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Computer Models of Complex Multiloop Branched Pipeline Systems

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Abstract—This paper describes the principal theoretical concepts of the method used for constructing computer models of complex multiloop branched pipeline networks, and this method is based on the theory of graphs and two Kirchhoff's laws applied to electrical circuits. The models make it possible to calculate velocities, flow rates, and pressures of a fluid medium in any section of pipeline networks, when the latter are considered as single hydraulic systems. On the basis of multivariant calculations the reasons for existing problems can be identified, the least costly methods of their elimination can be proposed, and recommendations for planning the modernization of pipeline systems and construction of their new sections can be made. The results obtained can be applied to complex pipeline systems intended for various purposes (water pipelines, petroleum pipelines, etc.). The operability of the model has been verified on an example of designing a unified computer model of the heat network for centralized heat supply of the city of Samara.

Keywords: pipeline system, computer model, theory of graphs, Kirchhoff's laws, pressure profiles, characteristics of pipelines and pumps, unified heat network, discrepancies in heads

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The computer model for calculating pipeline networks is based on the theory of hydraulic circuits, the physico-mathematical aspects of which have much in common with those of the theory of electric circuits. As the basic mathematical apparatus, the theory of graphs, matrix algebra, and vector algebra are implemented [1–5]. Computer models make it possible to entirely simulate hydraulic processes occurring in pipeline systems, if the latter are considered as single integral hydraulic systems. These models provide a way of determining pressures, flow velocities of a fluid medium, flow rates, head losses, and energy consumption for movement of a heat carrier medium at any point (or in any section) of a district heating network and other parameters [6–10].

In the construction of a computer model two Kirchhoff's laws were used the algorithm for implementing of which is considered further in the specific example of distribution of flow rates of the medium (water) in the network consisting of one loop (Fig. 1) and having three branches [11].

Flow rates of the medium with respect to the sections a, b, c, and d of the loop are denoted as Q_a, Q_b, Q_c, and Q_d, while those with respect to the branches, Q_1, Q_2, and Q_3. It is necessary to find the distribution of the flow rates with respect to the branches at the given flow rate Q at the entrance to the loop, if the flow rates of water with respect to the branches Q_1, Q_2, and Q_3 of the loop are known, and their sum is equal to the flow rate Q at the entrance to the loop network, i.e., $Q = Q_1 + Q_2 + Q_3$.

The first Kirchhoff law establishes the equal inflow and outflow of a fluid medium in each network mode, i.e., it is necessary to satisfy the flow rate balance equation:

$$\sum_{i=1}^{n} Q_i = 0, \qquad (1)$$

where n is the number of pipelines connected together in a node; Q_i ($i = 1, 2, 3, ..., n$) are flow rates of the medium with respect to all pipelines connected together in the given node.

According to the second Kirchhoff law, the sum of heads H_i for any closed circuit is zero, i.e.,

$$\sum_{i=1}^{n} H_i = \sum_{i=1}^{n} S_i Q_i^2 = 0, \qquad (2)$$

where S_i ($i = 1, 2, 3, ..., n$) is the hydraulic resistance of the ith section.

On the basis of the iteration method of calculation by using Eqs. (1) and (2), it is possible to find the distribution of flow rates with respect to all sections of the network at the known flow rate Q, which is preassigned at the entrance to the loop. In the first iteration step the arbitrary distribution of medium flow rates in each section of the loop is preassigned, i.e., values Q_a, Q_b, Q_c, and Q_d are preassigned. Then, for nodes 0, 1, and 2 we find from the first Kirchhoff law:

$$Q_d = Q - Q_a; \quad Q_a = Q_1 + Q_b; \quad Q_b = Q_2 + Q_c.$$

According to the second Kirchhoff law, on the basis of the previously adopted flow rates with respect to all