RESEARCH AND ASSESSMENT OF THE SITUATION MODEL OF THE PERFORMANCE INDICES ANALYSIS OF GAS SUPPLY NETWORK

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ABSTRACT

The paper poses and solves the problem of research and assessment of the situational model of making expert decisions to analyze the performance indices of the gas supply network. Information features and technical characteristics predetermine the requirements aimed at conducting a qualitative identification of technical and technological indices to increase the efficiency of gas transportation and to decrease various kinds of gas pressure losses in the pipeline.

KEYWORDS: Gas distribution network, Assessment, Dynamics, Pressure loss, Modeling, Expert decision, Identification, Operation, gas distribution station

INTRODUCTION

Natural gas is a highly efficient energy carrier, and gas consumption is the basis of the socio-economic development in our country; it ensures the improvement of working and living conditions of the population. The use of gas fuel allows the introduction of new and efficient methods of heat transfer and, at the same time, the creation of economical and high-performance heating units of smaller dimensions, low cost and high productivity. The growth of gas consumption in cities, towns and rural areas, as well as the scale of distribution systems, pose new and complex challenges for the gas supply engineers who deal with the issues of development and reconstruction of systems, increasing their reliability, with the need for economical use of gas and protection from pollution.

Distribution networks are complex multi-ring systems, the economical design of which should be based on modern optimization methods, taking into account the probabilistic nature of functioning and ensuring the required reliability of gas supply to consumers.

The gas supply system in the inhabited locality must ensure uninterrupted gas supply to consumers, be safe in operation, simple and easy to maintain; it should provide for the possibility of disconnecting its individual elements or divisions of gas pipelines to conduct repair and emergency works. Structures, equipment and units in the gas supply system should be of the same type. The adopted option of the system should have maximum economic efficiency and provide for the construction and commissioning of the gas supply system in parts.

The main factors characterizing the pipeline systems of gas supply facilities as a complex system are:

- multidimensionality - the presence of a large number of controlled parameters;
- multi-criteria nature - local criteria of optimality for subsystems and the generalized ones for the upper levels of the hierarchy;
versatility - the presence of dynamic, static, heuristic links, etc.

Taking into account the above, one of the effective methods for a comprehensive study of this process is a mathematical tool, a numerical algorithm and software for conducting a computational experiment on a computer.

Many scientists have dealt with the problem of mathematical modeling of the gas supply network and have obtained significant theoretical and applied results.

The study in [2] gives proposals for the possibility of considering new properties of the gas supply system in the mathematical model of generalized flow distribution problem in comparison with the traditional statement. The work used the methods of network analysis based on the theory of graphs to solve the problems of gas flow distribution in gas supply systems when solving the problems of their functioning under various conditions.

The study in [3] sets out the scientific provisions for the development of theoretical foundations to calculate the optimal operating parameters of natural gas distribution systems for consumers. Recommendations are given for determining the optimal loss of gas pressure along the gas network divisions, ensuring the saving of material and financial resources.

In particular, [6] provides an overview of the most relevant research work carried out to solve the problems of natural gas transportation via pipeline systems. Three main groups of gas pipeline systems are identified, namely: collection, transportation and distribution systems.

The authors in [7] studied the problem of leak detection in low-pressure gas distribution networks by probabilistic methods. A leak monitoring system called a Leak Analysis System (LAS) is presented; it uses a probabilistic approach to determine the leak location and the rate in low-pressure gas distribution networks. That work aimed to develop a reliable, cost-effective real-time online monitoring system for low-pressure gas distribution networks. Leak events are estimated using pressure and flow rate data from stationary modeling of gas network.

The widespread and extensive development of engineering pipeline systems requires scientific generalization and assessment of the applied hydraulic and economic calculation methods. This is due to the need for a deep quantitative and qualitative analysis of the tasks of the gas supply system in order to identify the best option.

The studies conducted have shown that the hydraulic calculation of the gas pipeline network involves the determination of the optimal parameters that ensure the throughput of required amount of gas at permissible pressure drops. Therefore, in mathematical modeling of the object, it is necessary to take into account the effect of these parameters on the change in the throughput capacity of the required amount of gas at permissible pressure drops.

MATHEMATICAL MODEL OF DISTRIBUTION OF DESIGN PRESSURE DROP BETWEEN THE DIVISIONS OF GAS NETWORK

The functioning of the gas distribution network is calculated for a certain pressure drop set by the expert service. Graphically, the model of the gas distribution network presents an expanded tree-like graph, the arcs of which (the division branches) are conditioned by the throughput capacity and are calculated for a lower pressure drop.

In accordance with the technical conditions of the developed project of the gas distribution network, knowing the length of the calculated divisions of the network and the estimated gas flow rate, the pipe diameter and the pressure loss are
determined; after that, the non-exceeding the standard value of the obtained pressure drop is checked. If this condition is not met, a corresponding adjustment of diameter selection is made. The distribution of the calculated pressure drop between the divisions of the gas network is one of the most important optimization problems [3, 5].

The minimum capital investment in the network is considered as an optimality criterion. When compiling the objective function, the work took into account the variable part of capital investments, depending on the gas-pipe diameter

$$k_i = b \times d_i \times l_i$$

$$d_i = a^{0.21} \frac{G_i^{0.368} \times l_i^{0.21}}{P_i^{0.21}} \Rightarrow \sum_{i=1}^{m} k_i = b \times a^{0.21} \sum_{i=1}^{m} \frac{G_i^{0.368} \times l_i^{1.21}}{P_i^{0.21}}$$

(1)

where $k_i$ is the coefficient of simultaneity;

$b$ – the cost coefficient, $uzbek$ som/(m);

$d_i$ - the diameter of the $i$-th division of the gas pipeline, cm;  

$l_i$ - the length of the $i$-th division of the gas pipeline, m;  

$a$ - the coefficient of proportionality, depending on the gas composition;  

$G_i$ - the gas flow rate of the $i$-th division of the gas pipeline, m$^3$/h;  

$P_i$ - the pressure drops of the $i$-th division of the gas pipeline, Pa;  

$m$ - the number of network divisions.

To determine the geometrical parameters of gas distribution networks, we will use the following assumptions:

- the layout of the gas supply area is of rectangular form;

- the distance between the centers of the buildings in the longitudinal and transverse directions are assessed by $a$.

As an example, consider a dead-end branched gas supply network, the diagram of which is shown in Fig. 1.
Figure 1: Diagram of a Dead-end Branched Gas Supply Network

\[ Z_{mk} \] - the number of the network divisions \((z = 15)\).

Gas flow rate in all divisions of the gas pipeline is determined by

\[ G = G_{TM} \times l_{TM} + G_{OTM} \times l_{OTM}, \tag{2} \]

where \( l_{TM}, l_{OTM} \) - are the lengths of the trunk pipeline and the branch;

\( G_{TM}, G_{OTM} \) - are the gas flow rates in the trunk pipeline and the branch, respectively, \( m/h \), determined by (3);

\[ G_{OTM} = 0.55 \times \sum_{i=1}^{n} G_{uac}^{\text{max}} \times n; \]

\[ G_{TM} = G_{OTM} \times k, \tag{3} \]

where \( G_{uac}^{\text{max}} \) is the maximum gas consumption per hour per apartment, \( m^3/(h\cdot kW) \);

\( n \) is the number of apartments;

\( k \) is the same value as in formula (1).

The following condition is used as a limitation of the objective function: the sum of the pressure drops in the divisions, from the supply point of the network to the end points with the given pressures, is equal to the calculated pressure drop in the network. To find the minimum of the objective function, we use the Lagrange method [4]. Let us write down the limitation condition in all directions of gas distribution:
The Lagrange function for this case is:

\[ \Phi = \sum_{i=1}^{m} k_i + \lambda_{m,1} (P_{0,1} + P_{1,1} + P_{2,1} + \ldots + P_{m,1} - P_p) + \\
+ \lambda_{m,2} (P_{0,1} + P_{0,2} + P_{1,2} + P_{2,2} + \ldots P_{m,2} - P_p) + \\
+ \lambda_{m,3} (P_{0,1} + P_{0,3} + P_{1,3} + P_{2,3} + \ldots P_{m,3} - P_p) + \ldots + \\
+ \lambda_{m,k} (P_{0,1} + P_{0,k} + P_{1,k} + P_{2,k} + \ldots P_{m,k} - P_p), \] (5)

where \( \lambda \) is the undefined Lagrange multipliers;

\( P_{m,k} \) are the pressure drops.

From the obtained optimal pressure drops, the optimal diameters of the distribution network divisions are determined by calculation according to the formula (2). Calculations according to the described method are reduced to performing successive algebraic actions.

**COMPUTATIONAL EXPERIMENT OF HYDRAULIC CALCULATION OF A GAS PIPELINE NETWORK**

A hydraulic calculation algorithm was formed for a comprehensive study, forecasting, synthesis of the basic parameters, as well as making management decisions.

The basis of the hydraulic calculation of the gas pipeline network is the determination of the optimal parameters that ensure the flow rate of the required amount of gas at permissible pressure drops. The calculation is based on the maximum possible gas consumption, the length of the gas pipeline division, the resistance coefficient and the pipe diameter.

The hydraulic calculation algorithm is conditioned by the implementation and consideration of the following actions (typical for the gas pipelines of low and medium pressure):

- hydraulic calculation of the gas supply network with a known value of the calculated loss of gas pressure between its divisions. The calculated pressure losses should be taken within the pressure limits accepted for the gas pipelines of medium and high pressure;
- an account for the calculated gas pressure losses in the distribution gas pipelines of low pressure (no more than 18 kPa);
- an account for the calculated gas pressure losses in the distribution gas pipelines of low pressure (no more than 18 kPa);
- the values of the calculated gas pressure loss in the design of gas supply networks of all pressure values for industrial, agricultural and household enterprises, as well as for public utilities, are taken depending on the gas pressure at the
point of their connection;

- the pressure drop in the gas supply network of low pressure should be determined depending on the mode of gas flow through the gas pipeline, characterized by the Reynolds number.

One of the most frequently used formulas for calculating pressure drops (losses) along the length of network sections - the Darcy-Weisbach formula - was applied in the solution to this problem. It is based on empirical data and is used primarily in system modeling. Friction loss is a function of fluid velocity and pipe resistance to fluid flow, expressed through the value of the pipeline wall roughness \([2, 3]\).

\[ \Delta H = \lambda \cdot \frac{L}{d} \cdot \frac{v^2}{2 \cdot g} \]  \hspace{1cm} (6)

where \(\Delta H\) is the head loss;

\(\lambda\) is the coefficient of friction;

\(v\) is the flow rate;

\(g\) is the acceleration of gravity \((g = 9.81 \text{m/s}^2)\)

The head and pressure losses are related by the relationship: \(\Delta p = \Delta h \rho g\), where \(\rho\) is the density, \(g\) is the acceleration of gravity.

Using transform (1) of the pressure loss along the length, we obtain

\[ \Delta P = \lambda \cdot \frac{l}{d} \cdot \frac{v^2}{2 \cdot \rho} \]  \hspace{1cm} (7)

where \(\Delta P\) is the loss of gas pressure in the \(i\)-th division;

\(d\) is the inner diameter of the pipe, \(\text{mm}\);

\(L\) is the length of the \(i\)-th division, \(\text{m}\);

\(v\) is the gas flow rate, \(\text{m/s}\);

\(\rho\) is the gas density, \(\text{kg/m}^3\).

Table 1 presents technical indices of the gas supply network, which includes 33 divisions with set values of the parameters of length, pipe diameters, the number of gas distributing plants (GSP) and other characteristics. The values of the gas pipeline parameters (the length of division, the diameter of the pipes) are introduced to the formula (2). The coefficient of friction (the pipe roughness) is substituted based on the condition \(0 < \lambda < 0.5\) mm, the flow rate – on the condition \(v \leq 30 \text{ m/s}\) (at different flow modes and gas pressure), \(\rho\) is the gas density in the range \(0.65 \leq \rho \geq 0.85 \text{ kg/m}^3\) [4].

In accordance with the formalized approach, a calculation automation program was developed, designed to rank factors by the method of direct expert assessment. The output data of the program are the estimates of the gas pipeline parameter and disturbing factors of the gas supply network functioning.
The software was developed in the object-oriented programming language C++. The work used the StringGrid components to work with the table, the CSpinEdit component to number the divisions of the gas supply network, the Edit components to enter the initial data. The developed program provides the users and experts with a convenient interface for entering and evaluating characteristics.

CONCLUSIONS

- An analytical and informational model of direct expert assessment for ranking indices of the gas distribution network functioning was formed.
• A computational experiment was formalized using the Darcy-Weisbach law of gas pressure loss in individual divisions of the gas pipeline;

• A ranking automation program was developed that allows the selection of the optimal values of the gas pipeline parameters.

REFERENCES


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