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МЕТРОЛОГІЯ, СТАНДАРТИЗАЦІЯ І СЕРТИФІКАЦІЯ

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O. Pistun,
F. Matiko, DSc., Prof.
Lviv Polytechnic National University, 12 S. Bandery Str., Lviv, Ukraine, 79013, e-mail: fedir.d.matiko@lpnu.ua

INVESTIGATING THE DEPENDENCIES OF ROTARY GAS METERS ERROR ON FLOWRATE FOR DESIGNING THE ADAPTIVE MEASUREMENT SYSTEM

О. Пістун, Ф. Матіко. **Дослідження залежностей похибки роторних лічильників газу від витрати з метою реалізації адаптивної системи вимірювання.** У цій роботі виконано дослідження похибки вимірювання витрати газу за допомогою роторних лічильників газу на основі результатів експериментальних досліджень метрологічних характеристик роторних лічильників газу, отриманих під час їх періодичної метрологічної перевірки. За результатами статистичної обробки значень похибки роторних лічильників газу, отриманих під час їх метрологічної перевірки, визначені усереднені значення похибки для кожного перевірюваного значення витрати. Таким чином отримано залежності усередненої похибки лічильника від вимірюваного значення витрати для різних типорозмірів роторних лічильників газу. Для кожної отриманої залежності обчислено значення середньоквадратичного відхилення усередненого значення похибки, яке підтверджує адекватність отриманих залежностей. Для оцінювання інтегральної систематичної похибки лічильників кожного окремого типорозміру за тривалий період експлуатації визначено середню зважену похибку за ДСТУ OIML R 137-1-2:2018, а також середнє значення похибки вимірювання об’єму газу протягом року за запропонованою авторами методикою. Наявність залежностей похибки лічильника газу від вимірюваного значення витрати дає можливість виділити невилучену систематичну складову похибки для довільного вимірюваного значення витрати. Реалізація такої залежності в програмному забезпеченні обчислювача витрати дає можливість розробити адаптивну систему вимірювання витрати та об’єму газу, яка здійснює коректування вимірюваного значення витрати із врахуванням невилученої систематичної похибки вимірювання витрати. Шляхом інтегрування систематичної похибки вимірювання витрати в такій системі формують архів значень систематичної похибки вимірювання об’єму газу. Наявність у архіві обчислювача значення систематичної похибки вимірювання об’єму газу дає можливість аналізувати цю похибку та розробляти заходи для її усунення.
Ключові слова: роторний лічильник газу, витрата газу, систематична похибка, метрологічна перевірка, адаптивна система вимірювання

*O. Pistun, F. Matiko***. Investigating the dependencies of rotary gas meters error on flowrate for designing the adaptive measurement system.** In this paper, the error of gas flowrate measured by rotary gas meters was investigated based on the results of experimental studies of the metrological characteristics of rotary gas meters obtained during their periodic metrological inspection. According to the results of statistical processing of rotary gas meters errors obtained during their metrological verification, the averaged errors for each verified flowrate were determined. In this way, the dependencies of the averaged meter error on the measured flowrate for various types of rotary gas meters were obtained. For each obtained dependence, the root mean square deviation of the averaged error was calculated, which confirms the adequacy of the obtained dependencies. To evaluate the integral systematic error of meters of each individual type over a long period of operation, the average weighted error was determined according to DSTU OIML R 137-1-2:2018, as well as the average measurement error of gas volume during the year according to the methodology proposed by the authors. The presence of the dependencies of gas meter error on the measured value of the flowrate makes it possible to isolate the unexcluded systematic error for every measured flowrate. The implementation of such a dependence in the flowrate computing software makes it possible to develop an adaptive system for measuring gas flowrate and volume, which corrects the measured value of the flowrate considering the unexcluded systematic error of the flowrate measurement. By integrating the systematic error of flowrate measurement in such a system, an archive of the systematic errors of gas volume is formed. The presence of gas volume systematic errors in the computer archive makes it possible to analyze this error and develop measures to eliminate it.
Keywords: rotary gas meter, gas flowrate, systematic error, metrological verification, adaptive measurement system

Introduction

Gas meters are widely used to measure the flowrate and quantity of fluids. Rotary gas meters are common for natural gas flowrate measurements. These devices are known for their high accuracy, wide measurement range, and low sensitivity to distortions of the flow kinematic structure. The design of rotary gas meters is based on the dependence of the rotation frequency of the rotors on the gas vol-

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ume passed through the meter [1]. However, the mechanism of the rotary meter, which is in the gas flow (rotors, rotor mounting bearings) is sensitive to contamination. When measuring the gas flowrate, which contains dust, moisture, particles of oil and oil fuel, and paraffin particles, contamination of the rotary meter's internal surfaces leads to a change in its metrological characteristics. From the preliminary analysis carried out by the authors [2], it is known that the change in the measurement error of the meter is especially significant in the range of low gas flowrate Therefore, it is relevant to investigate the error of rotary gas meters in the whole range of gas flow measurements. The dependence of the gas meter error on the measured flowrate makes it possible to determine unexcluded systematic errors and systematic errors of flowrate measurement. Such a dependence is the basis for the development of an adaptive system for gas flowrate and volume measurement, which takes this dependence into account during the measurement process and makes it possible to determine the systematic error of the gas volume measurement during a certain measurement period. Since systematic errors in gas volume measurement are the main reasons for gas volume imbalance, the use of an adaptive flow measurement system makes it possible to identify the causes of gas volume imbalance and reduce it [2].

Analysis of recent publications

Based on the results of the analysis [2, 3], during the operation of industrial gas meters, the authors discovered the following additional volume measurement errors: the additional error in gas volume measurement under operating conditions caused by the deviation of the working pressure from the gas pressure during meter calibration (metrological verification); the additional error of gas volume measurement under operating conditions caused by the deviation of the working temperature from the gas temperature during meter calibration (metrological verification); the additional error of gas volume measurement under operating conditions caused by a change in the calibration characteristic of gas meter obtained using air during its application to measure the volume of natural gas; the additional error of measuring the gas volume under operating conditions caused by meter contamination and the corresponding change in the pressure drop on the meter; the additional error of measuring the volume of gas under operating conditions caused by the incorrect installation of the meter and the occurrence of mechanical stresses in the meter constructive elements; the additional error of gas volume measurement under operating conditions caused by the reduction of straight sections of the measuring pipe upstream and downstream the meter and the distortion of the flow kinematic structure upstream the meter; the additional error caused by wearing and tearing of the tachometric gas meter mechanism during its operation.

In [4, 5, 6] the authors have shown that the means for measuring gas flowrate and volume, which operate at the inlet and outlet flows in gas transportation or gas distribution networks, can have systematic errors in gas volume measurement. These systematic errors form gas volume imbalances.

The main error of the measuring device, particularly the gas meter, is determined during its calibration and metrological verification using reference flowrate measuring facilities [6, 7]. The limits of the basic error are determined by the relevant regulatory documents, for rotary gas meters by the standard DSTU EN 12480:2019 [8]. However, meters whose metrological characteristics meet the requirements of the relevant regulatory documents, particularly the standard [8, 9], may also have unexcluded systematic components of flowrate measurement errors. These components can reach large values during the application of gas metering systems in the conditions of changes in gas flowrate within wide limits, especially during the operation of gas meters in the range from minimum to transient flowrate [7].

In [10, 11], an analysis of the change in the basic error of rotary gas meters RG-100, RG-250 was carried out and it was confirmed that their basic error is correlated with the registered gas volume, especially for the range from the minimum to the transition value of the flowrate. However, this research did not investigate the dependence of the error of rotary gas meters on the measured flowrate.

The purpose of the work is to investigate the dependence of the error of rotary gas meters on the measured value of gas flowrate based on the statistical processing of the results of their metrological verification and to develop the dependencies for use in adaptive systems for measuring the flowrate and volume of natural gas.

Study of the dependence of rotary gas meter error on the measured value of gas flowrate

A change in the metrological characteristics of rotary gas meters is caused by the mechanical wear of moving parts, contamination of the meter's internal surfaces, and changes in the characteristics of lubricating materials. To control changes in the meter's metrological characteristics, periodic metrological checks are carried out according to the requirements of regulatory [9] and operating documents.

According to the requirements of regulatory and operating documents, metrological inspection of rotary gas meters is performed after their cleaning and washing [9]. So, the additional systematic error resulting from the contamination of gas meters is eliminated. Since the meter is dismantled from the place of operation and installed on the flowrate measuring facility in the laboratory, the additional error due to mechanical stresses in the meter body is also eliminated. Thus, during the next metrological inspection of the gas meter, its main error is investigated, considering the additional systematic error caused by the wear of the mechanical rotating elements of the meter.

In this work, the investigation of the measurement error of the gas volume under operating conditions, considering the additional error due to the wear of the mechanism of tachometric industrial gas meters, is carried out based on the results of experimental studies of the metrological characteristics of industrial gas meters, obtained during their periodic metrological inspection.

The database on metrological verification of gas meters includes the protocols of verification of meters at the reference facilities in the laboratories of four gas distribution companies. Therefore, a database of checking protocols of industrial gas meters (545 protocols) obtained in the laboratories of four gas distribution organizations was formed.

During the processing of the experimental data, filtering was applied, and meter verification protocols were removed, for which the value of the flowrate measurement error indicates a complete metrological failure of the meter, i.e. it exceeds the permissible value by 10-100%. Based on the filtered database of protocols for each of the checked flowrate values Q_{min}, $0.2Q_{max}$, $0.5\ Q_{max}$, Q_{max}, a set of gas meter errors $D = \{\delta_{ij}\}$ is formed. Based on the results of the processing of the set of errors D, the average statistical meter error was determined for each verified flowrate, and the average dependence of the gas meter error on the flowrate was built for each standard type of rotary gas meter.

Rotary gas meters RG-100, RG-K-100

95 protocols (gas meter error sets) were included in the sample. The set of errors for each tested flowrate value is considered as a set of values of a random variable. According to the results of the analysis of the histograms of the error distribution for each of the tested flowrate (see Fig. 1), it was determined that the error distribution is close to the asymmetric normal [12]. Therefore, processing methods and statistical characteristics of the normal distribution law can be applied to such a sample.

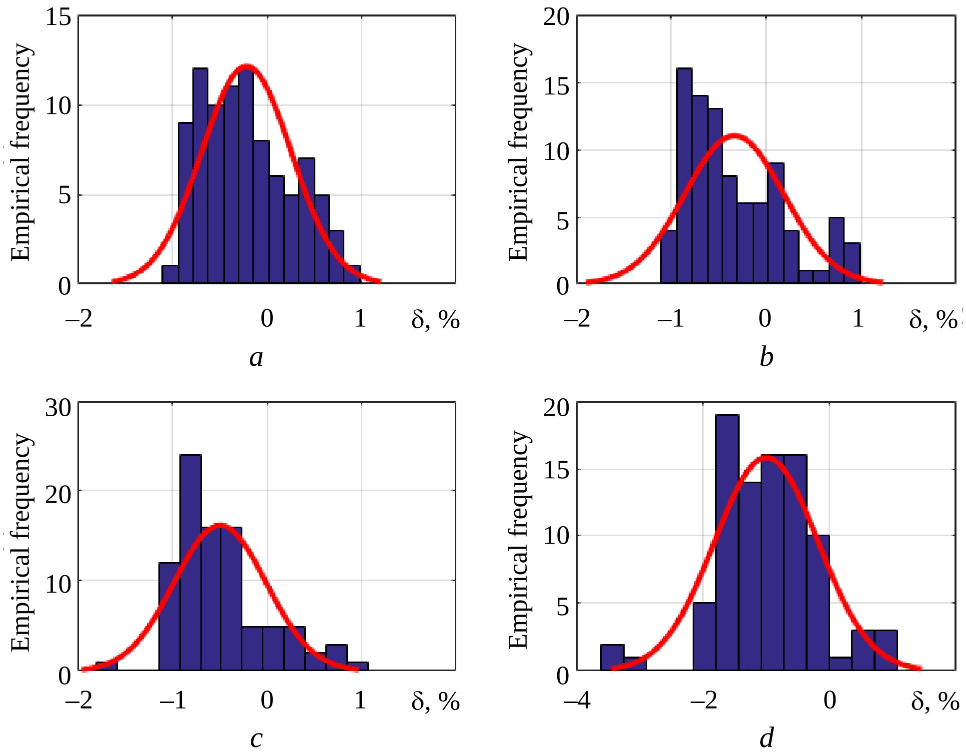

Fig. 1. Histograms of error distribution for gas meters RG-100, RG-K-100: *a* – for flowrate Q_{max}; *b* – for flowrate $0.5Q_{max}$; *c* – for flowrate $0.2Q_{max}$; *d* – for flowrate Q_{min}

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Fig. 2 shows the dependence of the error of the meters RG-100, RG-K-100 on the measured flowrate. The curve of the average error of the meters RG-100, RG-K-100 is plotted with a solid line.

The average error of the meter, which characterizes its operation over a long time, can be obtained as a weighted average error, determined according to the requirements of OIML R-137 [13]:

$$\delta_{WME} = \frac{\sum_{i=1}^{n}\left((Q_i / Q_{\max}) \cdot \delta_i\right)}{\sum_{i=1}^{n}\left(Q_i / Q_{\max}\right)}, \quad (1)$$

where n is the number of checked flowrate points in the range from $Q_{\min}$ to $Q_{\max}$ (here $n = 4$); Q_i is the flowrate, at which the relative error δ_i of the meter is determined; if the flowrate $Q_i > 0.9Q_{\max}$, then the value of the weighting factor $Q_i / Q_{\max}$ is equal to 0.4; $Q_{\max}$ is the maximum flowrate at which the meter error is normalized.

The value of the weighted average error for meters RG-100 calculated by formula (1) is $\delta_{WME} = -0.36\%$.

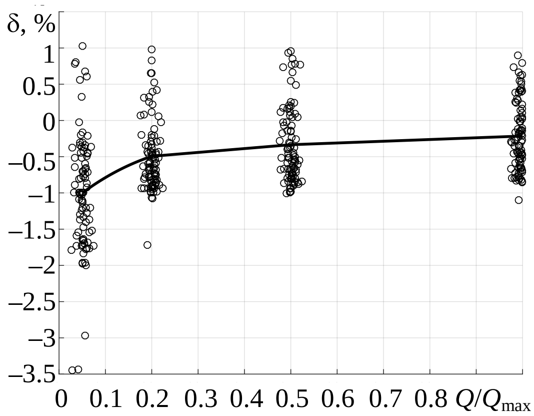

Fig. 2. Dependence of the error of the gas meters RG-100, RG-K-100 on the measured flowrate

The meaning of the weighted average error can be explained as follows. Under the condition of the correct choice of the standard type of the gas meter, during the heating period (6 months) it registers a gas flowrate close to the nominal one Q_n, and during the summer period a flowrate $(0.2Q_{\max} + Q_{\min})/2$. The total amount of gas registered by the flow meter for the year:

$$V = Q_n \cdot T_{heat} + \frac{0.2Q_{\max} + Q_{\min}}{2} \cdot T_{sum}, \quad (2)$$

where T_{heat} and T_{sum} are the duration of the heating and summer periods, respectively.

Absolute systematic error of gas volume measurement by meters during the year:

$$\Delta V = Q_n \cdot \frac{\delta_{heat}}{100} \cdot T_{heat} + \frac{0.2Q_{\max} + Q_{\min}}{2} \cdot \frac{\delta_{sum}}{100} \cdot T_{sum}. \quad (3)$$

The value of the gas meter error, which corresponds to the nominal flowrate Q_n and the error δ_{sum} for the flowrate $(0.2Q_{\max} + Q_{\min})/2$, should be determined by the curve of the averaged error (see Fig. 2).

Then the averaged relative systematic error of gas volume measurement per year is determined:

$$\delta_{av} = \frac{\Delta V}{V} \cdot 100\%. \quad (4)$$

The relative systematic error of gas volume measurement by the meter RG-100 per year, obtained by formulas (2)-(4) is equal $\delta_{av} = -0.37\%$.

Therefore, the average value of the systematic relative error of the meters RG-100, RG-K-100, which characterizes the difference between the registered gas volume and the real gas volume passed through the meter during the year equals $\delta = -0.37\%$.

Rotary gas meters RG-250, RG-K-250

59 protocols are included in the sample. Based on the results of the analysis of the histograms of the error distribution for each of the tested flowrates (see Fig. 3), it was determined that the error distribution is close to normal. Therefore, processing methods and statistical characteristics of the normal distribution law can also be applied to the analysed sample.

Fig. 3 shows the dependence of the error of the meters RG-250, RG-K-250 on the measured flowrate. The curve of the average error of the meters RG-250, RG-K-250 is plotted with a solid line.

The average value of gas meter error, which characterizes its operation over a long time, obtained according to OIML R-137 [13] is equal to $\delta_{WME} = -0.25\%$.

Considering that the nominal meter flowrate is about $0.7Q_{max}$, the error characterizing the gas meter operation in the whole range of flowrate during the year was calculated by the formulas (2)-(4) and it equals $\delta_{av} = -0.23\%$.

Thus, the average systematic relative error of the meters RG-250, RG-K-250, which characterizes the difference between the registered gas volume and the real gas volume that passed through it during the year, is equal $\delta = -0.25\%$.

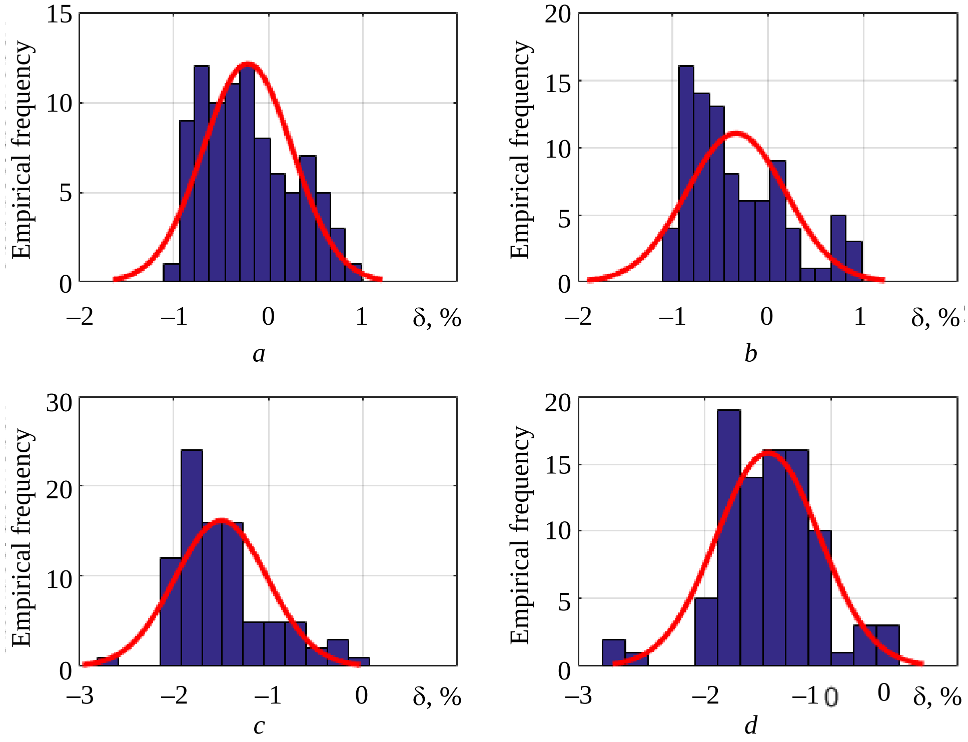

Fig. 3. Histograms of error distribution for gas meters RG-250, RG-K-250: *a* – for flowrate Q_{max}; *b* – for flowrate $0.5Q_{max}$; *c* – for flowrate $0.2Q_{max}$; *d* – for flowrate Q_{min}

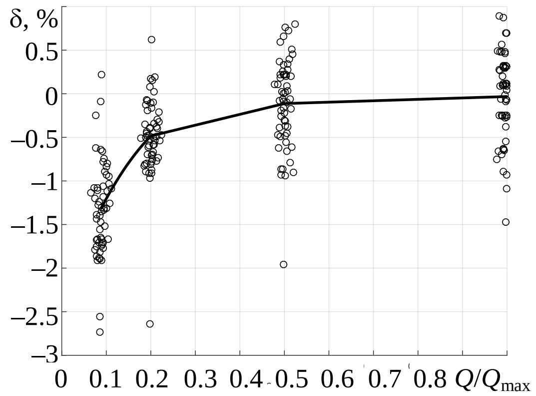

Fig. 4. Dependence of the error of the meters RG-250, RG-K-250 on the measured flowrate

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Statistical processing of errors of rotary meters of other types was performed in the same way as for rotary meters RG-100, RG-K-100, RG-250, RG-K-250. The results of statistical processing of the error of RG-type meters are presented in Tables 1, 2.

Table 1

Averaging the error of industrial rotary gas meters of RG type

Type of gas meter	Averaged error (%) for flowrate				Average annual error δ_{av}, %	Weighted average error δ_{WME}, %
	Q_{max}	$0.5Q_{max}$	$0.2Q_{max}$	Q_{min}		
RG-40, RG-K-40	–0.79	–0.85	–0.66	–1.37	–0.86	–0.82
RG-100, RG-K-100	–0.22	–0.34	–0.50	–1.00	–0.37	–0.36
RG-250, RG-K-250	–0.032	–0.11	–0.48	–1.32	–0.23	–0.25
RG-400, RG-K-400	–0.23	–0.27	–0.70	–1.79	–0.43	–0.45
RG-600, RG-K-600	–0.24	0.21	–0.13	–1.02	–0.06	–0.05

Table 2

Root mean square deviation of the average error of industrial rotary gas meters of RG type

Type of gas meter	Number of protocols in the sample	Root mean square deviation of the average error (%) for the flowrate			
		Q_{max}	$0.5Q_{max}$	$0.2Q_{max}$	Q_{min}
RG-40, RG-K-40	13	0.06	0.08	0.08	0.07
RG-100, RG-K-100	95	0.05	0.06	0.05	0.09
RG-250, RG-K-250	59	0.07	0.07	0.06	0.07
RG-400, RG-K -400	40	0.08	0.06	0.08	0.12
RG-600, RG-K-600	13	0.36	0.24	0.17	0.14

Dependencies of the error of each type of meter on gas flowrate according to Table 1 are presented in Fig. 5.

The dependencies of the meter error on the flowrate presented in Fig. 5 make it possible to calculate the value of the unexcluded systematic error of the flowrate measurement for every flowrate. Therefore, the prerequisites have been created for the development of an algorithm for correcting the results of flowrate measurement, considering its systematic error. Implementation of such an algorithm in the flowrate computer software makes it possible to develop an adaptive measurement system and increase the accuracy of gas flowrate and volume measurement.

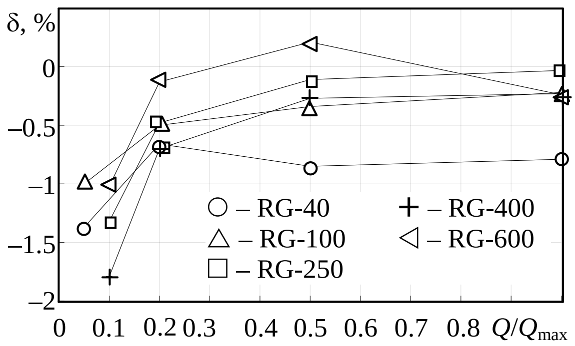

Fig. 5. Dependence of the average error of RG-type meters on the measured flowrate

Conclusions

According to the results of statistical processing of the errors of the rotary gas meters obtained during their metrological verification, the averaged errors for each verified flowrate were determined. In this way, the dependence of the averaged error of the meter on the measured flowrate for different standard types of rotary gas meters was obtained.

The presence of the dependencies of the error of the gas meter on the measured flowrate makes it possible to determine the unexcluded systematic error for every measured value of the flowrate. The implementation of such a dependence in the flow computing software makes it possible to develop an adaptive system for measuring gas flowrate and volume.

The adaptive system calculates the unexcluded systematic error of the flowrate for the real-time measured flowrate and makes correction of the measured flowrate considering the unexcluded systematic error. If the dependence of the meter error on the flowrate is developed based on a small sample (a small amount of data on meters metrological verification), the correction of the measured flowrate is not performed, and using the unexcluded systematic error of the flowrate measurement, the systematic error of gas volume measurement is calculated. The systematic error of the gas volume measurement is recorded in the computer archive together with the measured gas volume. The presence of the systematic error of gas volume measurement in the computer archive makes it possible to analyse this error and develop measures to eliminate it.

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Пістун Олег Ігорович; Oleh Pistun, ORCID: https://orcid.org/0000-0003-3096-8752
Матіко Федір Дмитрович; Fedir Matiko, ORCID: https://orcid.org/0000-0001-6569-2587

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