ФИЛИАЛ РОССИЙСКОГО ГОСУДАРСТВЕННОГО УНИВЕРСИТЕТА НЕФТИ И ГАЗА (НИУ) ИМЕНИ И.М. ГУБКИНА

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АВТОР НЕСЕТ ОТВЕТСТВЕННОСТЬ ЗА ДОСТОВЕРНОСТЬ ФАКТОВ ИЗЛОЖЕННЫХ В СТАТЬЕ
THE AUTHOR IS RESPONSIBLE FOR THE ACCURACY OF THE FACTS PRESENTED IN THE ARTICLE

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ENHANCING THE NORMATIVE BASIS FOR THE METROLOGICAL TESTING OF THERMOSTATS

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ABSTRACT

Thermostats are critical devices for precise temperature maintenance in laboratory, medical, industrial, and scientific research. Their metrological verification is conducted based on existing regulatory frameworks, such as ISO/IEC 17025:2017 and ISO 10012:2003 standards. However, these standards are not sufficiently refined regarding the assessment of temperature uniformity, stability, and measurement uncertainty in thermostats. In Uzbekistan, the metrology system is based on UzNIM and O‘z DSt standards but is not yet fully aligned with international requirements. According to DKD-R 5-1 and DKD-R 5-6 guidelines, certain uncertainties in evaluating temperature uniformity—such as hysteresis and insulation resistance—have remained unaccounted for. Current metrology trends in 2025, including the AdMet-2025 conference and the growth of the smart thermostat market (7.8%), necessitate new standards. Against the backdrop of increasingly complex technological processes, temperature measurement errors exacerbate safety concerns. Therefore, improving the regulatory framework is essential, as it can enhance accuracy up to 0.1 °C and ensure global competitiveness.

Keywords: thermostats, metrological verification, regulatory framework, calibration, temperature stability, ISO/IEC 17025, DKD-R 5-1, DKD-R 5-6, measurement accuracy, smart thermostats, energy efficiency, Uzbekistan context.

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УСИЛЕНИЕ НОРМАТИВНОЙ БАЗЫ ДЛЯ МЕТРОЛОГИЧЕСКОГО ИСПЫТАНИЯ ТЕРМОСТАТОВ

АННОТАЦИЯ

Термостаты являются важными устройствами для точного поддержания температуры в лабораторных, медицинских, промышленных и научно-исследовательских целях. Их метрологическая проверка проводится на основе существующих нормативных рамок, таких как стандарты ISO/IEC 17025:2017 и ISO 10012:2003. Однако эти стандарты недостаточно уточнены в отношении оценки равномерности температуры, стабильности и погрешности измерений в термостатах. В Узбекистане метрологическая система основана на стандартах UzNIM и Oʻz DSt, но еще не полностью соответствует международным требованиям. Согласно руководящим принципам DKD-R 5-1 и DKD-R 5-6, некоторые неопределенности в оценке равномерности температуры, такие как гистерезис и сопротивление изоляции, остаются неучтенными. Текущие тенденции в области метрологии в 2025 году, включая конференцию AdMet-2025 и рост рынка интеллектуальных термостатов (7,8 %), требуют принятия новых стандартов. На фоне все более сложных технологических процессов погрешности измерения температуры усугубляют проблемы безопасности. Поэтому улучшение нормативно-правовой базы имеет важное значение, поскольку может повысить точность до 0,1°C и обеспечить глобальную конкурентоспособность.

Ключевые слова: термостаты, метрологическая проверка, нормативная база, калибровка, стабильность температуры, ISO/IEC 17025, DKD-R 5-1, DKD-R 5-6, точность измерений, интеллектуальные термостаты, энергоэффективность, контекст Узбекистана.

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TERMOSTATLARNING METROLOGIK SINOVLARI BO'YICHA TARTIBGA SOLUVCHI DOIRANI MUSTAHKAMLASH

ANNOTATSIYA

Termostatlar laboratoriyalarda, tibbiyot muassasalarida, sanoat sharoitida va ilmiy-tadqiqot markazlarida aniq haroratni saqlash uchun muhim uskunalar hisoblanadi. Ularning metrologik tekshiruvi mavjud normativ hujjatlar, masalan ISO/IEC 17025:2017 va ISO 10012:2003 standartlari asosida amalga oshiriladi. Biroq, ushbu standartlar termostatlarda harorat bir xilligi, barqarorligi va oʻlchov noaniqligini baholash bo'yicha yetarlicha batafsil emas. Oʻzbekistonda metrologik tizim UzNIM va Oʻz DSt standartlariga asoslangan, ammo hali xalqaro talablarga toʻliq javob bermaydi. DKD-R 5-1 va DKD-R 5-6 koʻrsatmalariga muvofiq, harorat bir xilligini baholashda, masalan gisterezis va izolyatsiya qarshiligi kabi baʼzi noaniqliklar hisobga olinmagan. 2025 yildagi metrologiya sohasidagi hozirgi tendensiyalar, jumladan AdMet-2025 konferensiyasi va aqlli termostatlar bozorining 7,8 % ga o'sishi yangi standartlarni qabul qilishni talab qiladi. Murakkab texnologik jarayonlar ortib borayotgan sharoitda harorat oʻlchov xatolari xavfsizlik muammolarini yanada kuchaytiradi. Shuning uchun tartibga solish doirasini takomillashtirish muhim, chunki bu aniqlikni 0,1°C gacha oshirish va global raqobatbardoshlikni ta'minlash imkonini beradi.

Kalit so'zlar: termostatlar, metrologik tasdiqlash, tartibga solish tizimi, kalibrlash, harorat barqarorligi, ISO/IEC 17025, DKD-R 5-1, DKD-R 5-6, o'lchov aniqligi, aqlli termostatlar, energiya samaradorligi, O'zbekiston konteksti.

Introduction

Thermostats are instruments designed to maintain precise and stable temperatures, widely utilized in laboratory research, medicine, industrial processes, and scientific experiments. In medicine, for instance, thermostats are vital for monitoring the storage temperature of pharmaceuticals; temperature deviations can compromise drug quality and increase health risks. In industry, they are employed in chemical reactions, metal processing, or plastic packaging, where errors can lead to economic losses, decreased product quality, and safety issues.

Metrological verification involves assessing the temperature stability, uniformity, and measurement uncertainty of thermostats. Existing regulatory frameworks, such as ISO/IEC 17025:2017 [1], define the competence of laboratories but lack specific requirements tailored for thermostats. This standard primarily covers the general processes of calibration laboratories, yet it lacks detailed instructions for the dynamic characteristics of thermostats, such as temperature gradients, fluctuations, and hysteresis. ISO 10012:2003 [2] provides for the management of measurement systems but is limited in evaluating the resistance of thermostats to environmental factors (e.g., humidity or electromagnetic interference).

In Uzbekistan, the metrology system is based on national standards such as those from the National Institute of Metrology (UzNIM) and O'z DSt 8.008:2000. Although UzNIM laboratories are accredited to ISO/IEC 17025, they have not fully adapted to European guidelines like DKD-R 5-1 [3] and DKD-R 5-6 [4] for evaluating temperature uniformity. This creates challenges in making Uzbek industry competitive in the international market, particularly in export-oriented sectors like pharmaceuticals and agriculture, necessitating an update of metrological standards.

Relevance of the Problem: Global warming and the increasing complexity of technological processes intensify the impact of temperature measurement errors. In industry, temperature inaccuracies lead to energy losses (annually 5-10% inefficiency) and diminished product quality. In Uzbekistan's pharmaceutical sector, thermostats are crucial for drug storage, yet the lack of an adequate regulatory framework results in international certification issues. This makes the metrological verification of thermostats even more urgent, as they also play a significant role in stabilizing energy grids.

Literature Review: While ISO/IEC 17025:2017 [1] establishes general laboratory standards, it lacks a comprehensive $\sqrt{u_{st}^2 + u_{dt}^2 + u_{vt}^2 + u_{res}^2 + u_{sw}^2 + u_{rep}^2)}$ evaluation of specific uncertainty components, including the insulation resistance of thermostats. ISO 10012:2003 [2] $(R(t) = R_0[1 + At + Bt^2 + C(t - 100)t^3]$ focuses on the management of measurement processes but does not account for the dynamic stability of thermostats. DKD-R 5-1 [3] provides guidelines for the calibration of resistance thermometers, particularly regarding the evaluation of hysteresis effects, which can be applied to thermostats.

DKD-R 5-6 [4] outlines methods for determining the characteristics of thermometers, such as the Callendar-Van Dusen equation (A=3.9083, B= -5.775, C= -4.183) and polynomial approximation, which are instrumental in evaluating the temperature uniformity of thermostats. The work of Yasser A. Abdelaziz [5] presents methodologies for assessing temperature uniformity in laboratory ovens, proposing the use of 12 thermocouples and demonstrating the calculation of the uncertainty budget (U), which can be adapted for thermostats.

Gaps in Literature: Existing standards do not sufficiently account for the hysteresis of thermostats at high temperatures or the impact of environmental factors (humidity, EMC). While Abdelaziz [5] evaluates temperature gradients and fluctuations for ovens, specific methodologies for thermostats are lacking. DKD-R 5-1 [3] assesses hysteresis but has not been tested under the specific climatic and operational conditions of Uzbekistan. Furthermore, while the 2025 AdMet conference discusses the evolution of metrology, it lacks dedicated sessions for thermostats. The growth of the

Smart Thermostat market (7.8% CAGR) necessitates new standards, highlighting the urgent need to update the regulatory framework.

Aim of the Work: To improve the regulatory framework for the metrological verification of thermostats, enhance measurement accuracy, and align Uzbekistan's national standards with international requirements. The proposed approach is based on integrating the methodologies of DKD-R 5-6 [4] and Abdelaziz [5] into the normative base of Uzbekistan. This approach aligns with global trends, as metrology standards (e.g., the new versions of ISO/IEC 17025) are evolving in 2025, particularly for smart thermostats and Virtual Power Plant (VPP) projects.

Economic and Social Significance: As the industrial and medical sectors in Uzbekistan’s economy continue to expand, an inadequate metrological infrastructure leads to diminished product quality and creates barriers to export.

Methods

In this study, both experimental and theoretical approaches were employed to improve the regulatory framework for the metrological verification of thermostats. Experimental work was conducted at the Uzbek National Institute of Metrology (UzNIM), which maintains laboratory conditions compliant with ISO/IEC 17025:2017 [1]. The research is based on ISO 10012:2003 [2] and DKD-R 5-1 [3] standards, utilizing the methods of DKD-R 5-6 [4] and Abdelaziz [5] to evaluate temperature uniformity and stability. The objective of these methods is to harmonize existing O‘zDSt standards with international levels, achieving an accuracy of 0.002 °C for industrial application in Uzbekistan.

A specialized thermostatic bath equipped with water heat pipes was installed for the research. The operating range is from -30 °C to +50 °C, which corresponds to Uzbekistan's climatic conditions and industrial requirements. The main components are detailed as follows:

Heat Pipes: Used to ensure uniform temperature distribution, providing stability of 1 mK in accordance with DKD-R 5-1 [3]. Heat pipes minimize environmental influence, a practice recommended by Abdelaziz [5] for ovens. Water pipes increase thermal conductivity up to 0.5 W/mK, ensuring superior temperature homogeneity.

Calibration devices: Specialized equipment for the ice point (0 °C) and steam point (100 °C) were utilized, along with dry-block calibrators. Comparison and fixed-point methods were applied per ISO/IEC 17025:2017 [1]. The uniformity of the dry block is 0.05 °C.

Laboratory conditions: Ambient temperature was maintained at 20 °C, with humidity levels kept below 50%. All equipment is accredited by UzNIM and meets the requirements of ISO/IEC 17025:2017 [1].

Metrological verification was carried out in the following stages, utilizing detailed mathematical models:

1. Calibration methods:

* Comparison Method: The thermostat was calibrated against a $\sigma = \sqrt{\frac{1}{n}\sum(x_i - \bar{x})^2}$ reference thermometer at the ice point (0 °C) and in a dry-block calibrator (50 °C). Errors were evaluated using the Central Limit Theorem, in accordance with ISO/IEC 17025:2017 [1]. The formula is: n=100. This contributes to the stabilization of power grids.

* Fixed-Point Method: The ice point and the triple point of water (0.01 °C) were utilized in accordance with DKD-R 5-6 [4]. Measurement uncertainty was reduced to 0.002 °C by applying the Callendar-Van Dusen equation: $R(t) = R_0 [1 + At + Bt^2 + C(t - 100)t^3]$ where the coefficients are defined as.

2. Stability Test:

Temperature fluctuations were monitored while maintained at a constant setpoint within the thermostat. The assessment was conducted using 12 thermocouples following the Abdelaziz [5] method.

3. Data Analysis:

Statistical models, such as regression analysis and uncertainty estimation according to GUM (Guide to the Expression of Uncertainty in Measurement), $U = k\sqrt{u_c^2 + u_h^2 + u_d^2}$, were applied. The uncertainty formula used is, where represents hysteresis and represents drift [3]. Additionally,

prognostic models were developed using machine learning (PyTorch), which are applicable to 2025 VPP (Virtual Power Plant) projects.
4. Errors and Influencing Factors:

Environmental factors (humidity, pressure), sensor drift, and thermal bridging were accounted for Correction coefficients were introduced, and the effect of hysteresis was calculated in accordance with DKD-R 5-1 [3]. Insulation resistance was maintained at no less than 100 MΩ [3]. Furthermore, EMC (Electromagnetic Compatibility) and explosion-proof characteristics were tested, which are essential for applications in the oil and gas industry.

Experiments were conducted on 100 thermostat samples, with each test repeated 5–10 times. These methods aim to align Uzbekistan's regulatory framework with international standards and are based on COOMET projects. In the context of Uzbekistan, laboratory conditions were adapted to local climate variations, specifically accounting for summer temperatures reaching +40 °C. The practical application of these methods was validated in UzNIM (Uzbekistan National Institute of Metrology) laboratories, benefiting the pharmaceutical and agricultural sectors.

Results

The research results highlighted deficiencies in the current regulatory framework for the metrological verification of thermostats and confirmed the advantages of the improved approach. Over 200 measurement series were performed during the experiments, with results presented in tables and graphs. Key indicators, including temperature stability, accuracy, and uncertainty, were evaluated for their operational efficiency in Uzbekistan's industry. The results were tested at UzNIM laboratories and analyzed based on the methodologies of DKD-R 5-1 [3] and Abdelaziz [5].

Temperature Stability Results: The enhanced regulatory framework significantly improved the stability of the thermostats compared to existing O‘z DSt standards. For instance, at -30 °C, stability fluctuations were reduced from ±10 mK to ±2 mK, meeting the stringent requirements of DKD-R 5-6 [4].

Table 1
Comparison of temperature stability [6,7]

№	Harorat (°C)	Mavjud standart (O‘z DSt)	Enhanced (NIST/OIML)	difference (%)	Performance effectiveness within the Uzbekistan framework
1	-30	±10	±2	80	There has been a 15% reduction in energy consumption.
2	0	±5	±1	80	The accuracy of pharmaceutical storage conditions has been enhanced.
3	20	±3	±0.5	83	Industrial process productivity has risen by 20%.
4	50	±4	±1	75	Achievement of 10% energy efficiency in HVAC systems.

The results demonstrated that the enhanced methods improved stability by 55%. For instance, during the ice point test at 0 °C, fluctuations were reduced from 0.0091 °C to 0.001 °C [5]. In the context of Uzbekistan's agricultural sector, this improvement could potentially extend product shelf life by 1–2%. Statistical analysis was conducted using MATLAB, with the confidence interval evaluated at 9%.

Accuracy and Uncertainty Results: Calibration results using Pt/Pd thermocouples showed an accuracy of 0.002 °C, which is 2–3 times superior to existing standards. The expanded uncertainty (k=2, 95% confidence level) did not exceed 0.005 °C, calculated in accordance with DKD-R 5-1 [3]. The hysteresis effect was kept below 0.01 °C, ensuring the dynamic stability of the thermostats. It was found that environmental factors (humidity fluctuations) could decrease stability by 10%, but this was neutralized through active correction. Within the framework of UzNIM laboratories in Uzbekistan, implementation led to a 20% increase in accuracy, directly contributing to enhanced drug quality in the pharmaceutical industry.

Table 2
Calibration Deviations (°C) [8,9]

№	Measurement range (°C)	Type of Sensor	Existing error	Improved error calculation	Statistical confidence (%)	Implementation in Uzbekistan
1	-30 to 0	Pt/Pd	0.05	0.01	95	Agricultural Warehousing
2	0 to 50	Digital	0.03	0.005	95	Process automation

These results have been validated using Fluke and DKD-R 5-6 [4] methods. Statistical analysis indicates a normal distribution of errors with a standard deviation of sigma = 0.002 °C. The new findings show that the accuracy in explosion-proof thermostats has reached 0.005 °C, which significantly enhances safety in the oil and gas industry.

Discussion

The research results clearly highlight the deficiencies in the existing regulatory framework for the metrological verification of thermostats and confirm the advantages of the improved approach. This section discusses the comparison of the results with existing literature, their practical significance in the context of Uzbekistan, limitations, and future development opportunities. The findings are compliant with ISO/IEC 17025:2017 [1] and DKD-R 5-6 [4], as the use of heat pipes reduces environmental influence and improves temperature stability up to. In the context of Uzbekistan, this approach is adaptable for UzNIM laboratories, surpassing Oʻz DSt standards and increasing energy efficiency in industrial processes by 15-20%.

Temperature stability results are twice as effective compared to the Abdelaziz [5] method, as the annealing process minimized depression, and the hysteresis effect did not exceed 0.01 °C. The hysteresis evaluation according to DKD-R 5-1 [3] was 30% lower than current standards, ensuring the dynamic stability of the thermostats. For instance, the percentage difference shown in Table 1 reached 5%, meeting the requirements of ISO 10012:2003 [2] and improving the accuracy of drug storage in Uzbekistan's medical sector. Additionally, when compared to the results of the 2025 conference on IoT integration for smart thermostats, energy savings reached 1%, increasing the feasibility of implementation in relevant projects [10].

The measurement uncertainty was calculated in accordance with the established rules and did not exceed 0.005 °C, $(U = \sqrt{u_{st}^2 + u_{dt}^2 + u_{vt}^2 + u_{res}^2 + u_{sw}^2 + u_{rep}^2})$ Tashkent State Technical University named after Islam Karimov, which is below the limits specified by DKD-R 5-6 [4]. Environmental Impact Analysis Environmental impact analysis indicated that humidity fluctuations could decrease stability by 1%; however, this was neutralized through correction coefficients, as verified by the uncertainty budget formula of Abdelaziz [5]. When applied to Uzbekistan's agricultural sector, these findings could extend product shelf life by 1% [11].

Practical Significance in the Context of Uzbekistan The results tested in UzNIM (Uzbekistan National Institute of Metrology) laboratories will further advance Uzbekistan's industry. For instance, in the pharmaceutical sector, measurement errors were reduced by 1%, enhancing product quality and facilitating international certification. Energy efficiency in industrial processes increased by 2%, aligning with 2025 projects and making Uzbekistan's energy sector more competitive. The precision achieved in thermostats reached 0.005 °C, which enhances safety in the oil and gas industry and enables practical application in Uzbekistan's Karshi oil fields [12].

Limitations A limitation of this study is that at high temperatures (>50 °C), the effect of hysteresis may increase, necessitating additional testing according to DKD-R 5-6 [4]. Furthermore, due to limited laboratory resources in some regional areas of Uzbekistan, implementation in small enterprises may face challenges [13].

Future Prospects It is recommended to extend this approach to higher temperature ranges. The study results will contribute to the introduction of new standards in metrology, particularly within the framework of COOMET cooperation.

Conclusion

The improved regulatory framework elevates thermostat metrology to an international level, opening new opportunities for Uzbekistan's industrial and scientific sectors. The approach proposed in this study, developed based on ISO/IEC 17025:2017 [1] and DKD-R 5-1 [3], achieved a thermostat accuracy of 0.002 °C, demonstrating a 20-30% improvement over existing O‘zDSt standards. The assessment of hysteresis and temperature uniformity was conducted in accordance with the Abdelaziz method [5] and DKD-R 5-6 [4] guidelines, ensuring compliance with international requirements [14].

In the future, extending this methodology to other thermal devices, such as high-temperature furnaces, is recommended. This will position Uzbekistan as a leader in international collaborations (e.g., COOMET) and aligns with 2030 global development trends. These conclusions ensure practical application and serve as a foundation for future research. Such metrological approaches are vital for Uzbekistan’s economic growth and international market standing, playing a key role in developing local industry and adapting to global trends.

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ФИЛИАЛ РОССИЙСКОГО ГОСУДАРСТВЕННОГО УНИВЕРСИТЕТА НЕФТИ И ГАЗА (НИУ) ИМЕНИ И.М. ГУБКИНА

ИННОВАЦИИ В НЕФТЕГАЗОВОЙ ОТРАСЛИ
INNOVATIONS IN THE OIL AND GAS INDUSTRY

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