INVESTIGATION OF THE METROLOGICAL CHARACTERISTICS OF THE NATURAL GAS FLOW RATE STANDARD BASED ON VARIABLE PRESSURE DROP FLOWMETER

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Abstract:
The analysis of existing in World practice flow rate measurement standards for calibration of the gas flow and volume measuring devices for operating conditions is carried. A new idea of the design the flow rate measurement standard dedicated for calibration meters and flow meters of natural gas is considered. It apply the variable pressure drop method for measuring the flow rate and volume of gas using the diaphragm as the constriction device. Design features of standard and its calibration with use of the standard flow rate measuring bell-type device are given.

The numerical modelling of coefficients, which determine the metrological parameters of flow rate measurement standard during its calibration and work, is conducted. The zones of the improved stability of standards flow rate coefficient values are established. The extended uncertainties of flow rate measurement standard during calibration and working are estimated.

Keywords: natural gas, flow rate, measurement standard, variable pressure drop, metrological parameters

1. INTRODUCTION

Needs of the natural gas flow rate measurement, its economical and rational using is very important for the energy saving. A lot of research works is devoted to studying this question, however in the prevailing majority they concern only on development and improvement of measurement equipment and standards installations. It is commonly known that the exact gas flow rate measurement can't be realized without appropriate metrological support. Existence of the appropriate state system of reproduction and measurement the volume and flow rate of the natural gas is needed. Proper standards and transfers of units specified for gas to ensure the unity of measurements in the country are necessary.

The actuality of this problem is confirmed a specially in Ukraina because there are no approved algorithms of transfer gas flow rate measurement unit from the state (national) standards to the working measurement equipment of the natural gas. This problem is important practically for all countries in Europe and is not possible to solve it without standardized transfers and secondary standards in calibration laboratories for this area of measurements.

Mobile transfers systems are also used in the world practice, in particular designed on basis of devices with rotating elements or with a help of the stream constriction devices.

Since 80th years the company «Gasunie» (Groningen, Netherlands) [1] used a set of three rotary gas meters G40 type CVM (Constant Volume Meter), and have been applied to transfer the unit of air volume from a bell-type standard with a bell of 0.5 m^3 capacity and limited error ± 0.02% to a similar type standard with the larger bell of 4 m^3 capacity and error ± 0.10%. For calibration the company "Gasunie" applied the three mobile transfers based on rotary gas meters G250 of CVM type. They transfer the unit of flow to the primary standard of a high pressure of the same company. This transfer was created on the basis of turbine standards on flow rate to 4000 m^3/h with a pressure up to 0.8 MPa and had an limited error ± 0.13%.

During years 2004-2006 these transfers were applied by two laboratories of NMI (National Metrological Institutes) in Europe, ie. PIGSAR (Federal Physics and Technology Institute PTB, Germany) and NMI-VSL (NMI-VanSwinden Laboratories, Netherlands) to measure units of the natural gas volume at operating conditions [2, 3].

Later on these transfers were applied also for key comparison of standards of PTB and NMI-VSL laboratories with a standard of the French national metrological institute (BNM) [2]. This standard is created and based on PVTt-type installation. The measurement uncertainty didn't exceed ± 0.15%.

In Ukraine transfers are applied to transfer unit of air volume from the state standard to working standards on the basis of bell-type installations and on the basis of gas standard meters [4]. As transfer are used the drum gas meters EP-2 and EP-15 (producer of this flow rate measurement equipment is in Skutezh, the Czech Republic), the resonance free rotary meter Delta S-Flow with two three-blade rotors and the turbine meter TZ Fluxi 2200 (both of Actaris Gaszahlerbau Gmbh, Karlsruhe, Germany). They covered the range of measured flow rates (0.016 –2500) m^3/h with relative error not exceeded ± 0.15%.

In design of transfers a stream constriction devices without moving elements can be also used, mainly the critical nozzles [5].

In Ukraine, for metrological certification of the piston-type flow rate measurement installation, which works at the natural gas, the critical nozzles were also applied [6]. The set of five critical nozzles calculated for flow rate 500, 1050, 2100, 4200, 4250 m^3/h at operating conditions is used. These nozzels worked with pressure range 0.3 – 1.2 MPa.

Critical nozzles as a part of the transfer working on natural gas are also provided in the metrological center in Boyarka (Ukraine) [7].

The advantage of transfers with rotating elements over transfers with critical nozzles as the main part is: the possibility to achieve the high accuracy of the gas flow units traceability, creation mobile variants of calibration equipment and work on the air as well on the natural gas flow. Such realization demands a high technological level of the transfers' production, the availability of the corresponding standards installations for calibration with the proper methodical normative documents. The creation of standards operating on natural gas is also not ease. It is why a little number of standards installations which can operate on natural gas and have a small (less than 200 m^3/h) range of operating flow rates is existing. Besides that, with the transition of measurements operated on air to natural gas the metrological parameters of standards and working tools can significantly change. Therefore necessary such measuring tools should be developed, which could operate both on air and natural gas and at the same time would be enough reliable when working environment is changed. Consequently the development of flow rate's standards operating on air and natural gas with simultaneous realization of transfer of natural gas flow rate's and volume's unit to working measuring tools is still actual.

2. MATERIALS AND SIMULATIONS

In this work [8] the proposal of creation the transfer standard that fundamentally differs from well-known such standards is given. Preproduction model was already built and theoretical, experimental and metrology research are conducted. The novelty of this transfer is such that it is build on the base of variable pressure drop flowmeters and the diaphragm as a constriction devices (CD) is used [9].

The algorithm for measurement the volume flow rate of gas at operating conditions is:

$$q_V = \frac{\pi K_S K_K}{4\sqrt{1-\beta^4}} d^2 \sqrt{\frac{2\Delta p}{\rho}} \qquad (1)$$

where q_V –volume flow rate of gas at operating conditions of standard; K_S and K_K –calibration coefficient of flow rate and correction coefficient of results obtained for air if the natural gas flow is measured; β – relative diameter of CD orifice ($\beta = d/D$, where d -diameter of CD orifice and D –inside diameter of flowmeter measuring pipeline); Δp – pressure drop on CD; ρ – density of natural gas at operating conditions.

The coefficient K_S is determined by an experimental way. It represents a product of flow rate coefficient and coefficient of extension of working environment [9]. Methodology of calculation the coefficient K_K, which is less than one, is given in [8].

The feature of this standard is possibility of preliminary calibration on air for determination its metrological parameters and as first - the calibration coefficient K_S. For that the standard bell-type flow rate measuring installation is used (fig. 1). On this device it is possible to determine experimentally calibration coefficient K_S as a product of outflow coefficient of constriction device and coefficient of extension for working environment [8, 9].

At calibration process the air as working fluid is used in the bell-type installation (fig. 1), which is the working standard. The down part of the bell is immersed in the circular reservoir 4 with a liquid 5. Firstly, the valve 15 in an output pipeline 14 is closed and then the space under a

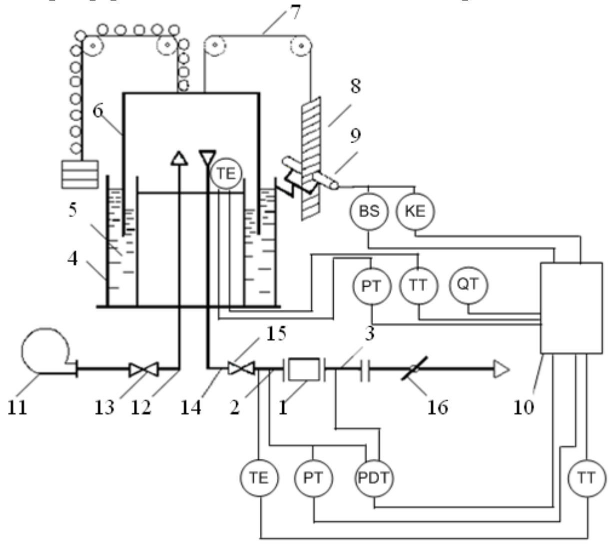

Fig. 1. Scheme of calibration of the gas flow standard with use the bell stand (explanation in text)

bell 6 is filled from the source of air flow rate 11. When this bell 6 becomes in stetted necessary position, valve 13 in an input pipeline 12 is closed, and the gas flow from the source 11 is stopped. Bell 6 now appears in the immovable weighted state. Further the setpoint device of flow rate 16 is set to the required value of the flow rate of gas and valve 15 is open. In the consequence of that the bell 6 under the action of own weight begins to go down and ousts the air through the constriction device 1 of the calibrated standard. (The input 2 and output 3 straight-line segments so long as needed are also on both sides of this device.) Then the optical sensor of linear displacement which contains linear control ruler 8 (connected by a rope 7 to the bell) and optronic pair 9, give a impulse signals to control volume of gas and time of its reproducing. These signals are counted by the electronic measuring device and the chronometer in the block 10 (box on right side of fig 1). Information about the working environment parameters of the working standard and of the calibrated standard nozzle is also collected. A calibration cycle ends when the bell 6 takes the extreme lower position and then valve 15 is closed. Device for computing the quality parameters of working environment Q is also included. It is used for determination of adiabatic index when the bell-type standard stand is operating of on the natural gas.

During the calibration of the transfer standard on air the density of used working fluid ρ corresponds to the density of air ρ_a at calibration conditions, and coefficient K_K =1.

Therefore formula (1) can be written as:

$$q_V = \frac{\pi K_S}{4\sqrt{1-\beta^4}} d^2 \sqrt{\frac{2\Delta p}{\rho_a}} \,. \qquad (2)$$

In the paper [8] the final uncertainty of standard during his work on natural gas is find. It is in the case when the calibration coefficient K_S determined is during the air flow throw the standard bell-type stand. After (1), the formula for the calculation of this coefficient is:

$$K_S = \frac{q_V \sqrt{1-\beta^4}}{\frac{\pi}{4} d^2 \sqrt{\frac{2\Delta p}{\rho_a}}} \tag{3}$$

In [8] is also shown that for the designed pre-production model of standard the uncertainty of its calibration coefficient determination $u(K_S)$ =1.310·10^{-3} and the mean value of coefficient K_S is equal $\overline{K}_S$ =0.5679. This total uncertainty $u(K_S)$ is determined according to a formula (3) taking into account the degree of influence through the partial derivatives of all influencing variables in the absence of correlations between them. It is given by formula:

$$u(K_S) = \sqrt{\left(\frac{\partial K_S}{\partial q} u_B(q)\right)^2 + \left(\frac{\partial K_S}{\partial \rho} u_B(\rho_a)\right)^2 + \left(\frac{\partial K_S}{\partial d} u_B(d)\right)^2 + \left(\frac{\partial K_S}{\partial D} u_B(D)\right)^2 + \left(\frac{\partial K_S}{\partial \Delta p} u_B(\Delta p)\right)^2} \tag{4}$$

where: $u_B(q)$, $u_B(\rho_a)$, $u_B(d)$, $u_B(D)$, $u_B(\Delta p)$ – uncertainties of B type at determination of parameters: q, ρ_a, d, D, Δp accordingly.

To study the change of coefficient K_S of standard at different conditions of its work on natural gas the metrological research of it is also necessary. For this purpose we use formula (3).

The real conditions of the standard work should be taken into account. They differ from conditions at its calibrating process. Furthermore, the density of working fluid (replacement from air to the natural gas), pressure drop on constriction device and change the measured flow rate ranges can be carry out by the numeral design of weighting coefficients for the range of variables values q = (100 ... 600) m^3/h, Δp = (0.5 ... 20) kPa, ρ = (0.7 ... 3) kg/m^3 for the conditions of work. Model of standard has d = 43.0 mm and D = 101.8 mm. For these data the relations of coefficients $\partial K_S/\partial q$, $\partial K_S/\partial \rho$, $\partial K_S/\partial \Delta p$ given by below algorithms (5) -(7) are simulated.

$$\frac{\partial K_S}{\partial q} = \frac{4\sqrt{\overline{\rho}}\left(\overline{D}^4 - \overline{d}^4\right)}{\pi \overline{d}^2 \overline{D}^2 \sqrt{2\Delta\overline{p}}} \tag{5}$$

$$\frac{\partial K_S}{\partial \rho} = \frac{2\overline{q}\sqrt{\overline{D}^4 - \overline{d}^4}}{\pi \overline{d}^2 \overline{D}^2 \sqrt{2\Delta\overline{p}\overline{\rho}}} \tag{6}$$

$$\frac{\partial K_S}{\partial \Delta p} = \frac{4\overline{q}\left(\overline{D}^4 - \overline{d}^4\right)\overline{\rho}}{\pi \overline{D}^2 \overline{d}^2 \Delta\overline{p}\sqrt{2\Delta\overline{p}}} \tag{7}$$

Next parameters of standard and natural gas: $\overline{K}_S$ =0.5679, $\overline{K}_K$ =0.9999; $\overline{d}$ =43.0 mm; $\overline{D}$ =101.8 mm; $\Delta\overline{p}$ =2.5 kPa; $\overline{\rho}$ =2.827 kg/m^3 for that simulation are used.

Numeral calculations of weighting coefficients from formulas (5)–(7) were carried out for the stable density of natural gas equal 3 kg/m^3. Influence of pressure drop higher than 6 kPa on coefficient $\partial K_S/\partial \Delta p$ found insignificant.

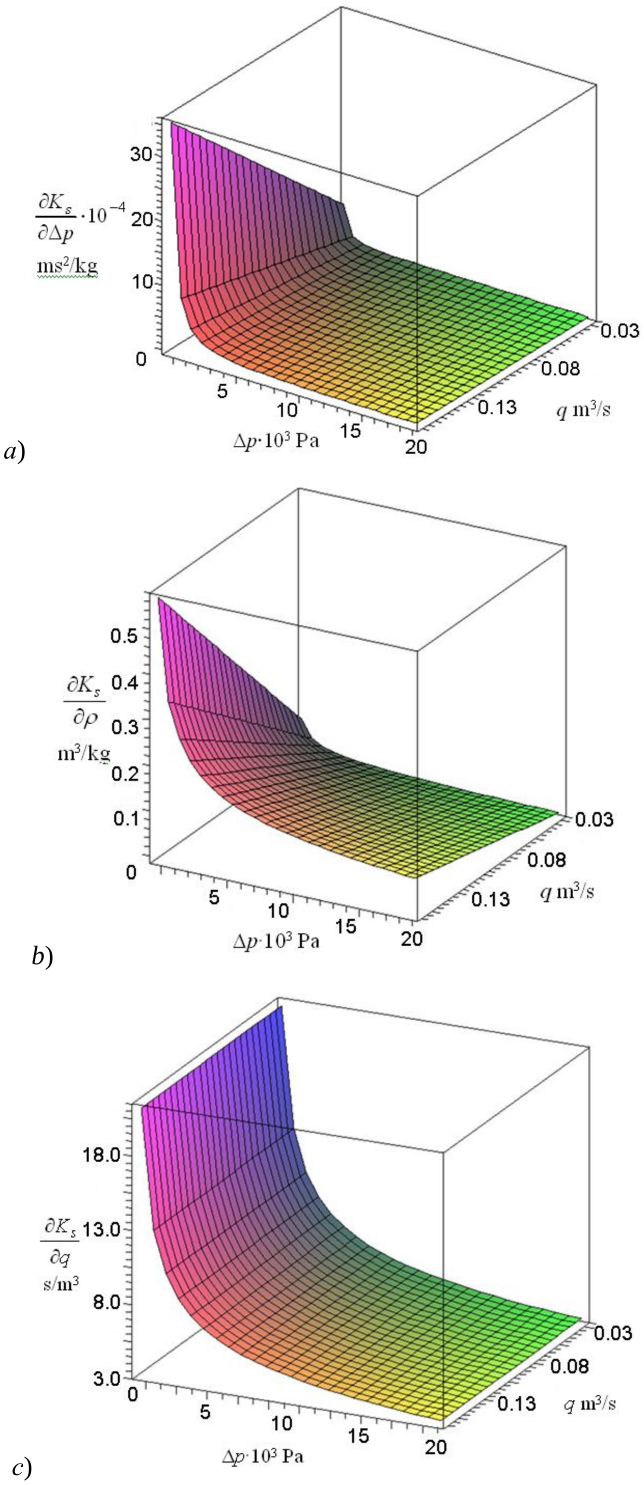

Fig. 2: Results of numeral simulation of the weighting coefficients: (a) $\partial K_S/\partial \Delta p$, (b) $\partial K_S/\partial \rho$ and (c) $\partial K_S/\partial q$ for the estimation of uncertainty of standard on the base of variable pressure drop flowmeter at the density of natural gas ρ = 3 kg/m^3.

This coefficient is practically independent from changes of flow rate q (fig. 2, a).

Influence of parameters Δp and q on a coefficient $\partial K_S / \partial \rho$ is noticeable essential (fig. 2, b). The necessity of its calculation or determination for standard's certain operating conditions is pointed on.

The coefficient $\partial K_S / \partial q$ depends on changes of pressure drop on the standard constriction device (fig. 2, c). The specification of numeral values for the conditions of its work is also required.

After a substitution to (4) the expected values of standard uncertainties and using values of the influence coefficients calculated in [8], the numerical value of total uncertainty of measurement of the natural gas flow rate is obtained as $U(\rho)$= 9.449 · 10^{-5} m^3/s.

If values of parameters $\overline{K}_S$ =0.5679, $\overline{K}_K$ =0.9999; $\overline{d}$ =43.0 mm; $\overline{D}$ =101.8 mm; $\Delta \overline{p}$ =2.5 kPa; $\overline{\rho}$ =2.827 kg/m^3 are taken to estimation, then in accordance with (1) the calculated value of the natural gas flow rate in operational conditions will be q= 0.0353 m^3/s (127.08 m^3/h). For that flow the related standard uncertainty is

$$\delta U(q) = \frac{U(q)}{\overline{q}} \cdot 100 = \pm 0.267\%. \quad (8)$$

The extended uncertainty of the flow rate measurement can be find if the standard uncertainty from (8) has to be multiply on the coverage coefficient k_0 for chosen probability. Accepting k_0 = 2 for the probability P=0.95 we will get:

$$U_r(q) = k_0 \delta u(q) = \pm 0.53\%. \quad (9)$$

The received results specify on the necessity of choice the optimal operating conditions of the standard, and as well on possibility to increase the accuracy if choice of conditions in the optimal zone are achieved.

3. CONCLUSIONS

The unconventional technical design of the standard of natural gas flow rate for gas flowmeters and meters with application of diaphragm as a constriction device is proposed and its facilities are considered in detail.

It is find that the influence of the pressure drop Δp and the volume flow rate q on weighting coefficient $\partial K_S / \partial \rho$ of the uncertainty component is essential. Determination of its value for certain conditions of standard operation is necessary from the point of view of increasing the measurement accuracy.

The influence of pressure drop on a diaphragm on the uncertainty component weighting coefficient $\partial K_S / \partial \Delta p$ at the values of pressure drop higher than 6 kPa is insignificant. Practically this coefficient is constant at the range of measured gas flow rates.

Relations of the coefficient $\partial K_S / \partial q$ on the pressure drop on a constriction device is also find.

Results of simulation testify the possibility of choice the optimal operating conditions of transfer standard. The achievement of them provides the increase of stability and improvement of metrological parameters of this unconventional type standard based on the variable pressure drop flowmeter for transferring flow rate and volume units for the natural gas measurements.

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