Optimization of Gas Pressure Modes in Gas Supply Systems

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Abstract: At present, general gasification on the basis of the natural gas is carried out without proper grounds for all the criteria affecting the efficiency of these systems. At the same time, the expediency of the natural gas provision must be carried out taking into account configuration of the networks in the settlement, density of the population in the gas-supply territory, type of the gas-using equipment installed at the consumer and other determining factors. The absence of these criteria often leads to huge unreasonable investments in the gas distribution systems, which sharply reduces their efficiency and effectiveness. The existing practice of operating gas distribution pipelines causes a low magnitude of the calculated pressure drop and, consequently, an increased material consumption of the gas networks. The introduction of the gas supply systems with house pressure stabilizers into design practice requires the development of scientifically based methods for their calculation and design. One of the most important prerequisites for the calculation of the gas distribution systems is the substantiation and optimization of the calculated pressure drop in the distribution gas pipelines. The purpose of this study: development of an optimal structure for the distribution of the natural gas, depending on the individual features of the gas fuel consumption.

1. Introduction

Optimization of the gas pressure modes in the gas distribution networks is the relevant, but not solved problem, yet. As studies show, the unevenness of the gas consumption with the gas pressure regulation system causes sharp changes of the pressure drops in front of the gas-using equipment, which worsens operation conditions and shortens service life, also it leads to uncontrolled gas losses [1÷5].

The task of optimization the gas pressure modes in the gas networks represents the maintenance of a certain mode, which nominal gas pressure for different categories of consumers does not exceed the limits of permissible norms with any change in the gas flow at any time. The solution of this problem is increase the gas pressure to 0,1 MPa and higher and use house gas pressure regulators to ensure the most efficient operating mode, stabilizing the gas pressure at the level of the nominal value. In the existing residential gas distribution systems, this method is unacceptable due to the fact that they designed for the low gas pressure (up to 5 kPa), but can be recommended, as economically feasible, for newly designed or reconstructed gas supply systems [6].

In 1956 Aleksander Levin [7] proposed a method for regulation output pressure of the gas from the reduction points for the changing gas flow in the network, however, so far stabilization of the output gas pressure after the gas control points is carried out by the principle of independence from changes in the gas flow.

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Classification of the gas pipelines by the size of the gas pressure first appeared in the edition of the building code in 1954, the only difference from modern gradation was the value pressure in the gas pipelines of average pressure - it was regulated to accept up to 0,1 MPa. Moreover, the gas pressure of 5 kPa was allowed while installation process individual reducing fixtures from consumers.

The current practice of designing urban gas distribution networks is guided by the provisions of the building code 42-101-2003 [4], the basic principles of which have not changed since 1963. In the updated version of the building code 42-01-2002 of 2014, was made an attempt to introduce drastic changes in the gas pressure in domestic gas pipelines and the classification of the gas pipelines by pressure, in particular, the gas pressure in the low pressure network changed to 0,1 MPa (house pressure regulator), but in September 2015, these changes were canceled.

Gas distribution systems of the low pressure are designed in most cities and settlements of the Russian Federation [8÷11]. Historically, single-stage low-pressure systems were the first systems put into operation in our country, at present they can be justified only with one power source. The most widespread use in the modern conditions has been two-stage gas supply systems, consisting of low and medium (or high) pressure gas pipelines. It is known, that the capital investments in the gas network are proportional to the value of the mean diameter, so it can be determined that the high-pressure network is more economical than the average pressure network more than 25% [6, 11÷13]. As practice shows, high pressure networks can provide a wider range of pressures and are more technological. Development of the modern technology is characterized by an increase in operation parameters, as a result, the productivity of the processes is increased and their cost is reduced [2, 14, 16]. In comparison with the indicators of the initial period of design and operation of the gas supply systems, the nominal gas pressures in front of the gas-using appliances and equipment and the estimated pressure drops in urban distribution networks have changed. However, these changes did not affect the circuit dicisions of the gas distribution network, which should consist of the medium-pressure gas pipelines rather than low-pressure pipelines [2, 15]. Numerical experiments have shown that the gas supply system based on medium-pressure gas pipelines has economic (almost twice more economic) and technical advantages in comparison with low-pressure gas pipelines. When the reduction points are located as close as possible to the consumers, it creates conditions for using gas at pressures close to the nominal values and providing the best conditions for the gas combustion. Implementation of such scheme provides installation of a pressure stabilizer for each consumer, which, for example, is mandatory used in European countries [15, 17, 18]. Such technical perfection will allow to reduce the material consumption of the gas network, increasing safety and creating optimal conditions for using gas fuel by the consumer.

One of the most important prerequisites for the implementation of the optimal centralization model of the gas distribution systems based on reducing points is the justification of the calculated pressure difference in the gas networks and its optimal distribution between main gas pipelines, branches and domestic gas pipelines, including house entries. Today these problems are very relevant and require an informed decision.

Gas-using equipment for household needs of consumers is produced for two values of nominal gas pressures: ΔP_{nom} = 1274 Pa and ΔP_{nom} = 1960 Pa [4, 12, 14]. Usage of the gas devices with an increased nominal pressure reduces the metal consumption of the gas networks, but requires additional containment requirements both as device itself and for its piping. Hydraulic operation modes of the gas networks predetermine the nature of the operation of the gas appliances, while the working gas pressure is different from the nominal value. So the equipment connected at the beginning of the route near the reduction points, operates at the maximum values of the gas pressure. At the same time, gas devices connected at the end of the route at a considerable distance from the reduction point operate at the minimum gas pressure values, that is, the existing pressure drop is not fully used and, as a result, the gas network is more expensive. Thus, the range of pressure changes in the gas network is determined by the difference between the maximum and minimum values of the gas pressure in the gas-using equipment [2].

In accordance with [1], the admissible variations in the thermal loads of the gas appliances are ± 20%, including ± 5% due to the gas composition. These recommendations are reflected in the normative documents [4] in the form of the value of $\Delta P_{rated} \leq 1800$ Pa. However, the new version of the State Standard uses a different approach, based on the composition of the natural gas. Thus, the value of the maximum pressure (in order to avoid flame separation) is determined for the mixtures with a high nitrogen content and the value of the minimum pressure (in order to avoid flame breakage) is for the mixtures with a high hydrogen content.

The values of the calculated drop, recommended by the State Standard, are much smaller than previously used values. In addition, recommended value for the calculations [4] for the available pressure fluctuation (pressure drop), dictated generally by the requirements for reliable and safe operation of the plants, does not take into account the pressure losses in the gas meters and does not take into account the peculiarity of the hydraulic modes of the gas reduction units, and also gas pressure influence on the value of efficiency. Therefore, the task of justifying the calculated differential requires additional studies.

According to predesign predictions, the optimal distribution of the design pressure drop in the low-pressure gas networks between the main sections of the pipeline network, depending on the nature of location, will reduce the metal- (material-) capacity of the gas supply systems to 10-15% with a decrease in their cost to 4-5% and is a progressive event. Today design organizations in the conduct of hydraulic calculation of the gas networks purposefully distribute the calculated pressure drop.

Diameter of the gas pipeline is selected according to the values of the calculated gas flow and the average specific loss of the pressure. After definition the total pressure loss on the calculated branch of the gas pipeline, there is an inspection of the obtained value, which is not exceeded by the standard values. At non-performance of this condition, diameter of some sections of the calculated gas-wire is corrected, this measures proceed more for constructive reasons, than for optimization of system.

A significant amount of scientific publications has been devoted to the substantiation of the magnitude of the calculated pressure drop and its distribution over the sections of the gas network. The most adequate solution of the problem of the optimal distribution of the pressure drop in the gas pipelines in rural settlements and cottage settlements, reflecting specific features of the modern gas distribution systems, was proposed in the author's researches [2, 6 and other].

Studies show that the instability of the working pressure of the gas directly depends on the calculated pressure drop and the level of its consumption along the route of the gas flow from the source to the gas-using facilities, from the operating mode of these installations and the method of reducing the gas pressure. Normal functioning of the gas equipment is possible only if the gas pressure is stable before them, which is achieved, to a greater extent, by the correct choice of the method for regulating the initial gas pressure. As is known, reliable, safe and economical operation of gas-using equipment and plants is ensured with a gas pressure close to the nominal value.

Maximum permissible changes in the gas pressure for the domestic gas appliances are fixed by the regulatory documents. Within these permissible limits, changes in the operating pressures of the gas ensure reliable and safe operation of the gas-using equipment with minimum gas flow rates and optimum efficiency.

Gas-using equipment operating at reduced nominal pressure has a high resistance to breakthrough and flame separation, while the degree of safety of the gas distribution systems is increased. These circumstances also explain the increase in the size of the permissible pressure drop. Therefore, the use of the instruments and equipment with a nominal pressure of 1300 Pa is more rational.

Disposable minimum calculated pressure drop in the gas network (at the minimum pressure value):

$$\Delta P_{min}^{rated} = 0,82 P_{max}^{app} - \Delta P_{meter} - \mathrm{P}_{min}^{app}, \quad (1)$$

where ΔP_{meter} is the pressure drop in gas flow meters, (Pa); $P_{max}^{app}, P_{min}^{app}$ are the maximum and minimum gas pressure in front of the gas-using appliance, (Pa)

Available maximum calculated pressure drop in the gas network (at the maximum pressure value):

$$\Delta P_{max}^{rated} = P_{max}^{reg} - \Delta P_{mater} - P_{min}^{app} = P_{max}^{app} - \Delta P_{mater} - P_{min}^{app}, \quad (2)$$

where ΔP_{max}^{reg} is the maximum outlet gas pressure from the gas pressure regulator, (Pa).

Then:

- for the gas-using equipment with a nominal gas pressure of 2000 Pa, the calculated pressure drop in the gas distribution network will be: a minimum pressure drop is 150 Pa; the maximum differential pressure is 600 Pa;

- for the gas-using equipment with a nominal pressure of 1300 Pa, the available calculated differential pressure in the gas distribution network will be [1,10]: the minimum pressure drop is 596 Pa; the maximum differential pressure is 914 Pa;

The analysis of the recieved results allows to draw the following conclusion: the available differential pressure drop in the gas distribution network changes more than five times and depends on the value of the nominal gas pressure in front of the gas-using instruments and equipment, as well as the pressure modes of the reducing devices. It should also be noted, that the calculated pressure loss in low-pressure gas pipelines, even for installing gas appliances with reduced nominal pressure, is much lower than the normative document. It can be concluded, that existing rules for the designing gas distribution systems from the condition that the pressure difference in 1800 Pa does not exceed the pressure of the household gas appliances and the risk of disrupting their stable operation will decrease.

The hydraulic calculation of the system from the condition of the most complete use of the available pressure drop is a prerequisite for reducing costs in the construction and operation of the gas supply system [6, 19÷21]. However, its presence creates a reduced gas pressure in front of the gas appliances, thereby lowering the efficiency of gas appliances, increasing gas consumption and, as a consequence, increasing the cost of the gas. Criterion function of the task is the discounted costs in the gas distribution system, consisting of the distribution gas pipelines and gas-using appliances. Assuming that the discounted costs in the gas-using facilities do not depend on the amount of the calculated differential pressure drop, we represent the variable part of the criterion function in the following form:

$$M=M_{gs}(\Delta P)+\Delta T(\Delta P)=min, \quad (3)$$

where M is the total discounted costs in the gas distribution system; M_{gs} is the discounted costs in distribution gas pipelines; ΔT is a fuel component [2].

We provide solution of the task for the transit gas distribution network.

Discounted costs in the distribution gas pipelines can be determined by the formula:

$$M_{gs}=(a+bd)l, \quad (4)$$

where l is the length of the pipeline, (m); a, b are the cost parameters of the network, which are adopted depending on the material and the type of the gas pipelines; d is the diameter of the gas pipeline, (cm), is determined by the expression:

$$d=\alpha^{0,21}V^{0,368}\left(\frac{l_p}{\Delta P}\right)^{0,21}, \quad (5)$$

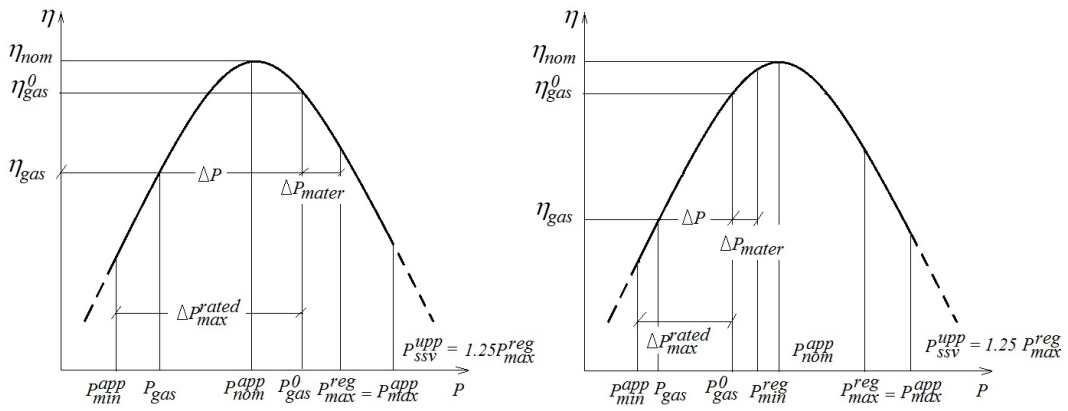
where α is the coefficient depending on the gas composition; V is the maximum hourly gas flow, ($m^3 \cdot h^{-1}$); l_p is length of the gas pipeline, (m).

Taking into account the pressure loss in the local resistances, increase in the calculated length of the gas pipeline is determined by the formula:

$$l_p = 1,1l, \quad (6)$$

where l is the actual length of the gas pipeline, (m).

Gas pressures in front of the gas-using equipment P_g have a significant effect on its efficiency η_g. And the greater fluctuation of this pressure from the nominal value established by regulatory documents, the lower efficiency of the gas use. We will analyze the mutual influence of these parameters. Figure 1 is a graph of the dependence of the efficiency of the gas-using unit on the value of the gas pressure in front of it.



a) at the maximum pressure at the exit from the reduction point

b) at the minimum pressure at the exit from the reduction point

Figure 1. Qualitative dependence of efficiency gas-using appliances from the value of the gas pressure in front of them: P_{min}^{app}, P_{nom}^{app}, P_{max}^{app} are the minimum, nominal and maximum gas pressures before the gas-using appliance; P_{SSV}^{upp} is the upper limit of the safety shut-off valve; P_{min}^{reg} P_{max}^{reg} are the upper and lower limits of the regulated gas pressure; ΔP_{mater} is the pressure loss in the gas meter; ΔP_{min}^{rated}, ΔP_{max}^{rated} are the minimum and maximum available design pressure differences in the gas pipeline; ΔP is calculated pressure drop; P_{gas}^{0} is the gas pressure in front of the device in the absence of the gas network resistance; P_{gas} is the gas pressure in front of the device in the presence of the gas network resistance; η_{nom} is the efficiency of the gas-using appliance at the nominal gas pressures; η_{gas}^{o} and η_{gas} are the efficiency of the gas-using appliance at the gas pressures in front of the device P_{gas}^{o} and P_{gas}.

According to the research results, the experimental dependence of the relative efficiency of the gas appliance on the relative gas pressure before it is described by the following approximate expression:

$$\eta_{rel} = -0.514P_{rel}^{6} + 2.355P_{rel}^{5} - 3.066P_{rel}^{4} - 0.765P_{rel}^{3} + 4.423P_{rel}^{2} - 2.992P_{rel} + 1.553, \quad (7)$$

where

$$P_{rel}^{o} = \frac{P_{gas}^{o}}{P_{nom}^{app}} \; ; \; P_{rel}^{gas} = \frac{P_{gas}}{P_{nom}^{app}} ; \; \eta_{rel}^{o} = \frac{\eta_{gas}^{o}}{\eta_{nom}} ; \; \eta_{rel}^{gas} = \frac{\eta_{gas}}{\eta_{nom}} . \quad (8)$$

Absolute values of the efficiency of the gas-using instrument are found by recalculating according to the formulas:

$$\eta_{gas}^{o} = \eta_{rel}^{o}\eta_{nom} ; \quad \eta_{\Gamma} = \eta_{отн}^{\Gamma}\eta_{ном} \; , \quad (9)$$

where η_{rel} is the relative efficiency of the gas appliance.

The fuel component of the function is determined by the formula:

$$\Delta T = C_{gas}V_{ann}\eta_{nom}\left(\frac{1}{\eta_{gas}} - \frac{1}{\eta_{gas}^{o}}\right), \quad (10)$$

where V_{ann} is the annual capacity of the gas, $m^3 \cdot year^{-1}$; C_{gas} is the gas price, $rub \cdot m^{-3}$.

Thus, a set of equations forms a mathematical model of the problem. In this case, the initial objective function of the problem can be represented in the form of the following functional:

$$M = M_{gs} \; d\left[\Delta P \;\; P_{gas}\right] + \Delta T\left[\eta_{gas} \;\; P_{gas}\right] = min . \quad (11)$$

Gas pressure in front of the gas-using device and the pressure drop in the gas distribution network are related to each other by the following equations:

- at the maximum pressure at the output of the reducing device: $P_{gas} = P_{max}^{reg} - \Delta P_{mater} - \Delta P$;

- at minimum output pressure from the reducing device: $P_{gas} = P_{min}^{reg} - \Delta P_{mater} - \Delta P$.

We will write down the restrictions to the objective function:

- gas pressure: $P_{min}^{app} \le P_{gas} \le P_{max}^{reg} \quad P_{min}^{reg} - \Delta P_{mater}$;

- pressure losses in the gas network: $0 \le \Delta P \le \Delta P \quad d_{\min} \quad \le \Delta P^{rated}$,

where $d_{\min}$ is the value of the smallest diameter of the gas main.

To find the optimal value of the control parameter ΔP_{opt} there was used a method of variant technical and economic calculations, in which the optimal value of the pressure loss corresponded to the minimum discounted costs to the system. The results of the numerical implementation of the mathematical model for pressure losses optimization show a decrease in annual costs by 10,3%. At the same time, the savings of annual costs for gas fuel is about 25,000÷35,000 rubles·(year · sq)$^{-1}$. With annual savings of the gas from 230 to 300 m^3·(year · sq)$^{-1}$.

Many years of experience in the design of AO «Giproniigaz» showed, that for a number of reasons, it is not always possible to fully utilize the available pressure drop (at a value of Z = 1). The extreme value of using this parameter is 50% and even more rare - 25%. The numerical value of Z = 1 is the maximum utilization of the available quadratic and linear difference in the absolute pressure values for all categories of the gas pipelines. As the results of calculations show, incomplete use of the available pressure drop significantly increases the cost of the gas distribution system and significantly increases the risk of the gas emissions from the damaged gas pipeline. For example, using a design pressure drop of 50% for high and medium pressure gas pipelines, the cost increases by almost 15%, and the emissions risk by 30%; for low pressure gas pipelines - by 16% and by 35%, respectively.

Results

Data on the optimal functioning of the gas distribution systems based on the natural gas, taking into account the required gas consumption, were obtained. Increasing the gas pressure in front of the instruments up to the nominal value increases the efficiency of the gas-using units by 2 ÷ 3% and ensures adequate gas fuel economy.

Conclusions

Parameters of the gas distribution systems are determined depending on the gas consumption capacity. The results of the study allow to draw a conclusion about efficiency of using medium-pressure gas networks with subsequent reduction to the required values by house pressure regulators or regulators-stabilizers. Recommendations on the practical application of the obtained research results are presented.

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