Influence of the temperature schedule of heating network and using differential pressure regulators on the reliability of heat supply systems

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Abstract. The methods of increasing reliability of heat supply systems are analyzed. A digital twin of the existing heat supply system has been created. Various modes operation of the system are modeled and control and decision-making system in the conditions operation of the heat network is considered on the example of one of heat supply systems of the Republic of Tatarstan. The indicators of reliability of heat supply to consumers at using these methods are determined. As a result of the application of control methods and increasing reliability of the thermal power systems, probability of failure-free operation and the coefficient of hydraulic stability of heat supply system were calculated, the influence of the temperature schedule and the use of differential pressure regulators (DPR) on the reliability of the system in general were analyzed. Special attention is paid to the hydraulic balancing of the heat supply system to increase her reliability.

1 Introduction

Reliability of heat supply is determined by the ability of projected and operating sources of thermal energy, heating networks and, in general, district heating systems to provide the required modes for a given time, parameters and quality of heat supply (heating, ventilation, hot water supply, as well as the technological needs of enterprises in steam and hot water) to provide regulatory indicators of the probability of failure-free operation [Pj], readiness factor [Kj], survivability [S] [1].

2 Measures to improve the reliability of district heating systems and methods of her calculation

Improving reliability of heat supply system during operation is a difficult arrangement. The basis of measures to improve reliability is laid at the design stage of heat supply systems. Many scientists from various universities and academic institutes are engaged in research on improving the reliability of district heating systems.

A method for assessing the reliability of a thermal network based on the definition of PFFO (Probability of failure-free operation), considering the duration of the service life of valves, was proposed at the Tomsk Polytechnic University [2].

The algorithm to implement the principle of increasing reliability of district heating networks through the development of a system model of a thermal network has been proposed at the Siberian Federal University [3].

Researchers of the Kazan State Power Engineering University have proposed a modernization of the method for calculating the failure rate of heat pipelines of decentralized heat supply systems [4].

3 Reliability indicators of the thermal network (main calculated dependencies)

The main method used to calculate the reliability of the heat network is described in the Guidelines for the development of heat supply schemes [5]. The aforementioned analysing tool of reliability of the system under study allows you to take into account the features and characteristics of the system itself, its complexity and structure, as well as the interdependence of components.

The failure rate of a heat pipeline λ, considering the time of its operation, is calculated as follows:

$$\lambda = \lambda^{init}(0.1 \cdot \tau^{expl})^{(\alpha-1)}, 1/(km \cdot h). \tag{1}$$

where λ^{init} - the initial failure rate of the heat pipeline corresponding to the period of normal operation, $1/(km \cdot h)$;
τ^{expl}- network segment exploitation period, years;
α - coefficient considering the duration of operation.

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$$\alpha = \begin{pmatrix} 0,8 \; for \; 0 < \tau^{expl} \leq 3 \\ 1 \; for \; 3 < \tau^{expl} \leq 17 \\ 0,5 \cdot e^{\left(\frac{\tau^{expl}}{20}\right)} \; for \; \tau^{expl} > 17 \end{pmatrix} \qquad (2)$$

The calculation of the failure rate of sections of thermal network with a service life of up to 25 years is performed according to the formula.

Sections of the network with a service life of more than 25 years are allocated to a separate group as potentially unreliable.

Based on an additional analysis of their condition, the sites that require priority shift are selected. For further calculations, it is assumed that the failure rate of these sections is equal to the failure rate of new sections, and not shifted sections – the maximum (that is, the same failure rate of sites with a service life of 25 years) [6].

The failure rate of the shut-off regulatory rebar (SRR) is assumed equal:

$$\lambda_{SRR} = 2,28 \cdot 10^{-7}, 1/h, \qquad (3)$$

Parameter of the failure flow of sections of thermal network:
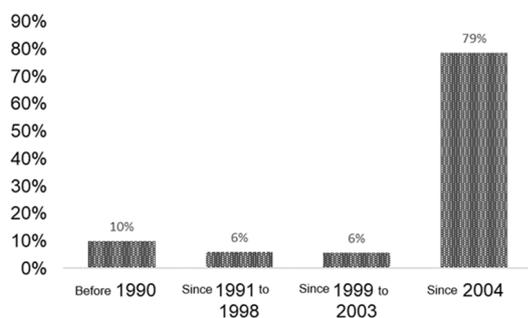
$$\omega = \lambda \cdot L, 1/h, \qquad (4)$$

where L - length of heat network section, km.

4 Reliability of centralized heat supply system in Kazan

The total length of the heating networks of the Kazan district heating system is 929 km in two-pipe calculation, including hot water supply networks (HWS) – 42.8 km.

The heating networks of the zone of the unified heat supply organization are made according to a ring scheme. The hot water supply system is closed. The temperature schedule of the 115/70 ° C. heating networks is made with the straightening of the HWS system at 70 °C.
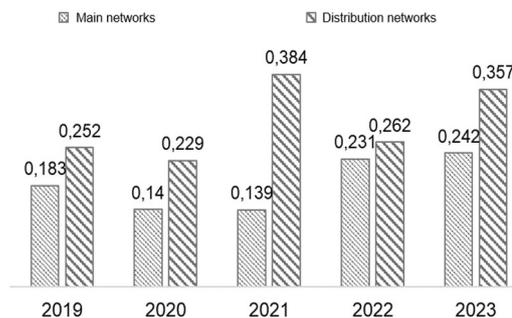
Figure 1 shows the percentage of all heating networks DHS (District heating system) of the city's, depending on the year of laying.

Fig. 1. Distribution by year of laying of heating networks of DHC of Kazan

As shown in the graph, 16% of the city's heating networks have a significant degree of wear and have been in operation for more than 25 years.

The dynamics of changes in failures in the main and distribution heat networks of the city over the past 5 years is shown on Figure 2.

Fig. 2. Specific (related to the length of heating networks) number of failures in the city's heating networks, 1/km/year

Taking into account the current situation in the city's heat supply system and the given retrospective statistics for the purpose of possible methods to improve the reliability of the city's DHC on the example of one of boiler rooms, a study was conducted that includes an analysis of coefficient of hydraulic stability of the system under various changing conditions and an assessment of the reliability of DHC [7].

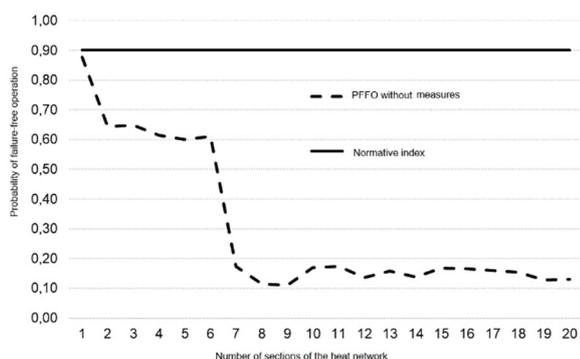**Fig. 3.** The scheme of heating networks from the considered boiler house

The system selected for the study is unbalanced and has a PFFO index of 0.86. Existing condition in the studied system was adopted on the basis of calculations and retrospective analysis given in the heat supply scheme of the city of Kazan.

During the research used a mathematical modeling method which based on the created digital twin (Fig. 3).

In creating a digital twin of the existing city heat supply system, the ZuluThermo software and calculation complex was used, which is part of the Zulu geoinformation system (GIS Zulu) of «Polytherm» LLC, designed to perform thermal and hydraulic calculations of heat supply systems.

In addition, a study of influence of the temperature schedule on operation of the system was conducted, and proposals were made to improve reliability of the heat supply system using a differential pressure regulator (DPR).

The calculation of the reliability of the system is presented on the example of the calculated values of the PFFO of the heat pipelines from the boiler room that are part of the system without any measures (Fig. 4).

Fig. 4. The probability of failure-free operation of relative sections of the heat network without any measures

The nodal principle used allows to obtain detailed indicators distributed throughout the system. This makes it possible to identify «tight» places in the system and optimally determine the necessary conditions to improve its reliability.

To ensure the reliability of the heat supply system, it is necessary to correctly select the parameters of the heat network operation depending on climatic conditions and consumer's needs. This includes optimization of the thermal regime, the use of effective management and control technologies for the system, regular maintenance and diagnostics of equipment.

Proper management and maintenance of the temperature schedule at optimal values will help prevent accidents and ensure smooth operation of the system.

For the system under consideration, it was proposed to switch to an increased operating schedule of the 115/70 °C thermal network. This will reduce the volume of circulating coolant in the heat supply system and ensure the required temperature regime inside heated rooms, depending on their purpose.

In operating thermal networks, one of the problems is to identify the parameters of the disadjustment and timely decision-making on the adjustment of the hydraulic regime. That requires performing flow distribution calculations, and in case of deviation of real costs from the calculated values, carrying out adjustment measures. Essentially, the adjustment measures consist in linking the hydraulic resistances of heat-consuming installations in accordance with the operating mode of the network equipment and the required coolant consumption [8].

In the result of modeling various operating modes of the system and working out measures for hydraulic balancing, it was possible to achieve temperature stabilization inside heated rooms, reduce pressure at the source and reduce coolant consumption in the system, which in turn reduced operating costs for pumping coolant by an average of 18.5%.

An indicator of the stabilization of the hydraulic regime is the coefficient of hydraulic stability of the system, which characterizes the ability of the system to maintain a constant flow of coolant at subscriber inputs when working conditions change.
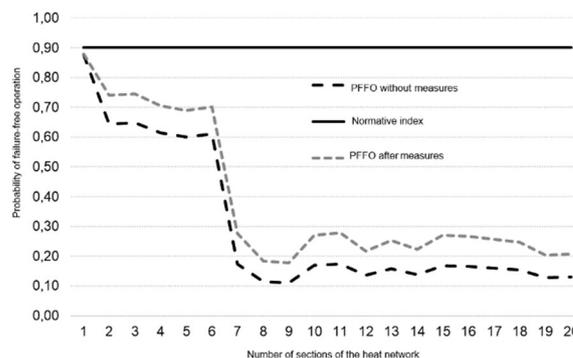
$$K = \frac{G_f}{G_c}, \tag{5}$$

where G_f - actual coolant consumption, t/h, G_c - calculated coolant consumption, t/h.

Violation of hydraulic stability negatively affects the reliability of the heat supply system, which is expressed by an increase in the failure rate [9].

The results of the PFFO calculation, after all the measures, are shown on Figure 5.

The results of the study showed that under the actual operating mode of the heat supply system, without carrying out measures for hydraulic balancing of the system and changing the temperature schedule, the coefficient of hydraulic stability is 0.8.

Fig. 5. The probability of failure-free operation of relative sections of the heat network after the measures in comparison with the actual operating mode

In modeling the operating mode for the increased temperature schedule and adjusting the parameters of the coolant at the consumer inputs, as well as changing the pressure at the heat supply source itself – the boiler room, the coefficient of hydraulic stability of the system was 0.96, which indicates stabilization of the operating mode and balanced flow distribution throughout the system.

The hydraulic balancing of the heat supply system and the change in the temperature schedule of the heat network allow to increase the efficiency PFFO of the system.
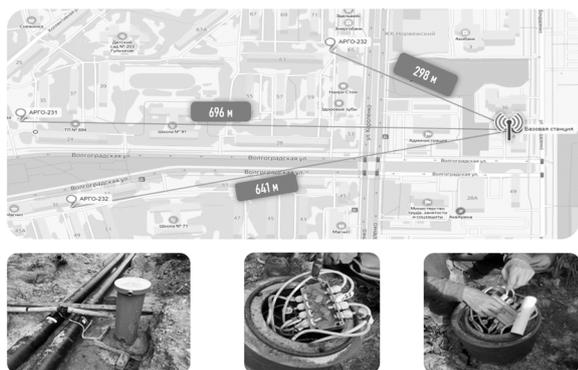
Besides to hydraulic balancing of the heat supply system by adjusting the parameters at the source of thermal energy and at consumers, an important role in terms of improving the reliability and efficiency of the system is played by the actual throughput of pipelines on the branches of the network and control of coolant flow.

For solving this issue, as an additional measure to increase the reliability of the heat supply system, it is proposed to establish dispatching control using a control and decision-making system and install differential pressure regulators with sensors in thermal chambers on the branches using the LoRaWAN wireless data transmission network.

Differential pressure regulators control and maintain the optimal pressure level and, accordingly, the flow rate of the coolant in the network, which prevents overheating and underheating of the system. Through to the use of pressure regulators, it is possible to reduce the probability of accidents and increase the efficiency of the heating network.

As the part of the implementation of the regional project "System for monitoring the condition SODC of the heating supply system based on through and through wireless communication technology" starting since 2021 TatAISEnergo LLC began building a LoRaWAN wireless data transmission network in three major cities of the Republic of Tatarstan: Kazan, Naberezhnye Chelny, Nizhnekamsk.

Over the past few years, TatAISEnergo LLC has carried out dispatching of a number of thermal chambers in the Kazan thermal networks and organized data transmission on temperature and pressure of the coolant in the pipeline based on LoRaWAN technology (Fig. 6).

Fig. 6. Operation of the base station LoRaWAN in Kazan

The control and decision-making system for the hydraulic balancing of the heat supply system, based on pressure control at the nodal points of the heat network, is a continuously functioning software package in conjunction with a dispatching control system [10].

The system allows you to monitor pressure surges online, determine the location of an emergency and eliminate problems on time, thereby increasing the reliability of heat supply.

The operation of the proposed pressure monitoring system in the system is carried out as follows. Pressure sensors, on command from the controller, measure the parameters, then transmit them back. LoRa transmitter transmits parameter values through LoRaWAN wireless channels received from sensors directly to the server via the LoRa receiver.

The management and decision-making system is a database for storing and processing the received data in real time. The operator of the control system (dispatcher) has instructions for making decisions depending on the situation, which already takes into account knowledge about all possible modes of operation of the thermal network at the moment and previous experience of personnel actions in similar situations.

In large cities of the Republic of Tatarstan, these systems are actively being implemented and have successfully undergone approbation. The actual experience of operating these systems in the Republic of Tatarstan shows that the response time to emerging emergencies is reduced from 30 to 60%, the "zone" of accident search and detection is narrowed, the period of disconnection of consumers and restoration of the operating mode of the heat supply systems is reduced by at least two times.

5 Conclusion

Based on the research results, it is possible to develop a strategy to improve the reliability of the heat supply system in conditions of changing temperature and hydraulic conditions. This may include upgrading equipment, improving the insulation of heating networks, developing backup action plans in case of extreme weather conditions, and other measures.

In general, the study of the influence of the temperature schedule on the heat supply system is an important step in ensuring the reliability and efficiency of engineering systems. It is only by analyzing and optimizing temperature control that it is possible to ensure a stable and uninterrupted supply of heat to consumers throughout the heating season.

Based on the existing experience of implementing a management and decision-making system, it is say for sure that the reliability indicator of the heat supply system, when implementing the DPR, tends to normative values.

The average time to eliminate an emergency situation and the time to turn off consumers is reduced by at least 1.5 times, thereby increasing the reliability of the heat supply system.

The main decrease in PFFO to a value below the standard is due to the significant service life of some of the longest sections of the thermal network.

With the introduction of a management and decision-making system, the probability of failure-free operation will increase significantly with increasing observation time.

Concerning hydraulic balancing and stabilization of the operating mode of the system as a whole, it should be noted that with an integrated approach of regime regulation of consumers themselves, together with the operation of differential pressure regulators with an installed control and monitoring system, the reliability of the heat supply system will be more than twice.

Subsequently, it is planned to study the effect of the operation of leak sensors and temperature control sensors on the efficiency of emergency detection and assess the relative reduction in the time to eliminate accidents.

References

1. SP 124.13330.2012. A set of rules. Heating networks. Updated version of SNiP 41-02-2003" (approved by the Order of the Ministry of Regional Development of Russia dated 30.06.2012 N 280)

2. 2. A.V. Savchenko, E. V. Kravchenko. *Assessment of the reliability of the thermal network*, in Proceedings of the IV All-Russian Scientific and Practical Conference «Thermophysical foundations of Energy Technologies», 2013, Tomsk, Russia, pp.179-182

3. M. V. Kolosov, Y. L. Lipovka, *Determination of the optimal pipeline replacement period*, Reliability and safety of energy, **14 №4** (2021), pp. 174-179

4. Yu.N. Zvonareva, Yu.V. Vankov, *Survivability indicators of interconnected engineering systems*,

in Proceedings of the IV International Scientific and Technical Conference "Energy-2019", **1** (2019), p.74

5. On approval of Methodological guidelines for the development of heat supply schemes, Order №212 of the Ministry of Energy of the Russian Federation dated March 5, 2019, URL https://docs.cntd.ru/document/553937025

6. D.V. Korpusov, A. A. Balashov, A. P. Korolev, *Improving the reliability of heat supply during the operation of a thermal network*, Bulletin of Tambov State Technical University, **29 №4** (2023) pp.594-604. doi:10.17277/vestnik.2023.04

7. Yu.N. Zvonareva, O.I. Zverev, *Improvement of heat supply systems through the introduction of AITP*, Bulletin of the Kazan State Energy University, **11 №1**(2019), pp. 10-18

8. V.P. Chernenkov, D.V. Popov, *Management of the hydraulic regime of thermal networks*, in Proceedings of the Far Eastern State Technical University, **134** (2003), pp.126-128

9. Yu.N. Zvonareva, K.S. Kuzborskaya, *Changing the parameters of heat supply systems during the phased implementation of AITP*, Bulletin of the Kazan State Energy University, **13 №2** (2021), pp.109-118

10. I.V. Prangishvili, System approach and management efficiency improvement, Nauka, 2005, p.422.