.

Individual ultrasonic heat meters are not commonly used in Kazakhstan; instead, electromagnetic heat meters remain the dominant technology. To maintain the uniformity and reliability of thermal energy measurements, these meters–similar to other instruments used for resource monitoring–must undergo periodic verification. Heat meters are verified using metrological instruments in accordance with the approved verification procedures. In Kazakhstan, such verification is governed by the Law "On Ensuring the Uniformity of Measurements" [10], by Order No. 934 of the Minister of Investment and Development of December 27, 2018, which sets the rules, frequency, and certification format for verifying measuring instruments [11], as well as by methodological documents such as ST RK 2.447-2017 "Heat Meters. Methods and Means of Verification" [12] and MI 2573-2000 "Heat Meters for Water Heating Systems. Verification Procedure" [13]. Additionally, the manufacturer's verification methods registered in the State Register are applied when the heat meter type is approved. In most cases, verification must be carried out by accredited laboratories, and meter owners are required to monitor the timing of verification. The verification of heat meters is important to ensure the accuracy of measurements and compliance with standards.

In 2024, the Law "On Thermal Energy" was enacted in Kazakhstan, becoming an important milestone in regulating and developing the national heat energy sector. The law introduces extensive reforms to address numerous longstanding issues in heat supply [14]. A major provision of the law concerns new requirements for planning and implementing thermal power projects–whether related to construction, reconstruction, modernization, or the installation and integration of equipment into centralized or local heat supply systems. According to the law, such projects must comply with heat supply development schemes and provide for the use of fuel appropriate to the specific system and location. They also need to include measures or technologies aimed at saving energy, improving efficiency, and reducing thermal energy losses during generation, transportation, and consumption, including solutions based on energy-efficient technologies, renewable energy sources, and other modern energy systems.

However, despite the widespread use of heat meters in the country, the issues of ensuring their accuracy and reliability remain relevant. Verification of heat meters is a mandatory process aimed at confirming the compliance of metrological characteristics with established standards and regulatory requirements. A properly functioning verification process is important for guaranteeing consistent measurements, protecting consumers, and meeting the legal standards defined in the legislation of the Republic of Kazakhstan.

At present, heat meter verification in Kazakhstan is often carried out according to broad international recommendations, which may fail to account for the particular climatic, technical, and operational features of the local environment. This requires the development of an adapted and optimized methodology that takes into account the specifics of the country's heating network, the structure of heat energy consumption and the available infrastructure of verification laboratories.

The purpose of this study is to analyze the existing methods of heat meter verification, identify their shortcomings in practice and possible solutions.

Materials and methods

In this paper, two regulatory documents on the verification of heat meters will be considered. The first regulatory document is ST RK 2.447-2017 – "Heat Meters. Methods and Means of Verification". It was chosen because it is the national standard of the Republic of Kazakhstan for the verification of heat meters. The second regulatory document is MI 2573-2000 – "Heat Meters for Water Heating Systems. Verification Procedure. General Provisions". This regulatory document, like the national standard, is widely used and applied in verification laboratories for the verification of heat meters.

The above verification methods are compared according to important characteristics in the field of ensuring the uniformity of measurements. These characteristics encompass:

- the organization or specialists responsible for developing the verification methodology;
- the scope and area of its applicability;
- the circumstances and conditions under which the methodology is used;
- the verification documents and techniques that served as the basis for its development;
- the sequence of verification operations;
- the measuring equipment required for performing verification;
- the qualification criteria established for verification personnel;
- types of verification of heat meters used in the methodology;
- verification conditions;
- the verification interval;
- safety requirements;
- external inspection;
- testing;
- complete verification. Error detection;
- piecemeal verification. Error detection;
- estimation of heat meter uncertainty;
- registration of the verification results.

These characteristics were selected for comparison in compliance with ST RK 2.63-2018 – "Methods of Verification of Measuring Instruments. The Procedure of Development, Approval and Application" [15].

Results and discussion

In the Russian Federation, the verification of heat meters is regulated by the Federal Law "On Ensuring the Uniformity of Measurements", PR 50.2.006-94 "The State System for Ensuring the Uniformity of Measurements. The Procedure for Verification of Measuring Instruments" [16], and regulatory documents endorsed on the basis of tests carried out for the approval of the measuring instrument type.

According to the decision of the State Standard of the Russian Federation, the right to verify measuring instruments may be granted to accredited metrological services of legal entities. The activities of these metrological services are carried out in accordance with the current legislation and regulatory documents on ensuring the uniformity of measurements of the State Standard of the Russian Federation. Verification activities carried out by accredited metrological services of legal entities are controlled by the State Metrological Service authorities at the location of these legal entities. The frequency of testing depends on the model of the device and is determined by the manufacturer. It usually ranges from 4 to 10 years. The exact date is indicated in the passport of the device, a note is also made there about the next verification, an additional act is drawn up and a certificate of verification is issued.

The verification process may vary in other countries. In the countries of the European Union, there are strict rules governing the inspection and certification of measuring instruments. It also uses a general Directive designed to harmonize legislation across the EU in relation to a range of measuring devices, including heat meters [17].

In the USA, verification may be less formalized, but it also requires verification of accuracy in accordance with local standards. There is only the A2LA accreditation organization, which conducts laboratory accreditation and verifies all the procedures used in the work, reflected in the Quality Assurance manual – this is a well-considered and not entirely public thing in which calibration methods can be found.

In France, accreditation is very expensive, and enterprises prefer not to have their own laboratories, but to send all the instruments to be verified to specialized metrological centers, or specialists specially commissioned from these centers are engaged in verification.

In Kazakhstan, the regulatory framework for the verification of heat energy meters is ST RK 2.447-2017 and MI 2573-2000 including steps illustrated in Figure 1.

A comparative analysis of the heat meter verification methods presented in Table 1 showed that the main differences between these regulatory documents are in references to the relevant standards and regulatory documents of each country. Since when using MI 2573-2000, there are legal difficulties in using reference normative legal documents that are not legally binding across the territory of the Republic of Kazakhstan. It should be noted that the general approaches to methods and means of checking heat meters remain similar, reflecting international practice in the field of metrology. In turn, the verification procedure described in ST RK 2.447-2017 was developed on the basis of verification methods that cover a limited number of types of heat meters.

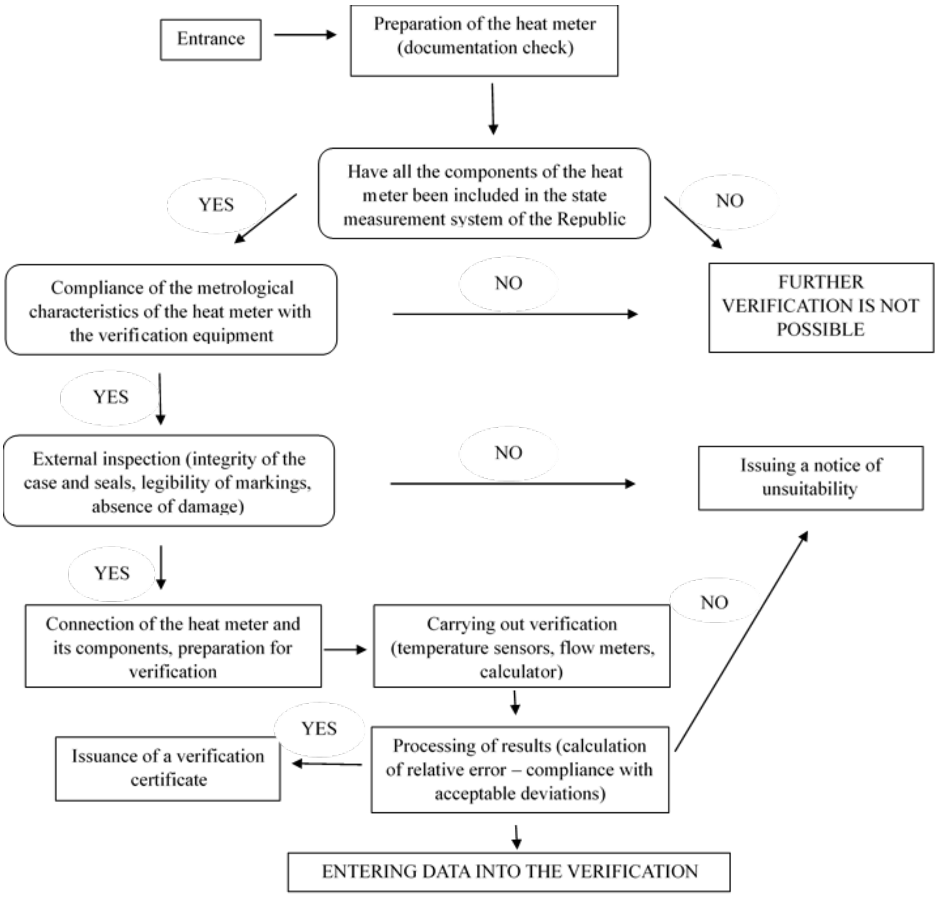

Figure 1 – Verification procedure of heat energy meters in the Republic of Kazakhstan

Table 1 – Comparative analysis of heat meter verification methods prescribed in ST RK 2.447-2017 and MI 2573-2000

Comparative characteristics	ST RK 2.447-2017 – Heat Meters. Verification Methods and Tools	MI 2573-2000 – Heat Meters for Water Heating Systems. Verification Procedure. General Provisions
1. Who developed the verification procedure?	"KazInMetr", KTRM of the Ministry of Investment and Development of the Republic of Kazakhstan	D.I. Mendeleev VNIIM and VNIIMS of the State Standard of Russia and TC 206 "Standards and verification schemes"
2. Scope of distribution	Heat meters	Heat meters
3. When it is applied	During the initial and periodic verification of heat meters	During the initial and periodic verification of heat meters
4. On the basis of which verification techniques, the methodology was developed	1) "KM-5 heat meters. Verification procedure"; 2) "Heat meters QALCOMETHEAT1. Verification procedure"; 3) "GSI. KST-22 heat meters. Verification procedure IVKA.407281.004 MP"; "GSI. PRAMER heat meters-HEAT. The method of verification of the CCP.30.0000.000.00 MP"	-
5. Verification operations	• External inspection • Testing • Determination of the heat meter error • Registration of verification results	• External inspection; • testing; • determination of the heat meter error • comparison of the obtained error values with the limits of the allowed error; • registration of verification results.

6. Measuring instruments for verification	- reference heat meter; - flow meter calibration unit, reproducible flow range from 0.005 m3/h to 800 m3/h; - resistance stores, the range of electrical resistance values from 0.001 ohms to 111111.10 ohms; - platinum exemplary resistance thermometer, measuring range from 0 to 250 °C; - liquid thermostats for creating temperatures in the range from 0 to 200 °C.; - multi-function calibrator, playback ranges: 1) DC power from 0 mA to 24 mA; 2) Pulse repetition rates from 5 Hz to 1000000 Hz; 3) the number of pulses in a packet from 1 pulse to 5x10 pulses; 4) time interval from 1000 microseconds to 6x10 microseconds; - DC power supply, output voltage from 0 to 30 V, output current from 0 to 3 A; - aspiration psychrometer, measuring range from minus 25 °C to 50 °C; - aneroid barometer, measuring range (610-790) mmHg. - mercury glass thermometer, measuring range from 0 to 50 °C.	Working standards, auxiliary SI, auxiliary equipment specified in the ED or ND verification.
7. Qualification requirements for verifiers	Certification as verifiers in accordance with ST RK 2.45	The qualifications of the verifiers must comply with the requirements of PR 50.2.012-94.
8. Types of verification of heat meters	Comprehensive, piecemeal	Comprehensive, piecemeal
9. Verification conditions	Normal conditions according to GOST 8.395	Normal conditions according to GOST 8.395
10. The verification interval	It is established for each type of heat meters when approving the type of measuring instruments or their metrological certification.	According to the test results for type approval purposes
11. Safety requirements	In accordance with the Order of the Minister of Energy of the Republic of Kazakhstan “On approval of Safety Regulations for the operation of electrical installations of consumers”, as well as those specified in the ND and ED on SI	In accordance with the “Safety rules for the operation of electrical installations of consumers”, “Rules for the technical operation of electrical installations of consumers”, as well as those specified in the ND and ED on SI
12.External inspection	The completeness of the heat meters to the ED requirements, the presence of seals, the absence of defects that prevent the reading of labels, markings and scale counting	The completeness of the heat meters to the ED requirements, the presence of seals, the absence of defects that prevent the reading of labels, markings and scale counting
13.Testing	1) With complete verification, the functioning of the heat meter; 2) in case of piecemeal operation, the functioning of the components, as well as the heat meter as a whole, and the response to input signals in accordance with the ED	1) With complete verification, the functioning of the heat meter; 2) in case of piecemeal operation – the functioning of the components, as well as the heat meter as a whole, responding to input signals in accordance with the ND
14.Complete verification. Error detection	By the method of direct comparison of a verifiable heat meter with a reference installation or with a reference heat meter.	The error of each measuring channel is determined and compared with the margin of error set for the channel being tested for the type of heat meter being tested.
14.1 Determination of the error in measuring the amount of heat	1. For heat meters that include one flow converter: 1) $\Delta t_{min} \leq \Delta t \leq 1{,}2\Delta t_{min}$; 2) $10°C \leq \Delta t \leq 20°C$; 3) $(\Delta t_{max} - 5\ °C) \leq \Delta t \leq \Delta t_{max}$; 4) $0{,}9G_{max} \leq G \leq G_{max}$; 5) $G_{nom} \leq G \leq 1{,}1G_{nom}$; 6) $G_{min} \leq G \leq 1{,}1G_{min}$. 2. For heat meters, one flow converter is	1. For heat meters that include one flow converter: 1) $\Delta t_{min} \leq \Delta t \leq 1{,}2\Delta t_{min}$; 2) $10°C \leq \Delta t \leq 20°C$; 3) $(\Delta t_{max} - 5\ °C) \leq \Delta t \leq \Delta t_{max}$; 4) $0{,}9G_{max} \leq G \leq G_{max}$; 5) $G_{пер} \leq G \leq 1{,}1G_{пер}$; 6) $G_{min} \leq G \leq 1{,}1G_{min}$. 2. For heat meters, one flow converter is

	located in the supply line and the other in the return line.: 1) Δtmin≤ Δt≤ 1,2Δtmin; 0,9G1max ≤ G1 ≤ G1max; G2min ≤ G2 ≤ 1,1G2min; 2) 10°C≤ Δt≤ 20°C; G1≥1,5G2nom; G2nom ≤ G2 ≤ 1,1G2nom; 3) (Δtmax– 5 °C) ≤ Δt≤ Δtmax; G1=G2min+ΔGmin; G2min ≤ G2 ≤ 1,1G2min. 3. When a verifiable heat meter is directly compared with a working standard, three measurements are performed in each mode: $\delta_Q = \frac{Qij-Qэij}{Qэij} \times 100\%$	located in the supply line and the other in the return line.: 1) Δtmin≤ Δt≤ 1,2Δtmin; 0,9G1max ≤ G1 ≤ G1max; G2min ≤ G2 ≤ 1,1G2min; 2) 10°C≤ Δt≤ 20°C; G1≥1,5G2пер; G2пер ≤ G2 ≤ 1,1G2пер; 3) (Δtmax– 5 °C) ≤ Δt≤ Δtmax; G1=G2min+ΔGmin; G2min ≤ G2 ≤ 1,1G2min. 3. When a verifiable heat meter is directly compared with a working standard, three measurements are performed in each mode: $\delta_Q = \frac{Qij-Qэij}{Qэij} \times 100\%$
14.2 Determination of the heat meter error when measuring heat flow	1. and 2. in accordance with paragraph 14.1 when the verifiable heat meter is directly compared with the working standard, three measurements are performed in each mode: $\delta_Ф = \frac{Фij-Фэij}{Фэij} \times 100\%$	1. and 2. in accordance with paragraph 14.1 when the verifiable heat meter is directly compared with the working standard, three measurements are performed in each mode: $\delta_Ф = \frac{Фij-Фэij}{Фэij} \times 100\%$
14.3 Error Determi-nation of a Heat Meter During Coolant Mass Measurement	1. and 2. in accordance with paragraph 14.1 3. When directly comparing the verified heat meter with the working standard, three measurements are performed in each mode: $\delta_M = \frac{Mij-Mэij}{Mэij} \times 100\%$	1. and 2. in accordance with paragraph 14.1 3. When directly comparing the verified heat meter with the working standard, three measurements are performed in each mode: $\delta_M = \frac{Mij-Mэij}{Mэij} \times 100\%$
14.4 Determination of the error of the heat meter when measuring the temperature of the coolant	1. in accordance with paragraph 14.1 2. When directly comparing the verified heat meter with the working standard, three measurements are performed in each mode: $\delta_T = \frac{Tij-Tэij}{Tэij} \times 100\%$ 3. The relative error introduced by the heat meter during temperature difference measurement of the coolant in the supply and return pipelines is calculated by performing three measurements in each mode, using the formula: $\delta_{\Delta T} = \frac{\Delta Tij-\Delta Tэij}{\Delta Tэij} \times 100\%$	1. in accordance with paragraph 14.1 2. When directly comparing the verified heat meter with the working standard, three measurements are performed in each mode: $\delta_T = \frac{Tij-Tэij}{Tэij} \times 100\%$ 3. The relative error introduced by the heat meter during temperature difference measurement of the coolant in the supply and return pipelines is calculated by performing three measurements in each mode, using the formula: $\delta_{\Delta T} = \frac{\Delta Tij-\Delta Tэij}{\Delta Tэij} \times 100\%$
14.5 Determination of the heat meter error during time measurements	The error of the heat meter in measuring time is determined if the metrological characteristics are normalized for them, according to which the error of the heat meters can be determined.	The determination of the error of the heat meter when measuring time is carried out according to the ND by checking specific types of heat meters.
15. Piecemeal verification. Error detection	During piecemeal verification, the error of each component of the heat meter is determined. The error of the components of the heat meter is determined if the metrological characteristics are normalized for them, according to which the error of the heat meter can be determined.	During piecemeal verification, the error of each component of the heat meter is determined. The error of the components of the heat meter is determined if the metrological characteristics are normalized for them, according to which the error of the heat meter can be determined.
15.1 Verification of flow converters (meters)	1. Verification of flow converters (meters), depending on their design, is performed in accordance with the requirements of ED heat meters by means of a working standard or simulation devices. 2. Verification is performed by output signals (for example, by electric current, frequency). The average verification time for expenses from Gm to Gmax should be at least five minutes, and for expenses from Gnom to Gmax at least twenty minutes. 3. For a flow converter with an output frequency signal, the minimum number of Nmin pulses recorded during measurements in a given flow mode:	1. Verification of flow converters (meters), depending on their design, is performed in accordance with the requirements of ED heat meters by means of a working standard or simulation devices. 2. Verification is performed by output signals (for example, by electric current, frequency). The average verification time for expenses from Gm to Gmax should be at least five minutes, and for expenses from Gnom to Gmax at least twenty minutes. 3. For a flow converter with an output frequency signal, the minimum number of Nmin pulses recorded during measurements in a given flow mode:

	$Nmin \geq \frac{300}{\delta пр}$ 4. The relative error of the flow converter is calculated: - for the flow rate of the coolant δG according to the formula: $\delta_G = \frac{Gj - Gэj}{Gэj} \times 100\%$ - for the volume of the coolant δV: $\delta_V = \frac{Vj - Vэj}{Vэj} \times 100\%$, where Gj is the reference flow value in the jth mode: $Gэj = \frac{Vэj}{t} \times \rho$	$Nmin \geq \frac{300}{\delta пр}$ 4. The relative error of the flow converter is calculated: - for the flow rate of the coolant δG according to the formula: $\delta_G = \frac{Gj - Gэj}{Gэj} \times 100\%$ - for the volume of the coolant δV - $\delta_V = \frac{Vj - Vэj}{Vэj} \times 100\%$, where Gj is the reference flow value in the jth mode: $Gэj = \frac{Vэj}{t} \times \rho$
15.1 Verification of flow converters (meters)	1. Verification of flow converters (meters), depending on their design, is performed in accordance with the requirements of ED heat meters by means of a working standard or simulation devices. 2. Verification is performed by output signals (for example, by electric current, frequency). The average verification time for expenses from Gnom to Gmax should be at least five minutes, and for expenses from Gm to Gm at least twenty minutes. 3. For a flow converter with an output frequency signal, the minimum number of Nmin pulses recorded during measurements in a given flow mode: $Nmin \geq \frac{300}{\delta пр}$ 4. The relative error of the flow converter is calculated: - for the flow rate of the coolant δG according to the formula: $\delta_G = \frac{Gj - Gэj}{Gэj} \times 100\%$ - for the volume of the coolant δV: $\delta_V = \frac{Vj - Vэj}{Vэj} \times 100\%$, where Gj is the reference flow value in the jth mode: $Gэj = \frac{Vэj}{t} \times \rho$ 5. When checking a pair of flow converters, three measurements are performed in each mode of paragraph 14.1.2. Then the converters' relative errors are calculated for the measurement of the flow difference: $\delta_{\Delta G} = \frac{\Delta Gi - \Delta Gэi}{\Delta Gэi} \times 100\%$ 6. During verification of the measuring channel (thermal calculator – HC) for volume (mass) measurement, resistance standards simulating the temperature sensors are applied. Their resistance values are set to create simulated coolant temperatures producing a temperature difference between 10 °C and 20 °C. The values of the coolant flow modes are selected according to clause 14.1. 7. Verification of the measuring channel intended for measuring volume (mass) is performed according to the readings of the digital HC display board or according to the readings of the output coded signal (RS232	1. Verification of flow converters (meters), depending on their design, is performed in accordance with the requirements of ED heat meters by means of a working standard or simulation devices. 2. Verification is performed by output signals (for example, by electric current, frequency). The average verification time for expenses from Gnom to Gmax should be at least five minutes, and for expenses from Gm to Gm at least twenty minutes. 3. For a flow converter with an output frequency signal, the minimum number of Nmin pulses recorded during measurements in a given flow mode: $Nmin \geq \frac{300}{\delta пр}$ 4. The relative error of the flow converter is calculated: - for the flow rate of the coolant δG according to the formula: $\delta_G = \frac{Gj - Gэj}{Gэj} \times 100\%$ - for the volume of the coolant δV: $\delta_V = \frac{Vj - Vэj}{Vэj} \times 100\%$, where Gj is the reference flow value in the jth mode: $Gэj = \frac{Vэj}{t} \times \rho$ 5. When checking a pair of flow converters, three measurements are performed in each mode of paragraph 14.1.2. Then the relative errors of the converters are calculated when measuring the flow difference: $\delta_{\Delta G} = \frac{\Delta Gi - \Delta Gэi}{\Delta Gэi} \times 100\%$ 6. When checking the measuring channel (thermal calculator – HC), designed for measuring volume (mass), resistance stores are connected to the HC, which simulate the vehicle. The resistance values are selected so that they simulate the temperature of the coolant in the temperature difference range of 10 °C ≤ Δt ≤ 20 °C. The values of the coolant flow modes are selected according to clause 14.1. 7. Verification of the measuring channel intended for measuring volume (mass) is performed according to the readings of the digital HC display board or according to the

	interface) in line with the requirements of the ED. 8. The relative error of the measuring channel intended for measuring volume (mass) δM and δV is estimated by performing three measurements in each flow mode: $\delta_V = \frac{Vij - Vэij}{Vэij} \times 100\%$ $\delta_M = \frac{Mij - Mэij}{Mэij} \times 100\%$	readings of the output coded signal (RS232 interface) in accordance with the requirements of the ED. 8. The relative error of the measuring channel intended for measuring volume (mass) δM and δV is estimated by performing three measurements in each flow mode: $\delta_V = \frac{Vij - Vэij}{Vэij} \times 100\%$ $\delta_M = \frac{Mij - Mэij}{Mэij} \times 100\%$
15.2 Verification of thermal resistance converters	1. Vehicle verification in accordance with the requirements GOST 8.461. 2. When a pair of vehicles is selected (for example, KTSPR-a set of platinum vehicles for measuring temperature differences, KTPTR-a set of platinum technical difference thermometers), each vehicle is verified in accordance with the requirements of GOST 8.461. 3. Verification of thermostable resistors, cold water temperature simulators, is performed in accordance with the requirements of this standard. 4. When checking the measuring channel (HM-HC) intended for temperature measurements, the mode values are selected according to clause 14.1. 5. The verification of the measuring channel (HM-HC) is performed according to the readings of the digital display board of the TV or according to the readings of the output coded signal (RS 232 interface) in accordance with the requirements of the ED. 6. The relative error of the measuring channel (HM-HC) δT is estimated by performing three measurements in each mode: $\delta_T = \frac{Tij - Tэij}{Tэij} \times 100\%$	1. Vehicle verification in accordance with the requirements GOST 8.461-82. 2. When a pair of vehicles is selected (for example, KTSPR-a set of platinum vehicles for measuring temperature differences, KTPTR-a set of platinum technical difference thermometers), each vehicle is verified in accordance with the requirements of GOST 8.461-82. 3. Verification of thermostable resistors, cold water temperature simulators, is performed in accordance with the requirements of this standard. 4. When checking the measuring channel (HM-HC) intended for temperature measurements, the mode values are selected according to clause 14.1. 5. The verification of the measuring channel (HM-HC) is performed according to the readings of the digital display board of the TV or according to the readings of the output coded signal (RS 232 interface) in accordance with the requirements of the ED. 6. The relative error of the measuring channel (HM-HC) δT is estimated by performing three measurements in each mode: $\delta_T = \frac{Tij - Tэij}{Tэij} \times 100\%$
15.3 Determination of the HC error when converting the coolant pressure	At the specified points in the pressure measurement range, three measurements are performed and the relative error HC is calculated when determining the coolant pressure δ_{BP}: $\delta_{вр} = \frac{Pij - Pэij}{Pэij} \times 100\%$	At the specified points in the pressure measurement range, three measurements are performed and the relative error HC is calculated when determining the pressure of the coolant δ_{BP}: $\delta_{вр} = \frac{Pij - Pэij}{Pэij} \times 100\%$
15.4 Determination of the HC error during conversion and calculation of volume (mass) the heat carrier	1. Resistance stores are connected to the TV. The modes for temperature must comply with clause 14.1.2. 2. Three volume measurements are performed for each mode, followed by an estimation of the HC's relative error in coolant volume determination δ_{BV}: $\delta_{BV} = \frac{Vij - Vэij}{Vэij} \times 100\%$ 3. In each mode, three mass determinations are performed and the relative error of the TV is estimated when determining the mass δ_{BM} of the coolant: $\delta_{BM} = \frac{Mij - Mэij}{Mэij} \times 100\%$, where M_{Eij}-i-e is the value of the simulated mass in the jth mode, indicated in the ND or calculated by the formula: $M_{Eij} = V_{Eij} \times \rho$,	1. Resistance stores are connected to the TV. The modes for temperature must comply with clause 14.1.2. 2. For each mode, three volume determinations are performed and the relative error of the HC is estimated when determining the volume of the coolant δ_{BV}: $\delta_{BV} = \frac{Vij - Vэij}{Vэij} \times 100\%$ 4. In each mode, three mass determinations are performed and the relative error of the TV is estimated when determining the mass δ_{BM} of the coolant: $\delta_{BM} = \frac{Mij - Mэij}{Mэij} \times 100\%$, where M_{Eij}-i-e is the value of the simulated mass in the jth mode, indicated in the ND or calculated by the formula: $M_{Eij} = V_{Eij} \times \rho$,

	where ρ is the density of the coolant. ρ at the appropriate values of temperature and pressure is determined according to the tables of the GSSD 98-86. If the error of the verified HC is commensurate with the error in determining the density of the coolant according to the above tables, then the equations given in MI 2412 are used to determine the density.	where ρ is the density of the coolant. ρ at the appropriate values of temperature and pressure is determined according to the tables of the GSSD 98-86. If the error of the verified HC is commensurate with the error in determining the density of the coolant according to the above tables, then the equations given in MI 2412-97 [18] are used to determine the density.
15.5 Determination of the HC error during conversion and calculation of the amount of heat and heat flow	1 – 2 – 3. The minimum value of the amount of heat Qmin recorded during the measurement in the set mode when checking the TV: $$Q_{min} \geq \frac{300 \times Q_{ц.мл.разр.}}{\delta_{BQ}}$$ 4. The relative error of the HC in determining the amount of heat δ_{BQ} is estimated by the formula: $\delta_{BQ} = \frac{Qij - Qэij}{Qэij} \times 100\%$ 5. The value of the amount of heat $Q_Э$, calculated over the time interval t for a verifiable heat meter consisting of a flow converter and two thermal converters: $Q_Э = M \times (h_1 – h_2)$, where h_1 and h_2 are the coolant enthalpy values in the supply and return pipelines according to MI 2412-97. 6. The heat amount Q_e, computed for the time interval t for a heat meter comprising two flow converters and two thermal converters, is determined by: $Q_Э = M_1 \times h_1 – M_2 \times h_2$ 7. If the composition of the verified heat meter includes thermostable resistors – cold water simulators (or set by the HC program), $Q_Э$: $Q_Э = M_1 \times (h_1 – h_X) - M_2 \times (h_2 – h_X)$, where h_X is the enthalpy of cold water. 8. In each mode specified in clauses 14.1.1, 14.1.2, three heat flux determinations are performed and the relative errors of the HC in determining the heat flux $\delta_{BФ}$ are estimated.: $\delta_{BФ} = \frac{Фij - Фэij}{Фэij} \times 100\%$	1. Electrical signals are applied to the input of the calculator, simulating the flow rate, volume, temperature and pressure of the coolant. 2. In each mode specified in clauses 14.1.1 and 14.1.2, three determinations of the amount of heat are performed, and the errors of the HC in determining the amount of heat are estimated depending on the completeness of the heat meter and the method of measuring the amount of heat. 3. The minimum value of the amount of heat Qmin recorded during the measurement in the set mode during HC verification procedures: $$Q_{мин} \geq \frac{300 \times Q_{ц.мл.разр.}}{\delta_{BQ}}$$ 4. The relative error δ_{BQ} of the HC in calculating the heat quantity is obtained from the formula: $\delta_{BQ} = \frac{Qij - Qэij}{Qэij} \times 100\%$ 5. The value of the amount of heat QЭ, calculated over the time interval t for a verifiable heat meter consisting of a flow converter and two thermal converters: $Q_Э = M \times (h_1 – h_2)$, where h1, h2 are the enthalpy of the coolant in the supply and return pipelines according to MI 2412-97 6. The value of the amount of heat $Q_Э$, calculated over the time interval t for a verifiable heat meter consisting of two flow converters and two thermal converters: $Q_Э = M_1 \times h_1 – M_2 \times h_2$ 7. If the composition of the verified heat meter includes thermostable resistors – cold water simulators (or set by the HC program), $Q_Э$: $Q_Э = M_1 \times (h_1 – h_X) - M_2 \times (h_2 – h_X)$, where h_X is the enthalpy of cold water. 8. In each mode specified in clauses 14.1.1, 14.1.2, three heat flux determinations are performed and the relative errors of the HC in determining the heat flux $\delta_{BФ}$ are estimated.: $\delta_{BФ} = \frac{Фij - Фэij}{Фэij} \times 100\%$
15.6 Determination of HC error when measuring time	They are performed if metrological characteristics are normalized for them, according to which the error of heat calculators can be determined.	They perform the ND according to the verification of specific HC sets.
15.7 Estimation of heat meter uncertainty	1. Carried out at the request of the applicants in accordance with the Guidelines on the expression of measurement uncertainty, Mendeleev VNIIM, St. Petersburg, 1999 and RMG 43. 2. The algorithm for calculating the uncertainty	-

	of measurements of the heat meter can be issued in the form of a report on the uncertainty of the measured value, the recommended form of which is given in appendix B.	
Registration of verification results	1. The measurement results obtained during verification are recorded in the protocol, the form (mandatory) of which is given in Appendix A. 2. If the verification results are positive, a verification certificate is issued in accordance with the form given in ST RK 2.4 and an impression of the verification stamp (label) is applied to the measuring instrument in accordance with [19]. 3. Seals with an impression of the verification stamp are placed in places that prevent access to the adjustment elements, the sealing places must comply with the requirements of the technical documentation. 4. In case of negative verification results, the heat meter is not allowed to be used and a notice of unsuitability is issued in accordance with the form given in ST RK 2.4.	1. The verification results are recorded in the verification protocol. 2. If the heat meter is recognized as suitable for use based on the verification results, then an impression of the verification stamp is applied to it and (or) the technical documentation and (or) a "Certificate of verification" is issued (the form of the “Certificate of Verification” is given in PR 50.2,006-94). 3. Seals with an impression of the verification stamp in accordance with the requirements of PR 50.2.007-94 are placed in places that prevent access to the adjustment elements. The sealing sites must meet the requirements technical documentation. 4. If the heat meter is found unsuitable for use based on the verification results, the impression of the verification stamp is extinguished, the “Verification certificate” is canceled, a “Notice of unsuitability” is issued in accordance with PR 50.2.006-94 or an appropriate entry is made in the technical documentation. 5. In case of negative verification results of heat meters, upon their release from production, they are returned to the manufacturer to eliminate defects with the possibility of being presented for re-verification.

After conducting a comparative analysis of the existing methods of checking heat meters, the following conclusions and recommendations can be drawn.

1. The National standard of the Republic of Kazakhstan takes into account all the features of the legislation of the Republic of Kazakhstan. While the MI conforms to the applicable legislation of the Russian Federation. Despite this, MI is allowed to be used, and is also actively used in verification laboratories in the territory of the Republic of Kazakhstan.

2. ST RK was developed on the basis of various methods of checking heat meters – “KM-5 Heat Meters. Verification Procedure”; “Heat Meters QALCOMETHEAT1. Verification Procedure”; “GSI. KST-22 Heat Meters. Verification Procedure IVKA.407281.004 MP”; “GSI. PRAMER Heat Meters-HEAT. The Method of Verification of the CCP.30.0000.000.00 MP”, which do not reflect the entire range of meters manufactured in the Republic of Kazakhstan. Therefore, there is a need to develop a national standard based on existing verification methods, covering all types of heat meters.

3. It is recommended to make changes and the supplementary amendments to the relevant national standard of the Republic of Kazakhstan due to the fact that the standard was issued in 2017 and was supposed to be revised in 2022, but there has been no revision of the standard for three years, and we also believe that there is no need to list measuring instruments that are not used in verification laboratories. However, there is a need to supplement the measuring instruments necessary to perform verification operations for heat meters with various modifications.

The measuring instruments listed in the national standard of the Republic of Kazakhstan for the verification of heat meters are mainly used for verification on non-automated installations, manually, without the use of information technology. In practice, in Kazakhstan, reference heat meters are not used when checking the heat meter. Their role is performed by automated installations with reference flow meters. The heat meter is checked using pulse generators, or using software built into the heat meter itself. Psychrometers are not used in calibration laboratories on the territory of the Republic of Kazakhstan to measure humidity and temperature, mainly VIT-1 psychrometric hygrometers with a range of readings (0-25)°C, with a scale division price of ± 0.2°C. The range of reproducible costs in the verification installation in the note to the "Verification tools" table could be left to the user's choice of methodology, since not every verification laboratory needs such a measurement range, it all depends on the scope of accreditation, as well as on the demand for verification of heat meters with different costs, mainly in the Republic of Kazakhstan – this is DN 15 and DN 32. In this case, it is sufficient to cover the measurement range of 1:3 expenses (the ratio of the standard expenses to the verified heat meter). Also in the note to the "Verification tools" table there is the following point – all verification tools must be verified and have valid verification certificates and/or impressions of verification stamps. Since 2019, due to changes in the legislation of the Republic of Kazakhstan "On Ensuring the Uniformity of Measurements", this note can be interpreted as follows. Since the verification tools are located and used in the verification laboratory, all verification tools must be calibrated and have valid calibration certificates.

The MI does not limit the measuring instruments used for verification. However, according to ST RK 2.63-2018 – "Methods of Verification of Measuring Instruments. The Procedure for Development, Approval and Application", in Kazakhstan, when developing a verification methodology, it is necessary to specify the measuring instruments used for verification.

4. The requirements for the qualifications of verifiers in the two regulatory documents are different. According to the requirements of ST RK 2.45, candidates holding a higher technical degree may be certified as verifiers even without prior professional experience in ensuring measurement uniformity. In contrast, individuals with non-technical higher education or secondary technical education must demonstrate at least two years of relevant work experience. Meanwhile, PR50.2.012-94 allows the attestation commission to admit, without additional specialized training, graduates of higher education institutions in metrology and measurement engineering who already possess practical experience in verification departments.

In Kazakhstan, when certifying verifiers, they are guided by the national standard and rules for certifying verifiers, therefore, the requirements described in the MI are not suitable for the Republic of Kazakhstan.

5. In the ST RK framework, verification intervals are defined individually for each heat meter type during its type approval or metrological certification, while in the MI system they are established from the test outcomes obtained for type-approval assessment. But in Kazakhstan, there are rules of the Committee for Technical Regulation and Metrology on the establishment of a single verification interval – Order No. 159-od "On Approval of a Single Verification Interval for Heat Meters" dated 05/12/2020, according to which a single verification interval of 4 years is established for heat meters.

Therefore, it is necessary to amend the national standard ST RK 2.447 in accordance with the KTRM Order dated 05/12/2020, because starting from this date there is a single verification interval for heat meters, since manufacturers set the verification interval according to this order when approving the type of measuring instruments.

6. In MI, compared with ST RK, they refer more to the regulatory document for the verification of the heat meter, in ST RK there are clarifications or a reference to the operational document of the thermal energy meter. This results from the situation that, within the jurisdiction of the Russian Federation, the manufacturer develops its own regulatory document for each type of heat meter. While across the national territory of the Republic of Kazakhstan we can use both a national standard or an interstate standard introduced in the Republic of Kazakhstan for verification of any measuring instrument, it is not necessary to develop a verification methodology for a specific type of product if all the necessary conditions for verification of this type of product are met in the selected ST RK or GOST.

7. At the point of determining the error in measuring the amount of heat in the ST RK, Gnom is used – the nominal flow rate of the coolant, in MI – GP – the value of the transient flow rate of the coolant.

8. The national standard does not specify the year of issue of the reference normative documents

throughout the text, therefore, when using this methodology, we can use an updated version of the reference documents. However, there are clarifications in MI, for example: to determine the density of the coolant, the equations given in MI 2412-97 are used; verification of resistance thermal converters in ST RK in accordance with GOST 8.461, MI – GOST 8.461-82.

9. When determining the error of the TV during conversion and calculating the amount of heat and heat flow in the MI, there are the following verification points. At the calculator input, electrical signals reproducing the coolant's flow rate, volume, temperature, and pressure characteristics are introduced. For each mode defined in clauses 14.1.1 and 14.1.2, three successive heat-quantity measurements are performed, and the resulting TV errors are determined with regard to both the meter's completeness and the selected method for calculating heat quantity. There are no such verification points in the ST RK.

When making changes and additions to the ST RK, it is necessary to add this verification point, since the heat meter is one of the components of the heat meter, which must also undergo the verification procedure, usually this happens using signals simulating the flow rate, volume, temperature and pressure of the coolant, as specified in MI 2573.

10. The ST RK specifies an assessment of the uncertainty of measurements, it is carried out at the request of applicants in accordance with [20], [21], there is a recommended form for calculating uncertainty. There is no information in the MI about the estimation of the uncertainty of the heat meter measurements.

When assessing the uncertainty of measurements in the ST RK, the following regulatory documents can be supplemented: ST RK 2.317-2015 "The State System for Ensuring the Uniformity of Measurements of the Republic of Kazakhstan. Expression of Uncertainty and Reliability of Mmeasurement Results" and procedural documents on the expression of measurement uncertainty of the national accreditation body.

Conclusion

As a result of the conducted research, a comparative assessment of two methods of verification of heat meters was carried out: ST RK 2.447-2017 and MI 2573-2000. The analysis showed that both methods are designed to maintain measurement accuracy and reliability of thermal energy in water heating systems. However, the national standard ST RK 2.447-2017 takes into account more relevant requirements for metrological characteristics and applies improved verification methods in the Republic of Kazakhstan. At the same time, MI 2573-2000 remains an important document, as it contains time-tested approaches and measurement principles in the CIS countries.

Despite the existence of the verification methodology for heat meters described in ST RK 2.447-2017, there is a need to develop a new or improved ST RK for heat meters, which would cover all the recommendations listed in the analysis of the methods. The technique will optimize the verification process, reduce time and material costs, and improve the accuracy and reproducibility of measurements. The introduction of the improved ST RK into the activities of domestic manufacturing enterprises and accredited calibration laboratories in Kazakhstan will substantially improve the competitiveness of national instrument engineering and contribute to more effective monitoring of thermal energy consumption.

Thus, the technical thermal-energy metering system in the Republic of Kazakhstan can be considered as an open evolving system, subject to both internal factors (changes in regulatory requirements, modernization of metering devices) and external (introduction of international practices, transition to digital and intelligent technologies). The development and implementation of an improved verification methodology for heat meters with elements of data mining reflects the natural development of an open system striving to improve accuracy, adaptability and sustainability. This approach is in line with current trends in integrating metrological processes into broader cyber-physical and energy systems.

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