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Methodology and software for measuring the specific differences of the calculated volumes of natural gas

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Abstract

The most accurate measurement of natural gas volumes by domestic meters can be achieved only in case when the gas parameters (pressure, temperature) are maximally approximated to the standard conditions. Otherwise, it is necessary to perform additional measurements of these parameters, but most domestic gas meters do not include the measuring instruments to obtain these quantities; or to carry out approximate mathematical calculations, which from the point of view of metrology is unreliable.

The purpose of the work is mathematical modeling of specific differences of the accounted volumes of natural gas and development of methods for their measurement.

The methodology of measurement by indirect methods of changing the volumes of natural gas in gas supply systems of residential buildings with domestic gas meters is developed. The dependence is obtained for estimating the specific differences of natural gas volumes in domestic consumers by measuring the volume of gas by a household gas meter, the temperature parameters of the air in the room near the gas pipeline and the gas and air meter. The physical quantities of the ambient air parameters are identified, which are determined by the method of direct measurement, and based on the obtained results, a methodology for estimating the metrological characteristics of the indirect measurement of the specific differences of natural gas volumes is developed.

The results obtained by theoretical development are confirmed by experimental studies on a certified calibration setup operating on natural gas.

The results obtained can be the basis for reviewing the existing and developing new regulatory documents for determining the specific differences in natural gas volumes recorded by domestic gas meters. Prospects for further research are the development of the structure of the information measurement system and devices for the determination of the specific losses of natural gas in house systems of gas supply.

Keywords: natural gas; specific differences of gas volumes; indirect measurements; methodology.

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1. Introduction

The most accurate measurement of natural gas volumes by domestic meters can be achieved only in case when the gas parameters (pressure, temperature) are maximally approximated to the standard conditions. Otherwise, it is necessary to perform additional measurements of these parameters, but most domestic gas meters do not include the measuring instruments to obtain these quantities; or to carry out approximate mathematical calculations, which from the point of view of metrology is unreliable. The concept [1] establishes the necessity of creating a multi-level automated accounting system for natural gas in the field of its extraction, transportation and storage. In [2], the aspects of the development of the house energy metering system on the basis of meters are proposed. However, the presence of a natural gas meter in house gas systems does not yet indicate accurate accounting of this energy source. There are several factors that cause gas losses, one of which is the gas component composition [3]. In order for the gas accounting to be accurate, the measurement of the gas volume by means of a meter shall be carried out under standard conditions or the volume of gas

measured by the meter shall be brought to the standard conditions [4] with the help of so-called correctors-compensators. According to [4], the calculation for the consumed gas shall be made when its temperature is 20 °C (293.15 K), pressure is 101.325 kPa and humidity is 0 %. The most influential factor is the gas temperature. In Ukraine, a significant part of domestic gas meters are used, in which there are no devices for gas temperature correction, therefore these meters account for the "physical" volume of gas, that is, without bringing it to standard conditions.

According to [5], the formula for converting the gas volume brought to standard conditions and the measured "physical" gas volume is as follows:

$$V_{\mathrm{b}} = \frac{T_{\mathrm{b}}}{T} \cdot V, \tag{1}$$

where V is gas volume under measurement conditions, m^3; V_{b} is gas volume at the base (standard) gas temperature, m^3; T is gas temperature under measurement conditions, K; T_{b} is the standard gas temperature – 20 °C (293.15 K). According to formula (1), when the temperature changes for every 1 °C with respect to the standard one of 20 °C, the volume of gas will vary by about 0.34%.

It was proved in [6] that when using gas meters without gas temperature correction devices, the accounting error, which is proportional to losses of gas supplying organizations, is 3.5–6.5%.

The purpose of the work is to establish mathematical dependencies for the determination of the specific differences between the accounted natural gas volumes.

2. Specific differences in metering of natural gas volumes

The need to reduce the specific differences in the accounted volumes of natural gas leads to the development of methods and instruments for identifying these differences and taking into account their values in determining the consumed volume of natural gas. An effective solution to this problem is possible provided that the values of these physical quantities are precisely determined.

According to [7], the gas volume by the indications of certain (i) meter brought to standard conditions ($V_{\mathrm{st}i}$, m^3), is determined by the formula:

$$V_{\mathrm{st}i} = V_{\mathrm{m}i} \cdot K_{\mathrm{cor}i}, \tag{2}$$

where $V_{\mathrm{m}i}$ are indications of domestic gas meter i under working conditions, m^3; $K_{\mathrm{cor}i}$ is the numerical value of the correction factor of the gas meter i indications, which is given in the tables of Methodology [7].

Specific difference in gas volumes for a certain accounting period (month) for each meter ($V_{\mathrm{sf}i}$, m^3) is determined by the formula [7]:

$$V_{\mathrm{sf}i} = \left(V_{\mathrm{st}i} - V_{\mathrm{m}i}\right). \tag{3}$$

The total specific gas volume differences ($V_{\Sigma\mathrm{sf}}$, m^3) are determined as the algebraic sum of the specific differences in the gas volumes of all available meters in consumers (n), to whom gas supply and gasification company provides its services [7], i.e.:

$$V_{\Sigma\mathrm{sf}} = \sum_{i=1}^{n}\left(V_{\mathrm{st}i} - V_{\mathrm{m}i}\right). \tag{4}$$

Taking into account formula (2), formula (4) will have a form:

$$V_{\Sigma\mathrm{sf}} = \sum_{i=1}^{n}\left(V_{\mathrm{m}i} \cdot \left(K_{\mathrm{cor}i} - 1\right)\right). \tag{5}$$

In the normative document [7], correction factors are given only for the regional centers of Ukraine. In addition, in this document there are no methodology for determining the factors for the remaining population centers of Ukraine and the values of climatic parameters (atmospheric pressure and ambient air temperature) which may differ significantly from similar values in the oblast centers. This is due to the different geographic location of these population centers above the sea level (mountainous regions of Ukraine).

3. The results of experimental studies

The results obtained by theoretical development are confirmed by experimental study on the certified calibration setup of PJSC "Ivano-Frankivskgas", which operates on natural gas.

According to the results of the experimental study given in [8], the correction factor of gas meter indications is determined by the formula:

$$K_{\mathrm{cor}i} = \frac{1 - 1{,}15 \cdot 10^{-4} h_i}{1 + \left(\frac{T_{\mathrm{amb}i}}{293{,}15} - 1\right) \cdot \exp\left(-21{,}77 D_{\mathrm{c}i} x_i - \frac{1{,}96 D_{\mathrm{c}i} x_i + 16{,}17 F_i}{q_{Vi}}\right)}, \tag{6}$$

where h_i is geographical height of the measuring point (the population center where gas meter i is located) above the sea level, m; $T_{\mathrm{amb}i}$ is ambient air temperature in a given calendar month of the year, K; $D_{\mathrm{c}i}$ is pipe diameter of the gas pipeline, m; x_i is distance from the point of introduction of the gas pipeline into the heating room to the inlet nozzle of gas meter i, m; F_i is heat transfer surface area in gas meter i, m^2; q_{Vi} – is volume flow rate of gas passing through gas meter i, m^3/h. Taking into account formula (6), formula (5) will have the form:

$$V_{\Sigma sf} = \sum_{i=1}^{n} \left(V_{mi} \cdot \left(\frac{1 - 1{,}15 \cdot 10^{-4} h_i}{1 + \left(\frac{T_{ambi}}{293{,}15} - 1 \right) \cdot \exp\left(-21{,}77 D_{ci} x_i - \frac{1{,}96 D_{ci} x_i + 16{,}17 F_i}{q_{Vi}} \right)} - 1 \right) \right). \quad (7)$$

In formula (7), parameter h_i is constant for the population center, where meter i is installed; D_{ci} and x_i are determined by one-time measurement and remain constant; F_i can be determined at the manufacturing plant of gas meter i and entered to gas meter certificate, as well as its specification; gas consumption q_{Vi} depends on the range of gas-consuming equipment, connected to gas meter i and is determined by the formula:

$$q_{Vi} = k_{so} \sum_{z=1}^{m} Q_z, \quad (8)$$

where m is quantity of gas-consuming equipment; Q_z is nominal gas consumption of equipment z (provided in the equipment certificate), m³/h; k_{so} is factor of simultaneity of operation of all gas-consuming equipment connected to gas meter i. Values of k_{so} are given in [8].

Taking into account formula (8), formula (7) will have the form:

$$V_{\Sigma sf} = \sum_{i=1}^{n} \left(V_{mi} \cdot \left(\frac{1 - 1{,}15 \cdot 10^{-4} h_i}{1 + \left(\frac{T_{ambi}}{293{,}15} - 1 \right) \cdot \exp\left(-21{,}77 D_{ci} x_i - \frac{1{,}96 D_{ci} x_i + 16{,}17 F_i}{k_{so} \sum_{z=1}^{m} Q_z} \right)} - 1 \right) \right). \quad (9)$$

Based on the above, it follows that the quantities the measurements of which have be carried out continuously are V_{mi} and T_{ambi}. For the convenience of calculations, we will make a series of substitutions in formula (9):

$$1 - 1{,}15 \cdot 10^{-4} h_i = P, \quad (10)$$

$$-21{,}77 D_{ci} x_i - \frac{1{,}96 D_{ci} x_i + 16{,}17 F_i}{k_{so} \sum_{z=1}^{m} Q_z} = R. \quad (11)$$

The values of quantities P and R are determined once by formulas (10) and (11) and used in subsequent calculations. Taking into account formulas (10) and (11), the formula (9) will become the following:

$$V_{\Sigma sf} = \sum_{i=1}^{n} \left(V_{mi} \cdot \left(\frac{P}{1 + \left(\frac{T_{ambi}}{293{,}15} - 1 \right) \cdot \exp(R)} - 1 \right) \right). \quad (12)$$

4. Metrological analysis of determination of specific differences in gas volumes

Let's evaluate the error of the determination of the specific differences in gas volumes by the formula (12) when their accounting by gas meter i. Since the measurements are indirect, according to the requirements [9], it is necessary to evaluate the limits of non-excluded systematic error (NSE) $\Theta_{V_{\Sigma sf}}$ and root-mean-square deviation (RMS) $S_{V_{\Sigma sf}}$ of the indirect measurement results, which are determined as follows:

$$\Theta_{V_{sfi}} = \pm \left| \left(\frac{\partial V_{sfi}}{\partial V_{mi}} \cdot \Delta_{V_{mi}} + \frac{\partial V_{sfi}}{\partial T_{ambi}} \cdot \Delta_{T_{ambi}} \right) \right|, \quad (13)$$

$$S_{V_{sfi}} = \sqrt{\left(\frac{\partial V_{sfi}}{\partial V_{mi}} \right)^2 \cdot S^2_{V_{mi}} + \left(\frac{\partial V_{sfi}}{\partial T_{ambi}} \right)^2 \cdot S^2_{T_{ambi}}}, \quad (14)$$

where $\Delta_{V_{mi}}$, $\Delta_{T_{ambi}}$ are the measuring instrument errors of volume (gas meter), ambient air temperature in the room around the gas meter, and ambient air (temperature sensors), respectively; $S_{V_{mi}}$, $S_{T_{ambi}}$ are RMS of the measurement results of volume V_{mi} and temperature T_{ambi}, respectively; $\frac{\partial V_{sfi}}{\partial V_{mi}}$, $\frac{\partial V_{sfi}}{\partial T_{ambi}}$ are influence factors, which are derivatives of specific differences in gas volumes with respect to variables V_{mi}, T_{ambi}, and are represented as:

$$\frac{\partial V_{sfi}}{\partial V_{mi}} = \frac{P}{1 + \left(\frac{T_{ambi}}{293{,}15} - 1 \right) \cdot \exp(R)} - 1, \quad (15)$$

$$\frac{\partial V_{sfi}}{\partial T_{ambi}} = - \frac{V_{mi} P \cdot \frac{\exp(R)}{293{,}15}}{\left(1 + \left(\frac{T_{ambi}}{293{,}15} - 1 \right) \cdot \exp(R) \right)^2}. \quad (16)$$

The relative measurement error of the specific differences in natural gas volumes during their accounting by gas meter *i* is calculated by the formula given in [9]:

$$\delta_{V_{\text{sf}i}} = 1{,}1\frac{\sqrt{S^2_{V_{\text{sf}i}} + \frac{\Theta^2_{V_{\text{sf}i}}}{3}}}{V_{\text{sf}\,i}} \cdot 100\%. \qquad (17)$$

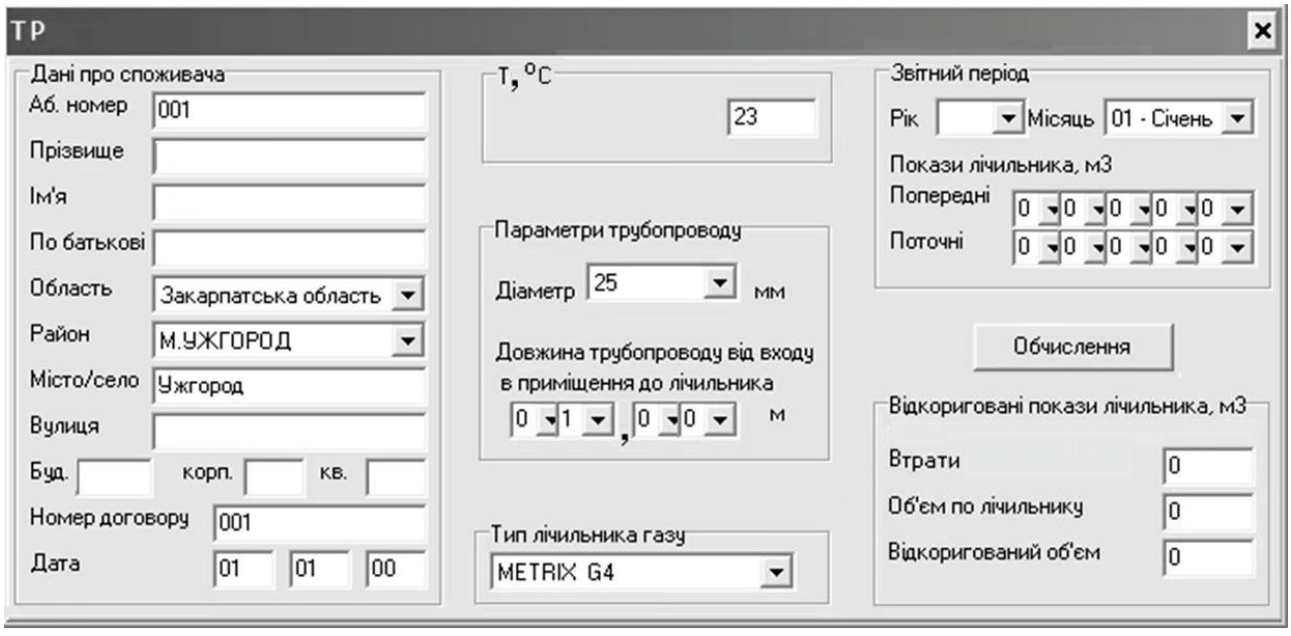
Similar to the metrological requirements related to the accurate characteristics of measuring the natural gas volumes by domestic gas meters, the accuracy of measurement of the specific differences of natural gas volumes will be sufficient if the relative measurement error of these differences $\delta_{V_{\text{sf}i}}$ does not exceed $\pm 1.5\%$.

Implementation of the developed methodology will allow to reduce the specific differences in natural gas volumes of those accounted in the municipal sector to 5%, as proved in [6].

The current normative document [7] establishes the methodology for calculating the specific differences in natural gas volumes in the case of not bringing to the standard conditions the measurement results of low-pressure gas volumes, which are measured by gas meters without special devices for automatic bringing their indications to standard conditions when changing pressure and/or gas temperature. This methodology proposes to use, when calculating the consumed volumes of natural gas, correction factors that are developed only for regional centers of Ukraine and do not take into account the influence of climatic conditions on the accuracy of gas accounting in other population centers. The need to take into account these factors is proved in [10]. Document [7] establishes mathematical methods for calculating the specific differences in natural gas volumes, which is less reliable than measuring these differences. Therefore, the use of the methodology developed in this paper, which is based on the measurement of these quantities, is more objective for their estimation.

5. The software implemented on the basis of a mathematical model of measuring specific differences of volumes of natural gas

The practical significance is in the development of software for calculations on the basis of the mathematical model for measuring the specific differences in natural gas volumes proposed by the authors of this paper (Fig.).



Program for calculating the specific differences in natural gas volumes

The software (Fig.) contains a database of elevations of settlements above sea level h_i. The value h_i is selected from the database based on data on place of residence of the consumer of natural gas; these data are entered in the field "Consumer data" of the program (Fig.). The program generates a database of ambient air temperatures $T_{\text{amb}i}$ (field "T"), diameter values D_{ci} and the length of the pipeline x_i (field "Pipeline parameters"). The software also contains a database of surface area of heat transfer gas meters F_i. Value F_i is selected from the base in the field "Type of gas meter". Gas meter readings for a given calendar month are entered into the field "Reporting period". The function "Evaluation" allows to determine specific gas volumes (losses) $V_{\text{sf}i}$, consumed volumes $V_{\text{m}i}$ and adjusted values for gas volumes taking into account losses $V_{\Sigma\text{sf}}$. The results of the calculations are displayed in the field "Adjusted meter readings".

6. Conclusions

The mathematical model is obtained in the form of analytical dependence for indirect measurement of specific differences of natural gas volumes based on direct measurements of consumed volumes of gas and air meter of the environment.

The methodology developed in this paper can serve as the basis for the drawing-up of normative legal documents for the determination of specific differences in gas volumes.

Методологія та програмне забезпечення вимірювання питомих різниць облікованих об'ємів природного газу

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Анотація

Найбільш точним вимірювання об'ємів природного газу побутовими лічильниками буде лише у випадку, коли параметри газу (тиск, температура) будуть максимально наближені до стандартних умов. Інакше необхідно проводити додаткові вимірювання цих параметрів, але більшість побутових лічильників газу не містять засобів вимірювань цих величин; або здійснювати приблизні математичні обчислення, що з точки зору метрології є недостовірним.

Метою роботи є математичне моделювання питомих різниць облікованих об'ємів природного газу та розроблення методів їх вимірювання.

Розроблено методологію вимірювання непрямими методами зміни об'ємів природного газу в системах газопостачання житлових будинків, у яких наявні побутові лічильники газу. Отримано залежність для оцінки питомих різниць об'ємів природного газу в побутових споживачів шляхом вимірювання об'єму газу побутовим лічильником газу, температурних параметрів повітря в приміщенні біля газопроводу та лічильника газу і повітря навколишнього середовища. Виокремлено фізичні величини параметрів повітря навколишнього середовища, які визначаються методом прямих вимірювань, та на основі отриманих результатів розроблено методологію оцінки метрологічних характеристик опосередкованого вимірювання питомих різниць об'ємів природного газу.

Результати, отримані шляхом теоретичної розробки, підтверджені експериментальними дослідженнями на еталонній установці, що працює на природному газі.

Отримані результати можуть бути основою для перегляду існуючих та розроблення нових нормативно-правових документів з визначення питомих різниць об'ємів природного газу, облікованого побутовими лічильниками газу. Перспективи подальших досліджень полягають у розробленні структури інформаційно-вимірювальної системи та пристроїв для визначення питомих втрат природного газу в будинкових системах газопостачання.

Ключові слова: природний газ; питомі різниці об'ємів газу; опосередковані вимірювання; методологія.

Методология и программное обеспечение измерения удельных разниц учтенных объемов природного газа

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Аннотация

Цель данной работы – математическое моделирование удельных разниц учтенных объемов природного газа и разработки методов их измерения.

Разработана методология измерения косвенными методами изменения объемов природного газа в системах газоснабжения жилых домов, в которых имеются бытовые счетчики газа. Получена зависимость для оценки удельных разниц объемов природного газа у бытовых потребителей путем измерения объема газа бытовым счетчиком газа, температурных параметров воздуха в помещении возле газопровода и счетчика газа и воздуха окружающей среды.

Выделены физические величины параметров воздуха окружающей среды, которые определяются методом прямых измерений, и на основе полученных результатов разработана методология оценки метрологических характеристик косвенного измерения удельных разниц объемов природного газа.

Результаты, полученные путем теоретической разработки, подтверждены экспериментальными исследованиями на эталонной установке, работающей на природном газе.

Полученные результаты могут служить основанием для пересмотра существующих и разработки новых нормативно-правовых документов по определению удельных разниц объемов природного газа, учтенного бытовыми счетчиками газа.

Ключевые слова: природный газ; удельные разницы объемов газа; косвенные измерения; методология.

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