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Research Article

The Variable Resistance on the Calculation of the Hydraulic Regime of a District Heating System

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Abstract

District heating systems (DHS) comprise complex hydraulic networks that include multiple consumers, distribution pipe networks, and power sources. By analyzing key parameters such as pressure, flow rate, and resistance within a hydraulic system, it is possible to predict system performance and optimize adjustments. Calculating the hydraulic regime of a heat supply system means solving a system of large-scale quadratic equations. Unlike electrical systems, typically modeled by linear equations, hydraulic systems require nonlinear equations, making analysis more challenging and often necessitating iterative methods. In defining the scope of our study, we focused on stabilizing the network's hydraulic regime by adjusting the supply water temperature at the source. We observed that changes in a user's automatic valve resistance altered the total resistance, causing the entire system to operate in a variable mode. Conversely, we analyzed how variations in source pressure influenced user resistance. Our study aimed to characterize constant and variable resistances in hydraulic systems and to determine the system's equivalent total resistance. Kirchhoff's laws are applied to determine resistance, head loss, and flow distribution. Yet, many nonlinear equations call for transforming the problem into a linear system under hydraulic stability assumptions. This paper proposes a methodology to simplify computations by distinguishing between variable and constant hydraulic resistances, representing them as equivalent resistances for enhanced modeling accuracy. When performing hydraulic calculations of heat supply systems, we mainly relied on software from countries such as Russia and Denmark. As a result, engineers often neglected the theoretical development of hydraulic calculation methods. To address this issue, we began investigating these methods and developed a hydraulic calculation model, which we aim to improve through ongoing research. Based on this foundation, we present this study.

Keywords

Hydraulic Resistance, Hydraulic Regime, District Heating, Pressure Drop

1. Introduction

The hydraulic regime of a heat supply system refers to the interrelationships of parameters that define the system based on the results of hydraulic calculations. Calculating the hydraulic regime of a heat supply system means solving a system of large-scale quadratic equations [1-8].

In defining the scope of our study, we focused on

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stabilizing the network's hydraulic regime by adjusting the supply water temperature at the source. We observed that changes in a user's automatic valve resistance altered the total resistance, causing the entire system to operate in a variable mode. Conversely, we analyzed how variations in source pressure influenced user resistance. Our study aimed to characterize constant and variable resistances in hydraulic systems and to determine the system's equivalent total resistance. We have primarily relied on software from countries like Russia and Denmark to perform hydraulic calculations for heat supply systems [9-15]. As a result, engineers have often neglected the theoretical development of hydraulic regime calculation methods. To address this, we began researching these methods and developed the Hydro-C 1.0 hydraulic calculation model, which has been registered with the Intellectual Property Office of Mongolia (Order No A/14, 2019). Based on this foundation, we present this study to advance the next-generation Hydro-C 2.0 model. Figure 1 shows the software's functionality and copyright certificate.

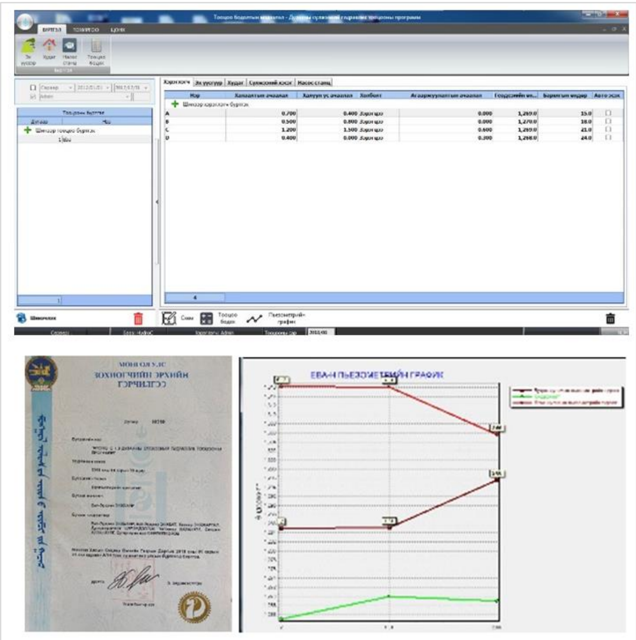

Figure 1. *Copyright of the Hydro-C 1.0 hydraulic calculation program.*

2. Theoretical Part

Hydraulic calculations for DHS are generally based on constant data. The primary methodology involves first defining the main line of the network and then assuming that the sum of each unit's pressure drops along the main lines equals the total head. However, analyzing the interrelationships within the system resulting from these calculations requires solving large systems of nonlinear quadratic equations. The pressure drop of each component in the system is related to the hydraulic resistance by the equation (Eq. 1), and the system's equations are formulated according to Kirchhoff's 1st and 2nd laws. A simple example is illustrated in Figure 2.

The calculation of a hydraulic mode is based on the basic equations of hydrodynamics. In district heating networks, the square-law dependence of pressure drop on the flow rate, as a rule, takes place:

$$H = S \cdot V^2 \quad (1)$$

Where: $S -$ the characteristic of resistance representing pressure drop at a unit of the flow of the heat carrier; $V -$ the flow rate of the heat carrier.

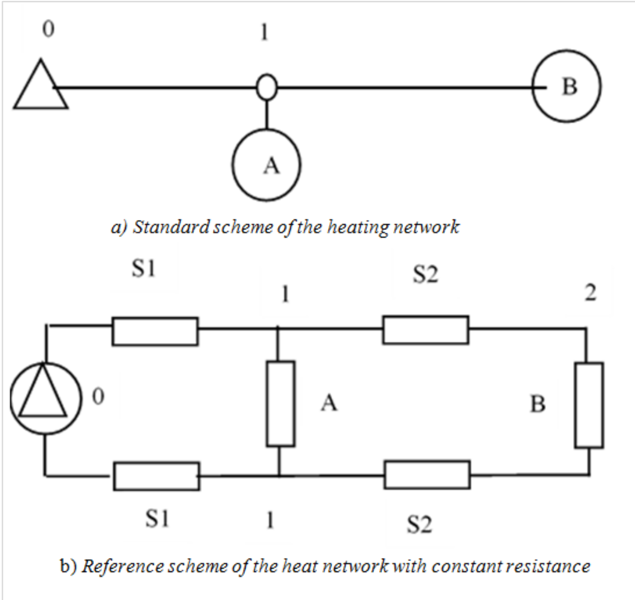

Figure 2. *Scheme of the heating network.*

From Figure 2 (b), let's break down the total network pressure drop for the right, left, and outer loops. Here:

For the outer loop of the system:

$$H_{0-1} = 2 \cdot S_1 \cdot (V_A + V_B)^2$$

$$H_{1-2} = 2 \cdot S_2 \cdot (V_B)^2$$

$$H_B = S_B \cdot {V_B}^2$$

$$\sum H = H_{0-1} + H_{1-2} + H_B \quad (2)$$

For the left-hand loop:

$$H_A = S_A \cdot {V_A}^2$$

$$H_{0-1} = 2 \cdot S_1 \cdot (V_A + V_B)^2$$

$$\sum H = H_{0-1} + H_A \quad (3)$$

For the right-hand loop:

$$H_A = S_A \cdot V_A{}^2$$

$$H_A = H_{1-2} + H_B$$

$$S_A \cdot V_A{}^2 = 2 \cdot S_2 \cdot (V_B)^2 + S_B \cdot V_B{}^2 \quad (4)$$

Defined by total resistance:

$$\sum H = S_e \cdot (V_A + V_B)^2 \quad (5)$$

Table 1 illustrates how resistances are arranged in series and parallel, similar to resistances in an electrical system.

Table 1. The resistance of the hydraulic system.

	series	parallel
Hydraulic system	$S = S_1 + S_2$	$\frac{1}{\sqrt{S}} = \frac{1}{\sqrt{S_1}} + \frac{1}{\sqrt{S_2}}$
Electrical system	$R = R_1 + R_2$	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

Hence, the total hydraulic resistance of the standard heat supply system shown in Figure 2 can be written correspondingly:

$$S_e = 2 \cdot S_1 + \left(\frac{S_A(2 \cdot S_2 + S_B)}{\left(\sqrt{S_A} + \sqrt{2 \cdot S_2 + S_B}\right)^2} \right) \quad (6)$$

Where: $H_{0-1}, H_{1-B}, H_B, \sum H -$ head drop on the parts and total head drop, m; $S_A, S_B -$ consumer's characteristic of resistances, $V_A, V_B -$ consumer's flow rate; $S_1, S_2 -$ section resistances; $S_e -$ total resistance of the network.

Within the framework of mathematical methods, our goal is to solve the system of equations. We start by forming a matrix from the equations and calculating its determinant to verify whether a solution exists. If it does, we compute the necessary matrix and apply Newton's method iteratively to refine the solutions. Because solving nonlinear systems directly can be complex, we simplify the problem by converting it into a system of linear equations using hydraulic stability, which remains constant under uniform resistance. However, in scenarios with variable resistance, this direct relationship cannot be applied, necessitating an approximation and a detailed study of the problem.

3. Case Study

In our study of heat supply systems, we make quality adjustments at the source by controlling the supply water temperature of the network. The adjustments are made based on factors such as outdoor air temperature, heat consumption, and user satisfaction. As a result, the system's flow regime is stabilized. In recent years, the introduction of automatic equipment at the user end has caused changes in total system resistance. As user resistance changes, the system operates under continuously varying conditions. In line with this situation, we examined how user resistance changes depending on the overall pressure while performing quality adjustments at the source and how the entire system changes as a result. For the hydraulic system we are considering, S_1 and S_2 are the pressure drops and constant resistances falling on the network. But the resistances S_A and S_B of the user nodes are auto-adjusting valves with variable resistances or constant resistances with mechanical valves, so that the system can have 3 general forms:

1) Constant resistance;
2) Variable resistance;
3) Mixed constant and variable resistance.

Typically, it is considered that when the head changes in a hydraulic system, the flow rate changes.

$$\frac{H}{H'} = \frac{V^2}{V'^2} \quad (7)$$

When users A and B in our example have variable resistance heating equipment, to fulfill the given task in the condition of reduced system head, their resistances can also be reduced to the limit of the valve's full opening.

$$\frac{H}{H'} = \frac{S_A}{S_A'} \quad or \quad \frac{H}{H'} = \frac{S_{var}}{S_{var}'} \quad (8)$$

After the automatic valve is fully opened, the resistance becomes constant, so the conditions for the change in flow will start to be fulfilled.

These two different situations create a need to determine the appropriate method for the system in situations where some users do not have automatic installation and some do.

Let's see if the system we are considering is defined by its constant and variable resistance, it will have the following form, Figure 3.

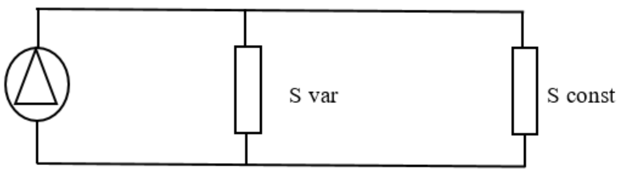

Figure 3. Scheme of the heating network with constant and variable resistance.

After calculating in many variants, we have classified them by similar characteristics and solved to determine equivalent resistances.

If A is variable

$$S_{var} = \frac{H}{V_A^2} \quad (9)$$

The following conditions are fully met for each calculation.

$$\frac{H}{H'} = \frac{S_A}{S'_A}$$

If B is constant

$$H = S_{const} V_B^2 \quad (10)$$

$$\frac{H}{H'} = \frac{V_{const}}{V'_{const}}$$

Since these 2 resistors are connected in parallel, the following conditions must also be met.

$$\sum H = S_e(V_A + V_B)^2 = S_{var}V_A^2 = S_{const}V_B^2 \quad (11)$$

$$\frac{1}{\sqrt{Se}} = \frac{1}{\sqrt{Svar}} + \frac{1}{\sqrt{Sconst}} \quad (12)$$

According to the calculations, it has been proven that the total flow and resistance of the system change at the same time because of the consumer's constant and variable resistances.

$$\sum H = (V_{const} + V_{var})^2 \cdot \left(\frac{S_{const}S_{var}}{\left(\sqrt{S_{const}}+\sqrt{S_{var}}\right)^2}\right) \quad (13)$$

As a result of the research, the methodology is to decompose the constant resistance of the network into parts related to the user's variable and constant resistance. By using this method in the next model (HYDDRO-C 2.0) of the heat supply hydraulic calculation software, which was developed in cooperation with a team of consulting scientists, it solves the difficulty of thinking about nonlinear equation systems and simplifies repeated calculations. Apart from that, this study would not deny the methodologies and calculation algorithms of similar foreign software used by us.

4. Conclusions

It is crucial to investigate how a user's variable resistance impacts a hydraulic system when the central quality adjustment, such as network water temperature, is modified by outdoor air temperature to maintain a constant heating flow.

A key indicator that simpler methods have long been sought is the concept of hydraulic stability and the head-flow relationship. Engineers cannot always derive a large nonlinear system of equations for every component.

Our research identifies conditions where these assumptions fail and proposes appropriate solutions. We briefly summarize our conclusions below.

In a hydraulic system with constant resistance, hydraulic stability and other formulas can be used when changing the pressure.

In a system with variable resistance, changes in the head cause proportional variations in the system's total equivalent resistance due to fluctuations in the user's resistance (Eq. 8). This relationship should be incorporated into the system's calculation methodology.

In a system with mixed resistance, it was determined that the total equivalent variable resistance changes in the same ratio as the change in the head (Eq. 13), and the total consumer flow in the constant resistance part changes in approximately the same ratio, so these will be reflected precisely in the HYDRO-C 2.0 model.

Abbreviations

DHS	District Heating System
Const	Constant
Var	Variable

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Author Contributions

Enkhbayar Bat-Erdene: Conceptualization, Methodology, Writing - original draft

Tserendolgor Dugargaramjav: Conceptualization, Methodology, Writing - review & editing, Supervision

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Purevjal O., Landannorov J., Bavudovjii S., Enkhtuya Y., The results of the hydraulic test of the heating network, Energy & Engineering, 2000, 2/8, pp. 16-19.

[2] Purevjal O., Numerical load adjustment of the heat supply system, //International scientific conference on "Energy production and ecology", Compilation of speeches, May 26-30, 2010, pp. 177-181.

[3] Purevjal O., On the problem of changing the heat distribution adjustment method in the heat supply system with variable consumption, Energy & Engineering, 2019-8(186) pp. 27-31.

[4] Tserendolgor D., Tsetsegee S., Erdenechimeg B., A study on the transition to a consumption-based heat billing system, Journal of Energy Transition, vol. 2, No. 1, pp. 1-8, Dec. 2024. https://doi.org/10.59264/jet.v2i1.53

[5] X. Lin, N. Zhang, Z. Luo et al., Balanced operation strategies of district heating systems based on dynamic hydraulic-thermal modeling, Energy and Built Environment 6 (2025) 466-483. https://doi.org/10.1016/j.enbenv.2024.01.005

[6] S. Kuntuarova et al., Design and simulation of district heating networks: A review of modeling approaches and tools, Energy 305 (2024) 132189. https://doi.org/10.1016/j.energy.2024.132189

[7] O. Angelidis et al., Development and experimental validation of a hydraulic design and control philosophies for 5th generation district heating and cooling networks, Energy 308 (2024) 132835. https://doi.org/10.1016/j.energy.2024.132835

[8] T. Dugargaramjav, B. Pashka, and B. Munkhbaatar, Study of the Influence of Electromagnetic Fields on the Corrosion of District Heating Pipelines: Corrosion of District Heating Pipelines, Journal of Energy Transition, vol. 2, no. 1, pp. 15-21, Dec. 2024. https://doi.org/10.59264/jet.v2i1.54

[9] Stanislav Chicherin et al., The new method for hydraulic calculations of a district heating network, Energy, volume 260, 2022, 125071. https://doi.org/10.1016/j.energy.2022.125071

[10] Z. I. Shalaginova, Mathematical model for calculation of the heat-hydraulic modes of heating points of heat-supplying systems, Thermal Engineering, 63, 2016, pp. 222-232.

[11] Anton Eremin et al., Computer models of hydraulic systems of district heating, MATEC Web of Conferences 193, 02028, 2018. https://doi.org/10.1051/matecconf/201819302028

[12] Luo, P.; Wang, H.; Liu, Y.; Du, Q.; Zhang, Z. Resistance Characteristic Parameters Estimation of Hydraulic Model in Heating Networks Based on Real-Time Operation Data. Buildings 2022, 12, 743. https://doi.org/10.3390/buildings12060743

[13] Abdulaev. D. A. et al. Hydraulic stability of the thermal network, Construction of Unique Buildings and Structures, 1(52), 2017, pp. 67-85. https://doi.org/10.18720/CUBS.52.6

[14] Stanislav Chicherin, Hydraulic Balancing of District Heating Systems and Improving Thermal Comfort in Buildings, Energies 2025, 18, 1259, 2-26. https://doi.org/10.3390/en18051259

[15] F. Agner et al., Hydraulic parameter estimation for district heating based on laboratory experiments, Energy 312 (2024) 133462. https://doi.org/10.1016/j.energy.2024.133462

Biography

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