TEMPERATURE FIELD INSIDE THE DIAPHRAGM GAS METER

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A large proportion of natural gas consumption is metered by diaphragm gas meters with no temperature compensation. For billing purposes, an estimate of the gas temperature inside the meter is used. The estimate is currently based on ambient temperature (atmospheric temperature). Whenever a converter has been installed, the gas temperature used for the compensation of the gas volume is measured at the outlet of the meter, i.e. at the spot where the temperature sensor of the converter resides. In this article, we focus on determining the operating temperature of the gas, i.e. the mean temperature inside the diaphragm chambers of the meter where the volume of the passing gas is actually measured. The results also describe the temperature field inside the diaphragm gas meter at different volumetric gas flow rates. The measured data were used to describe the relationship between the operating temperature and the temperature at the outlet of the meter. The results of this article may help clarify the relationship between the ambient temperature and the operating temperature of the gas inside the diaphragm gas meter, and so refine the formula for the conversion of the gas volume measured into the volume billed to the customer.

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1. Introduction

Consumption of natural gas in almost all residential and other low-demand installations is measured by diaphragm gas meters. In some countries diaphragm gas meters are gradually being replaced by ultrasonic gas meters that enable remote shutdown, remote reading of gas consumption, etc. [1, 2]. Nevertheless, the diaphragm gas meter still retains great advantages, including its durability, long-term stability, low pressure drop, heat fire resistance (up to 650 °C), low cost, etc. [3, 4].

Measurement of gas consumption is carried out by measuring the volume of the gas that had passed through the meter at the operating pressure and the operating temperature inside the measuring chambers with diaphragms. When invoicing, the actual measured volume must be recalculated into the volume at reference conditions (15 °C, 101 325 Pa) [5].

The amount of energy delivered during the given billing period is calculated as:

$$Q = V_p.k.H_0, \tag{1}$$

where Q is the amount of energy supplied, V_p is the operating volume of the gas [m^3], H_0 is the average calorific value of the gas delivered during the billing period at reference conditions of 15 °C and 101 325 Pa [kWh/m^3], k is the volumetric conversion factor [-] comprising the conversion of the operating volume V_p (measured at the operating temperature and operating pressure) to the billable volume V_u valid for the same amount of gas at the reference conditions. The volumetric conversion factor is therefore the ratio between the volume of the gas at reference conditions V_v and the operating volume V_p. For zero gas humidity:

$$k = \frac{V_v}{V_p} = \frac{T_v}{T_p}.\frac{p_p + p_b}{p_v}.\frac{z_v}{z_p}. \tag{2}$$

Where V_v is the volume of gas at reference conditions (101 325 Pa, 15 ° C) [m^3], V_p is the operating volume of the gas [m^3], T_v is the reference temperature (288.15 K) [K], T_p is the operating temperature of the gas [K], p_p is the operating pressure [Pa], p_b is the atmospheric pressure at the gas sampling point [Pa], p_v is the reference pressure (101 325 Pa) [Pa], z_v is the compressibility factor at reference conditions [-], z_p is the compressibility factor at operating conditions [-] [6].

When billing the consumed volume of natural gas, it is expected that the meter indicates the operation volume of gas V_p measured at the operating temperature t_p and the absolute pressure

$$p_{abs} = p_p + p_b. \tag{3}$$

Both the operating temperature t_p, and the absolute pressure p_{abs} express average values in the gas meter, which change over the billing period. A specified single value of the operating temperature for the entire billing period for a gas meter without any temperature compensation therefore always represents only an estimate [7].

To find the difference between the measured and the actual amount of gas consumed, which results from metering the amount of natural gas with the help of a diaphragm gas meter with no temperature compensation, it is necessary to know the effect of ambient air temperature on the temperature inside the gas meter. In other words, it is necessary to determine the temperature distribution inside the gas meter. The ultimate goal is to

a) Determine the operating temperature t_p, i.e., the mean temperature in the diaphragm chambers of the meter at which the meter actually measures the volume of the passing gas.

b) Compare the determined operating temperature t_p, with the temperature at the exit of the meter. The comparison is done in consideration of meters containing a conversion device where the temperature sensor of the converter is always placed at the exit of the meter.

2. Experimental

The laboratory apparatus consisted of two diaphragm gas meters without temperature compensation connected in series. One meter was type Actaris Gallus 2000 size G4 (maximum volumetric flow rate of 6 m^3/h) and the second meter was type MKM size G2.5 manufactured by Premagas (maximum volumetric flow rate of 4 m^3/h).

The meters were connected in a closed circuit with a fan, a heat exchanger and a silica gel column. Both gas meters and other parts of the apparatus were connected via copper pipes and socket joints with rubber seals. The total length of the piping was 501 cm. A section of the piping was exposed to temperatures in the laboratory and a section resided in an air conditioning box. The first meter was placed inside the air conditioning box in which the temperatures were alternately set at 0 °C, -5 °C and -10 °C. This meter (type MKM size G2,5) simulated a gas meter located outside a home and exposed to atmospheric temperatures. The second meter was placed in the laboratory. Gas circulation through the piping and the gas meters was carried out with the help of a fan (Type 401 – Standard). The gas flow rate was adjusted using triac speed control of the fan. An adsorber containing silica gel resided behind the fan in order to remove any moisture before it could condense inside the gas meter in the conditioning box. The dry gas progressed from the adsorber to the meter inside the air conditioning box and then to the meter in the laboratory. Behind the gas meter in the laboratory, in the direction of gas flow, there was a manometer and a ball valve whose partial closure maintained a slight positive pressure in the apparatus (with the exception of immediate intake of the fan). To compensate for the heating of the gas occurring during its passing through the fan, a cooler was placed between the fan and the adsorber.

Platinum resistance temperature detectors Pt100 were used to measure the temperature of the gas. The detectors were placed at the inputs and outputs of the two gas meters, the input and output of the air conditioning box and the cooler. Identical detectors were also placed nearby the two gas meters to measure the ambient temperature in the laboratory and the temperature within the air conditioning box. The gas flow rates through both diaphragm gas meters were measured using impulse sensors. The measured data were recorded and collected in a datalogger MS3 made by Comet Systems. The recorded data were then transferred to a computer and evaluated. The measuring apparatus with the air conditioning box is shown in figure 1. The gas meter in the laboratory was placed under a metal cover from which only the counter of the meter was visible. The purpose of the cover was to shield the gas meter from rapid fluctuations in temperature and air movement caused by traffic in the laboratory (opening doors, windows, movement of persons etc.).

With regard to safety, experiments were performed using air instead of natural gas.

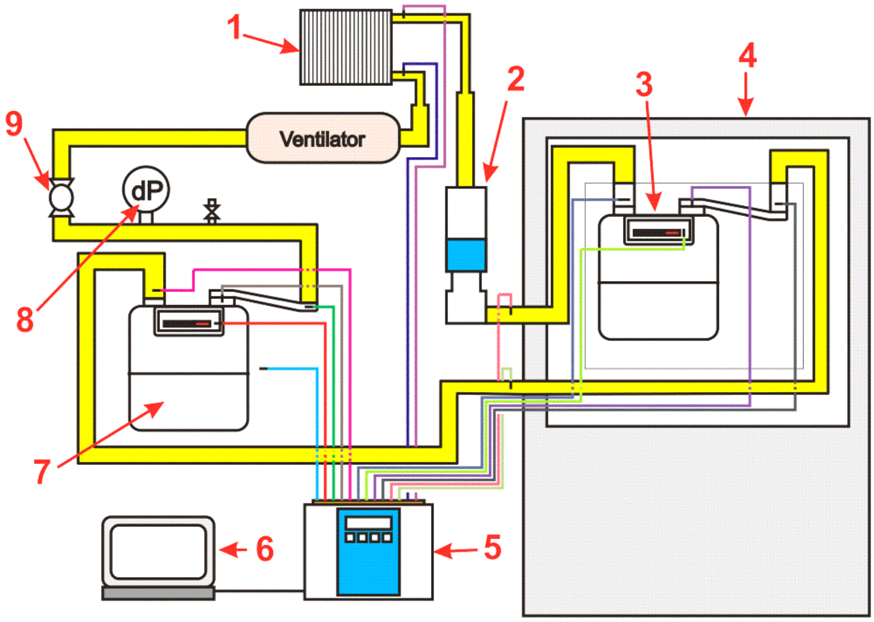

Fig. 1 Layout of the apparatus

Description: (1) cooler; (2) adsorption column with silicagel ; (3) diaphragm gas meter placed in the air conditioning box; (5) datalogger; (6) computer; (7) diaphragm gas meter; (8) manometer; (9) ball valve.

The following figures 2 and 3 show a dismantled gas meter with temperature sensors.

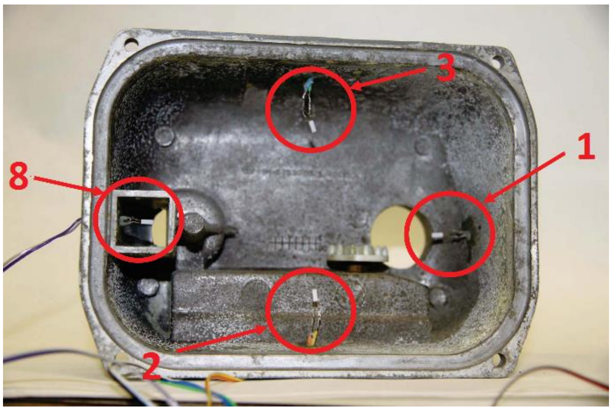

Fig. 2 The upper part of the meter G2.5 MKM with mounted temperature sensors

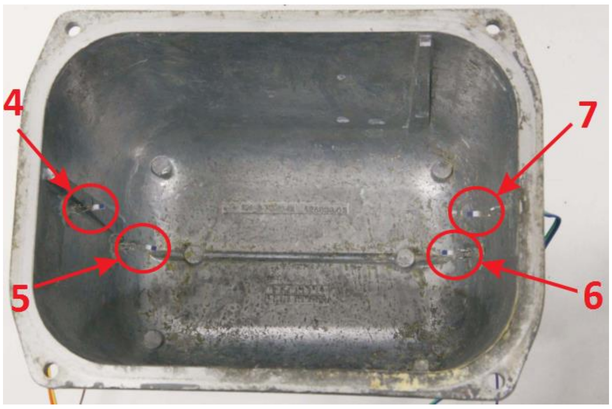

Fig. 3 The lower part of the meter G2.5 MKM with mounted temperature sensors

The temperature in the conditioning chamber was consecutively adjusted at 0 °C, -5 °C and -10 °C. At each temperature, three volumetric gas flow rates were used so as to cover the entire working range of the volumetric flow rate in G2.5 MKM diaphragm gas meter (0.025 - 4 m^3/h). Before each measurement, the apparatus was tempered, i.e., at the set temperature in the air conditioning box, the volumetric flow rate of the gas was maintained at zero. After tempering, which lasted approximately three hours, the desired flow rate of the gas was set up with the help a triac controller of the fan's speed. During the measurements, the temperature changes were monitored and after the temperature had stabilized, the measurement was stopped.

Temperatures measured by the temperature sensors and the volumetric flow rates measured with the help of transmitter impulses were recorded in the data logger MS3 and then exported to the computer where the results were evaluated.

Figure 4 shows the temperature sensors located inside the diaphragm gas meter. Temperature sensors were placed so that they had best chance of detecting the changes of the temperature along the flow of the gas through the gas meter.

The gas enters through the inlet line to the top part of the meter *1*. Here the gas is slightly delayed. Then it proceeds through the front opening *2* or the rear opening *3* (movable stopper) into the space with diaphragms. From there the gas flows into the bottom part of the meter in both directions *4* and *7*. There a portion of the gas moves towards the bottom part *5* on the left. At the same time the gas is exhausted through the narrow opening towards the outlet *8*. From there, the gas is directed to the outlet of the meter t_e.

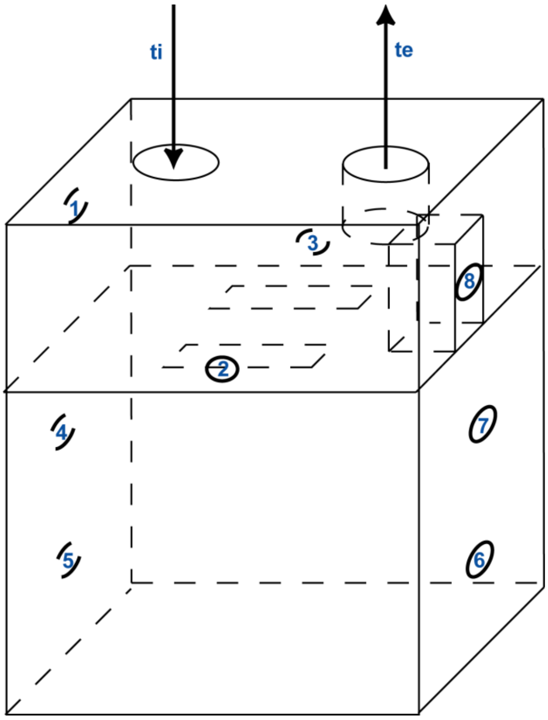

Fig. 4 Location of the temperature sensors inside the diaphragm gas meter

Position of temperature sensors: t_i – inlet of the gas meter; 1 – behind the entrance into the meter; 2 – inlet to the front diaphragm; 3 – inlet to the rear diaphragm; 4 – lower part on the left, outside the diaphragm; 5 – down in the lower part on the left, outside the diaphragm; 6 – down in the lower part on the right, outside the diaphragm; 7 – bottom part on the right; 8 – exhaust of the gas in the gas meter; t_e – outlet from the gas meter.

3. Results and discussion

Figures 5, 6 and 7 display the results of measurements for three different values of the temperature around the gas meter inside the air conditioning box. Labeling of the measurements corresponds with the indications of temperature sensors in figure 4.

The graphs display the measured temperatures plotted against the locations of the temperature sensors in the diaphragm gas meter. It shows that the lowest temperature is indicated by the sensor *6*.

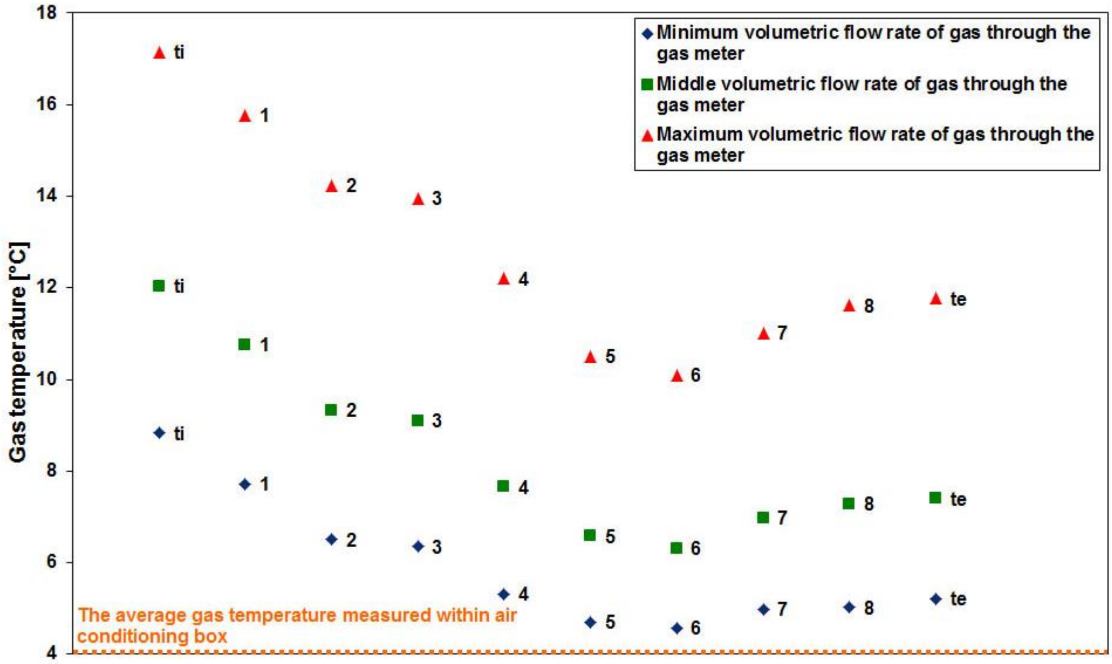

Fig. 5 Temperatures measured within the diaphragm gas meter. Temperature in the air conditioning box 0 °C

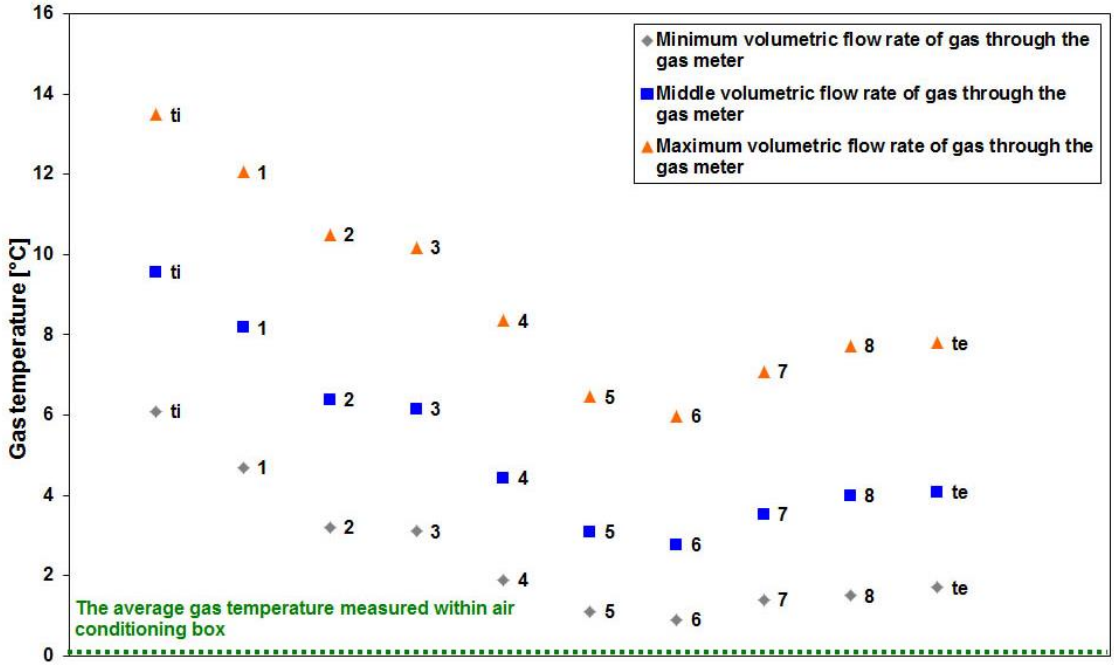

Fig. 6 Temperatures measured inside the diaphragm gas meter. Temperature in the air conditioning box -5 °C

This sensor is located down on the right, in the bottom part of the meter. Behind this point, in the direction of the gas flow, the passing gas undergoes slight heating. This can be explained by the heating of the passing gas by the gas from the top of the meter, which has a higher temperature. These two parts of the meter are separated by a thin wall, and thus there may be heat transfer from warmer to the cooler gas.

Prior to entering the meter, during its passage through the inlet piping that is exposed to the ambient temperature t_a, the gas is cooled to the temperature t_i. From the inlet the gas proceeds to sensor 1 in the upper space of the gas meter and then it is divided into the two diaphragm chambers. Temperature sensor 2 detects the temperature of the gas in the front chamber and sensor 3 detects the temperature in the rear chamber.

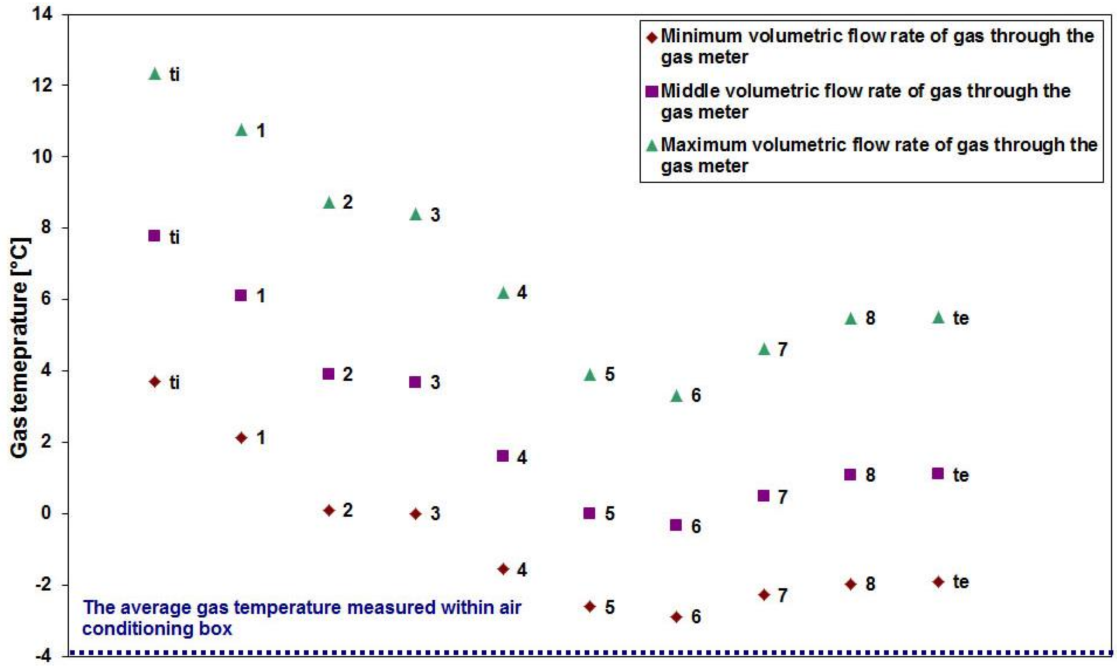

Fig. 7 Temperatures measured within the diaphragm gas meter. Temperature in the air conditioning box -10 °C

These sensors should be equivalent and should show the same temperature. Systematically higher temperature t_2 detected by sensor 2 can be attributed to the fact that a portion of the space in the front part of the gas meter is occupied by the counter. The gas passing over sensor 2 therefore has a higher velocity then the gas passing over sensor 3. The temperature at the inlet of the diaphragm chambers was consequently expressed as the average of t_2 a t_3. The temperature at the outlet of the membrane chambers is best expressed by t_4 because the sensor 4 is directly and only exposed to the gas exiting from the diaphragm chambers. In a similar position towards the outputs of the diaphragm chambers as sensor 4 is sensor 7. However, due to the proximity of the outlet from the gas meter, sensor 7 is exposed to a mixture of the gas leaving the chambers and the gas that has passed through the entire volume of the bottom part of the gas meter and was there cooled by the meter's wall. This situation is reflected by the temperature t_5 that is lower than t_4, and subsequent temperature t_6 that is again lower than the temperature of the opposite gas stream t_5.

The desired operating temperature, i.e. the temperature inside the diaphragm chambers t_p, could not be found by sensors directly placed inside the diaphragm chambers as the sensors would interfere with diaphragm movement. Therefore t_p, was expressed as the average of the temperatures measured immediately upstream and downstream of the chambers, i.e.

$$t_p = \frac{t_2 + t_3 + 2t_4}{4} \,. \tag{4}$$

In the above formula, temperature t_4 is weighted by a factor of 2 because t_4 alone represents the temperature behind the chambers, while for the temperature in front of the chambers we have data from sensor 2 and sensor 3.

Next, we will examine the dependence of the operating temperature t_p on the ambient temperature in the vicinity of the gas meter t_a , the temperature at the inlet to the gas meter t_i, and the flow rate of the gas through the meter.

The measured values of the gas temperature at the outlet of the meter t_e and the calculated operating temperature t_p are listed in table 1.

Tab. 1 The measured values of the gas temperature at the outlet of the gas meter and the calculated operating temperatures

t_a box [°C]	Temperature	Low flowrate	Medium flowrate	High flowrate
0	t_e [°C]	5.2	7.4	11.8
	t_p [°C]	5.9	8.4	13.1
-5	t_e [°C]	1.7	4.1	7.8
	t_p [°C]	2.5	5.3	9.3
-10	t_e [°C]	-1.9	1.1	5.5
	t_p [°C]	-0.7	2.7	7.4

The correlation between the output and the operating temperature of the gas is shown in the graph (Fig. 8).

4. Conclusion

When calibrating a gas meter without temperature compensation it is assumed that the operating temperature t_p is identical to the temperature of the gas exiting the meter t_e. This assumption is valid for calibrations performed at a constant gas temperature that is equal to the temperature of the surroundings of the meter.

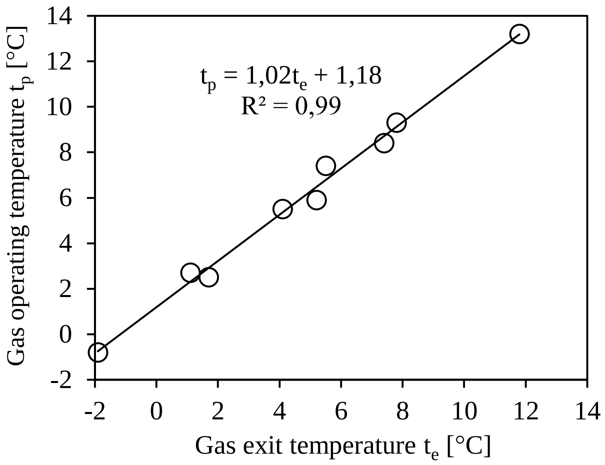

Fig. 8 The relationship between the output temperature and the operating temperature of the gas

Such a calibration procedure is described for example by international and domestic standards [8]. Under the operating conditions, the temperatures of the measured gas t_i, t_e, and the temperature of the gas meter's surroundings t_a differ. Although the operating temperature t_p must lie in the interval $<t_i; t_e>$, the calibration formula $t_p = t_e$ stated by the standards does not have to be valid. Measurements described in this article provided values of t_p needed for the correct billing of the amount of consumed gas shown by a gas meter with no built-in temperature compensation. The measurements show that for a diaphragm gas meter G 2.5, over its working range of flow rates and outside temperatures from 0 to -10 °C, there is a close relationship between the operating temperature t_p and the temperature of the gas at the outlet of the meter t_e. It is still necessary to apply the same methodology to study the effects of the size of the gas meter and the effects of respective volumetric flow rates on the operating temperature in the examined meters.

Literature

1. Jena, A.; Mágori, V.; Russwurm, W. Ultrasound gas-flow meter for household application. *Sensor and Actuators A* **1993**, *37-38*, 135–140.
2. Buonnano, G. On field characterization of static domestic gas flowmeter. *Measurement* **2000**, *27*, 277–285.
3. Ficco, G. Metrological performance of diaphragm gas meters in distribution networks. *Flow Measurement and Instrumentation* **2014**, (37), 65–72.
4. Treloar, R. D. *Gas installation technology*, 2nd ed.; Wiley-Blackwell: Oxford, 2010.
5. Nath, B. Temperaturverhalten von Balgengaszählern. *Gas-Erdgas* **1995**, *136*, 1-6.
6. International Recommendation OIML R 137 - 1&2. *Gas Meter*. Paris: Organisation Internationale de Métrologie Légale, 2012. 70 p.
7. Jandačka, J.; Malcho, M. Simulácia stavových zmien zemného plynu v membránovom plynomere. *Acta Metalurgica Slovaca* **2005**, (11), 127–132.
8. Cascetta, F.; Comayyi, M.; Musto, M.; Rotondo, G. An experimental intercomparison of gas meter calibrations. *Measurement* **2012**, (37), 1951–1959.