Definition of Equivalent Roughness of Internal Surface of a Measuring Pipeline

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Abstract* – Literature on the methods for defining the equivalent roughness of the internal surface of a measuring pipeline was analyzed. The equation for calculating the hydraulic resistance coefficient of friction of natural gas on the internal surface of the measuring pipeline was developed. The equation for calculating the equivalent roughness of the internal surface of the measuring pipeline was obtained. This equation provides improvement of accuracy of natural gas flow rate and volume measurement by means of the differential pressure method.

Key words – equivalent roughness, flow, natural gas, differential pressure method, standard orifice plate, hydraulic resistance coefficient of friction.

I. Introduction

Saving of fluid energy resources, which include natural gas, is an important task for Ukraine. One of the steps to perform this task is to improve the accuracy of measurement of flow rate and volume of natural gas. The most common method of measuring these values is the differential pressure method. The main provisions for this method are described in the national standard of Ukraine DSTU GOST 8.586.1:2009 [1] and in the international standard ISO 5167-1: 2003 [2]. Orifice plate is most commonly used as primary differential pressure transducer for measurement of flow rate and volume of natural gas by this method [3]. One way to improve the accuracy of the result of measurement of flow rate and volume of natural gas is application of advanced analytical dependences for calculating the coefficients of equation of natural gas flow rate and the accuracy of measurement values of input variables in real time. One of these input variables is equivalent roughness of the internal surface of the measuring pipeline R_{III}. Therefore, increasing the accuracy of measurement of the equivalent roughness of the internal surface of the measuring pipeline in real time is an important task.

II. Method of equivalent roughness measurement

To determine the equivalent roughness of the internal surface of the measuring pipeline, the method of direct measurement of the equivalent roughness R_{III} is used. This method can only be used during manufacturing of a pipeline before putting it into operation. According to DSTU GOST 8.586.1:2009 [1] the equivalent roughness R_{III} is measured at the same sections of pipeline that are used for definition and verification of the internal diameter of the measuring pipeline. But we do not know the value of R_{III} along all the distance (10D) of the pipe section upstream of the orifice plate. Another disadvantage of this method is that the roughness of the internal surface of the measuring pipeline changes during operation.

Profilometers and profilografs are used for measurement of the equivalent roughness. Measurement of the equivalent roughness of the internal surface of the measuring pipeline should be carried at a distance l upstream of the inlet face of a standard orifice plate:

- if the distance L from the first fitting to the inlet face of a standard orifice plate is larger than 10D, then according to DSTU GOST 8.586.1:2009 [1]

$$l = 10 \cdot D\,; \tag{1}$$

- if the distance L from the first local resistance to the inlet face of a standard orifice plate is less than 10D, then according to DSTU GOST 8.586.2:2009 [3]

$$l = L(\beta)\,, \tag{2}$$

where D is the internal diameter of the measuring pipeline at the operating temperature, β is the diameter ratio of the standard orifice plate. The value of L is selected from the standard DSTU GOST 8.586.2:2009 [3] depending on the diameter ratio of the orifice plate opening β for each type of fitting.

Therefore the method of direct measurement does not provide accurate values of equivalent roughness R_{III}.

After the research we propose to define the equivalent roughness of the internal surface of the measuring pipeline by eans of an indirect measurement.

In this case, it is determined by Colebrook-White equation through measured value of hydraulic resistance coefficient λ of friction of natural gas in the internal surface of the measuring pipeline [4]

$$R_{III} = \left(3.71 \cdot 10^{-\frac{1}{2\cdot\sqrt{\lambda}}} - \frac{9.34}{\mathrm{Re}\cdot\sqrt{\lambda}} \right) \cdot D\,, \tag{3}$$

where Re is the Reynolds number.

III. Definition of roughness based on its measurement in real time

Hydraulic resistance coefficient λ of friction of natural gas can be defined from the system of the differential equations of motion of natural gas. This system of equations is formed of the law of conservation of stream energy of natural gas, the equation of the law of conservation of stream mass of natural gas and natural gas equation of state [5]

$$\begin{cases} \dfrac{dp}{\rho} + \dfrac{\lambda}{D} \cdot \dfrac{v^2}{2} dx = 0 \\ q_m = \rho v F = const\,, \\ p = \rho \cdot z \cdot \dfrac{R}{M} \cdot T \end{cases} \tag{4}$$

where dp is the change of the pressure of natural gas along the length of the straight section l upstream of the standard orifice plate; ρ is the density of natural gas; v is the linear velocity of natural gas in the measuring pipeline; dx is the elementary section of the pipeline; q_m is the mass flow rate of natural gas; F is the cross sectional area of the measuring pipeline; z is the compression factor; R is the universal gas constant ($R = 8.31451$ kJ/mol·K); M is the molar mass of natural gas; T is the temperature of natural gas in the measuring pipeline.

Let us reduce the system of equations to one differential equation of natural gas pressure distribution in the horizontal measuring pipeline

$$pdp + \frac{\lambda \cdot q_m^2 \cdot z \cdot R \cdot T}{2 \cdot D \cdot M \cdot F^2} dx = 0 . \quad (5)$$

Now we shall integrate the Eq. (5) over the pressure and over the length of the measuring pipeline

$$\int_{p_1}^{p_2} pdp + \frac{\lambda \cdot q_m^2 \cdot z \cdot R \cdot T}{2 \cdot D \cdot M \cdot F^2} \int_0^l dx = 0 , \quad (6)$$

where p_1 is the natural gas pressure at a distance l from the standard orifice plate; p_2 is the natural gas pressure at the inlet face of a standard orifice plate. Natural gas pressure at a distance l from the standard orifice plate is determined by measuring the pressure of natural gas at the inlet face of a standard orifice plate and the pressure loss Δp_l between the inlet face of a standard orifice plate and at a distance l from the standard orifice plate that arise due to friction of natural gas on the wall of the measuring pipeline,

$$p_1 = p_2 + \Delta p_l . \quad (7)$$

As a result of integration we obtain the following equation

$$p_2^2 - p_1^2 + \frac{\lambda \cdot q_m^2 \cdot z \cdot R \cdot T}{D \cdot M \cdot F^2} \cdot l = 0 . \quad (8)$$

From Eq. (8) we obtain the expression

$$\lambda = \frac{\left(p_1^2 - p_2^2\right) \cdot D \cdot M \cdot F^2}{q_m^2 \cdot z \cdot R \cdot T \cdot l} . \quad (9)$$

Mass flow rate q_m of natural gas is determined by the equation

$$q_m = \frac{\pi \cdot \mathrm{Re} \cdot \mu \cdot D}{4} , \quad (10)$$

Substituting Eqs. (7) and (10) in Eq. (9) and taking into account the equation of state of natural gas, we obtain the equation for determining the hydraulic resistance coefficient of friction of natural gas

$$\lambda = \frac{\Delta p_l \cdot \left(2 \cdot p_2 + \Delta p_l\right) \cdot \rho \cdot D^3}{\overline{p} \cdot \mathrm{Re}^2 \cdot \mu^2 \cdot l} , \quad (11)$$

where $\overline{p}$ is the average value of pressure along the pipeline section between the points of selection of pressure values p_2 and p_1. We obtained the equation for calculating the average value of natural gas pressure along the section l

$$\overline{p} = \frac{2}{3} \cdot \frac{3 \cdot p_2 \cdot \left(p_2 + \Delta p_l\right) + \Delta p_l^2}{2 \cdot p_2 + \Delta p_l} . \quad (12)$$

Substituting Eq. (11) in Eq. (3) we obtain the equation for determining the equivalent roughness of the internal surface of the measuring pipeline

$$R_{Ш} = 3.71 \cdot D \cdot 10^{-\frac{\mathrm{Re} \cdot \mu}{2 \cdot} \sqrt{\frac{\overline{p} \cdot l}{\Delta p_l \cdot (2 \cdot p_2 + \Delta p_l) \cdot \rho \cdot D^3}}} - -9.34 \cdot \mu \cdot \sqrt{\frac{\overline{p} \cdot l}{\Delta p_l \cdot \left(2 \cdot p_2 + \Delta p_l\right) \cdot \rho \cdot D}} . \quad (13)$$

Conclusion

The existing methods of measurement of the equivalent roughness of the internal surface of the measuring pipeline is analyzed in this paper.

New analytical dependences for defining the average value of pressure along the section l and the equivalent roughness $R_{Ш}$ of the internal surface of the measuring pipeline along this section in real time are obtained.

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