Improvement of accuracy of natural gas metering by means of household gas meters

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The paper deals with the new technique for calibration of the household gas meters according to the working conditions in order to reduce the error caused by non-conversion of gas volume to base conditions. To apply this technique the studies of gas pressure and temperature variations in household gas meters during a year were carried out, the ratio of gas volumes consumed by household consumers during the cold and warm seasons of the year is defined. Based on the studies the average annual gas temperature and pressure weighed by the consumed gas volumes are defined. Based on the weighed values of gas temperature and pressure the nominal values of gas temperature and pressure are defined in order to convert the readings of the gas meters to these nominal values. Application of the developed technique provides reduction of unaccounted volume of gas and reduction of unbalances in gas distributing companies.

Introduction

The amount of gas can be defined in mass units or in volumetric units. Usually when measuring the amount of gas and paying for the consumed gas, the volumetric units are used. Since gas is compressible, the same mass of gas will occupy different volume at different temperature and pressure. Thus during the custody transfer metering, the volume of gas is converted to the volume the gas would occupy at base conditions, i.e. the base temperature T_b and base pressure P_b. The values of the base temperature and pressure are different in different countries. In Ukraine and Russia these values are defined by GOST 2939-63 [1]. According to this standard the base temperature T_b is 20° C (293.15 K) and the absolute base pressure P_b is 760 mmHg (101.325 kPa). The value of the base pressure P_b in Europe is the same, and the value of base temperature T_b is different for different countries: T_b=15° C or T_b=0° C [2].

The result of gas volume measurement by a gas meter is the volume of gas V_w which passed though the meter at working conditions, i.e. at gas pressure P and temperature T in the gas meter.

Conversion of the measured gas volume V_w to base conditions is carried out according to the formula

$$V_b = V_w \cdot (P \cdot T_b)/(T \cdot P_b \cdot K), \qquad (1)$$

where V_b, V_w are gas volumes at base and working conditions respectively; P, T are absolute gas pressure and temperature in the gas meter at working conditions; P_b, T_b are absolute pressure and temperature of gas at base conditions; K is gas compressibility coefficient.

In industrial gas meters, conversion of gas volume to the base conditions is made according to formula (1) by means of microprocessor correctors of gas volume. In household gas meters this correction is usually not made.

During the work of a household gas meter the gas pressure and temperature in the meter are different from the base pressure and temperature. That is why systematic errors of gas metering take place.

1. Error caused by non-conversion of gas volume

It should be mentioned that because of the difference between the working conditions and base conditions the following two types of errors are present: methodical and instrumental.

The first one (methodical) is caused by gas compressibility (the amount of gas in a given volume depends on gas pressure and temperature) and is present when there is no conversion to base conditions. This error is defined as follows

$$\delta_{nc} = (V_w - V_b) / V_b\ 100. \qquad (2)$$

By substituting (1) to (2) the following formula for the δ_{nc} error will be received

$$\delta_{nc} = \left(\frac{T \cdot P_b \cdot K}{P \cdot T_b} - 1\right) \times 100 = \left(\frac{T \cdot P_b \cdot Z}{P \cdot T_b \cdot Z_b} - 1\right) \times 100, \qquad (3)$$

where Z, Z_b are gas compressibility coefficients calculated for working conditions (P, T) and base conditions (P_b, T_b) respectively.

As we can see from (3) the value of δ_{nc} error depends on the base values of pressure and temperature (P_b, T_b) as well as on the P and T. It also can be seen from (3) that the range of δ_{nc} error can be really large.

The calculated values of δ_{nc} error according to formula (3) for base pressure P_b = 101.325 kPa and for three base values of temperature being applied in [2] T_b = 20° C, T_b = 15° C and T_b = 0° C are given in Table 1.

Table 1

Values of the δ_{nc} error

Gas temperature, ° C	error δ_{nc} (%) for the base temperature T_b		
	0° C	15° C	20° C
-20.0	-7.39	-12.25	-13.75
-15.0	-5.54	-10.50	-12.03
-10.0	-3.69	-8.75	-10.31
-5.0	-1.85	-7.00	-8.59
0	0	-5.25	-6.87
5.0	1.85	-3.50	-5.16
10.0	3.69	-1.75	-3.44
15.0	5.54	0	-1.72
20.0	7.38	1.75	0
25.0	9.23	3.50	1.72
30.0	11.07	5.24	3.44

We can see from Table 1 that in the range of gas temperatures between -20° C (273.15 K) and +30° C (303.15 K) the δ_{nc} error can be positive and negative for all the three base temperatures.

It is obvious that gas pressure *P* and temperature *T* vary in working conditions and, as a consequence, the δ_{nc} error also varies. It means that when defining the gas volume for a long enough period of time (for example a year) there could be some compensation of the δ_{nc} error. If gas temperature *T* in the meter is equal to T_b then δ_{nc}=0.

2. Unaccounted losses of gas during a year

Based on the results of our studies [3] it was defined that the gas temperature in a household pipe reaches the temperature of ambient air at the distance of 3 m after escaping from underground. Thus the gas temperature in a household gas meter installed outside is equal to the temperature of ambient air and can be in the range of -20° C to +30° C during a year.

To analyze the ambient air temperatures during a year (for Ukraine) we used the data registered by the State Hydro-Meteorological Organization of Ukraine during a five-year time period. Based on these data the monthly average temperatures of air for Ukraine and for various regions of Ukraine were defined.

The curve of average air temperatures for Ukraine during a year based on the monthly average temperatures is shown on Fig.1.a. Since the gas temperature in a meter installed outside is equal to the ambient air temperature, the curve at Fig.1.a describes the average gas temperature in a gas meter installed outside. The curve of average day consumption of gas by household consumers in Ukraine during a year is given at Fig.1.b.

We can see from Fig.1 that the gas temperature is close to the base temperature (T_b= 20° C) only during some part of the warm season of the year. During the whole heating season (cold season of the year) the gas temperature in the meter is lower than the base temperature T_b and that is why the δ_{nc} error is negative. Thus during the heating season τ_{hs} there is a negative systematic error of gas volume measurement which leads to unaccounted volume of gas $-\Delta V_{loss}(\tau_{hs})$. The value of $-\Delta V_{loss}(\tau_{hs})$ is defined as a difference between the gas volume converted to base conditions $V_{gas.b}(\tau_{hs})$ and the volume of gas according to the meter readings $V_{gas.w}(\tau_{hs})$ (see Fig.1.b). During the heating season when the temperature of ambient air is low and gas consumption is high, the unaccounted volume of gas $-\Delta V_{loss}(\tau_{hs})$ is considerable.

During some part of the warm season τ_{ws} the gas temperature in the meter is also lower than the base temperature T_b, that is why the δ_{nc} error is still negative here and the unaccounted volume of gas $-\Delta V_{loss}(\tau_{ws})$ is created. During some other part of the warm season τ_{ws+} the gas temperature is higher than the base temperature T_b and the δ_{nc} error is positive. As a result the excessive accounted gas volume $+\Delta V_{loss}(\tau_{ws+})$ is created. Since gas flow rate during high ambient air temperatures is very small, the gas volume $+\Delta V_{loss}(\tau_{ws+})$ does not exceed the unaccounted gas volume during the warm season $-\Delta V_{loss}(\tau_{ws})$. Thus the unaccounted gas volume during the heating season $-\Delta V_{loss}(\tau_{hs})$ is not compensated.

The volume of the unaccounted gas losses during a year is

$$\Delta V_{loss}\ (\text{year}) = -\Delta V_{loss}(\tau_{hs}) - \Delta V_{loss}(\tau_{ws}) + \Delta V_{loss}(\tau_{ws+}). \quad (4)$$

Based on the results of our research it was defined that the relative value of the unaccounted gas losses ΔV_{loss}(year) caused be the difference between the gas temperature and the base temperature in the climate conditions of Ukraine is approximately 0.6% of the gas volume consumed by people where the gas meters are installed outside.

3. Reduction of the non-conversion error

There are three ways to reduce the δ_{nc} error:

1. To use the microprocessor correctors for conversion of the gas volume to the base conditions (like it is made for the industrial gas meters);

2. To introduce and normalize such a values of the base temperature and pressure (individual for each country or group of countries) that the δ_{nc} error is minimum;

3. To calibrate the household gas meters at the previously defined average annual values of gas pressure and temperature weighed by the volumes of the consumed gas for each country or group of countries.

Let's consider the possibilities for application of the options mentioned above.

Application of the microprocessor correctors for conversion of the gas volume to the base conditions is a universal method providing the solution for the problem under consideration no matter what base values of temperature and pressure are applied in each country. The only difficulty in application of this method is measurement of the gas absolute pressure in the meter which is caused by the price of the absolute pressure measuring transducers. However, for the household gas meters there is no need to make the correction of gas volume by the gas pressure (it will be shown later). The process of measurement of gas temperature in the gas meter and calculation of gas volume according to formula (1) by a special microprocessor corrector can be done easily (the corrector can be installed on the gas meter instead of the mechanical counter). Moreover, such a correctors can transmit the results of measurement of gas volume converted to base conditions to the distributing services and the examples of such applications are known. Though the price of the gas meters with the microprocessor correctors today is higher than the price of those without the correctors.

The second way of solving this problem (i.e. introduction of the base values of temperature and pressure equal to the average annual values of gas pressure and temperature of the ambient air weighed by the volumes of the consumed gas in each country or group of countries) is implemented in a number of countries. However, as it is shown above, this approach will not solve this problem completely because it cannot be applied simultaneously to the gas meters installed outside and inside. It means that for T_b= 15° C the gas meters installed outside will not take into account the volume of consumed gas by more than 5% and for T_b= 0° C the readings of the gas meters installed inside will exceed the real volume of consumed gas by approximately 5%.

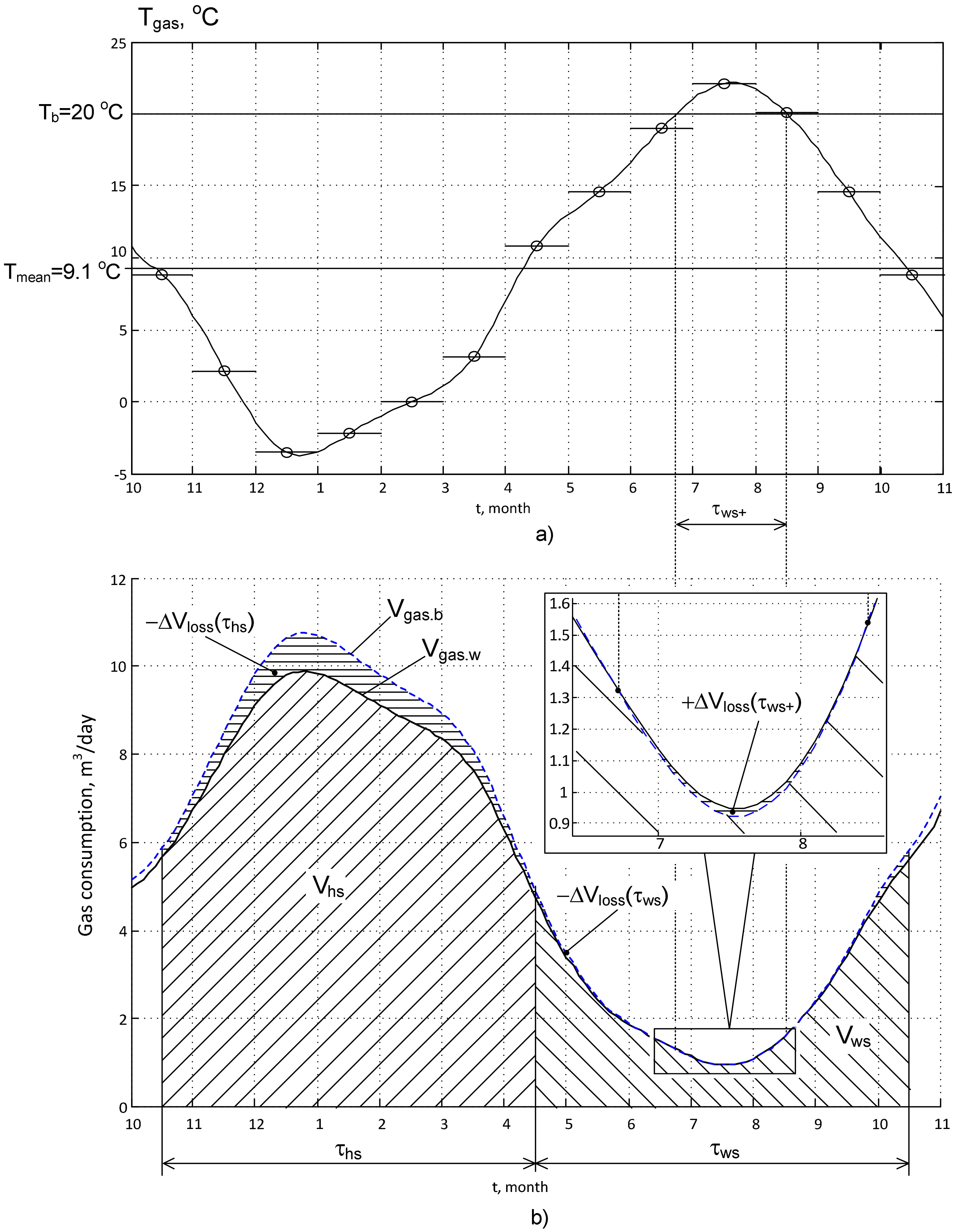

Fig.1. Curve of average air temperatures for Ukraine during a year based on the monthly average temperatures (a) and curves of gas consumption and gas losses caused by non-conversion of gas volume to base conditions (b) for gas meters installed outside.

It should be mentioned that by changing the values of T_b the "virtual" gas losses will not be reduced because it will not make any changes in operation of a lot of the installed gas meters calibrated at another value of T_b.

Our proposal is to calibrate the gas meters at the average annual values of gas pressure $\bar{P}_{gas}$ and temperature $\bar{T}_{gas}$ weighed by the volumes of the consumed gas. In order to do this the values of $\bar{P}_{gas}$, $\bar{T}_{gas}$ should be defined for each country or for group of countries.

The following values should be defined:

- average monthly gas pressure and temperature of ambient air;
- average gas pressure and temperature of ambient air during the heating season (cold season of the year) and warm season of the year;
- average volumes of consumed gas by the household consumers during the heating season and warm season of the year;
- average annual values of gas pressure and temperature weighed by the volumes of the consumed gas in the gas meters at the place of installation.

4. Average annual values of gas pressure and temperature weighed by the volumes of the consumed gas in household gas meters

To define the average annual values of gas pressure and temperature weighed by the volumes of the consumed gas the gas meters should be divided into two groups: meters installed inside and meters installed outside the houses with heating.

As it was mentioned before, the gas temperature in gas meters installed outside is equal to the temperature of ambient air. That is why the average monthly gas temperatures in such meters are taken as equal to average monthly temperatures of ambient air in various regions based on a five-year period of observation. Based on the average monthly gas temperatures the average values of gas temperature during the heating season (months I, II, III, X, XI, XII) and warm season (months IV, V, VI, VII, VIII, IX) were defined.

To define the gas temperature in gas meters installed inside the houses with heating the study on variation of gas temperature in pipes upstream of such meters was carried out. Based on the characteristics of the pipes, average flow rate of gas and average temperature of the ambient air inside the houses with heating, the values of gas temperature in the gas meters installed inside during the heating season and during the warm season of the year were defined.

According to the data from the gas distributing companies in Ukraine the ratio of the consumed gas volumes in the household sector during the cold and the warm months of the year is 4:1. This ratio should be taken into account when defining the average annual gas temperature weighed by the volumes of the consumed gas $\bar{T}_{gas}$ in Ukraine. The value of $\bar{T}_{gas}$ is defined as follows with taking into account the difference in gas consumption volumes during the cold and the warm moths of the year

$$\bar{T}_{gas} = k_{hs} \times T_{hs} + k_{ws} \times T_{ws} \,, \qquad (5)$$

where T_{hs} and T_{ws} are average gas temperatures in the meter during the heating and the warm season respectively; k_{hs}=0.8 and k_{ws}=0.2 are weight coefficients defined from the ratio k_{hs}/k_{ws}=4 and from the condition of $k_{hs}+k_{ws}$=1 to take into account the ratio of the consumed gas volumes in the household sector during the cold and the warm months of the year of 4:1.

The defined value of the average annual gas temperature weighed by the volumes of the consumed gas $\bar{T}_{gas}$ is equal to

+4°C for gas meters installed outside;

+12.4°C for gas meters installed inside the houses with heating.

The similar research work was done to study the gas pressure in a household gas meter.

5. Technique for calibration of household gas meters

To implement the function of conversion of the gas volume to the base conditions in the gas meters it is proposed to correct the calibration curve of a gas meter during calibration (each gas meter is calibrated by the manufacturer) in such a way that in working conditions the δ_{nc} error is minimal. For this purpose during calibration the gas meter readings should be converted to the values of gas temperature and pressure close to those in working conditions. This is the basis of optimization of household gas meters work to minimize the error of gas volume measurement caused by non-conversion of gas volume to base conditions during the year.

According to the proposed technique the concepts of nominal working pressure P_n and temperature T_n of gas are introduced. These values should be specified in the technical documentation for the gas meter and on the panel of the gas meter counter from which the gas volume is converted to base pressure and temperature. Here it is proposed that the nominal values of gas pressure P_n and temperature T_n are close to the average annual values of gas pressure and temperature weighed by the volumes of the consumed gas:

- nominal working pressure P_n =101 325 Pa is defined by the formula $P_n=P_a+P_{over}$, where the atmospheric pressure P_a= 99 440 Pa (average annual value of atmospheric pressure in Ukraine weighed by the volumes of the consumed gas) and the overpressure P_{over} = 1 885 Pa (average overpressure of gas in the gas distributing networks in Ukraine);
- nominal working temperature T_n = 288.15 K (15 °C) for gas meters installed inside the houses with heating or T_n = 273.15 K (0 °C) for gas meters installed outside the houses with heating (the corrected average annual values of gas temperature weighed by the volumes of the consumed gas).

During calibration of a gas meter according to the new technique the relative error of the *i*-th meter with taking into account the pressure loss and temperature difference between the inlet of the meter and the inlet of the reference meter is calculated as follows

$$\delta_i = \left(\frac{V_i}{V_0} \cdot \frac{P_i}{T_i} \cdot \frac{T_0}{P_0} \cdot \frac{P_b}{T_b} \cdot \frac{T_n}{P_n} - 1 \right) \times 100, \qquad (6)$$

where P_i, T_i are absolute pressure and temperature of air at the inlet of the meter under calibration; P_0, T_0 are absolute pressure and temperature of air at the inlet of the reference meter; V_0 is the volume of gas according to the readings of the reference meter; V_i is the volume of gas according to the readings of the meter under calibration.

Thus during calibration of a gas meter according to the developed technique the calibration curve is shifted in such a way that the readings of the meter correspond to the volume of gas converted to base conditions which are normalized in each country. The curves of the δ_{nc} error versus gas temperature for gas meters calibrated for nominal temperatures of T_n = 20° C, T_n = 15° C and T_n = 0° C are shown on Fig.2. We can see from Fig.2 that the methodical error δ_{nc} can be minimized by taking the correct value of the nominal gas temperature.

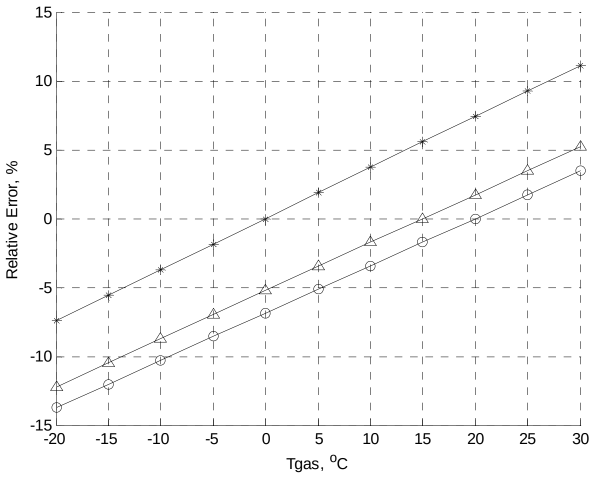

Fig.2. Curves of the δ_{nc} error versus gas temperature for gas meters calibrated for nominal temperatures of T_n = 20° C (o), T_n = 15° C (Δ) and T_n = 0° C (*) at gas pressure of 101.325 kPa

So the technique for calibration of the household gas meters consists of the following steps:

1) Definition of the average annual values of gas pressure and temperature weighed by the volumes of the consumed gas (see above).

2) Definition of the nominal gas pressure P_n and temperature T_n to minimize the gas losses. Conversion of gas volume to the base conditions is done from the nominal values of gas pressure and temperature. The appropriate values of P_n and T_n are those equal to the average annual values of gas pressure and temperature weighed by the volumes of the consumed gas in the gas meters. It is allowed that the values of P_n and T_n deviate from the average weighed values $\bar{P}_{gas}$, $\bar{T}_{gas}$. The nominal values should be defined in such a way that the deviation of pressure is compensated by the deviation of temperature so that the combined δ_{nc} error is equal to zero.

3) Calibration of gas meters for nominal values of gas pressure P_n and temperature T_n (introduction of a shift to the calibration curve of a gas meter).

There is no contradiction between this approach (technique) and the international normative documents, [4] in particular. And there is a need to introduce some slight changes, which are prepared by us, to the Ukrainian normative documents [5, 6, 7].

If the gas meter calibration is done at the temperature of 20±2° C, like it is specified in EN 1359:1998 [4], then due to conversion of the gas meter readings to the base values from the temperature of 15° C for the gas meters installed inside, or from the temperature of 0° C for the gas meters installed outside, the δ_{nc} error is eliminated.

To eliminate the instrumental error caused by the difference between the gas temperature in operating conditions and the base temperature, the specified calibration of the gas meter should be done exactly at nominal temperature T_n. These values for Ukraine are T_n=15° C for the gas meters installed inside and T_n=0° C for the gas meters installed outside.

However, taking into account the complexity and the price of calibration of gas meters at 15° C and especially at 0° C, as well as taking into account the fact that the value of the instrumental error usually does not exceed 0.5%, there is no need to carry out calibration at these values of the temperature. At the same time verification of the combined value of the instrumental error as a function of temperature across the whole range of the gas meter working temperatures should be done according to clause 7.1.3 of EN 1359:1998 [4].

Conclusions

Application of the developed technique for calibration of the household gas meters will provide in a simple way the possibility to take into account additionally 4% of gas being consumed in the household sector. This volume of gas will be measured by the gas meters (after calibration according to the new technique) and as a result will be paid for by the consumers. It means that the significant "virtual" gas losses caused by non-conversion of gas volume to the base conditions in the gas distributing companies will be eliminated.

References

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[2] ISO 13443:1996 Natural gas – Standard reference conditions.

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[5] DSTU 3607-97 Household gas meters. Rules for commissioning and methods for testing.

[6] DSTU 3336-96 Household gas meters. General technical requirements.

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