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DETERMINATION OF THE CALORIFIC VALUE OF NATURAL GAS USING PREDICTIVE MODELLING

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Summary. *The analysis of the measured data on the calorific value of natural gas in different regions of Ukraine for 2014–2019, which are in the public domain, has been carried out. Since 2020, such data has not been published. This predetermines the need to use calculation methods for determining this physical quantity for subsequent years in different regions of Ukraine. It is proved that during 2018–2019 there was a trend for the stability of calorific value of natural gas, and fluctuations of calorific value had a smaller amplitude (within the range of 9.31–9.80 kW·h/m^3), the spread in the values of the calorific value almost halved: from 0.88 to 0.49 kW·h/m^3 compared to 2014–2017. Therefore, the measured data for the calorific value of natural gas for the period 2018–2019 were taken as a basis for predictive modeling of this physical quantity.*

It has been established that for most regions of Ukraine it is possible to use a single average value of the calorific value of natural gas for the subsequent determination of the energy of this energy carrier. The exceptions are Donetsk, Ivano-Frankovsk, Lugansk and Chernivtsi regions, in which the measurement data of the calorific value of natural gas are described with sufficient accuracy by the trigonometric cosine function. By the method of predictive modeling, a mathematical model has been developed to determine the calorific value of natural gas for a specific month of the year in Ukraine. The adequacy of the developed model has been verified by the example of measuring data on the calorific value of natural gas along route 406 (Ivano-Frankivsk region). It was found that the relative error in calculating the combustion heat of natural gas on this route does not exceed plus 1, minus 3%, which is comparable with the accuracy of measuring the volume of natural gas with household gas meters (the volume of gas and its heat of combustion are parameters for determining the energy of natural gas). Thus, a predictive mathematical model has been developed with sufficient accuracy to describe the change in the calorific value of natural gas and can serve as a basis for calculating this gas parameter in the absence of measurement data.

Key words: *natural gas, combustion heat, predictive mathematical model.*

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Statement of the problem. Nowadays, in Ukraine natural gas is metered in cubic meters. However, depending on the origin of the gas and the technology of its preparation, natural gas may have different energy performance, including combustion heat. Since the amount of energy directly depends on the heat combustion of natural gas, it is important to measure this value and on its basis to calculate the energy of natural gas.

Analysis of recent researches. Instrumental metering of natural gas energy in Ukraine is only at the stage of implementation. However, as emphasized in [1], a number of current regulations [2, 3] require the accounting of natural gas in units of energy. In addition, the document [3] allows the calculation of natural gas consumption in cubic meters, which must be brought to standard conditions and expressed in units of energy. The method of such calculation is given in [1].

Objective of research is to evaluate the measured data on the combustion heat of natural gas in different regions of Ukraine in 2014–2019 and on their basis to carry out predictive modeling of this physical quantity in the coming years.

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Formulation of the problem. The official website of JSC Ukrtransgaz [4] provides information on physical and chemical parameters of natural gas in all regions of Ukraine (monthly) since 2014. Fig. 1 shows the graphical dependences of the combustion heat (calorific value) of natural gas in each month of the year from 2014 to 2019.

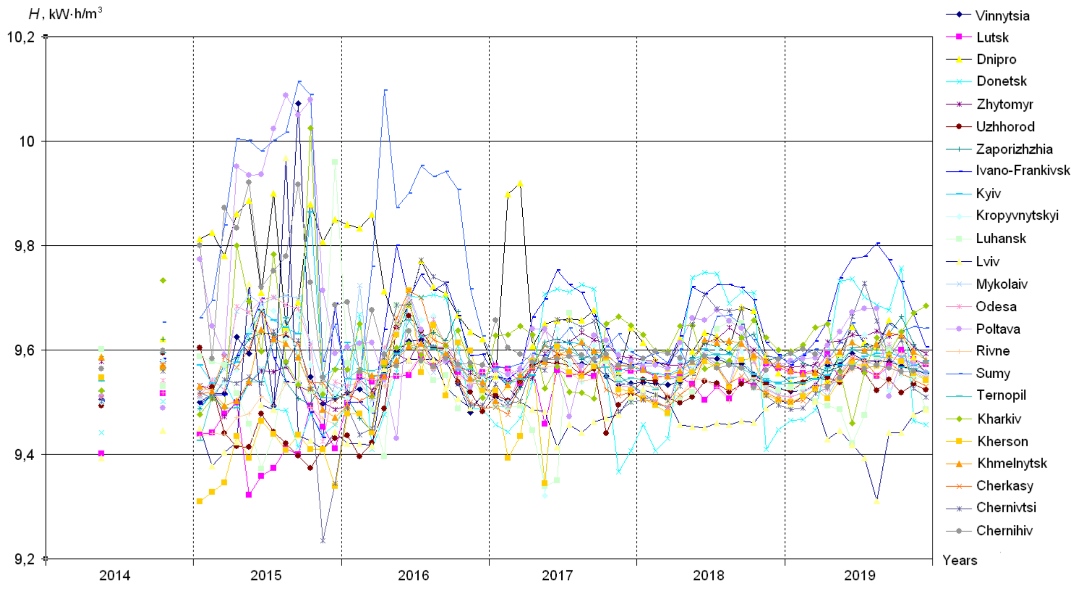

Figure 1. Characteristics of calorific value of natural gas in 2015–2019

As can be seen from Fig. 1, combustion heat of natural gas *H* during 2014–2016 ranged from 9.23 kWh/m^3 to 10.11 kWh/m^3, and since mid-2017, its value has become more stable. In 2018–2019, the trend of stability of calorific values of natural gas persisted, and fluctuations in combustion heat values had a smaller amplitude (in the range of 9.31–9.80 kWh/m^3), the scatter of combustion heat values decreased almost twice: from 0.88 kWh/m^3 to 0.49 kWh/m^3.

Based on the above analysis, to assess the calorific value of gas, it is reasonable to consider the combustion heat of natural gas only for the last two years (Fig. 2).

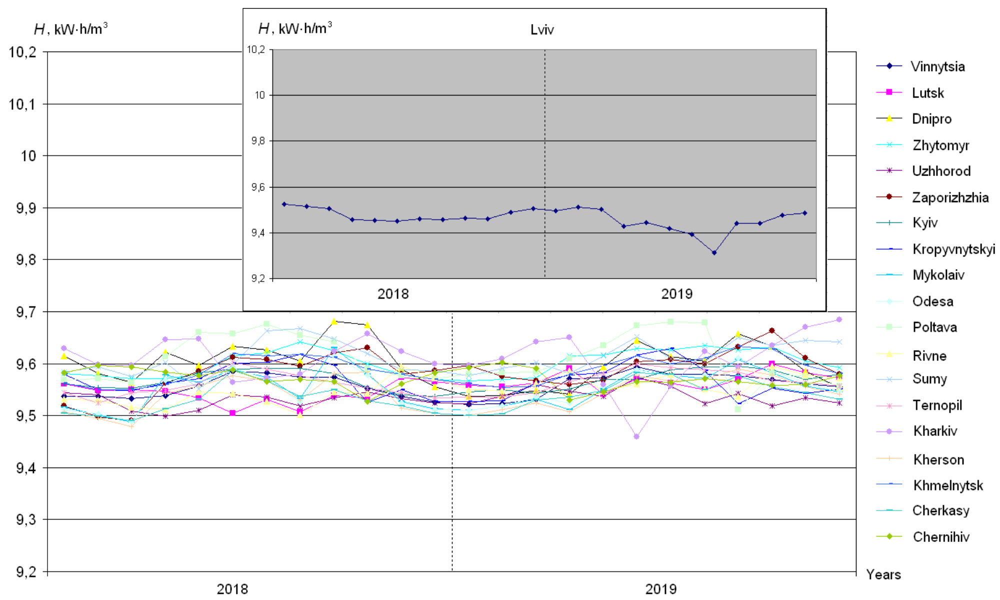

Figure 2. Characteristics of calorific value of natural gas in 2018–2019

According to the results of the analysis of the measured data, the graphical representation of which is shown in Fig. 2, it is established that their average value is 9.57 kWh/m^3, and the maximum deviations of the measured values from the average are 2.4% and minus 2.7%. The exception is Lviv region, where the average combustion heat of natural gas is 9.46 kWh/m^3, and the maximum deviations of the measured values from the average are 0.7% and minus 1.6%. It is known that the combustion heat and the volume of natural gas are used to calculate the energy of natural gas [5]. Given that domestic gas meters measure natural gas volumes with an error of 3% and minus 6%, and the maximum deviations of the measured values of combustion heat of gas from the average value are within these limits and do not exceed the error limits of volume measurements gas; then, when calculating the energy of gas, a single (average) value of the combustion heat of the gas can be used.

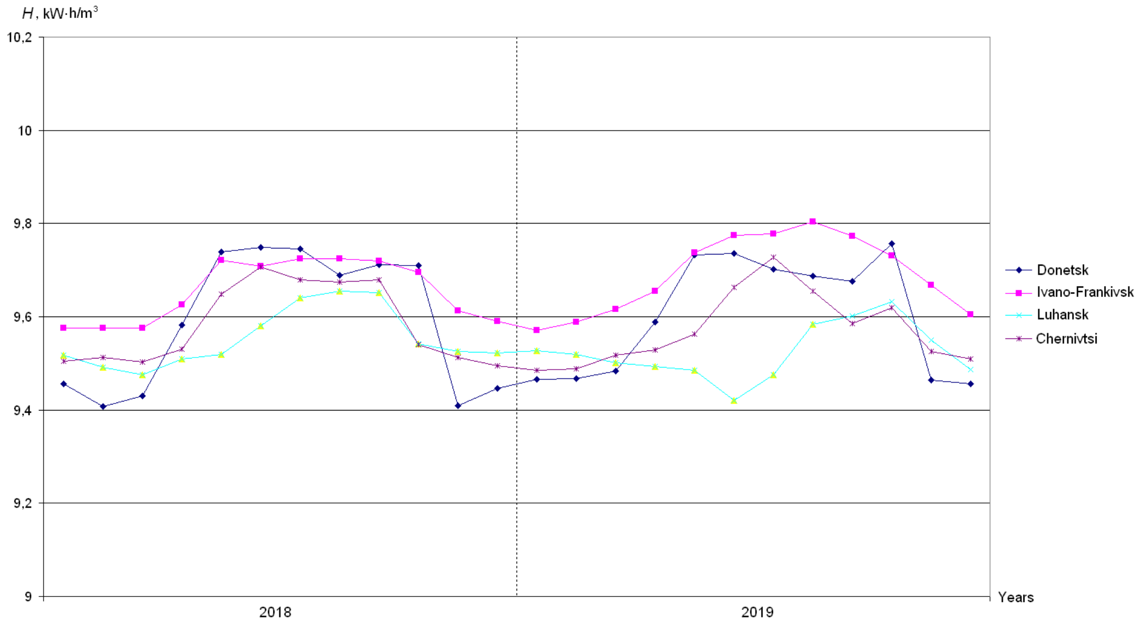

Figure 3. Characteristics of calorific value of natural gas in some regions

As can be seen from Fig. 3, which is a part of Fig. 2, in four regions: Donetsk, Ivano-Frankivsk, Luhansk and Chernivtsi, the dependence of the combustion heat of natural gas on the month of the year can be described by trigonometric cosine function.

Methods of research. The combustion heat, similarly to [6], will be recorded as:

$$H_n = \overline{H} + A\cos(\varpi\tau - \varepsilon). \quad (1)$$

The parameter ε is assumed to be zero. The value A is determined by the formula:

$$A = -(H_{07} - H_{01})/2, \quad (2)$$

where H_{07}, H_{01} are the combustion heat of natural gas in July and January, respectively.

Since time reading is from the beginning of January, we have the equation $H_{01} = \overline{H} + A$, hence:

$$\overline{H} = H_{01} - A, \qquad (3)$$

$$\omega = \frac{2\pi}{\tau_{\text{p}}} = \frac{2\pi}{365 \cdot 24} = 0{,}717259 \cdot 10^{-3}\,\text{год}^{-1}, \qquad (4)$$

where τ is time in hours. The value ω is calculated by the equation $\omega\tau_{\text{p}} = 2\pi$, τ_{p} is the number of hours per year.

Assume that each month has the same number of hours $\tau_{\text{m}} = 365 \cdot 24/12 = 730$ (τ_{m} is the number of hours in 1 month of the year). In this case, formula (1) can be written in a slightly different form:

$$H_n = \overline{H} + A\cos\left(0{,}717259 \cdot 10^{-3} \cdot (n-1) \cdot 730\right), \qquad (5)$$

where n is the number of the month in the year.

Having performed certain mathematical transformations in formula (5), we obtain the dependence:

$$H_n = \overline{H} + A\cos\left(0{,}5236(n-1)\right). \qquad (6)$$

Results of the research. Parameters A and $\overline{H}$ for the above regions, calculated by equations (2) and (6), are given in Table 1.

Table 1

Parameters A and $\overline{H}$ for Donetsk, Ivano-Frankivsk, Luhansk and Chernivtsi regions

Equation parameters / region	Donetsk	Ivano-Frankivsk	Luhansk	Chernivtsi
A, kWh/m^3	-0.103513	-0.122115	0.074432	-0.05815
$\overline{H}$, kWh/m^3	9.598245	9.622662	9.513288	9.577305

Based on the obtained data, a mathematical predictive model was developed to determine the combustion heat of natural gas for a certain month of the year in Ukraine.

$$\begin{cases} H_{\text{D}n} = 9{,}598245 - 0{,}103513\cos\left(0{,}5236(n-1)\right) \\ H_{\text{IF}n} = 9{,}622662 - 0{,}122115\cos\left(0{,}5236(n-1)\right) \\ H_{\text{Lg}n} = 9{,}513288 + 0{,}074432\cos\left(0{,}5236(n-1)\right) \\ H_{\text{Ch}n} = 9{,}577305 - 0{,}05815\cos\left(0{,}5236(n-1)\right) \\ H_{\text{Lv}n} = 9{,}46 \\ H_{\text{other}n} = 9{,}57 \end{cases}, \qquad (7)$$

where H_{Dn}, H_{IFn}, H_{Lgn}, H_{Chn}, H_{Lvn} is the combustion heat of natural gas for a certain n-month of the year in Donetsk, Ivano-Frankivsk, Luhansk, Chernivtsi and Lviv regions, $H_{other\,n}$ is the combustion heat of natural gas in all other regions of Ukraine.

To quantify the developed model, it is necessary to calculate the combustion heat of natural gas in a certain region of Ukraine on a certain route of natural gas supply in a year following 2018–2019 (based on measured combustion heat for these years predictive modeling was carried out). Route 406 in Ivano-Frankivsk region was randomly selected. The results of determining the combustion heat of natural gas on this route according to the developed model (7) are given in Table 2. Data for calculations are taken from the official website of RGC «Ivano-Frankivskgas» [7] for the last annual period (from July 2020 to June 2021).

Table 2

Results of determining the combustion heat of natural gas on route 406

Month/ year	07 20	08 20	09 20	10 20	11 20	12 20	01 21	02 21	03 21	04 21	05 21	06 21
H_{IFn}, kWh/m^3	10.01	9.96	9.91	9.76	9.56	9.57	9.56	9.57	9.56	9.53	9.88	9.98

The relative error between the values of the heat of combustion of natural gas calculated by formula (7) and the measured data of this physical quantity obtained from [7] is shown in Fig. 4.

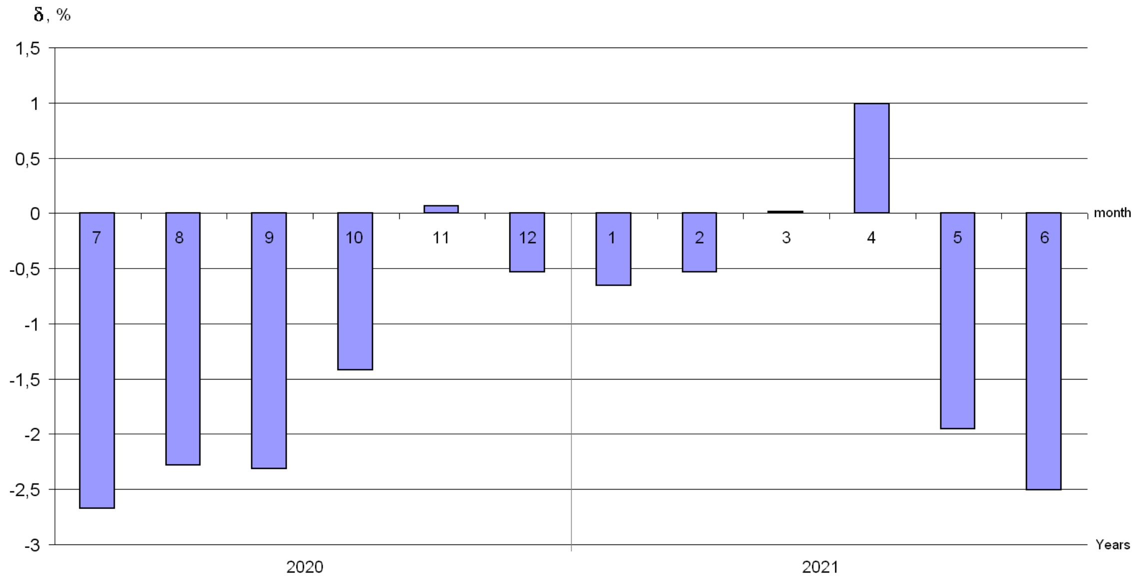

Figure 4. Relative error in calculating the combustion heat of natural gas on route 406

Thus, the developed model describes the change in combustion heat of natural gas in Ivano-Frankivsk region with sufficient accuracy (relative error in calculating the combustion heat of natural gas on this route does not exceed plus 1, minus 3%) and can be a basis for calculating this gas parameter.

Conclusions. Based on the analysis of measurement data of combustion heat of natural gas in different regions of Ukraine in 2014–2019, it was found that during 2018–2019 there was a trend of stability of calorific values of natural gas. It is substantiated that for most regions of Ukraine it is possible to use a single average value of combustion heat of natural gas 9.57 kWh/m^3 to further determine the energy of this energy source. In this case, the maximum deviations of the measured values from the average will be plus 2.4% and minus 2.7%. The exception is Lviv region, where the average value of combustion heat is 9.46 kWh/m^3, the maximum deviations of the measured values from the average is plus 0.7% and minus 1.6%.

In a number of regions: Donetsk, Ivano-Frankivsk, Luhansk and Chernivtsi, the measured data of natural gas combustion heat are described with sufficient accuracy by the trigonometric cosine function.

By applying the method of predictive modeling, a mathematical model was developed to determine the combustion heat of natural gas for a certain month of the year in Ukraine. The adequacy of the developed model was tested on the measurement data of combustion heat of natural gas on route 406 (Ivano-Frankivsk region), which was selected by random method. It was found that the relative error in calculating the combustion heat of natural gas on this route does not exceed plus 1, minus 3%, which is proportional to the accuracy of measuring the volume of natural gas by household gas meters.

Hence, the developed mathematical predictive model accurately describes the change in the combustion heat of natural gas and can be used as a basis for calculating this gas parameter in the absence of measured data.

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ВИЗНАЧЕННЯ ТЕПЛОТИ ЗГОРЯННЯ ПРИРОДНОГО ГАЗУ МЕТОДОМ ПРОГНОЗНОГО МОДЕЛЮВАННЯ

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Резюме. *Здійснено аналіз вимірювальних даних теплоти згоряння природного газу в різних регіонах України за 2014–2019 рр., які знаходяться у відкритому доступі. З 2020 року такі дані не оприлюднюються. Це зумовлює необхідність використання розрахункових методів визначення цієї фізичної величини для наступних років у різних регіонах України. Доведено, що впродовж 2018–2019 рр. спостерігалася тенденція стабільності показників калорійності природного газу, а коливання значень теплоти згоряння мали меншу амплітуду (в межах 9,31–9,80 кВт·год/м*^{3}*), розкид значень теплоти згоряння зменшився майже вдвічі: з 0,88 до 0,49 кВт·год/м*^{3} *у порівнянні з 2014–2017 роками. Тому вимірювальні дані теплоти згоряння природного газу за період 2018–2019 рр. були взяті за основу для прогнозного моделювання цієї фізичної величини.*

Встановлено, що для більшості областей України можна використовувати єдине середнє значення теплоти згоряння природного газу для подальшого визначення енергії цього енергоносія. Винятком є Донецька, Івано-Франківська, Луганська та Чернівецька області, в яких вимірювальні дані теплоти згоряння природного газу з достатньою точністю описуються тригонометричною функцією косинуса. Методом прогнозного моделювання розроблено математичну модель для визначення теплоти згоряння природного газу для певного календарного місяця року в Україні. Адекватність розробленої моделі перевірено на прикладі вимірювальних даних теплоти згоряння природного газу на 406 маршруті (Івано-Франківська область). Встановлено, що відносна похибка обчислення теплоти згоряння природного газу на даному маршруті не перевищує плюс 1, мінус 3%, що співрозмірно з точністю вимірювання об'єму природного газу побутовими лічильниками газу (об'єм газу та його теплота згоряння є параметрами для визначення енергії природного газу). Таким чином розроблена прогнозна математична модель з достатньою точністю описує зміну теплоти згоряння природного газу і може служити основою для розрахунків цього параметра газу у випадку відсутності вимірювальних даних.

Ключові слова: *природний газ, теплота згоряння, прогнозна математична модель.*

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