Investigation of Changes in Main Error of Rotary Gas Meters during Their Operation

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Received: October 16, 2023. Revised: December 18, 2023. Accepted: December 21, 2023.

Abstract

The main error of rotary gas meters may change during their operation because of mechanical wear of the meter moving parts. Control of changes in metrological characteristics of meters is carried out during periodic metrological verifications. In this paper, an investigation of the change in a main error of rotary gas meters during their operation was carried out based on the results of their metrological verification. The paper considers the results of periodic metrological verifications of rotary gas meters in the laboratories of four gas distribution companies. According to the results of processing the metrological verification protocols, the correlation of the rotary gas meter error with the measured gas volume was confirmed. Based on processing the set of meter error values and the measured gas volume for each of the checked flowrate values, regression dependencies of the error of the meter on the measured gas volume were developed. By averaging the obtained regression dependencies, a generalized dependence of the systematic error of RG-250 rotary gas meter on the measured gas volume was developed. The regression dependencies make it possible to estimate the change in the main error of RG-250 gas meters according to its measured volume and to decide on their additional (out-of-plan) metrological verification. This makes it possible to detect in time gas meters operating with a significant systematic error, and therefore to eliminate this error.

Keywords: rotary gas meter; main error; metrological verification; gas volume; correlation coefficient.

1. Definition of the problem to be solved

Systematic errors in gas volume measurement are the significant reason for gas volume imbalance in gas transportation and gas distribution networks. Therefore, determining and reducing the systematic errors in gas volume measurement is one of the necessary conditions for reducing the gas volume imbalance [1]–[3].

According to the results obtained by the authors in [1], [2], additional errors that may occur during the operation of industrial gas meters are highlighted:

δ_{Vp_P} is the additional error of gas volume measurement under operating conditions caused by the deviation of the working gas pressure from the fluid pressure during the calibration (metrological verification) of the gas meter;

δ_{Vp_T} is the additional error of gas volume measurement under operating conditions caused by the deviation of the working gas temperature from the fluid temperature during the calibration of the gas meter;

δ_{Vp_air} is the additional error of gas volume measurement under operating conditions caused by a change in the calibration characteristic of the gas meter obtained in the air during its use for natural gas volume measurement;

$\delta_{Vp\_\Delta P}$ is the additional error of gas volume measurement under operating conditions caused by meter pollution and the corresponding change in the pressure drop on the gas meter;

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This paper should be cited as: F. Matiko, O. Pistun. Investigation of changes in main error of rotary gas meters during their operation. *Energy Engineering and Control Systems*, 2023, Vol. 9, No. 2, pp. 136 – 142. https://doi.org/10.23939/jeecs2023.02.136

δ_{Vp_M} is the additional error of gas volume measurement under operating conditions caused by improper installation of the meter and mechanical stresses in the meter's constructive elements;

δ_{Vp_L} is the additional error of gas volume measurement under operating conditions caused by the reduction of straight sections of measuring pipe upstream and downstream of the meter and the distortion of the flow kinematic structure upstream of the meter;

δ_{Vp_V} is the additional error caused by the wearing of the tachometric gas meter mechanism during its operation.

The additional errors in gas volume measurement that occur during the operation of industrial gas meters can have the most significant systematic effects [1]–[3]. Therefore, the task of this work is to investigate the change in the main error of rotary gas meters, which can also be considered as an additional error caused by the wearing of the mechanism of the rotary gas meter during its operation.

2. Analysis of the recent publications and research works on the problem

Additional errors in gas flowrate and volume metering devices have a direct impact on forming unaccounted gas volumes and gas volume imbalances [2]. Particularly, the research [2]–[4] shows that gas metering devices that operate for a long time in gas transportation or gas distribution networks can have systematic errors that lead to unaccounted gas volumes.

The main error of the gas meter is determined during its calibration and metrological verification, for which appropriate procedures have been developed [5]. The limits of the permissible main error are determined by the relevant regulatory documents, particularly for rotary gas meters by DSTU EN 12480:2019 [7]. However, even if the meter main error is within the limits defined by relevant documents, in particular [7], it may contain unexcluded systematic components. It is especially important to consider such unexcluded systematic errors when using gas metering systems in conditions of wide gas flowrate changes, which leads to the operation of gas meters in the range from minimum to transient flowrate [6].

In [9], an analysis of the main error of RG-100 rotary gas meters was carried out and it was confirmed that their main error is correlated with the measured gas volume. However, to consider these correlations when using gas meters as part of modern automated measurement systems based on microprocessor gas volume correctors, it is necessary to investigate such correlations for meters of other types.

3. Formulation of the goal of the paper

Therefore, the aim of this research is to carry out a statistical processing of the results of metrological verification of RG-250 rotary gas meters, based on which it is possible to determine the correlation between the change in the main error of these meters and the measured gas volume. If the correlation relationship is confirmed, the authors should develop regression dependencies of the gas meters' main error on the measured gas volume.

4. Investigation of changes in the main error of gas volume measurement under operating conditions caused by wearing the mechanism of rotary industrial gas meters

During the operation of gas meters, their metrological characteristics change because of many factors such as mechanical wearing of moving parts, pollution of the meter internal surfaces, and changes in the characteristics of lubricating materials. Control of changes in metrological characteristics of gas meters is carried out during periodic metrological verifications.

Metrological verification of industrial gas meters, in particular rotary gas meters, is carried out according to the requirements of DSTU 9034:2020 [8] and operational documentation. According to the operational documents, rotary gas meters are cleaned of dirt, washed and blown with air before the verification. Despite this, metrological verification shows that the metrological characteristics of some gas meters do not meet the requirements of DSTU 9034:2020. For example, the meter main error exceeds the permissible value. That is, the gas meter works for a certain part of the inter-verification interval (the interval between metrological verifications) in the mode of metrological failure and thus causes unaccounted gas losses [1], [9].

Determining the change in the main error of gas volume measurement under operating conditions caused by wearing the mechanism of tachometric industrial gas meters is based on the results of experimental studies of the metrological characteristics of industrial gas meters. Experimental studies were carried out as part of periodic metrological verification of industrial meters, which were carried out in gas supply enterprises. The authors developed a form of protocol for collecting data on the verification results and the gas volume values measured by the gas meters.

As mentioned above, periodic metrological verification of gas meters is carried out for meters that were preliminary prepared i.e., cleaned of dirt and dust and their internal surfaces were washed. That is, a clean meter is checked on a test unit under conditions close to normal during a periodic verification [8]. Therefore, according to the results of periodic metrological verification, it is possible to determine the change in the main error of the gas meter because of wearing-out of the mechanism of the industrial gas meter. At the same time, the change in the main error can be considered as an additional systematic error of the gas meter because of wearing-out of the tachometric meter mechanism.

The processing of the results of the periodic metrological verification of industrial gas meters confirms the additional systematic error in gas volume measurement by meters. The value of this negative error depends on the measurement principle of a specific device (rotor, turbine), the quality of the device, and operating conditions.

The authors carried out the statistical processing of data on periodic metrological verification of industrial gas meters obtained in the laboratories of gas distribution enterprises. Based on the results, we have determined the value of the additional error caused by wearing the rotary meter mechanism and the dependence of this error on the gas volume measured by the meter.

The gas volume measured by the meter characterizes the intensity of its operation and, accordingly, the degree of mechanical wear of its parts and the degree of the meter pollution. In addition, the total volume of gas measured by the meter for a certain period is a parameter that is determined by each operating meter and is stored in the archive of the corrector and does not require improvement of the existing flowrate and volume measurement systems.

The database on metrological verification of gas meters includes the protocols of meter verification at testing facilities in the laboratories of PJSC "Mykolaivgaz", "Dnipropetrovskgaz", "Zhytomyrgaz", "Khmelnytskygaz". In this way, a database of protocols for industrial gas meter verification (545 protocols) obtained in the laboratories of four gas distribution organizations was formed. The results of the metrological verification of meters are sorted by the types and sizes of meters.

At the first stage of processing the database of protocols, filtering was applied: protocols were excluded from the database, for which the value of the flowrate measurement error indicates a complete metrological failure of the meter, i.e. exceeds the permissible value by 10–100%. Based on the filtered base for each of the checked flowrate values Q_{min}, $0.2Q_{max}$, $0.5Q_{max}$, Q_{max}, a set $\boldsymbol{D} = \{\delta_{ij}\}$ of meter error values determined at the facility and a set $\boldsymbol{V} = \{V_j\}$ of the measured volume values before the meter verification was obtained. Particularly, for RG-250, RG-K-250 rotary gas meters, a set of error values for each ***i***-th flowrate value (i=1,2,3,4) and, accordingly, a set of the measured volume values contains 54 values (j=1,2,3 ... 54). The sets of pairs (V_j, δ_{ij}) formed for each ***i***-th flowrate are presented in Fig.1.

One can see from Fig.1, the set of points (V_j, δ_{ij}) obtained for each checked flowrate value indicates a probable relationship between the meter main error and the gas volume V calculated by this meter. The form of the correlation can be approximately determined by averaging the error value δ_{ij} at individual intervals of volume change. In this paper, the averaging of the error δ_{ij} in five sub-ranges (m=5) of the calculated volume is carried out (see Fig.1). Location of the averaged error points indicates that the dependence $\delta=f(V)$ is close to linear $y=a\cdot x+b$ for the flowrates Q_{min}, $0.2Q_{max}$, $0.5Q_{max}$. To quantify the correlation between the averaged values of the error δ_{ik} ($k=1... m$) and the averaged values of the measured volume V_k, the correlation coefficient r_i was calculated for each of the checked flowrate.

The authors have used a well-known dependence [10] to calculate the correlation coefficient r_i of the error and the measured volume:

$$r_i = \frac{\sum_{k=1}^{m}(x_k - \bar{x})(y_k - \bar{y})}{(m-1)\cdot S_x \cdot S_y} = \frac{\sum_{k=1}^{m}(\delta_{ik} - \bar{\delta}_i)(V_k - \bar{V})}{\sqrt{\sum_{k=1}^{m}(\delta_{ik} - \bar{\delta}_i)^2 \sum_{k=1}^{m}(V_k - \bar{V})^2}}, \quad (1)$$

where x, y are the sets of correlated values, which are identical to $x \equiv \delta$, $y \equiv V$; $\bar{x}$, $\bar{y}$ are the mean values of the set x

and y; S_x, S_y are the mean square deviations of values x and y, respectively; δ_{ik} is the error of the meters determined for the i-th value of the flowrate averaged over the k-th sub-range of the volume change; $\bar{\delta}_i$ is the mean value of errors δ_{ik}, obtained for i-th checked flowrate, $\bar{\delta}_i = \sum_{k=1}^{m} \delta_{ik} / m$; V_k is the mean value of gas volume in k-th sub-range; $\bar{V}$ is the mean value of gas volume V_k, $\bar{V} = \sum_{k=1}^{m} V_k / m$.

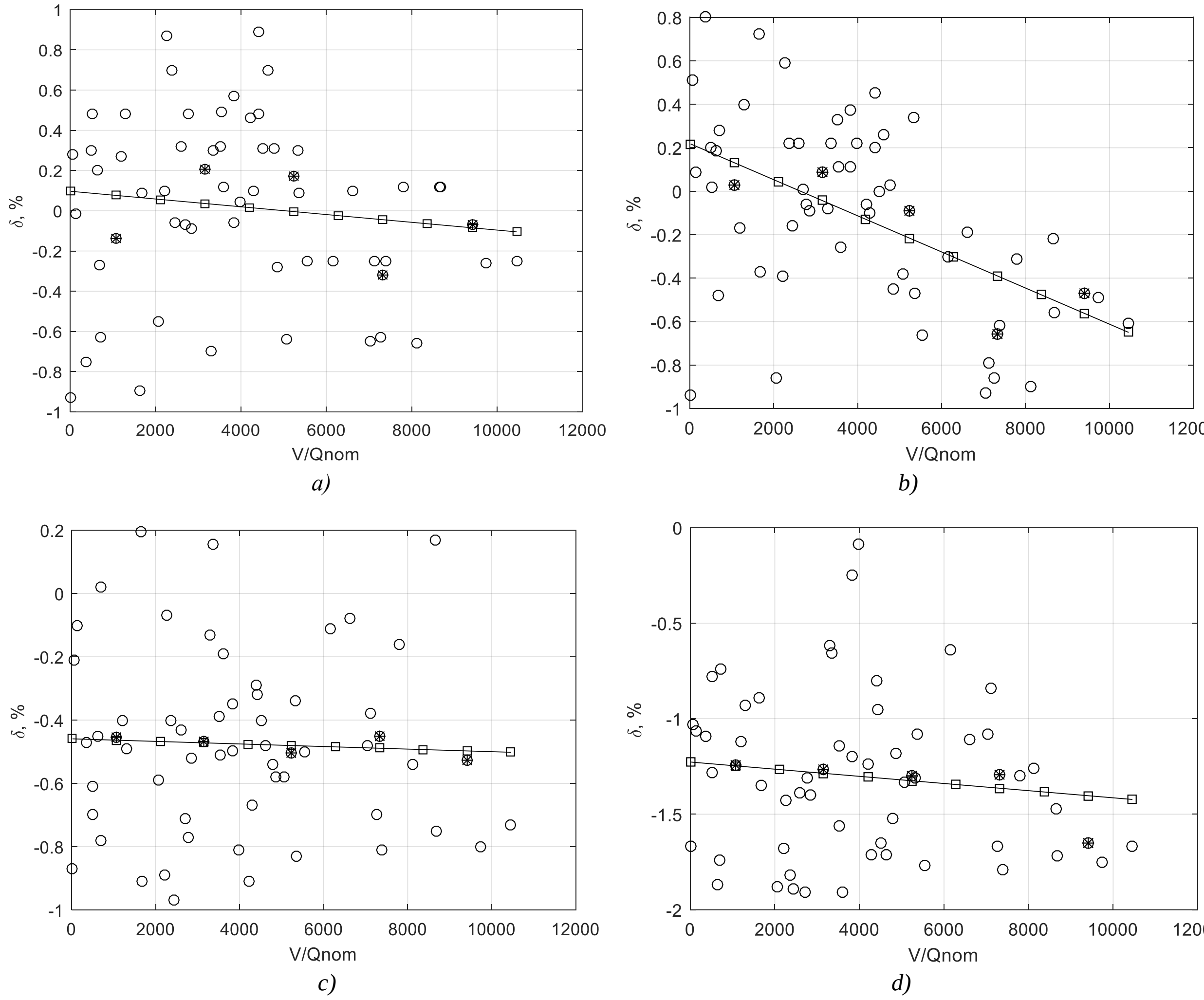


Fig.1. Analysis of the dependence of the error of RG-250, RG-K-250 rotary gas meters on the measured volume (readings) before metrological verification:
a) at the flowrate Q_{max}; *b)* at a flowrate $0.5Q_{max}$; *c)* at a flowrate of $0.2Q_{max}$; *d)* at the flowrate Q_{min};
o – data according to the meter verification protocol, ⊗ – average error value, □ – regression line.

The calculated values of the correlation coefficients are shown in Table 1. One can see from Table 1 that the correlation between the error δ and the volume V exists for all checked values of the flowrate, although for the flow Q_{max} the value of the correlation coefficient is much less by the modulus than 1 (see Table 1). However, this does not mean that there is no relationship between the meter error δ and the measured volume V for these flowrates. A larger set of errors and volume values should be collected to determine this dependence. We should also note here that the correlation coefficient is a measure of the linear relationship between values [10].

Table 1. Statistical characteristics of the dependence of the main error of RG-250, RG-K-250 gas meters on the measured volume.

i	Flowrate	Correlation coefficient of averaged error and volume, r_i	Mean square deviation of the averaged values δ_{ik}, $\sigma_{\bar{\delta}}$, %	Mean square deviation of the error δ_{ij}, σ_{δ}, %
1	Q_{max}	-0.276	0.20	0.44
2	0.5 Q_{max}	-0.842	0.29	0.38
3	0.2 Q_{max}	-0.601	0.03	0.29
4	Q_{min}	-0.783	0.15	0.43

Based on processing a set of points (V_j, δ_{ij}) for each of the checked flowrate, a regression dependence of the gas meter error on the measured volume for each flowrate is proposed:

$$\delta_1 = -1.931\cdot 10^{-5}\cdot V + 0.097, \text{ for } Q_{max}; \tag{2}$$

$$\delta_2 = -8.309\cdot 10^{-5}\cdot V + 0.2192, \text{ for } 0.5\, Q_{max}; \tag{3}$$

$$\delta_3 = -0.407\cdot 10^{-5}\cdot V - 0.4592, \text{ for } 0.2\, Q_{max}; \tag{4}$$

$$\delta_4 = -1.875\cdot 10^{-5}\cdot V - 1.2268, \text{ for } Q_{min}, \tag{5}$$

where $V = v/Q_{nom}$, v is the measured volume, m^3; Q_{nom} is the nominal flowrate for the corresponding gas meter (Q_{nom} = 250 m^3/h).

The coefficients of equations (2)–(5) are obtained by the method of least squares. The dependencies (2)–(5) are presented graphically in Fig.2. As can be seen from equations (2)–(5), the regression dependencies obtained by the method of least squares have negative coefficients a_i, which shows an increase in the modulus of the negative error with an increase in the gas volume measured by the meter for all four checked flowrates (Q_{min}, 0.2Q_{max}, 0.5Q_{max}, Q_{max}). That is, the rotary gas meter of the considered type after measuring some volume can have a negative error in the whole measuring range of gas flowrate. To characterize the change in the main error of the gas meter not for a certain flowrate, but for the whole range of metering device, the general dependence of the error on the measured volume was obtained by averaging the dependencies for the four checked flowrate values.

Averaging is performed based on weighting factors, the values of which correspond to the relative values of the flowrate. The weighting factor is equal to 1 for flowrate Q_{max}, 0.5 for flowrate 0.5 Q_{max} , 0.2 for flowrate 0.2 Q_{max}, and the average ratio Q_{min}/Q_{max} for the analyzed set of gas meters for flowrate Q_{min}. Thus, the average dependence of the error of gas meters RG-250 on the measured volume will look like:

$$\delta = A\cdot V + B, \tag{6}$$

where $A = \sum_{i=1}^{4}(k_i \cdot a_i) \Big/ \sum_{i=1}^{4} k_i$, $B = \sum_{i=1}^{4}(k_i \cdot b_i) \Big/ \sum_{i=1}^{4} k_i$; a_i, b_i are the coefficients of the regression equation for the i-th flowrate; k_i are the weighting factors, k={k_{min}, 0.2, 0.5, 1.0}.

The value of the k_{min} is determined for the investigated set of gas meters based on the values of the minimum flowrate:

$$k_{\min} = \frac{\sum_{j=1}^{N} Q_{\min.j} / Q_{\max.j}}{N} = 0.0877, \tag{7}$$

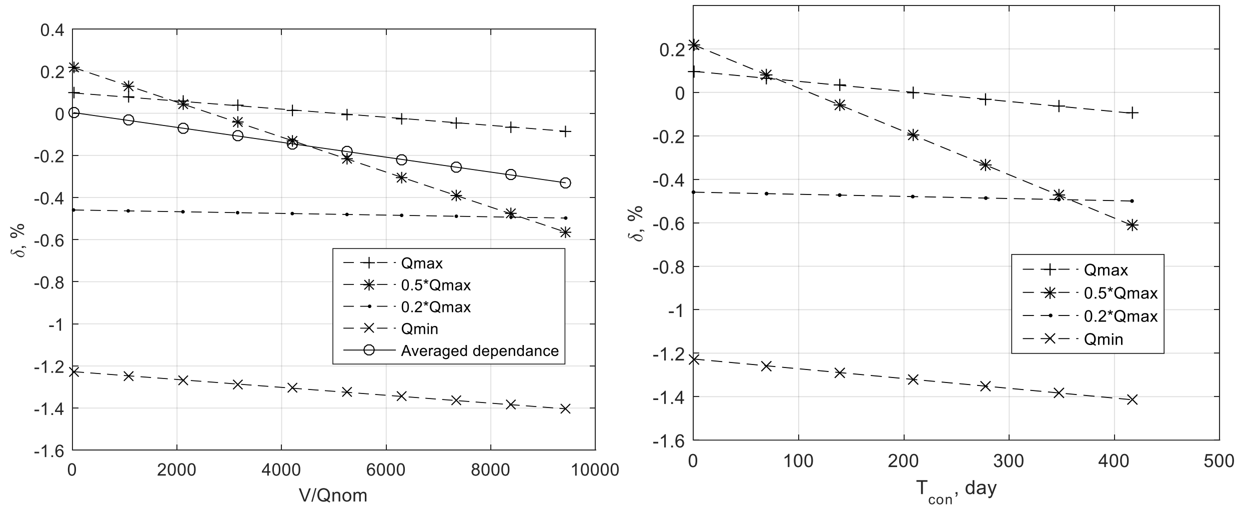
where V is the relative measured volume, $V = v/Q_{nom}$.

So, the average dependence for gas meters RG-250, RG-K-250 is as follows:

$$\delta = -3.5414\cdot 10^{-5}\cdot V + 0.004. \tag{8}$$

Regression dependencies of the error of rotary gas meters RG-250, RG-K-250 on the measured volume for the specified values of flowrate and the averaged dependence (8) are presented in Fig.2.

Figure 2,*a* and formula (8) show that the average dependence of the error of gas meter RG-250, RG-K-250 on the measured volume has a negative coefficient $a_i = -3.5414\cdot 10^{-5}$ %. That is, the non-excluded systematic error of these meters has a constant component $\delta_{const} = b_i = 0.004$ % and progressive component $\delta_{progr} = (-3.5414\cdot10^{-5}\cdot V)$ %. The value of the progressive component depends on the intensity of the meter's operation, namely on the value of the measured volume.



a) *b)*

Fig.2. Dependencies of the error of gas meter RG-250, RG-K-250:
a) on the measured gas volume; *b)* on the conventional operating time of gas meter.

The obtained dependencies of gas meter error on the measured gas volume make it possible to estimate the main error of the meter based on the measured volume and, accordingly, to decide on its additional (out-of-plan) verification. To estimate the time interval during which the main error of the gas meter can reach the limit value, the calculation of the meter error was carried out according to dependencies (2)–(5) for the conventional operating time of the meter. Here, we consider the nominal operating time T_{con} of meter is the time of operation at nominal flowrate. That is, 1 hour of conventional time for RG-250, RG-K-250 is equal to 250 m^3 of the measured gas volume, respectively, 1 conventional day is equal to 6000 m^3 of the measured gas volume.

Let us estimate from Figure 2,*b* the conventional time during which the error of RG-250 rotary meters, calculated according to dependencies (2)–(5), reaches the limit value determined by DSTU EN 12480:2019 [6]. According to [7], the limits of the maximum permissible error for rotary gas meters with accuracy class 1.0 equals to:

$$\begin{aligned} &\pm 2.0\ \%\ \text{for flowrate from the range}\ Q_{min} \le Q \le Q_t\,; \\ &\pm 1.0\ \%\ \text{for flowrate from the range}\ Q_t \le Q \le Q_{max}. \end{aligned} \qquad (9)$$

As can be seen from Figure 2, the change in the meter error at the flowrate of $0.5Q_{max}$ is the most critical since the progressive error for this flowrate $\delta_2 = (-8.309\cdot10^{-5}\cdot V)$ is the highest. However, during the 400 conventional days (time of operation at the nominal flowrate), the error for the flowrate of $0.5Q_{max}$ reaches –0.6%, which is less than the limit value of ±1.0%.

The comparison of the research results presented in this paper and in [9] show that both the constant and progressive errors for RG-250 meters are significantly less than these errors for RG-100 meter. That is, the change in the main error during the operation of RG-250, RG-K-250 meters is not as significant as for RG-100.

In particular, the main error does not go beyond the limits defined in [7] during the 1 conventional year of gas meter operating. However, within 200 conventional days, the error for all flowrates becomes negative, i.e., even when operating in the whole flowrate range, RG-250, RG-K-250 gas meters can undercount a certain amount of gas, which can also be the reason for their additional (out-of-plan) metrological verification.

5. Conclusion

The following conclusions are made based on the research results:

1) The main error of the rotary gas meter and the measured volume are correlated values. The significance of the correlation coefficients for the checked flowrate $0.5Q_{max}$, $0.2Q_{max}$, Q_{min} was confirmed. To confirm the correlation for all flowrate values, it is necessary to increase the set size of gas meter verification results.

However, it should be noted that research results represent the properties of a separate group of gas meters for which the results of the metrological verification were obtained.

2) Based on the processing of the experimental data obtained by metrological verification of RG-250 rotary meters, a regression dependence of the gas meter error on the measured volume was obtained for each of the checked flowrates. It was established that these gas meters have a systematic error with a negative sign that cannot be excluded, which has constant and progressive components.
3) The obtained regression dependencies of the meter error on the measured volume of gas make it possible to evaluate the change in the main error of RG-250 gas meters based on its measured volume and, accordingly, to decide on its additional (out-of-plan) metrological verification. This makes it possible to select gas meters that work with a significant systematic error, and therefore to eliminate this error and reduce the unaccounted gas volume.

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Дослідження зміни основної похибки роторних лічильників газу під час їх експлуатації

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Анотація

У цій роботі виконано дослідження зміни основної похибки роторних лічильників під час їх експлуатації на основі опрацювання результатів їх метрологічної перевірки. Розглянуто результати періодичної метрологічної перевірки роторних лічильників газу у лабораторіях чотирьох газорозподільних підприємств. За результатами опрацювання протоколів метрологічної перевірки підтверджено кореляцію похибки роторного лічильника газу з виміряним об'ємом газу. На основі опрацювання множини значень похибки лічильника та виміряного об'єму газу для кожного із перевірюваних значень витрати побудовано регресійні залежності похибки середньостатистичного лічильника від виміряного об'єму газу. Шляхом усереднення отриманих регресійних залежностей отримано узагальнену залежність систематичної похибки роторного лічильника газу типорозміру РГ-250 від виміряного об'єму газу. Отримані регресійні залежності дають можливість оцінити зміну основної похибки лічильників типорозміру РГ-250 за його виміряним об'ємом і, відповідно, прийняти рішення про виконання їх позачергової метрологічної перевірки. Це дає змогу своєчасно виявляти лічильники, які працюють із значною систематичною похибкою, а отже й усувати цю похибку.

Ключові слова: роторний лічильник газу; основна похибка; метрологічна перевірка; об'єм газу; коефіцієнт кореляції.