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# The Route Selection Method for Natural Gas Pipelines

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**Abstract.** The efficient functioning of gas distribution systems requires a feasibility study of rational gas transport circuit solutions and the choice of optimal parameters. The choice of gas pipeline routing has a significant impact on the functioning of the gas distribution system. The optimal solution to this issue will significantly reduce the cost of construction and operation of the gas supply system. This study formulates some provisions for the design of inter-settlement (intercity) gas distribution systems, designed to improve the efficiency of their operation. In this study, the choice of the optimal variant of the gas pipeline route is reduced to identifying such a position of the main pipeline, at which the costs of building and operating the system will be minimal. This task can be solved both analytically and supplemented by graphical methods. The possibility of using the least squares method and Newton's method for solving problems in the field of gas supply to consumers is shown.

## 1. Introduction

Increasingly, it becomes necessary to determine the optimal parameters of interregional and intercity (inter-settlement) gas fuel distribution systems when drawing up gas supply schemes for settlements. These parameters include: the optimal number of settlements connected to one gas distribution station (GDS), the optimal placement of the GDS, the optimal routing of the inter-settlement (intercity) gas pipeline on the plan of the gas-supplied territory, the number of branches from the gas pipeline, their tie-in points, etc. [1, 2, 3, 4, 5]. Currently, the specified parameters of gas supply systems are determined, as a rule, by variant calculations, or taken arbitrarily. The issues of optimal functioning of gas distribution systems are widely covered in the studies of domestic and foreign scientists [6, 7, 8, 9, 10, 11, 12]. Modern district (inter-settlement) gas distribution systems are a intricate technological complex that includes branches from main gas pipelines, gas distribution stations (acting as a gas supply support point) and a network of inter-settlement gas pipelines. With a large number of settlements requiring the provision of natural gas and their significant dispersion, the determination of the rational location of the gas distribution station requires preliminary technical and economic studies. It should be noted, that the solutions obtained by the authors are based on a number of assumptions which existence significantly affects the accuracy of the final results.

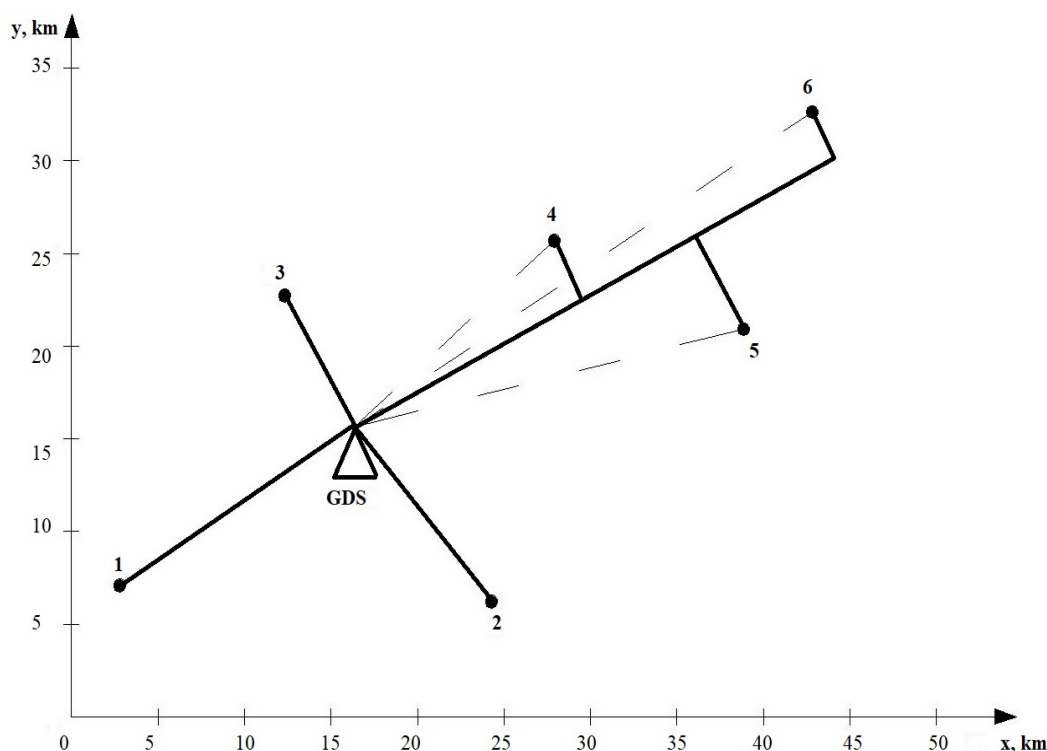
At solution of the problem of an optimal layout of the gas-main pipeline (inter-settlement), the authors use the minimum cost condition for the construction and operation of branches to consumers as an objective function of the target [13]. It is assumed that the costs to the main line do not depend on its position, that is, are accepted as permanent. It should be noted that the various options for layout



the primary line do not have a noticeable effect on its length. At the same time, for a given value of the pressure difference along the route ( $P_{begin}^2 - P_{end}^2$ ), distribution of the calculated pressure difference between the pipeline sections has a significant effect on its diameters. Change in the pressure difference, in turn, causes a change in the initial pressure on the branches and thus, at a given value of the final pressure, causes a change in the diameters of the branches. These considerations require, therefore, minimization of the objective function of the complex: the primary line - branches.

## 2. Materials and methods

As the analysis shows, the number of branches and routing of inter-settlement (intercity) gas pipelines depends on numerous factors, such as: the location of consumers in the gas-supplied territory, the volume of gas consumption in each settlement, the distance from the main gas pipeline to a remote consumer, the share of industrial load in the total volume of fuel consumption, factors of geographic and geological nature, etc. [1]. The selection of a rational route from the inter-settlement (main) gas pipeline should begin with determining the optimal number of settlements supplied with gas from one GDS, then determine the optimal location of the GDS and then proceed to calculate the optimal gas distribution schemes between the GDS and gas fuel consumers. In a particular case, it is proposed to use one of the methods of mathematical statistics - the method of least squares, which makes it possible to find the equation of a straight (curved) line located at a minimum distance from several random points [14]. The essence of the choice of the optimal route of the gas pipeline branch lies in the fact that a coordinate system  $xoy$  is arbitrarily applied on the master plan of a settlement (gas-supplied territory) and the position of consumers is fixed on it (fig. 1) [14, 15].



**Figure 1.** Task design scheme.

The position of the gas distribution station based on the condition that a separate gas pipeline is laid to all consumers. The optimal routing found from the equation:

$$y_i = A + B_{opt} \cdot x. \quad (1)$$

$$B_{max} = (y_i^{max} - A)x_i^{-1}; \quad B_{min} = (A - y_i^{min})x_i^{-1}. \quad (2)$$

The algorithm for solving the problem is as follows: for each value of  $B$  in the range  $B_{min} \leq B \leq B_{max}$ , it is necessary to find the coordinates of tie-ins of the branches to the consumers, then identify the lengths of the sections on the headline and the lengths of the branches, find the diameters on the sections of the headline and branches based on the results of hydraulic calculations, and, finally, determine the minimum costs in a dead-end branched gas network at.

Since the change in the position of the route has an insignificant effect on the change in its diameter and length, we will take the total discounted costs for the construction and operation of branches and headline as the objective function of the problem:

$$C = \sum_{i=1}^{n-1} C_{hl,i} + \sum_{i=1}^n C_{br,i}, \quad (3)$$

where  $C_{br,i}$  is the discounted costs for the construction and operation of the  $i$  – branch, rubles $\times$ year $^{-1}$ ;  $C_{hl,i}$  – discounted costs for the construction and operation of the  $i$  – line, rubles $\times$ year $^{-1}$ .

$$C_{br,i} = CI_{br,i} + \sum_T^t (1+E)^{-t} \cdot (\varphi \cdot CI_{br,i} + \psi \cdot \ell_{br}), \quad (4)$$

$$C_{hl,i} = CI_{hl,i} + \sum_T^t (1+E)^{-t} \cdot (\varphi \cdot CI_{hl,i} + \psi \cdot \ell_{hl}), \quad (5)$$

where  $CI_i$  is the capital investments in the structure, rubles;  $E$  is the coefficient of efficiency of capital investments, year $^{-1}$ ;  $\varphi$  – annual deductions for gas pipelines depreciation, year $^{-1}$ ;  $\psi$  is the cost of maintenance 1m of the gas pipeline, rubles  $\times$  (year $\times$ m) $^{-1}$ .

Original objective function (3), taking into account all components:

$$C = \sum_{i=1}^n \left[ b \left( \left[ 3.36 \cdot 10^{-3} \cdot Q_{br,i}^2 (P_{begin,i}^2 - P_{end}^2)^{-1} \right]^{0.19} \cdot \left( [y_i - (A + B \cdot x_i)]^2 - [y_i - (A + Bx_i)] B (B^2 + 1)^{-0.5} \right)^2 \right)^{0.595} \right] \times + \left[ \left( 1 + \sum_{t=1}^T (1+E)^{-t} \cdot \varphi \right) + \sum_{t=1}^T (1+E)^{-t} \cdot \psi \cdot \left( [y_i - (A + B \cdot x_i)]^2 - [y_i - (A + Bx_i)] B (B^2 + 1)^{-0.5} \right)^2 \right)^{0.5} \right] + \sum_{i=1}^{n-1} \left[ b \left( \left[ 3.36 \cdot 10^{-3} \cdot Q_{hl,i}^2 (P_{begin,i-1}^2 - P_{end,i}^2)^{-1} \right]^{0.19} \cdot \left( (x_{i+1} - x_i) (B^2 + 1) + B [y_{i+1} - y_i - B(x_{i+1} - x_i)] (B^2 + 1)^{-0.5} \right)^2 \right)^{1.19} \right] \times \left[ \left( 1 + \sum_{t=1}^T (1+E)^{-t} \cdot \varphi \right) + \sum_{t=1}^T (1+E)^{-t} \cdot \psi \cdot (x_{i+1} - x_i) (B^2 + 1) + B [y_{i+1} - y_i - B(x_{i+1} - x_i)] (B^2 + 1)^{-0.5} \right] \right] \quad (6)$$

To determine the optimal values of  $A_{opt}$ ,  $B_{opt}$  and the optimal pressure distribution  $P_{begin,i}$ , we differentiate equation (6) by the sought parameters and equate the obtained derivatives to zero. When differentiating by  $P_{begin,i}$ , it should be taken into account that the final pressure of the  $i$ –section of the headline is equal to the initial pressure of the subsequent section (when the sections are numbered in the direction of gas movement). When restricted:

$$\sum_1^{n-1} (P_{i-1} - P_i) + P_{end} - P_{GDS} = 0. \quad (7)$$

compose the Lagrange function:

$$\phi = f(A, B, P_i) + \sum_1^n \lambda_i \sum_1^{n-1} (P_{i-1} - P_i) + P_{end} - P_{GDS}. \quad (8)$$

To solve the proposed problem, mathematical models using the physical and mathematical package Mathcad [16] with the enabled SmartMath artificial intelligence system in combination with the C-Sharp programming language, a program was compiled that allows you to obtain the equation for the optimal routing of the gas pipeline and the optimal values of pressure along the network sections (pressure in branch insertion points). An additional software module allows you to obtain a visual diagram of the gas pipeline route on the plan of the gas-supplied territory [17]. In the developed program, the initial data are: the number of gasified villages, their coordinates on the ground, types of installed gas-using equipment, as well as the gas pressure at the outlet of the gas distribution station. The program results the final equation of the optimal routing of the inter-settlement gas pipeline is derived in the form:

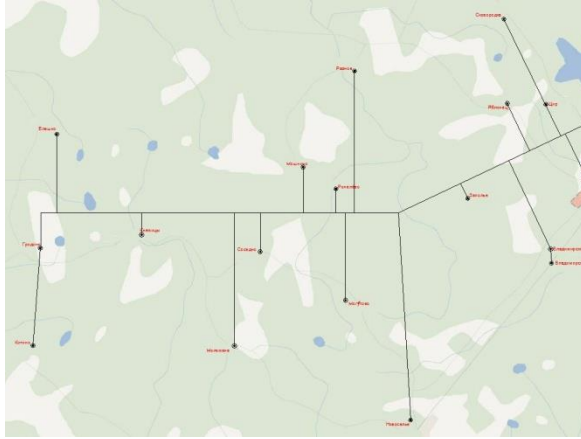
$$y = A_{opt} + B_{opt} \cdot x. \quad (9)$$

### 3. Results and discussion

For the numerical implementation of the proposed model, the corresponding calculations were carried out. After obtaining the optimal parameters of the route, it is necessary to make adjustments taking into account the real design conditions. To solve the problem by a graphical method, it is proposed to use the method of constructing an optimal Steiner tree [18]. To do this, load the required map of the gasified area into the AutoCAD program. Then we connect all the points in sections according to the Steiner principle, indicating the approximate structure of the connecting network of gas pipelines. Now we know all the branches and embranchments of the gas pipeline (figure 2a). In the next step, it is necessary to equalize the adjacent sides with each other so that they are located relative to each other at an angle of 120°. To do this, at each branch of the gas pipeline, it is necessary to set an angular dimension at two of the three adjacent sides and align them. AutoCAD will display changes in angle values at the same time, thereby indicating an approach to the desired point or in the wrong direction. Once the required point is found, then all angles will be equal to 120°, which means that this point will be optimal for connecting the segments. Having carried out this technique on all branches, we obtained the optimal gas pipeline network, the length of which is 97.6 km (fig.2a). For comparison, fig. 2b) and 2c) show the traditional schemes of gas networks applicable in the given area.



**Figure 2a.** Scheme of gas networks with a length of 97.6 km.



**Figure 2b.** Scheme of gas networks with a length of 115.3 km.



**Figure 2c.** Scheme of gas networks with a length of 102.8 km.

**Figure 2.** Construction of the optimal route of the gas network using the optimal tree.

Comparison of the schemes shows that the method of optimizing the construction of gas networks using the Stern tree can significantly save material and financial resources.

Along with the radial-beam option for tracing inter-settlement gas pipelines, it is advisable to connect individual gas consumers located on adjacent beam gas pipelines according to a radial-dead-end scheme. The presence of a combined (radial-beam and radial-dead-end) routing scheme for inter-settlement gas pipelines significantly changes the general configuration of gas distribution networks and the optimal location of the gas distribution station. To determine the coordinates of the GRS, one can use Newton's method, based on the principles of simple iteration and, according to which, the search for a solution is carried out by constructing successive approximations.

Replacing several beams with one radial dead-end is advisable due to cost savings. The radial dead-end variant is adopted with optimal routing and optimal diameters. Then the radial dead-end gas pipeline is reduced to a radial-beam version with one consumer from the condition:

$$C_{rb}(\ell, d, (P_{begin}^2 - P_{end}^2), Q_{loc}) = 3_{rde}(\ell, d, (P_{begin}^2 - P_{end}^2), Q_{loc}). \quad (10)$$

$$(P_{begin}^2 - P_{end}^2)\ell^{-1} = Q_{loc}^{0.368} (d^{4.25})^{-1}. \quad (11)$$

The coordinates of the gas pipeline tie-ins branch to consumers are found from the solution of the system of equations:

$$y_{loc} = (x_{loc} - x_{GDS})B^{-1} + y_{GDS}; \quad x_{loc} = [x_{GDS} + y_{GDS} \cdot B - A \cdot B](1 + B^2)^{-1}. \quad (12)$$

We get a new radial-beam version of the scheme and find a new GDS landing using the above algorithm. The desired route will be characterized by the optimal ratio between the length of the gas pipeline and its average diameter, therefore, when choosing the optimal option, it is necessary to take into account not only the number of GDS, but also the distribution of gas consumption loads over the gas-supplied territory [13]. This iterative process is repeated until the next iteration step refines the solution by no more than 2÷3% in terms of discounted costs.

The problem of finding the shortest network is relevant not only for power lines, road construction, but also for gas supply systems. In any of these industries, its correct solution would contribute to a significant reduction in material costs and reduce the cost of projects in general [2, 19, 20]. The authors of this study investigated the possibility of optimizing gas supply networks from gas distribution stations on rough terrain, approaching the issue from the point of view of geometry and

conditions for the minimum reduced costs for the construction and operation of the system, and, on the basis of the studies carried out, came to an optimal routing algorithm for gas distribution networks.

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