Application experience of the theory hydraulic circuits methods and modern technologies for organizing operating conditions of Mongolian district heating systems

Nikolay Novitsky[1], *Zoya* Shalaginova[1,*], *Vyacheslav* Tokarev[1], *Aleksandr* Alekseev[1], and *Tsevegjav* Unurmaa[2]

[1]Melentiev Energy Systems Institute of Siberian Branch of the Russian Academy of Sciences (ESI SB RAS), 130 Lermontov Str., Irkutsk 664033, Russia
[2]National Dispatching center of the Power System of Mongolia, Parliament Building – 14 Khan-Uul district Micro Chinggis avenue. Ulaanbaatar 14191, Mongolia

Abstract. An analysis of the district heating systems (DHS) current state in Mongolia and the problems of their functioning is given. The experience of applying the theory hydraulic circuits methods and the information-computer complex «ANGARA- HN» developed at the ISEM SB RAS for modeling and organizing the operating conditions of the Mongolia DHS is given. Ways have been outlined to improve the reliability, efficiency and quality of DHS work. The tendencies, directions and possibilities of overcoming the existing problems in operating conditions control are outlined. including, - the development of scientific, methodological and software for solving new problems of operational control (monitoring the state, calibrating models, active identification and optimization of modes) based on the creation of a common digital space.

Key words: hydraulic circuit's theory, district heating systems, computer modeling, functioning problems, information technology.

1. Introduction

The theory of hydraulic circuits (THC) is an intersectoral scientific direction formulated and developed at the ESI SB RAS [1]. The subject of the THC is the general issues of mathematical and algorithmic support for the problems of functioning and optimal design of pipeline and other hydraulic systems, characterized by arbitrary schemes with the flow of liquid and gas. ESI SB RAS, on the basis of the THC, has accumulated unique experience in creating methodological and software for solving problems of calculating and optimizing heat supply systems [1-3]. In particular, information-computing complex (ICC) «ANGARA-HN» was developed for the analysis and working out of operating modes of heating networks [4], which has a developed user interface that simplifies the process of

[*] Corresponding author: shalaginova@isem.irk.ru

entering, checking information and performing calculations to the maximum. The latest version of ICC «ANGARA-HN» has a multilingual interface that can be adapted to any language. To date, Russian, English and Chinese interface languages have been implemented.

2. The current state and problems of control the functioning in Mongolia DHS

Mongolia is in harsh climatic conditions, which generates a high demand for heat supply services. The main direction of Mongolian energy development is thermal power engineering: 95.7% of electricity is generated at combined heat and power plants, which are concentrated in three large cities (Ulaanbaatar, Erdenet, Darkhan). The largest DHSs is located in the country's capital, Ulaanbaatar. Heat energy in the city is produced at four sources of combined generation: CHP-2, CHP-3, CHP-4 and the Thermal Station "Amgalan" [5].

Historically, Mongolia has used common approaches and technologies of DHS with Russia. This also determines similar problems of control their functioning [6,7].

Modern district heating systems have a complex heterogeneous structure, organized according to a hierarchical principle to ensure multi-stage regulation: at sources, at intermediate stages - central or individual heating points, include sources of various types (CHP, boiler houses) operating on common extended and looped heating networks, pumping stations , other nodes of regulation. DHS have a large dimension, are spaced apart in space and are characterized by the variability of the structure, load level, parameters and operating conditions. The general aging of equipment leads to the impossibility of maintaining the specified temperature schedules, at the same time, the transition to a reduced schedule cannot be carried out with insufficient bandwidth of networks originally designed for an increased schedule.

DHS are not sufficiently equipped with control and measuring and regulating devices and, as a result, they have poor controllability and low reliability. At the same time, the bulk of measuring instruments is concentrated on heat sources, pumping and other control structures, and to a lesser extent on pipelines and at consumers. Recently, the situation has been gradually changing - work is being intensified on the introduction of technical means for measuring, regulating and accounting for heat supply from consumers. Nevertheless, the saturation of systems with automatic control means leads to the variability of hydraulic operating conditions and complicates the processes of controlling their modes to an even greater extent.

Due to the increase in population in recent years, Ulaanbaatar's DHS is experiencing a shortage of thermal energy, which requires an increase in capacity, implementation of energy saving measures and improvement of the energy efficiency of the existing DHS. In particular, it is necessary to adjust heat consumption systems, automate individual heat points, install metering units [8, 9]. The issues of including heat accumulators and heat pumps in the general scheme of district heating (both at heat sources - in the circulation water supply scheme of DHS), and for new consumers after central heating points are actively considered. Due to the shortage of capacity, a project has been developed to modernize the heat supply system in Ulaanbaatar, within the framework of which it is planned to carry out a number of activities in the main areas of development of the heat supply system. To increase the throughput capacity in order to connect new consumers, it is planned to reconstruct the main pipelines of the heating network and expand the scale of the heating network. To improve the efficiency of the system, it is planned to create a single integrated GPRS system to control the consumption of thermal energy / coolant, pressure and temperature of network water; accounting for the consumption of heat and power resources, reducing all types of losses; damage detection. To control the operation of heat networks in a remote mode using SCADA, it is planned to create control points for monitoring heat networks and create a unified system for dispatching heat networks [5, 8].

The implementation of these solutions to improve the reliability, efficiency, and quality of the DHS requires technical re-equipment and will significantly complicate the operating conditions of the system as a whole. To overcome these problems and modernize the DHS, it is necessary to involve methods of mathematical modeling and the introduction of modern information and computing technologies for the analysis and development of appropriate measures.

3. Brief description of the ICC «ANGARA-HN» for DHS simulation

The fourth-generation «ANGARA- HN» information-computer complex developed at the ESI SB RAS is designed to solve traditional and new problems in the field of analysis and control of operating conditions of large DHS. One of the main ways to analyze and development of operating conditions is to perform thermal-hydraulic calculations, the needs for which arise at the stages: development of HSS, design, reconstruction, operation and dispatch control. The calculation of thermal-hydraulic conditions is a necessary element for assessing the feasibility of decisions made at all stages of control.

ICC «ANGARA-HN» includes an information-computing environment (ICE) for creating electronic models of DHS and a software-computer complex for solving applied problems.

ICE has a set of graphical, informational and analytical functions necessary for creating, editing and analyzing DHS schemes on an urban development plan [10], and provides the ability to create graphical, hierarchically linked databases on heat supply systems. Analytical functions of the ICE allow users to search for plan and network elements on the map of the settlement by any DHS parameter, highlight the elements of the scheme with color and size, convert graphic data, generate reports, samples, and much more.

The software-computer complex provides the solution of the following tasks: single- and multi-level adjustment and verification calculations of hydraulic and thermal modes; search for sectioning places; calculation and construction of piezometric and temperature graphs; determination of violations on the permissible values of the condition parameters; calculation of the parameters of throttling devices on subscriber systems of consumers and in the heating network; calculation of hydraulic and thermophysical parameters of pipelines [4].

4. Experience of using ICC «ANGARA-HN» for the Mongolia DHS

ESI SB RAS have a long history of fruitful cooperation with scientific and energy enterprises of Mongolia in the field of formation and modernization of DHS. The experience of interaction lies in line with the current global trends in the modernization of DHS based on their digitalization and intellectualization [11-13].

The scope of joint activities includes the following main areas:

- development and approbation of computer technologies for the efficiency analysis of heat supply systems functioning;
- development and application of methods and information-computer complexes for solving the problems of organization thermal power systems of operating conditions.
- development of concepts for control the DHS operating conditions, taking into account new requirements, equipment and technologies.

In the process of cooperation at the Mongolia enterprises, the ICC «ANGARA- HN» was introduced, which was used to analyze and development of operating conditions the Ulaanbaatar and Darkhan heating networks (Fig. 1).

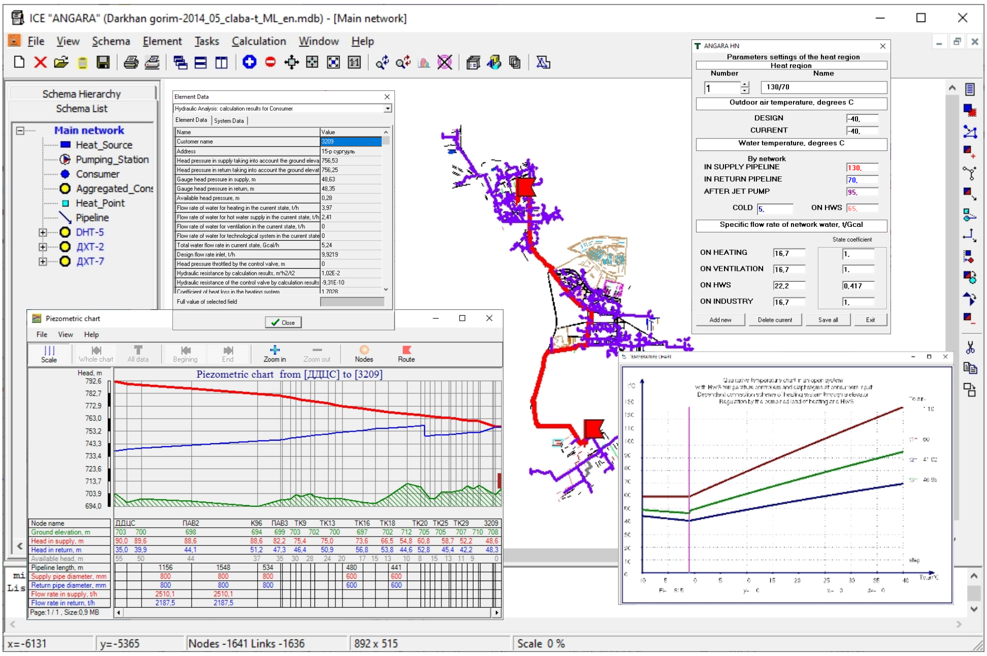

Fig. 1. Interface of the ICC «ANGARA-HN».

Interaction was organized with the Mongolian University of Science and Technology on the basis of the Thermal Power Engineering Department in the field of application of ESI SB RAS software developments in Mongolia. Cooperation is underway with the National Dispatch Center for Energy Systems of Mongolia in the development and application of computer technologies to analyze functioning efficiency DHS and solve the problems of organizing the thermal power systems operating modes.

The calculation of DHS modes requires the creation of heat network computer model, which includes: initial data on the scheme of the heat network on the local plan and the elements parameters (heat sources, pipeline sections, pumping stations, consumers). For this purpose, graphical databases were created for the DHS in Ulaanbaatar and Darkhan (Fig. 1), calculations and analysis of existing thermal and hydraulic conditions were carried out, weaknesses of these systems were identified, and measures were developed to improve heat supply. The organization of conditions and adjustment measures carried out with the help of the ICC made it possible to improve the quality of heat supply to cities, significantly reduce circulating water flow, make-up water and drains by the population, reduce heat losses, and reduce the cost of electricity for coolant pumping.

5. Trends, directions and opportunities to overcome problems of the DHS functioning

Over the past decade, the processes of technological transformation and modernization of the DHS have been activated through the introduction of new equipment and materials, control, monitoring and measurement tools, computer technology, mathematical modeling methods, computer systems for collecting and processing measurements and decision-making on control. The main goal of these transformations is the intellectualization of district heating systems, which consists in developing a fundamentally new platform for coordinating the interests, requirements and capabilities of all parties involved in the processes of producing, transporting, distributing and consuming heat. At the same time, the consumer is assigned the role of an active, equal participant influencing consumption volumes, quality and prices [2, 14, 15].

The main features of the DHS intellectual: the presence of a common information space; high level of observability and controllability; dynamic pricing; high proportion of digital, information, telecommunication technologies, methods of mathematical modeling and optimization. The transition to the intellectual DHS platform will require the solution of a large complex of scientific, legal, technical, technological, economic, informational and other issues. Among other things, it is necessary to revise the existing practice of design, operation and dispatching control of intellectual DHS.

6. Scientific and methodological directions of information technologies development

6.1. Technology for creating a common enterprise digital space (CEDS). In practice, information about the system, as a rule, is incomplete, fragmented and often contradictory, and information support is of a focal nature, which hinders the application of smart control concepts. To solve this problem, ESI SB RAS has developed a concept for creating a CEDS based on the ICE «ANGARA», which makes it possible to combine all available information resources (cartography, electronic models, SCADA systems, billing, dispatch logs, etc.) into a common information system and provide access to all interested specialists and services, both inside and outside the enterprise (city services, related enterprises, consumers) [16].

6.2. Technologies of remote access to CEDS. Due to the significant spatial distribution of pipeline system facilities, their maintenance requires remote access to the CEDS. For these purposes, a mobile version of the ICE has been developed - the mobile information complex «MIC ANGARA», which works on mobile devices in the Windows system ("smartphone" or "tablet"). The program provides users with a basic set of functions: searching, editing, displaying the pipeline system against the background of satellite maps of the area, logging operations, automatic data synchronization with the CEDS and others.

6.3. Scientific and methodological directions of development of modeling methods. One of the most important areas of DHSs intellectualization is the widespread use of modeling methods in real processes of analysis and decision-making in operational control. For the tasks of operational dispatch control on the basis of ICE «ANGARA», the «Heat Network Dispatcher» ICC – «ANGARA-DHN» was developed. In this case, the heat network scheme is displayed in a two-pipe design and includes all control elements of the system. Calculation functions of the ICC: search for disconnected fragments and switching; operational hydraulic calculations; conditions admissibility assessment. The ICC includes electronic logs of defects and switching, reference books on contractual and current loads of consumers.

The primary task of DHSs intellectualization is the organization of monitoring of their actual conditions and state. Currently, methods for solving and implementing them in real time based on the processing of measurement data are being developed [17]. There is experience in updating design schemes and calibrating models based on measurement results.

An original technique of active identification has been developed for testing DHSs on hydraulic and thermal losses [18]. The technique ensures the extraction of maximum information with a minimum number of tests and the possibility of conducting them for DHSs of arbitrary structure and configuration without disconnecting consumers. The implementation of methods for tracking actual conditions in practice will create the necessary conditions for setting and solving problems of intelligent control of modes. ESI SB RAS has groundwork in this area, including methods for hierarchical optimization of conditions of a heat network of arbitrary structure and dimension [19].

The research was carried out under State Assignment Project (no. FWEU-2021-0002) of the Fundamental Research Program of Russian Federation 2021-2030

References

1. A.P. Merenkov, V.Y. Hasilev, *Theory of hydraulic circuits*, (Moscow: Nauka, 1985), [in Russian].
2. A.P. Merenkov, E.V. Sennova, et al., *Mathematical modeling and optimization of heat,-water,-oil and gas supply systems*, (Novosibirsk: Nauka, 1992) [in Russian].
3. A.A. Atavin, N.N. Novitsky, M.G. Suharev, et al., *Pipeline systems in energy sector*, (Novosibirsk: Nauka, 2017), [in Russian].
4. N.N. Novitsky, V.V. Tokarev, Z.I. Shalaginova, et al., Proceedings of IrSTU, **11**, 126 (2018), [in Russian].
5. E.G. Gasho, H. Enkhzhargal et al., News of heat supply, **4,** 18**, (**2021), [in Russian].
6. Z.I. Shalaginova, V.V. Tokarev, Thermal engineering. 66, 10, 714, (2019)
7. N. Novitsky, Z. Shalaginova, V. Tokarev, et al., Energy Systems Research, 5, 3(19), 27, (2022).
8. E.G. Gasho, News of heat supply, **10**, 18, (2003), [in Russian].
9. B. Namkhayyam, *Heat supply system* (Ulaanbaatar: MGNiT, EI, 2015).
10. A.V. Alekseev, N.N.Novitsky, Scientific Bulletin of NSTU, **3,** 26 (2017), [in Russian].
11. N.N. Novitsky, V.V. Tokarev, et al., Proceedings of the International scientific conference «Energy and market economy», 323, (Mongolia, Ulaanbaatar, 2005).
12. N.N. Novitsky, V.V. Tokarev, Z.I. Shalaginova Proceedings of the International Scientific Conference on Energy Industry Development and Ecology, 145, (Mongolia, Ulaanbaatar, 2010).
13. V.V. Tokarev, N.N. Novitsky, and Z.I. Shalaginova, Proceedings of the International Scientific Conference: Improving the planning of modes of district heating systems, 53, (Mongolia, Ulaanbaatar, 2014).
14. N.N. Novitsky et al., *Energy of Russia in the XXI century*, 378 (Irkutsk: ESI, 2015), [in Russian].
15. N.N. Novitsky, Z.I. Shalaginova, A.A. Alekseev, et al., Proceedings of the IEEE, DOI: 10.1109/JPROC.2020.2990490, (2020).
16. A. Alekseev and N. Novitsky, IOP Conference Series: Materials Science and Engineering, **667**, ID 012003 (2019).
17. N.N. Novitsky, V.V. Tokarev, Thermophysics and Aeromechanics, **14, 2,** 289 (2007).
18. O.A. Grebneva, N.N. Novitsky, Thermal Engineering, **61, 10**, 754 (2014).
19. N.N. Novitsky, A.V. Lucenko, J. Global Optimization, **66, 1**, 83, (2016).