Determining of Volume of Natural Gas Losses Caused by Damages of Distribution Networks

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Abstract – The algorithm of calculation of gas volume losses caused by damages of above-grounded pipelines is proposed in this paper. The mathematical model of natural gas movement in the pipeline is developed for the implementation of the algorithm. The model is used to determine the parameters of the gas flow at the leakage point. The equation for calculation gas flowrate through the holes in the pipeline wall is developed on the basis of the formula of Saint-Venant-Wentzel. The equation is valid for subcritical and critical regime of gas flow. The equation for determining discharge coefficient of the holes in the pipeline wall for gas pressure up to 1.2 MPa is proposed.

Key words – pipeline, damage, mathematical model, gas leakage rate, gas losses.

I. Introduction

Losses of natural gas occur during the operation of gas distribution networks (GDN). They are the result of the constant leakage of gas through pipelines and equipment tightness and of equipment damages. The methods for determining the losses of gas at suppositive normative tightness of the GDN elements are presented in the existing Ukrainian normative documents for determining the technological losses of natural gas, particularly in [1]. However there is no method for determining volume losses of natural gas caused by pipelines damages. Therefore developing the mathematical model of gas losses from the pipelines and equipment caused by their damages is an urgent task.

II. Determining the Volume Gas Losses

The problem of determining the parameters of natural gas at the damage point and the gas flowrate through the damage arises during the modeling the process of gas leakage through the holes in pipelines.

Differential equation of changes of gas pressure along the length of the tilted section of pipeline is obtained from the equation system that contains the equation of saving of mechanical energy of isothermal gas flow [2], the flow continuity equation and the equation of state of real gas

$$\begin{cases} \frac{dp}{\rho} + \frac{d\left(v^2\right)}{2} + gdy + gdh_x = 0; \\ q_m = \rho v F = const; \\ p = \rho z \frac{R}{M} T. \end{cases} \qquad (1)$$

where v is the linear velocity of natural gas in the pipeline; g is gravity acceleration; dy is change of the height of vertical marks of pipeline; dh_x is the pressure loss along the length of the pipeline (friction loss); q_m is mass flowrate of gas; F is the line flow area of the pipeline; p, T, ρ, z, M are pressure, temperature, density, compressibility factor and molar mass of natural gas; R is universal gas constant.

The differential equation of change of the gas temperature along the long tilted pipeline is obtained from the heat balance equation of the pipeline section. Thus mathematical model of natural gas movement in pipeline is a system of differential equations of changes in pressure and temperature of gas along the pipeline, which is completed with the equation of state of real gas [3]:

$$\begin{cases} \frac{dp}{dx} = \frac{-\left[\frac{p^2 gM}{zRT}\frac{\Delta y}{L} + \frac{8\lambda q_m^2 zRT}{M\pi^2 D^5}\right]}{\left(p - \frac{16 q_m^2 zRT}{pM\pi^2 D^2}\right)}; \\ \frac{dT}{dx} = -\left[\alpha\left(T - T_{gr}\right) - D_i\frac{dp}{dx} + \frac{g\Delta y}{c_p L}\right]; \\ \alpha = k_t \pi D_z / (q_m c_p), \\ z = f\left(p, T, x_a, x_y, \rho_c\right); \end{cases} \qquad (2)$$

where T_{gr} is the absolute temperature of the soil; Δy is the difference between the final and the initial heights of pipeline location; L is the length of the pipeline section; λ is the coefficient of hydraulic resistance; D_i is Joule-Thomson coefficient; c_p is isobar heat capacity of natural gas; k_t is the coefficient of heat transfer from the gas to the soil; D_z, D are the outer and the inner diameters of pipeline; ρ_c is the gas density at standard conditions.

The example of application model (2) to build gas pressure distributions along the damaged pipeline is presented in Figure 1.

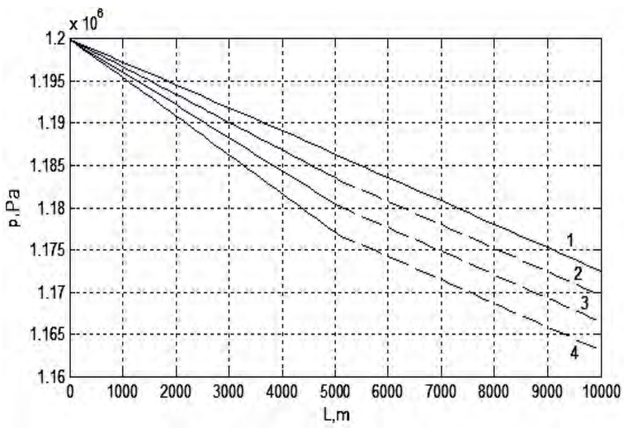

Fig. 1. Pressure distribution along the length of the pipeline: without leakage (line 1), with leakage $0.1q_1$ - (2), $0.2q_1$ - (3), $0.3q_1$ - (4)

The authors proposed the formula to calculate the gas flowrate through the holes in the pipeline based on the parameters of gas at the damage point calculated using (2). It is obtained using the formula of the gas velocity at the adiabatic outflow through the nozzle (the formula of Saint-Venant-Wentzel) taking into account the conditions of subcritical ($p_b / p > 0.54$) and critical ($p_b / p \le 0.54$) modes of gas flow:

$$Q_c = \begin{cases} 0.1564 \cdot \mu_p F_{hole} p \cdot \\ \sqrt{\dfrac{1}{\rho_c TK}\left[\left(\dfrac{p_b}{p}\right)^{1.53} - \left(\dfrac{p_b}{p}\right)^{1.77}\right]}, \\ for \quad (p_b / p) > 0.54; \\ 0.0359 \cdot \mu_p F_{hole} \dfrac{p}{\sqrt{TK\rho_c}}, \\ for \quad (p_b / p) \le 0.54. \end{cases} \qquad (3)$$

where p_b is the barometric pressure; μ_p is the leakage coefficient; F_{hole} is the area of hole; K is the compressibility coefficient.

The authors determine the maximum gas losses caused by the pipeline damages and use discharge coefficients of round holes that are obtained experimentally by the other researchers for calculating the gas losses. In addition, the authors have got experimentally the values of the discharge coefficient at low pressure ($p < 5$ kPa). The equation for determining the discharge coefficient is proposed by the authors based on their research [3]

$$\mu_p = 0.588(p_b/p)^3 - 0.983(p_b/p)^2 + \\ + 0.163(p_b/p) + 0.843; \qquad (4)$$

The methodic error of equation (4) is $\delta_m = 1.7$ % for the range of gas pressure in the gas distribution networks ($0.1 \le p \le 1.2$ MPa) taking into account the error of reference data on the basis of which this equation is obtained.

Applying the proposed mathematical models the authors have developed the following algorithm to determine the volume of gas losses caused by pipeline damage: a) localization of the damage and determining its parameters (the distance from the measuring stations of gas parameters, the area of damage); b) calculating the gas parameters (pressure, temperature) at the point of leakage by solving the system of equations (2); c) calculating the volume of gas losses caused by damage using the equation (3).

Algorithm for computing the volume of gas losses can be iterative or noniterative depending on the configuration of the area of damage and a set of measuring parameters at stations. Particularly for the configuration of the damaged pipeline, shown in Figure 2, this algorithm is noniterative (see. Figure 2, b). However there are some configurations with the larger number of unknown parameters than the presented configuration. In this case iterative algorithms should be used.

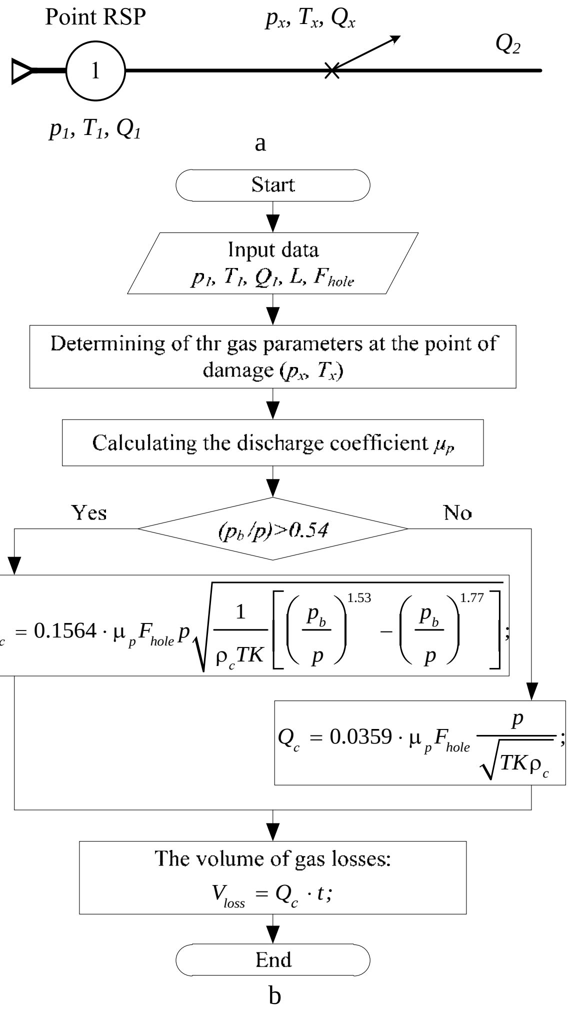

Fig. 2. Calculating the volume of gas losses: (a) configuration of the damaged section of the pipeline; (b) the block diagram of calculating the volume of gas losses

Conclusion

Application of the developed mathematical models and algorithms of calculation of the volume of gas losses allows determining the maximum value of the volume of gas losses from the damaged sections of pipelines.

References

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