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ANALYSIS OF EMERGENCY OPERATION OF WATER PIPELINES

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Abstract. In this work, the influence of individual sections of the water supply network on the dynamics of nodal heads in emergency operating modes is investigated. During accidents in the network sections, the dynamics of the head changes, the supply of water to the network decreases, areas with insufficient heads are formed. The subject of the analyzed stage of research is the influence of individual sections of the network on the location and size of areas with insufficient head. To determine the influence of individual sections of the network on head dynamics, methods of mathematical modeling of flow distribution in the water supply network, methods of hydraulic calculations of water supply networks were used.

The results of studies of formation and change of areas with insufficient head taking into account emergency situations for networks with different structure and configuration are presented. The tasks to be performed by the flow management system at the network design stage are defined. Based on the results of the studies, the water supply conditions were evaluated during the formation of areas of insufficient pressure.

Proposed algorithm consists of visualization of network structure, simulation of emergency situations, hydraulic calculations of network in normal and emergency operation modes, determination of actual head in network nodes, clarification of location of control nodes, calculation of required head of pumps in emergency operation mode. The proposed method allows you to determine the priority selection of network sections during its reconstruction and restoration. Modeling and analysis of pressure zones in the network allows you to change the number and location of pressure control units depending on the need. The proposed recommendations on flow management can be implemented in the work of utility dispatch services.

Keywords: water supply network, nodal pressure, modeling, hydraulic calculation, insufficient pressure.

Introduction. Total length of water supply systems in Ukraine is more than 104154.0 km from which according to the Ministry of Regional Development, Construction and Housing in critical condition there are more than 36296.0 km or 34.9% of the total length of networks. The situation existing in the sphere of water supply of the Zaporizhzhia region and in the country leads to considerable losses of drinking water when transporting and also to deterioration of drinking water due to its pollution. The solution of problematic issues of water supply is possible on condition of realization of actions for reconstruction and modernization of objects of water economy. Insufficient financing is the greatest problem at realization of such actions. Replacement of the most worn-out and emergency networks 10-15 km long with own forces and for own means is annually planned and carried out. For example, since 2016 about 80 km of water supply and sewer systems were executed replacement. In certain cases, because of big capital intensity and limitation of local sources of financing construction and reconstruction are conducted within 5-10 and more years. Therefore the problem of management of streams in water supply systems taking into account emergency operation of work has relevance.

Analysis of the last researches or publications. The rate of losses of water in city networks is very high and is within 0.4-3.0 m^3/km a year, in comparison with indicators in Western Europe which make 0.1-0.4 m^3/km a year [1]. A condition of accident rate of water supply systems taking into account material of pipelines were it is analyzed in works of foreign experts [2, 3]. For the Ukrainian cities the condition of accident rate of water supply systems is characterized by 1-2 emergency leaks on 1 km of a pipe, these indicators of accident rate by data [4] at 5-20 times exceed the corresponding indicators in Europe.

Use of geoinformation technologies in work of utility companies for the analysis of a condition of water supply systems increases possibilities of studying the hydraulic modes. Observation on-line mode as it is specified in work [5] is a widespread way of the analysis of pressure. Use of the information City Com platform by data [6] expands opportunities for hydro-modeling and audits of water supply systems. But information technologies in work of utility companies, mainly, are applied to storage and information processing about a condition of elements of water supply systems. Networks of water supply divide into certain sectors for simplification of observation of their state [7] that, according to experts [8] optimizes management of water flows in them. Similar zoning is applied to decrease in big pressures [9]. According to experts [10], zonings of a water supply system by certain sectors are facilitated by control of nodal pressures as within the certain sector it is easier to regulate pressure in the limited number of control knots. Pressure control in similar zones as experts [11] consider, is more effective for maintenance of minimum necessary pressures. Additional researches of influence of hydraulic operating modes of water supply systems on arrangement and the sizes of zones with insufficient and excess pressures are necessary for localization of network on certain sectors.

The main methods of identification of leaks on water supply systems is the visual control and methods connected with use of the measuring equipment. So experts [12] offer application of a method of "a lazy dragon" for definition of a priority of work on restoration of sites of water supply systems. The method considers leak consequences, allows to calculate duration and the cost of its elimination. The majority of methods of localization and elimination of leaks are developed for networks which are a long time in operation. Forecasting of formation of zones with insufficient and excess pressures at a design stage of water supply systems will allow to define the most economic option of trace of network, to establish problem sites and to equip them with devices for control.

Purpose and tasks. The purpose of work is the research of influence of emergency operation of network functioning on distribution of pressure in its knots, formation of zones of insufficient and excess pressures. Achievement of the goal provided performance of the following tasks: performance of hydraulic calculation under the chosen schemes taking into account an emergency on certain sites of network; calculation of piezometric marks and nodal pressures at normal and emergency operation of work; definition of influence of certain sections on the sizes and arrangement of zones of pressures in network; assessment of consequences of emergence of emergencies on certain sections.

Materials and methods of research. Researches were conducted for water schemes which are projected. Schemes of networks are provided in Table 1 and operation parameters are specified: the general daily expense of Q_{day}, (m^3/day), junction points of conduits, elements of network for which emergency operation of work was modelled:

– water supply system (scheme A) from 10 contours, 18 nodes and 27 sections;

– water supply system (scheme B) from 15 contours, 25 nodes and 39 sections;

– water (scheme B) from 9 contours, 18 nodes and 26 sections.

For configurations of water supply systems which schemes presented in Table 1, were created basic data for performance of hydraulic calculation of networks:

– the design flowrate of water taking into account the number of inhabitants and a rated consumption of water is defined;

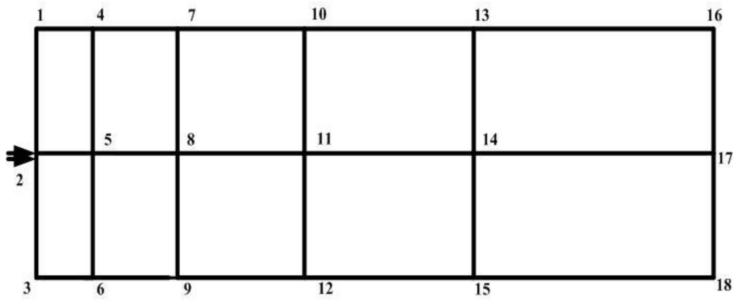
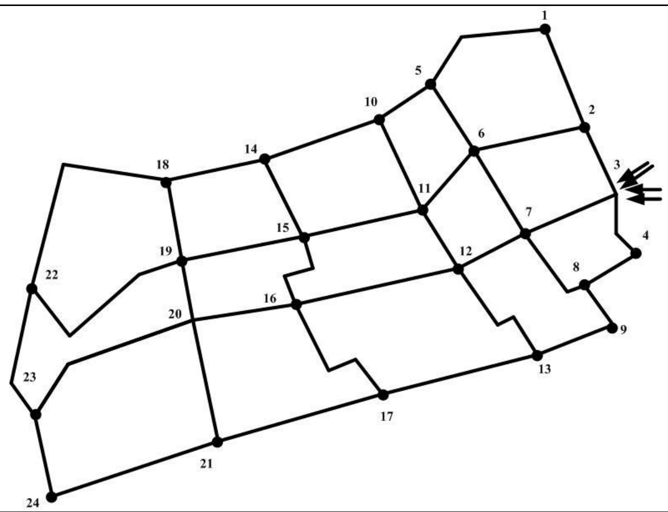
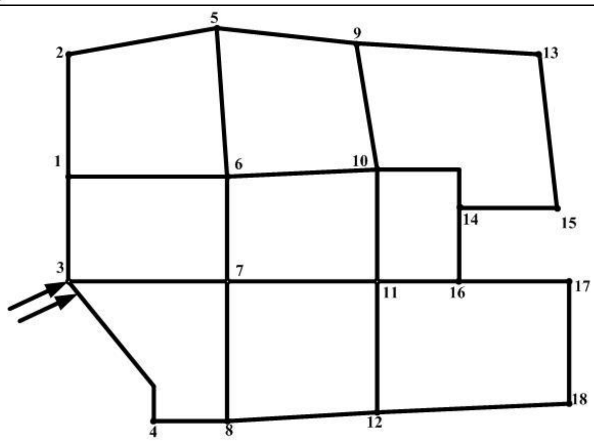
– the settlement scheme according to the plan of the city is made, sections and nodes are designated;

– nodal expenses are defined, initial distribution of streams is executed;

– basic data for performance of hydraulic calculation which are provided in Table 1 are created.

Thus, researches were conducted on the example of water supply systems by Q performance = 7700-96470 m^3/day. For each option of emergency operation of network functioning hydraulic calculations of network were executed and the areas of districts with an insufficient pressure are determined. Influence of emergency operation of network functioning on distribution of pressure in its nodes was investigated on the example of water supply systems which schemes are presented in Table 1. When modeling emergencies of network, the options which are brought closer to real conditions were considered.

Table 1 – Characteristics of schemes of water supply systems

Configuration of network	Scheme of network	Modeling of emergency operation
Scheme A Q_{day} =15000, m^3/day		1) 1-2 and 1-4; 2) 4-7; 3) 7-10; 4) 10-13; 5) 13-16 and 16-17; 6) 2-5; 7) 6-8; 8) 8-11; 9) 11-14; 10) 14-17.
Scheme B Q_{day} =7700, m^3/day		1) 2-6; 2) 6-11; 3) 11-15; 4) 15-19; 5) 19-23; 6) 3-7; 7) 7-12; 8) 12-16; 9) 16-20; 10) 20-24.
Scheme C Q_{day} =96470 m^3/day		1) 2-5; 2) 1-6; 3) 6-10; 4) 7-11; 5) 10-14; 6) 3-7; 7) 8-12; 8) 12-18; 9) 4-8; 10) 5-9.

For each of the considered schemes of network hydraulic calculations were executed and free pressures in its nodes at normal and emergency operating modes are defined. Under normal conditions free pressures in nodes were defined rather critical point, when modeling emergencies on certain sections – regarding the power supply.

For schemes A-C the areas of districts with an insufficient pressure which can be formed at emergency operation of work are analyzed.

Results of researches. For each of the considered options of emergency operation of work the areas of districts with an insufficient pressure are calculated. Borders of these areas are determined by knots with a pressure which corresponds to a condition**:**

$$H_{fi} < H_n, \quad (1)$$

where H_{fi} is the value of a free pressure in the node, m;

H_n is the value of a necessary pressure [13], m.

$$H_n = 10 + 4\,(n-1), \quad (2)$$

where n is the number of floors in houses, in researches residential areas with five-floor building are considered.

Borders of a zone are formed as a result of a projection to a water supply system of a virtual piezometric surface at $Z_i + H_n$ concerning ground level of Z_i. Borders of a zone are defined by lengths of sections on a water supply system which transport water to buildings on condition of (1).

For example, in Fig. 1 the areas of districts with an insufficient pressure in a water supply system (scheme A) which appear at leaks on certain sites are presented. In the drawing four emergencies are presented (fragments a-d). The location of regions of an insufficient pressure was defined on condition of preservation of a settlement pressure in a junction point of conduits to network. Apparently from Figure 1, when modeling emergencies, the largest area of a zone of an insufficient pressure of $F_{z.i.p.}$ of rather total area of F_{gen} ($F_{z.i.p.}/F_{gen}$ = 85.1%) should be expected in case of leakage at the section 2-5.

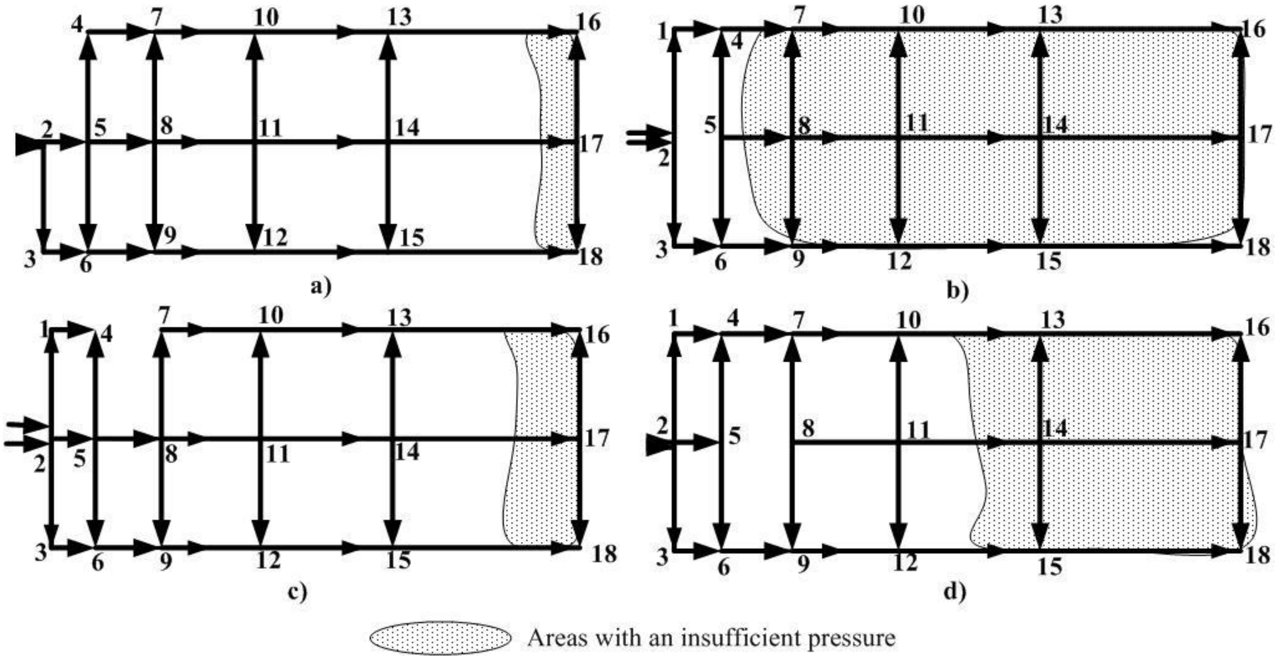


Fig. 1. Zones of an insufficient pressure taking into account emergency operation of network functioning: a – on section 1-2 and 1-4; b – on section 2-5; c – on section 4-7; d – on section 5-8

The least area of a zone with an insufficient pressure ($F_{z.i.p.}/F_{gen}$ = 6.6%) is formed at leaks on sections 1-2 and 1-4 (Fig. 1, a). For this case it is explained by the minimum participation of the specified sections in the general distribution of streams.

In Figure 2 schedules of insufficient pressures are presented to networks B which can appear at leaks on sites. The biggest areas with an insufficient pressure should be expected at change of capacity of the sites located in the center of a water supply system: so at leak №6 on section 3-7 (Fig. 2, a) $F_{z.i.p.}/F_{gen}$ = 31.9%, and at leak № 3 on section 11-15 – Fz.i.p./Fgen = 25.6% (Fig. 2, a). It is explained by a smaller reserve of capacity of the remote sections which at leaks on the specified sections accept the main stream.

The chart submitted in Fig. 2 (a fragment b), illustrates increase in a necessary pressure ΔH in a junction point of conduits in comparison with a settlement pressure for the normal mode of operation and reduction of water supply in network (according to scheme v) at leaks. At leaks on sections 3-7 and 8-12 the water supply decreases by 11.7%, these sections as much as possible participate in distribution of streams. But not all central sections significantly influence changes of hydraulic characteristics of network: for example, at leak on sections 5-9, 10-14 (the scheme C in Table 1) the general giving decreases within 0.2-0.4%.

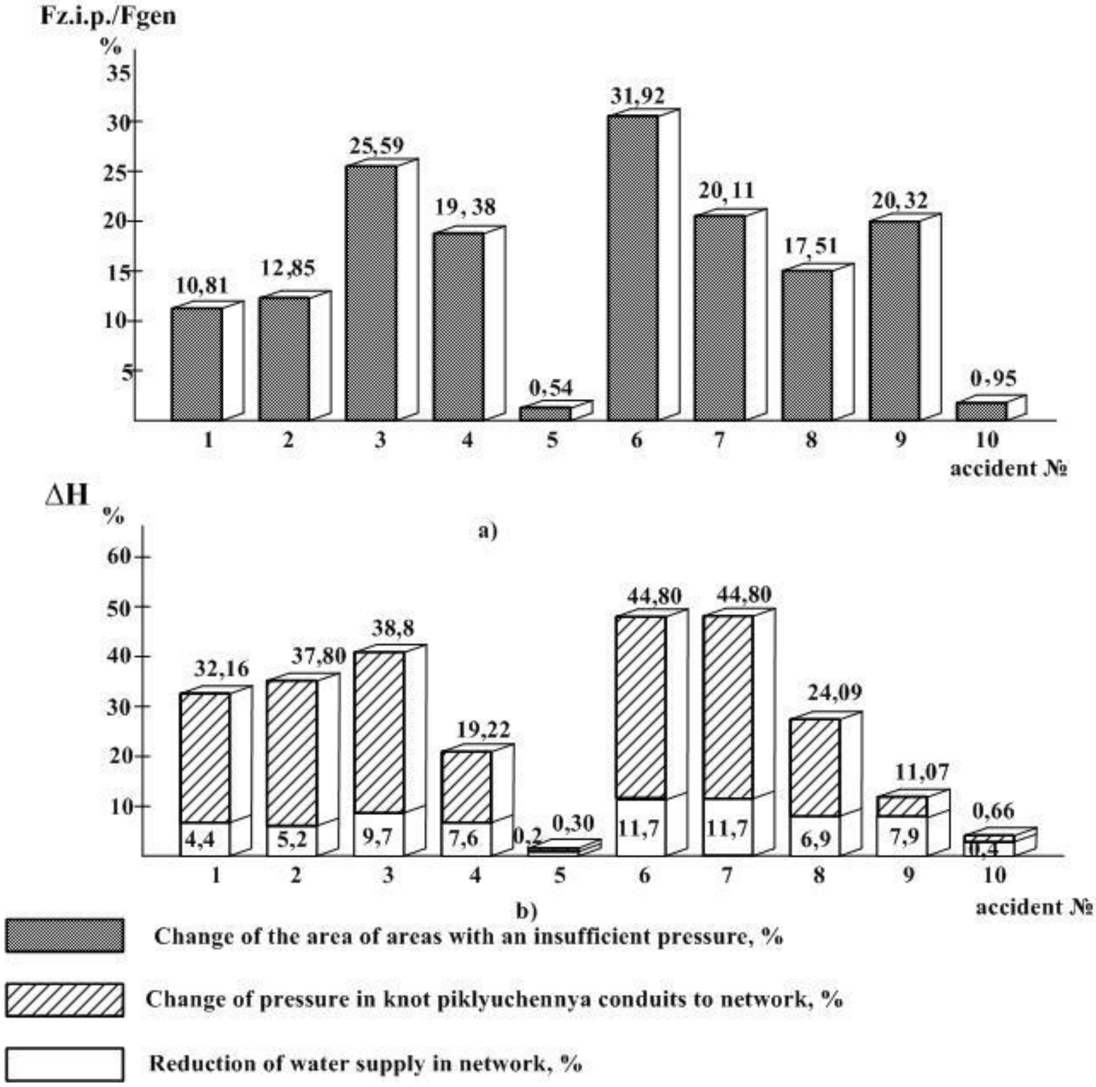


Fig. 2. Charts of pressures and water supply in network:
a – change of the area of insufficient pressures in a water supply system; b – increase of a necessary pressure of ΔH in a junction point of conduits

Conclusions. In case of leakage at the certain sections of network the general distribution of streams in network can change. Modeling of leaks at design of network by an exception of the settlement scheme of certain sites will allow the dispatcher to reveal "narrow" places – the most overloaded sites on which it is recommended to control pressure, to define consumers who will be most limited in water supply and to choose reserve sources of water supply. Optimum criterion for the analysis of the possible directions of streams in network is water supply of "priority consumers" – hospitals, the enterprises with continuous technological process.

The method of consecutive calculation of emergency operation allows to define the priority choice of sections of network at its reconstruction and restoration. Realization of a method of mathematical modeling of streams in a water supply system taking into account emergency operation of its work includes the following stages:

1. Drawing of the scheme of network and creation of the database of its actual parameters. At this stage the actual binding of a configuration and elements of a water supply system to the area is carried out. Geoinformation mapping allows designers or dispatchers to analyze distributions of pressure in network that will allow to analyze dynamics and trends of formation of possible zones of insufficient and excess pressures already at a design stage. Further work assumes addition of the existing database to indicators in recent years (changes of characteristics of sections, additional elements on network: sections, equipment, etc.). At the same time specification of places of the equipment of control nodes and additional designing of sections of network is carried out.

2. Hydraulic calculation for the normal and emergency modes at a design stage of networks, definitions of expenses on sites, these expenses are valid at measurement of pressure in control points of a water supply system.

3. Measurement of a difference of pressure in control points, at this stage software module is used for correction of basic data. For networks which are designed the modeling of possible leaks on sites by correction of basic data is carried out: changes of number of sites and their diameters:

$$d_{f.i}= K_c\times d_{sit.i}, \quad (3)$$

where $d_{sit.i}$ and, $d_{f.i}$ is the output and fictitious diameters of the considered section of network respectively, m;

K_s – is the coefficient of change of resistance:

$$K_s=1-P/100, \quad (4)$$

where P is the percent of change of capacity of a pipe, %.

4. Definition of the actual free pressures in nodes, determination of nodes in which the condition is satisfied (1). These nodes are on borders of areas with an insufficient pressure. Thus, there is a possibility of the analysis of the predicted or actual situation. It allows to analyze distribution of nodal pressures.

5. The analysis of expenses on sites and free pressures in knots of network for determination of knots of control and distribution of streams in network.

6. Calculation of pumps pressure taking with considering necessary pressure in separate knots.

The actual service conditions prove that there are problems of obtaining actual data about a condition of water supply systems. In comparison with similar methods of a number of control knots determination and distribution controls of streams [11] the analysis of emergency operation allows to define criterion for determination of number of additional control knots. It is the size of possible zones of an insufficient pressure in network. Results of hydraulic calculations with considering leaks can be used by on utility companies for determining of consumers who feel the shortage of water. The analysis of leaks allows to define their number with considering the number of floors in buildings, to determine repair duration.

Modeling of emergencies for water supply systems which are projected and timely elimination of consequences in water supply systems will allow to reduce leaks and expenses on energy consumption in pump stations. For example, prevention of water losses Q at 70 emergency leaks within a year lasting 1 day for sites with a diameter of 300 mm (0.3 m) at a speed of current of 3.0 m/s makes:

$$Q=3.0\times3.14 \times 0.3^2/4=0.212 \text{ м}^3\text{/s or } 18312.5 \text{ m}^3\text{/days}.$$

Considering coefficient of distribution control of streams 0.04 [13] and an average tariff for water of 14.5 UAH/m^3, in a year it is possible to preserve the sum of 743 thousand UAH:

$$E=18312.5\times70\times(0.015+0.015+0.01)\times14.5=743487 \text{ UAH/year}.$$

Introduction of this action will allow to reduce unproductive leak of water of drinking quality and to considerably reduce operating costs, to improve quality indicators of the centralized water supply of the city.

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АНАЛІЗ АВАРІЙНИХ РЕЖИМІВ РОБОТИ ВОДОПРОВІДНИХ МЕРЕЖ

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Анотація. У даній роботі досліджено вплив окремих ділянок водопровідної мережі на динаміку вузлових напорів при аварійних режимах роботи. При аваріях на ділянках мережі змінюється динаміка напорів, зменшується подача води в мережу, утворюються райони з недостатніми напорами. Предмет аналізованого етапу досліджень – вплив окремих ділянок мережі на розташування і розміри районів з недостатніми напорами. Для визначення впливу окремих ділянок мережі на динаміку напорів були застосовані методи математичного моделювання потокорозподілу у водопровідній мережі, методи гідравлічних розрахунків водопровідних мереж.

Представлені результати досліджень утворення та зміни площі районів з недостатнім напором з урахуванням аварійних ситуацій для мереж з різною структурою і конфігурацією.

Визначено завдання, які повинна вирішувати система управління потокорозподілом на стадії проєктування мереж. За результатами досліджень виконано оцінку умов водопостачання при утворенні районів недостатнього напору.

Запропоновано алгоритм послідовного розрахунку аварійних режимів роботи водопровідної мережі, який складається з візуалізації структури мережі, моделювання аварійних ситуацій, гідравлічних розрахунків мережі при нормальному та аварійному режимах роботи, визначення фактичних напорів у вузлах мережі, уточнення розташування контрольних вузлів, розрахунку необхідного напору насосів при аварійному режимі роботи. Запропонований метод дозволяє визначити пріоритетний вибір ділянок мережі при її реконструкції та відновленні. Моделювання та аналіз зон напорів в мережі дозволяє в залежності від необхідності змінювати кількість і розташування вузлів контролю тиску. Моделювання аварійних ситуацій для проєктованих водопровідних мереж та своєчасне усунення наслідків в діючих мережах дозволить зменшити витоки та витрати на енергоспоживання в насосних станціях, значно знизити експлуатаційні витрати, покращити якісні показники централізованого водопостачання міста. Запропоновані рекомендації з управління потокорозподілом можуть бути реалізовані в роботі диспетчерських служб комунальних підприємств.

Ключові слова: водопровідна мережа, вузловий напір, моделювання, гідравлічний розрахунок, недостатній напір.

АНАЛИЗ АВАРИЙНЫХ РЕЖИМОВ РАБОТЫ ВОДОПРОВОДНЫХ СЕТЕЙ

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Аннотация. В данной работе исследовано влияние отдельных участков водопроводной сети на динамику узловых напоров при аварийных режимах работы. При авариях на участках сети изменяется динамика напоров, уменьшается подача воды в сеть, образуются районы с недостаточными напорами. Предмет анализируемого этапа исследований – влияние отдельных участков сети на расположение и размеры районов с недостаточными напорами. Для определения влияния отдельных участков сети на динамику напоров были применены методы математического моделирования потокораспределения в водопроводной сети, методы гидравлических расчетов водопроводных сетей.

Представлены результаты исследований образования и изменения площади районов с недостаточным напором с учетом аварийных ситуаций для сетей с различной структурой и конфигурацией. Определены задачи, которые должна решать система управления потокораспределением на стадии проектирования сетей. По результатам исследований выполнена оценка условий водоснабжения при образовании районов недостаточного напора.

Предложен алгоритм последовательного расчета аварийных режимов работы водопрводной сети, который состоит из визуализации структуры сети, моделирования аварийных ситуаций, гидравлических расчетов сети при нормальном и аварийном режимах работы, определения фактических напоров в узлах сети, уточнения расположения контрольных узлов, расчета необходимого напора насосов при аварийном режиме работы. Предложенный метод позволяет определить приоритетный выбор участков сети при ее реконструкции и восстановлении. Моделирование и анализ зон напоров в сети позволяет в зависимости от необходимости изменять количество и расположение узлов контроля давления. Предложенные рекомендации по управлению потокораспределением могут быть реализованы в работе диспетчерских служб коммунальных предприятий.

Ключевые слова: водопроводная сеть, узловой напор, моделирование, гидравлический расчет, недостаточный напор.

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