Structural Solutions of Territory Gas Distribution System

Tatiana N. Beloglazova[a], Tatiana N. Romanova[b] and Aleksandr I. Burkov[c]
Perm National Research Polytechnic University, Perm, Russia
tabeloglazova@yandex.ru, botinkin@yandex.ru, vvstf@pstu.ru

Keywords: Gas distribution network, Natural dry gas, Gas pressure regulating stations, Population density, Heat supply.

Abstract: Modern development of gas supply systems covers a wide range of tasks. In the article, the relationship between the structure of gas distribution networks of territories and planning zoning of the territory, natural and climatic factors, volumes of gas consumption is considered. The main areas of use of gas fuel, such as industrial, household purposes, heating have their own characteristics. For these categories of consumers, different volumes and pressures are required. Consumption unevenness for territories depends on the number and variety of consumers. Planning of gas distribution network structure is based on the principles of reliability, environmental safety, social significance, economic efficiency. The choice of technical solutions is carried out on the basis of a multivariate and integrated approach. Modern gas equipment, digital and telecommunication technologies are used in the gas distribution system projects. One of the questions of the feasibility study is the choice of rational structure of the gas distribution system. Variants of the gas distribution system take into account the differentiated population density. The method for calculating the gas distribution network is based on the distributed nature of the heat supply load. The obtained results show that the material characteristic of the gas distribution system increases with increasing building density. An increase in the number of gas reduction points leads to a decrease in network diameters, and reliability increases.

1 INTRODUCTION

The energy system is a necessary component of the country's developing territories. The mechanisms of functioning and sustainable development of the energy sector are a priority in the strategic development of the state (Fortov, 2019; Bugaeva & Novikova, 2019). The creation of a reliable system for providing the economy with various types of energy resources ensures energy security in general (Dixon & Easaw, 2001; Lu, Su, Zhang, Hao, Fath, 2016; Mišík & Nosko, 2017; Gillessen, Heinrichs, Hake & Allelein, 2019). Despite the fact that a global trend has emerged - the diversification of energy resources (Fortov, 2019), the dominance of fossil fuels remains for most regions.

In modern conditions, along with the search for alternative energy sources, the scientific and technological process of development of the countries of the world requires the expansion of natural gas consumption (Georgakopoulos, 2018; García Kerdan, Jalil-Vega, Toole, Gulati, Hawkes & Giarola, 2019; Weir, 1999; Zakikhani, Nasiri, & Zayed, 2020; Belinsky, 2018). Pipeline transport has a number of technological and economic advantages for transportation over short and medium distances (Krupnick, Kopp, Hayes & Roeshot, 2018; Medvedeva, 2018). In Russia, gas fuel is predominantly used in most regions. At the same time, the unevenness of the gasification level of the regions remains (Bobyleva & Khripunova, 2016). Investments in the gas distribution system intended for the sale of gas on the domestic market are one of the conditions for the development of Russian regions.

Structural changes in the gas distribution system are determined by legislative, economic, technological factors. It is advisable to form a reliable and safe structure of gas distribution networks taking into account regional economic factors, natural climatic features (Bobyleva & Khripunova, 2016).

[a] https://orcid.org/0000-0002-8221-0938
[b] https://orcid.org/0000-0002-4430-1978
[c] https://orcid.org/0000-0001-6762-9661

2 MATERIALS AND METHODS

The development of gas distribution system structure is carried out taking into account the future development and functional planning of territories. The nature of gas consumption is based on the example of Perm. The mutual arrangement of functional zones determines the nature of gas consumption in the territory, analysis of gas supply sources and possible options for gas distribution networks structure by pressure, gas volume, network length is carried out. As a rule, territories have the current situation of the location of functional zones. The structure of gas distribution networks is multi-stage (Solov'eva, 2018). A feature of modern conditions for the regions of Russia, when using main gas, is a significant change in the nature of gas consumption. During the development of the existing structure of the gas distribution network, industrial consumption and district heating prevailed. The change in the volume of gas fuel consumption is associated with a changing in the volume of industrial facilities production, the construction of facilities with a modern level of thermal protection, and an increase in the energy efficiency of technological equipment. Gas consumption is one of the main factors influencing the structure of the territory's gas distribution networks. The table 1 presents data on functional zones - STN (standardized areas) using the example of the Perm city (Russia) (Perm city Duma, 2011).

Perm consists of 7 administrative districts. The distribution of the population by district is shown in the figure (Fig. 1). The nature of the distribution across regions is uneven. The total number of residents for 2020 is 1,055,397. All districts of the city have the ability to connect to the gas supply system from the main gas pipelines.

The presence of high and medium pressure gas distribution systems in these zones ensures reliable supply of consumers. The location of production facilities and the volume of gas consumption determine the structure of the network.

Table 1: Functional zoning of the urban area of Perm.

Functional zones	Square, ha	Percentage of total area, %	Maximum density of residential buildings, residential units/ha**	The volume of annual gas consumption, million m^3/ year*
1. Zones of residential and other buildings - including:	10808	50,3		70,7
1.1. urban center core zone (STN-A)	191	0,9	150	1,7
1.2. urban center zone (STN-B)	713	3,3	160	9,0
1.3. zone of multifunctional development in the middle part of the city (STN-V)	1278	6,0	125	18,0
1.4. multifunctional residential area (STN-G)	1257	5,9	100	18,4
1.5. residential area (STN-D)	880,4	4,1	50	5,3
1.6. zone of remote urban centers (STN-E)	1475	6,9	70	13,0
1.7. zone of medium and low-rise buildings (STN-Zh)	2146	10,0	20	3,5
1.8. low-rise building zone (STN-I)	2896	13,5	15	1,8
2. Industrial areas including:	10666	49,7	-	-
2.1. production and communal zone (TSP-P)	2456	11,4	-	-
2.2. industrial and trade zone (TSP-PT)	8210	38,2	-	-

* by the population for the purpose of food preparation

** residential unit - a separate apartment, or an individual residential building

Source: (Perm city Duma, 2011).

The construction of gas pipelines is carried out taking into account the terrain, geological and hydrological conditions, natural and artificial barriers. The main gas pipeline or storage and regasification receiving station (SRRS) is used as a source of natural gas for gas distribution systems of the territories. In regions with a developed gas transmission system in the immediate vicinity of the main ones, the gas distribution structure from gas distribution stations, gas distribution network systems and gas pressure regulating stations is most widely used. The use of liquefied natural gas (LNG) is possible in the absence of trunk gas pipelines in the immediate vicinity of the territory, and at the same

time, it is envisaged to create a system for liquefying and transporting LNG by road, rail and water transport. The spatial model of gas consumption for the territory is of practical importance for the structure of the gas distribution system (Bugaeva & Novikova, 2019).

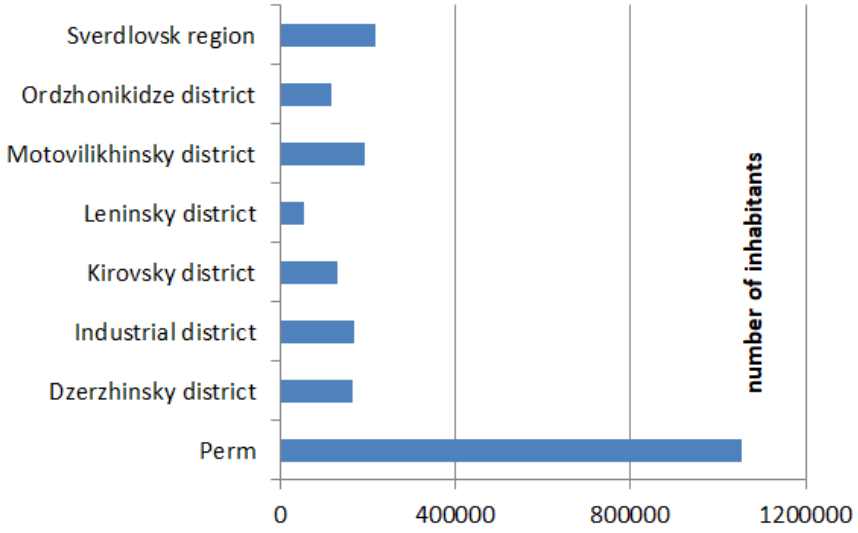

Figure 1: The population in the areas of Perm.
Source: (Perm city Duma, 2011)

To plan of the city's energy systems development, based on the functional zoning for the functional zones of the city, data on the annual and hourly gas volume are required. Prospective gas consumption is determined on the basis of planning the development of the city's territories and is made according to normative calculation methods. For the economic substantiation of the source of gas supply, the collection and analysis of information on the annual and estimated gas consumption by various volume for all areas of activity in a given territory is carried out according to statistical and planned data. The annual volume gas for consumers on the territory is distributed according to such consumer groups as household, industrial consumption, heat supply. For residential areas, the following directions of gas use are considered: for heating and ventilation, hot water supply, food preparation.

$$Q_g^y = \sum Q_i^y + \sum Q_{hs}^y + \sum Q_{hh}^y$$

That Q_g^y – general gas consumption per year on the territory, m^3/year; Q_i^y – industrial gas consumption, m^3/year; Q_{hs}^y – gas consumption for heat supply, m^3/year; Q_{hh}^y – household gas consumption per year, m^3/year.

For residential areas, the following directions of gas use are considered: for heating and ventilation, hot water supply, for cooking. The volume gas consumption per hour for cooking depends on uneven consumption.

$$Q_{hh}^h(N) = Q_{hh}^y K_m f(N)$$

That Q_{hh}^h – volume gas consumption per hour for cooking, thousand m^3/h; K_m – maximum ratio, N – number of residents. Gas consumption for heat supply is determined according to specific standards.

For residential areas, the calculation of gas distribution networks is carried out the heat supply and cooking consumption load. Medium pressure ring gas distribution networks are designed with the transport reserve to increase the network capacity in an emergency. An emergency situation is a failure of one of the gas regulation equipment. In the event of an accident at one of the gas pressure regulating stations, the gas flow geometry of the ring network changes. The comparison criterion for variants of the gas distribution system is the material characteristic of the network

$$M = \sum_{i=1}^{n} M_i = \sum_{i=1}^{n} (d_i \cdot l_i)$$

That M – material characteristic gas distribution networks, (m·mm); d_i – gas pipeline section diameter, mm; l_i – gas pipeline section length, m.

The network model is designed to provide consumers with specified parameters gas in emergency situations and in normal operation.

3 RESULTS

The functional zoning data presented in Table 1 show that the percentage of the area of production and industrial, communal and trade zones is 46.8%. The development of production, communal and industrial-trade zones provides for the prospective use of natural gas for production, heat supply and electric power generation. High and medium pressure gas distribution networks (GDN) ensure reliable gas supply to industrial areas. Location of industrial zones and volumes of gas consumption determine the structure of the gas distribution network. Distribution systems with medium and low pressure GDN and regulators and stabilizers devoices for consumes in residential buildings have economic advantages (Solov'eva, 2018). The load on heat supply for the conditions of the city of Perm exceeds the load on household needs (Fig. 2).

In residential areas of the Perm city there are low-pressure gas pipeline systems that provide mainly household consumption. The area of low-rise and medium-rise buildings in terms of the volume of gas consumption does not exceed 5.3% of the total for household needs. For the development zone of the middle part of the city STN-V, multifunctional residential development STN-D, zones of remote urban centers – STN-E, the existing low pressure gas distribution systems require reconstruction in order to be able to connect consumers to provide heating and ventilation loads (Fig. 3).

For area of 263 hectares with a population density of 100 to 550 persons per hectare, variants of medium-pressure gas distribution networks are considered. The combined network with ring and dead-end sections provides gas consumption for heat supply and cooking. A rational choice of the location of gas pressure regulating stations as sources and the length of the sections for a given territory leads to a decrease in the material characteristic medium-pressure gas distribution network with the same population density. The material characteristics of the developed options increase by 104%, while the number of consumers increases 5.5 times.

DISCUSSION

If gas is used for heating purposes, then the volume of consumption increases significantly. The use of pressure regulators at consumers technologically ensures stability when changing gas consumption. The model for calculating the network with a distributed load of the gas network makes it possible to implement both medium-pressure networks and low-pressure networks in residential areas.

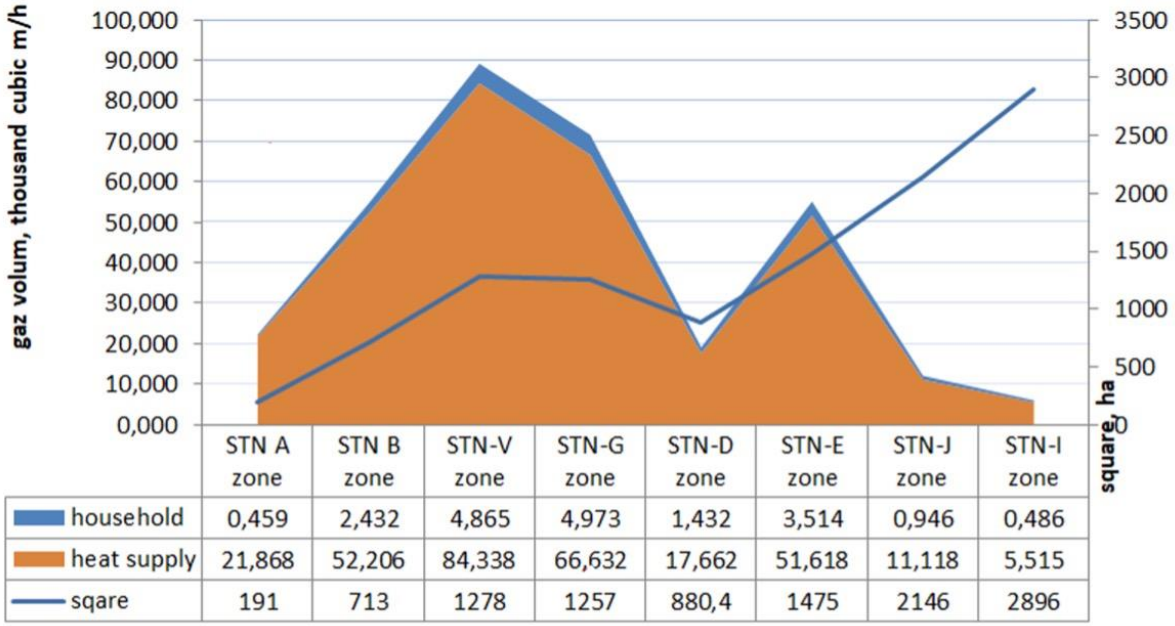

Figure 2: The gas volume for heat supply and for cooking by standardized areas per hour.

There is a possibility of phased commissioning of network sections. Partially, this smoothes out the lag in consumer readiness to receive gas. The factor of subscribers' unpreparedness to receive leads to the fact that the constructed gas pipelines have not been loaded to their design capacity for a long time. In order to effectively resolve these issues, organizational and technological solutions are needed for joint work of PJSC Gazprom organizations and the administrations of the constituent entities of the Russian Federation, aimed at the synchronous creation of the gas pipeline-consumer complex and the loading of the constructed facilities from the moment of operation (Miller, 2016).

Since gas distribution networks made of polyethylene serve for 50 years, there is uncertainty about connecting consumers' equipment. The service life of gas-powered equipment is usually 10 to 15 years. Therefore, the gas distribution system must take into account the prospect of changes in consumption associated with the development of the territory, replacement of equipment. During operation, when connecting a new load, it is necessary to check by calculating the pressure for all network consumers. The mathematical modeling of the gas supply system should be checked in practice during the operation of the network. Compliance with the model of the existing gas distribution system ensures the adoption of technically sound decisions when connecting consumers.

CONCLUSION

Gas volumes for the territory are determined on the basis of the plan for the long-term development of territories. As a source of gas supply based on a feasibility study, options are being considered for connecting to main gas pipelines or building an SRRS.

Gas distribution systems in residential neighborhoods with population density of more than 100 inhabitants per hectare, with heating period of more than 200 days, and estimated heating temperature of less than -30°C is recommended to be designed taking into account the heat supply load. The multistage gas distribution structure of the system ensures reliable, economical gas supply to the territory. The number of gas pressure regulating stations must be at least two.

The calculation of the gas distribution network taking into account the heat supply load is carried out on the basis of a distributed load model of the gas flow rate. This calculation model allows to ensure the economic efficiency of gas supply projects under the conditions of commissioning network sections given order of priority.

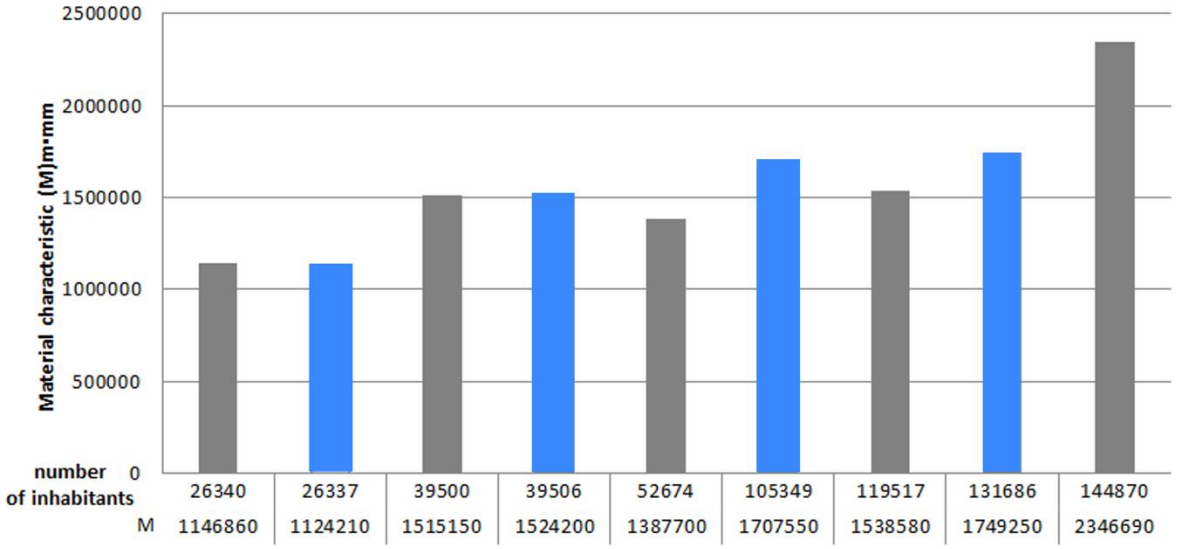

Figure 3: Dependence of the material characteristics of the medium pressure gas distribution network on the population density of the territory.

REFERENCES

Russian regions (econometric approach). *Gas industry*, *S2* (770), 6-13.

Bobyleva, T. A., Khripunova, A. S., 2016. Research of problematic issues of gasification in Russia and ways to solve them. *Bulletin of the University*, *7-8*, 12-18.

Bugaeva, T. M., Novikova, O. V., 2019. Modern methods of planning the city's power system. *Energy. Proceedings of higher educational institutions and energy associations of the CIS*, *62*(4), 377-387.

Dixon, H., Easaw, J., 2001. Strategic responses to regulatory policies: what lessons can be learned from the U.K. contract gas market? *Review of Industrial Organization*, *18*(4), 379-396.

Fortov, V. E., 2019. Opening speech of the Chairman of the Council on priority, academician of the Russian Academy of Sciences V. E. Fortov. *Bulletin of the Russian Academy of Sciences*, *89*(4), 318-320.

García Kerdan, I., Jalil-Vega, F., Toole, J., Gulati, S., Hawkes, A., Giarola, S., 2019. Modelling cost-effective pathways for natural gas infrastructure: a Southern Brazil case study. *Applied Energy*, *255*, 113799.

Georgakopoulos, N., 2018. Hydrocarbon resources and energy policy in Greece to improve security of supply. Proceedings from SGEM 2018: *18th International Multidisciplinary Scientific GeoConferences Conference proceedings*. 441-448. Albena, Bulgaria.

Gillessen, B., Heinrichs, H., Hake, J.-F., Allelein, H.-J., 2019. Natural gas as a bridge to sustainability: infrastructure expansion regarding energy security and system transition. *Applied Energy*, *251*, 113377.

Krupnick, A.J., Kopp, R.J., Hayes, K., Roeshot, S., 2018. The Natural Gas Revolution: Critical Questions for a Sustainable Energy Future. Retrieved from http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-Rpt-NaturalGasRevolution.pdf.

Lu, W., Su, M., Zhang, M., Hao, Y., Fath, B.D., 2016. A systematic method of evaluation of the chinese natural gas supply security. *Applied Energy*, *165*, 858-867.

Mišík, M., Nosko, A., 2017. The Eastring gas pipeline in the context of the Central and Eastern European gas supply challenge. *Nature Energy volume*, *2*, 844–848.

Medvedeva, O.N., 2018. Comparative evaluation of the energy and economic efficiency the gas supply systems of small towns. *Russian Journal of Building Construction and Architecture*, *1*(37), 29-41.

Miller, A., 2016. *On the implementation of the gasification Program for the regions of the Russian Federation*.

Perm city Duma, 2011. *The general plan of Perm City* (December 17, 2010 No.205 (editing on 30.08.2011 No.175, 28.01.2014 No. 2, 28.01.2014 No. 3). Perm, Russia.

Solov'eva, E. B., Luchaninova, D. A., Fedorova, T. A., 2018. The choice of optimal distribution systems. *Agricultural research magazine*, *4*, 59-62.

Weir, Ch., 1999. Regulation and the development of competition in the U.K. gas supply industry. *Review of Industrial Organization*, *15*(2), 135-147.

Zakikhani, K., Nasiri, F., Zayed, T. A., 2020. Review of failure prediction models for oil and gas pipelines. *Journal of Pipeline Systems Engineering and Practice*, *11*(1), 03119001.