Problems of organization of operating conditions of large heat supply systems and their solutions based on multilevel modeling[†]

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Abstract. The paper unveils relevance of applying the methodology of multi-level modeling of thermal-hydraulic conditions of heat supply systems (HSS) and the software which are realized in the information-computing system "ANGARA-TS", which make possible development of operating conditions and adjustment measures in HSS of any structure and complexity including non-standard circuit designs. Application of the multi-level modeling of HSS that is based on integration of mathematical models, methods and information technologies allows one to link the main principle of mathematical modeling that contributes to rational correspondence of the degree of mathematical model detail with the goals of its use, and modeling for different purposes. Information-computing system is implemented in a variety of real HSS of large cities in the organization of regimes and development of adjustment activities. The paper describes the experience of using new methods for development of operating conditions of large HSS in real towns.

1. Introduction

The present day HSS of cities are complex spatial high-dimensional objects which are developing in time and combine a set of heterogeneous elements. Frequently several heat sources supply heat to looped heat networks with the installed pumping stations, central heat points, pressure controllers and other control devices. All these factors complicate problems of operation, and control of HSS, planning and development their conditions.

Over the past decade the volumes and structure of heat consumption as well as the structure of systems themselves have changed considerably. The emerging new trends of semi-voluntary (without adequate validation) connection of new townhouse villages with low heat loads and direct connection of heating systems substantially complicate development of thermal-hydraulic conditions of HSS. This is explained by the fact that the excess heads at the points of connection to these houses cannot be reduced technically even with the minimum diameters of feed pipelines and installation of throttlers at the points of connection with minimum diameters. As a consequence, the higher (in comparison with the

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required) heat carrier flows circulate through such consumers, which results in overheating of the considered houses, increase of water temperature in the return main pipeline, high heat losses (due to discharge of the unspent heat carrierз into the return main pipeline) and in essential increase of circulating flow rates in the whole system. Consumers connected close to the heat source influence operating conditions most significantly.

General ageing of equipment installed in HSS makes it impossible to maintain the target temperature charts. At the same time transition to a low temperature chart is impossible because of insufficient throughput of heat networks which were originally designed for a higher temperature chart. Increase of head losses in local heat consumption systems that is caused by their clogging because of absence of planned cleaning and overhauls of the internal distribution pipelines leads to the fact that the hydraulic jet pumps installed at the connection points cannot ensure a required mixing rate even with sufficient available heads.

In view of the permanently rising prices of thermal energy, consumers actively install heat meters and autonomous control devices. As a result, the thermal-hydraulic conditions of the system change and the processes of system operation and control of conditions become more complicated. The traditional techniques, however, are not adapted to development of operating conditions and adjustment measures in such HSS, where some consumers have manual connection nodes, other consumers are equipped with autonomous control devices. The techniques for fully automated systems are unavailable as well.

Changes in administrative and economic management brought about direct interests of operating enterprises in economical consumption of heat carriers and heat, and its maximum efficient use. This requires the adjustment measures to be carried out before each heating season, as well as development of operating conditions of HSS to guarantee their reliability and quality. Conventionally, specialized organizations were engaged in development of the adjustment measures, tests of networks and calculations of different conditions. However, recently despite the reference documents, which include the need for annual adjustment of networks, such works have been performed irregularly. Often the issue about their execution and financing arises after emergencies and considerable material and losses.

2. Purposes and tasks of work

The currently formed operation environment of HSS motivates topicality of applying the methodology of multi-level modeling developed at MESI SB RAS, special methods and techniques to calculate normal operating conditions in terms of the above factors [1-7].

The purpose of the work was: approbation of a multilevel approach to modeling the conditions of large heat supply systems hierarchical structures on real HSS, the definition of bottlenecks and the specifics of the organization of their conditions. The novelty of the work is to generalize the problems of the organization of HSS conditions and to modify the methods and algorithms of calculation in order to automate their solution. To overcome the difficulties of regimes organization, it was necessary to develop both a methodological base and software tools for adjustment of thermal-hydraulic conditions and calculation of throttling devices.

3. Means and approaches to the development of HSS conditions

The Laboratory of Pipeline and Hydraulic Systems at MESI SB RAS has been engaged for some years in theoretical and applied studies in the area of modeling, analysis and optimization of HSS [8-19]. The information-computing system (ICS) “ANGARA-TS” [20-21] is a latest design that is an integration of information-computing environment [4, 7] and program-computing systems [1, 5] to develop operating conditions of heat networks (normal, repair, post-emergency). The multi-level modeling of HSS, which is the basis of the

ICS, enables to overcome the problems of: fragmented initial information, provision with methods, models, and algorithms to solve different tasks arising at the stage of planning and development of conditions and adjustment measures; high dimensionality of current HSS; efforts to validate quantitatively and coordinate solutions on HSS control. Moreover, it enables to link the basic principle of mathematical modeling, which ensures rational correspondence of the degree of the mathematical model detail with the goals of its application, and perform modeling for different purposes. This new information-computational technology satisfies main requirements for creation of the automated control systems of district heating objects “Heat networks” [22]. The technology is a qualitatively new generation of software [17], which integrates information functions and a practically full set of computational modules, needed for solving the problems of adjustment and operation of HSS, planning, development and analysis of operation conditions of heat networks. The list of problems solved using the ICS is presented in [17].

4. Specific features of problems on development of HSS conditions

Consider the issues of development of operation conditions of HSS by the example of real towns which were resolved by the efforts of MESI SB RAS using the ICS “ANGARA-TS”. HSS of modern cities are characterized by highly heterogeneous connection schemes of consumers to heat networks: automated and manual connection nodes; dependent (direct, through hydraulic jet pumps, with a mixing pump) and independent connection of heating systems; open and closed water extraction for hot water supply; different connection schemes of heaters for hot water supply (single-stage – parallel or series; double-stage – series or mixed); water extractions for hot water supply from heating networks; availability (absence) of heat metering units; great scatter of load values and geodesic marks of consumers; multi-stage control, etc. Hence, development of conditions was connected with the following main difficulties.

1. Connection of consumers to heat networks through the hydraulic jet pumps of heating systems requires high available heads at the connection nodes. At the same time direct connection of private houses with a low heat load to these heat networks makes it impossible to decrease high excess heads at their connection nodes that are conditioned by the hydraulic jet pumps. Therefore, the multi-stage decrease of heads in the network and at consumers called for development of nonstandard solutions (Fig.1).

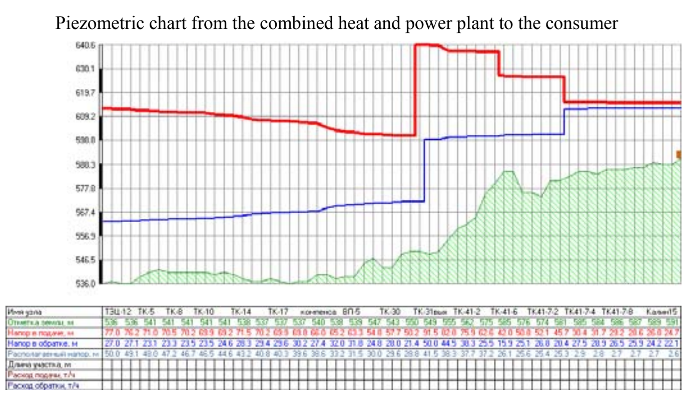

Fig.1. Multistage throttling of heads in the heat network.

2. Low velocities of a heat carrier in distribution networks which connect houses with a low heat load led to large heat carrier cooling down and impossibility of serving the required heat load to consumers with the existing hydraulic condition. In the general case the heat losses in heat networks can be compensated by: increasing the flow rates with temperature preservation and making the corrections in the temperature chart. Transition to a higher temperature chart should be justified economically and is not always possible because of equipment state. Therefore, if the throughput of heat networks is capable of cover-

ing heat losses by increasing the flow rate, the heat carrier temperature was no corrected. Otherwise, the temperature chart was corrected [18].

3. In some towns insufficient throughput of heat networks to supply heat to consumers based on the temperature chart 95/70°C necessitated transition to the higher temperature chart 150/70°C that was initially accepted as a design chart for heat networks. On the other hand, the wear of heat source equipment did not allow the support of this curve. In addition, transition to a higher temperature curve required the mixing points to decrease the temperature of water coming to local heating systems which were dismantled because of their work based on the lower curve for years. The formed situation demanded justification and development of temperature curves. The formed situation demanded justification and development of the temperature curve with cutting during the period of low temperatures (Fig.2).

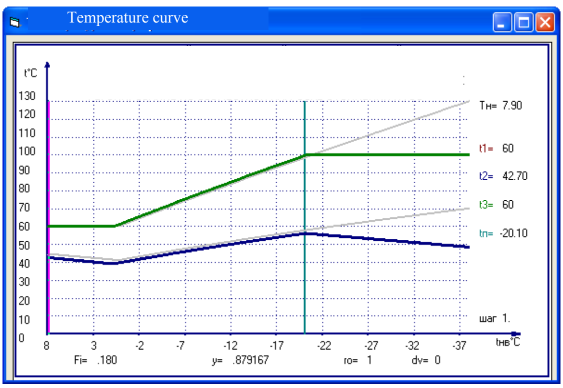

Fig.2. Temperature curve of heat supply from CP-12 in the Cheremkhovo town.

4. Availability of group mixing nodes did not always provide a required mixing ratio because of high head losses in distribution networks.

5. Availability of water withdrawal for hot water supply from heating networks (in the closed HSS with four laid pipes) at some consumers necessitated refinement of the technique for adjustment calculation of thermal-hydraulic condition subject to unauthorized water withdrawals.

6. Rugged topography, which narrows an admissible region of decisions made, demanded multivariant calculations of thermal-hydraulic conditions using multistage throttling on the network and at consumers (see Fig.1).

7. Absence of funds for proper reconstruction of heat networks and upgrading of central heat points.

5. Development of methodological base for solving the problem of operating conditions calculation for HSS

The indicated difficulties in development of conditions could be overcome by evolution of both the methodology and software for adjustment calculations of thermal-hydraulic conditions and calculation of throttlers. Within the framework of the ICS “ANGARA-TS” the following techniques were developed and applied.

1. The technique of the single-and multi-level adjustment calculation of thermal-hydraulic condition of HSS subject to heterogeneity of connection schemes of consumers to heat networks [23–25]. It makes it possible to supply a required amount of heat to consumers, provided the constraints on heat carrier parameters at all system nodes are observed (Fig. 3). The technique is based on the calculation of corrections to heat carrier flow rates that are differentiated for each consumer and required to compensate for heat losses in heat networks. Besides, it is used to determine parameters of the throttlers simultaneously for all consumers and in the heat network. The technique enables to automatically obtain the coordinated operation conditions of heat networks of different levels with multi-stage heat supply, to significantly improve development of conditions and to reduce the time of heat network adjustment by far.

2. The technique for determination of master consumers to calculate heat carrier parameters at the control nodes: make-up water pressure, available heads of heat sources, cen-

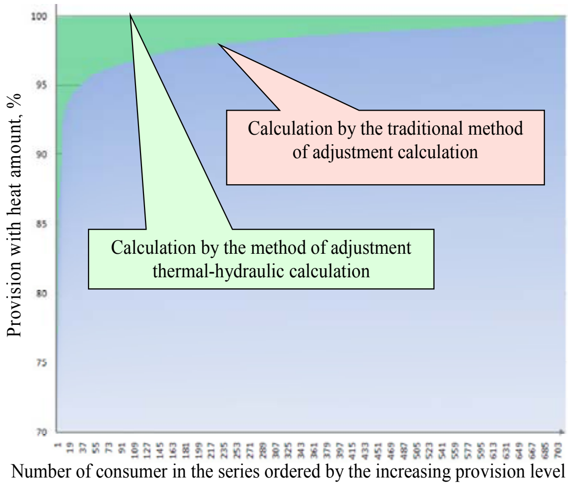

Fig. 3. Graph of consumer provision with heat load.

tral heat points and pumping stations. The technique is based on the analysis of condition feasibility [26-27] and allows the automated determination of the minimum necessary values of parameters of control elements.

3. The technique of adjustment calculation of thermal-hydraulic conditions of hot water supply networks which allows one to determine individual corrections of circulating flow rates of consumers to support the required temperatures at the takeoff nodes. The technique assures required temperatures and water use for hot water supply in accordance with the Construction Rules and Regulations and contractual loads, valid circulating flow rates and substantially decreases water discharges by population [25].

4. The method of multi-stage throttling in heat networks and at consumers, which is topical for highly rugged relief (Fig.1).

5. The technique of searching for a rational flow distribution by sectioning of heat networks with a multi-loop structure. The technique is based on the goal-oriented enumeration of the variants of cleavage close to the nodes of flow junction with further correction of the solution. The solution is corrected in two stages based on the criterion of the total excess hydraulic power [28].

6. The effectiveness of the proposed approaches to the operating conditions calculation

The methods and algorithms applied in the ICS were extensively tested in calculations of HSS in the following towns and cities: Irkutsk, Angarsk, Bratsk, Shelekhov, Ust-Kut, Cheremkhovo, Kiev, Moscow, St. Petersburg, Ulan-Bator, Tyumen, Tambov, Petropavlovsk-Kamchatsky, etc. This became possible owing to the long-standing close cooperation with some design and operation institutions, research institutes and universities.

Development of conditions and adjustment measures on the basis of the suggested technology of calculations improved quality of heat supply to towns and simultaneously to identify and realize the great potential of energy saving due to reduction of: circulating flow rates; make-up water flow rate and water discharges by population; heat losses; electricity consumption for heat carrier pumping and chemical water treatment; switched some distribution networks to operation by a lower temperature curve, which became possible owing to substantial decrease of circulating flow rates after elaboration of adjustment measures.

The annual economic effect of the development of conditions and adjustment measures in the cities of the Irkutsk region amounted to, million rubles: Irkutsk - 274; Angarsk -125; Bratsk -43; Cheremkhovo - 9.

7. Conclusion

1. The work identifies and summarizes the problems of the development of operating conditions HSS.

2. A set of methods and the technology of calculations applied in the ICS are suggested. They make it possible to elaborate adjustment measures in HSS of any structure and complexity, including those with nonstandard schemes. This made it possible to significantly reduce setup time and achieve significant improvements in the development of operating conditions with limited funds for network re-routing and system upgrading.

3. Application of the multi-level modeling allowed the calculations of conditions of large HSS with intermediate control steps.

4. The developed techniques of adjustment calculation substantially decreased an adjustment period and significantly improved arrangement of conditions subject to limited funds for removal of existing networks and modernization of systems.

5. The suggested methodology was applied to development of conditions and adjustment measures in the heat supply systems of real cities. Implementation of the planned measures improved quality of heat supply to consumers without capital investment in networks reconstruction and essentially decreased circulating flow rates.

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