Eurasia Journal of Science and Technology
ISSN: 2663-1016
DOI: https://doi.org/10.61784/ejst3042

HYDRAULIC IMBALANCE IN HEATING SYSTEMS PROBLEM ANALYSIS

XiaoFei Chen, Jing Qin*, XueZe Zhang, XingGuo Sun
Department of Energy Engineering, Hebei University of Architecture , Zhangjiakou 075000, Hebei, China.
Corresponding Author: Jing Qin, Email: Qinjings123@sina.com

Abstract: This paper focuses on four main research topics related to hydraulic balance of heating system, including the causes of hydraulic imbalance, the adjustment method of hydraulic balance, the influence of hydraulic balance on the economic benefits of heating system, and the relationship between operation optimization of heating system and hydraulic balance. This paper analyzes the research questions, controversial views, and research deficiencies under each topic, and lists relevant cases, aiming to comprehensively sort out the research status in this field and provide reference for further research.
Keywords: Hydraulic equilibrium; Heating systems; Modulation methods; Optimize your operation

1 INTRODUCTION

With the progress of China's society and technology, the centralized heating network industry has developed rapidly.The quality requirements are getting higher and higher, but at this stage, there is still a serious injustice between the development of China's central heating industry and people's needs balance mismatch problem [1]. The hydraulic balance of the heating system is of great importance to ensure the quality of heating, improve energy efficiency and reduce operating costs. However, in the actual heating project, the problem of hydraulic balance is complex and diverse, involving many aspects of research. Several key research themes are analyzed in detail below.

2 CAUSES OF HYDRAULIC IMBALANCE

2.1 Research Questions

Hydraulic unbalance is a common problem in Chinese district heating (DH) systems. Hydraulic unbalance has resulted in poor flow distribution among heating branches and overheating of apartments. Studies show that nearly 30% of the total heat supply is being wasted in Chinese DH systems due to a lack of pressure and flow control[2].The causes of hydraulic imbalance in heating systems are manifold. At the design level, the unreasonable design of the pipe network is an important factor. If the pipe diameter is too small, the water flow speed will be accelerated, and the resistance along the route and local resistance will increase significantly, which will easily cause excess user flow at the near end and insufficient flow at the far end. On the contrary, if the pipe diameter is too large, the flow rate will be too low, which is not conducive to the stable operation of the system. The unreasonable direction of the pipeline, such as the existence of too many elbows, tees and other complex pipe fittings, will also increase the local resistance and destroy the hydraulic balance. In terms of terminal equipment design, improper selection of radiator model, mismatch of resistance characteristics with the system, or unreasonable installation location affecting thermal cycling may cause hydraulic imbalance. In the design of the control system, the selection of the control valve is unreasonable, such as the flow characteristics of the control valve do not meet the system requirements, or the control strategy does not consider the differences in the needs of different users, which will also have a negative impact on the hydraulic balance.
In terms of operation management, unreasonable heating parameters are a common problem. If the water supply temperature is too high or the pressure is too high, the flow rate of the proximal user will exceed the design value, and the flow rate of the remote user will decrease. Unreasonable heating scheduling, such as failure to adjust the distribution of heating load in time according to outdoor temperature changes, can also lead to hydraulic imbalance. Inadequate maintenance, such as fouling in the pipeline and valve damage, will increase the system resistance and affect the hydraulic working conditions.
The influence of the user's thermal behavior on the hydraulic balance cannot be ignored. If the user modifies the heating equipment without permission, such as increasing the number of radiator pieces or changing the pipe connection method, the local resistance characteristics will be changed. Arbitrary adjustment of the heating valve, especially over-regulation or closing of the valve, can upset the hydraulic balance of the entire system. External factors also play a significant role. Temperature changes can change the heat load demand of a building, which in turn affects the hydraulic condition of the heating system. Changes in the groundwater level may create buoyancy or pressure on buried pipelines, affecting the normal operation of pipelines and leading to hydraulic imbalances.

2.2 Disputed Views

There are different views on the importance of the causes of hydraulic imbalance. Some scholars emphasize the leading role of the design stage, believing that as long as various hydraulic factors are fully considered in the design process, and the design is carried out in strict accordance with the specifications and accurate calculations, most of the hydraulic imbalance problems can be fundamentally avoided. They believe that although the follow-up operation management and external factors have an impact, they are relatively secondary, and can be dealt with by reserving a certain amount of adjustment margin through reasonable design. However, other scholars have pointed out that in actual operation, operation management and user behavior factors often have a more prominent impact on hydraulic imbalance. Because it is difficult to predict all the actual operating conditions completely and accurately during the design stage, such as changes in occupancy rates of users, differences in users' heating habits, etc. Moreover, even if the design is reasonable, poor operation management during long-term operation, such as failure to repair and adjust in time, will gradually lead to hydraulic imbalance.

2.3 Insufficient Research

The current research is still insufficient to quantify the specific contribution of different causes to hydraulic imbalance. Although it has been established that various factors can cause hydraulic imbalances, the weight of each factor that causes imbalances in a particular heating system has not yet been established. For example, for a specific district heating system, it is difficult to accurately determine the proportion of design factors, user behavior factors, etc., which makes it difficult to formulate targeted prevention and solution measures. The difficulty of this quantitative study lies in the complexity of the heating system, which involves the interaction of many factors and the characteristics of different systems are quite different.

The long-term and dynamic effects of user thermal behavior and external factors are not well studied. Taking the user's heat use behavior as an example, although it is known that the user's unauthorized modification and other behaviors will affect the hydraulic balance, there is a lack of in-depth research on the law of the user's heat use behavior with the season and socio-economic factors. For example, the frequency and magnitude of the valve adjustment may vary from season to season, and it is not fully understood how this variation relates to the hydraulic imbalance in the heating system. For external factors, the long-term mechanism of action under different geological and climatic conditions also needs to be further explored. For example, in the case of large seasonal changes in groundwater level in coastal areas, the long-term impact model on the hydraulic balance of heating pipe networks needs to be studied more deeply.

3 ADJUSTMENT METHOD OF HYDRAULIC BALANCE

3.1 Research Questions

When it comes to static hydraulic balancing regulation, accurate selection and installation of static hydraulic balancing equipment is key. Static hydraulic imbalance is due to the design, construction, and pipe quality of the pipe network system, resulting in the ratio of the pipeline resistance coefficient being different from the ratio of the pipeline resistance coefficient required by the design, so that the flow of the secondary pipe network cannot be reasonably distributed according to the design value, resulting in the hydraulic imbalance of the secondary network [3]. For example, the selection of static hydraulic balancing valves is based on the flow rate, differential pressure and other parameters of the system. Selecting the right valve type (e.g., equal percentage, straight, etc.) requires an in-depth understanding of the hydraulic characteristics of the system. During installation, the position and orientation of the valve and the way it is connected to the surrounding pipes all affect its adjustment effect. Determining whether the system has reached static hydraulic equilibrium requires a suitable detection method, such as measuring the flow rate and differential pressure of each branch and comparing the design values.

For dynamic hydraulic balance adjustment, the working principle of various types of dynamic hydraulic balance equipment is quite different. The dynamic flow balancing valve maintains the set flow rate by automatically adjusting its own opening, which is not affected by system pressure fluctuations; The dynamic differential pressure balancing valve keeps the differential pressure at both ends of the valve constant. Automatic adjustment relies on advanced sensors and control systems. Sensors monitor the water flow in the system and relay real-time data to the control system, which then adjusts to preset parameters [4]. Understanding the scenarios in which these devices are suitable is essential for effectively adjusting the hydraulic balance. In a complex heating pipe network, the needs of different regions and different users are different, and a variety of adjustment methods need to be used comprehensively. For example, for areas with uneven distribution of heat users and large changes in heat load, it may be necessary to combine static and dynamic adjustment methods, while considering the characteristics of different branches for targeted adjustment.

3.2 Disputed Views

In the choice of adjustment method, there is a controversy between traditional method and intelligent method. Some researchers believe that traditional mechanical adjustment methods, such as control valve adjustment, have the advantages of mature technology and high reliability. Control valves have a long history of use in heating systems, and operators are familiar with their regulation methods, and their costs are relatively low. However, another group of researchers is more inclined to intelligent adjustment methods, such as AI-based adjustment systems. This kind of system can automatically adjust the parameters of the adjustment equipment according to the real-time monitoring data (such as temperature, flow, pressure, etc.), with high adjustment accuracy and strong adaptability. For example, the hydraulic change trend of the heating system can be predicted and adjusted in advance through the neural network algorithm, but the cost of this method is high, and the current technology is not mature enough, and there are problems such as poor adaptability to complex environments and the accuracy of the algorithm needs to be improved.

3.3 Insufficient Research

There is a lack of unified evaluation standards for the comprehensive regulation effect of complex heating pipe networks. Unfortunately, to the authors' knowledge, there are no long-term field studies demonstrating the level of energy savings achieved in engineering practice with commonly used valves, such as thermostatic radiator valves (TRV), differential pressure control valves under risers (DPCV), pressure-independent balanced radiator valves (PIBRV), and their combinations[5]. For complex heating networks, it is difficult to accurately measure and compare the effects of different combinations of adjustment methods in practical applications. For example, in a large urban heating network, a static balancing valve, a dynamic flow balancing valve and an intelligent control system are used for hydraulic regulation at the same time, it is difficult to determine whether this regulation scheme is optimal, and it is difficult to judge whether the regulation effect in different areas meets expectations due to the lack of unified evaluation criteria. This leads to great difficulties in selecting the optimal accommodation regimen, often relying on empirical or local experimentation.

There is insufficient research on the long-term compatibility between new intelligent regulation equipment and traditional regulation equipment in the actual heating system. In the process of upgrading and renovating heating systems, it is common for old and new equipment to be mixed. For example, in the renovation of some old heating systems, some of the original control valves may be retained, and new intelligent balance valves may be installed. However, there is little research on the problems that may arise when the old and new equipment is mixed, such as control signal interference, the effect of hydraulic coupling between different devices, etc., and how to optimize their interoperability. This can lead to equipment failures or poor regulation in actual operation.

4 THE INFLUENCE OF HYDRAULIC BALANCE ON THE ECONOMIC BENEFITS OF HEATING SYSTEM

4.1 Research Questions

Hydraulic balance regulation has an important impact on the energy consumption of heating systems. By adjusting the hydraulic balance, the flow distribution of each user can be more reasonable, and the phenomenon of overheating and overcooling of some users can be avoided, thereby reducing energy waste. But how to quantify this energy saving effect is a key question. For example, it is necessary to determine how much energy consumption per unit area of heating is reduced by means of hydraulic balance adjustment, as well as the proportion of the total energy consumption of the entire heating system.

The improvement of heating quality can bring significant economic benefits. Energy consumption management is an inevitable choice for the current central heating enterprises to meet the development of the times, and it is also the only way for the country to advocate energy conservation and consumption reduction. Central heating enterprises should conduct in-depth analysis of the current problems, improve the quality of heating and reduce energy consumption by upgrading heating equipment and optimizing the design of heating systems, actively respond to the call of the state, and at the same time achieve the sustainable development of central heating enterprises [6]. Reducing user complaints and improving user satisfaction are important aspects. For example, increased user satisfaction may reduce economic losses such as refunds due to heating problems, while also benefiting the reputation and market competitiveness of heating companies. Evaluating these values requires appropriate methods, such as user surveys, complaint rate statistics, etc., to quantify the impact of changes in user satisfaction on economic benefits.

From the perspective of extending the life of the equipment and reducing the maintenance cost, the hydraulic balance adjustment makes the equipment operate under more reasonable working conditions. For example, a reasonable flow rate and pressure can reduce wear and tear on equipment such as water pumps, reducing the frequency and cost of maintenance. However, it is necessary to accurately calculate how much the life of the equipment is extended before and after the hydraulic balance adjustment, and how much the maintenance cost is reduced.

4.2 Disputed Views

There are differences among different researchers regarding the quantitative evaluation of economic benefits. Some researchers believe that the existing evaluation methods are too simplistic, only considering the direct energy saving and some cost reduction factors, and cannot fully reflect the comprehensive economic benefits brought by hydraulic balance regulation. For example, existing approaches may ignore the assessment of the long-term market benefits of increased user satisfaction. However, other researchers believe that in practice, it is difficult to obtain all relevant data accurately, and that overly complex evaluation methods are not practical. For example, it is difficult to accurately assess the impact of user satisfaction on a company's long-term market share, as it is interfered with by a variety of market factors.

4.3 Insufficient Research

There is no well-established model to evaluate the economic benefits of hydraulic balance from the perspective of the whole life cycle. Most of the existing evaluations focus on short-term energy savings and partial cost reductions, and lack comprehensive consideration of the economic benefits of hydraulic balance in the whole life cycle of the heating system, including equipment renewal and technology upgrading. For example, in the 10-20 years of operation of the heating system, with the aging of equipment and technological upgrading, the influence of hydraulic balance regulation on economic benefits at different stages is not fully understood.

There is a gap in the comprehensive evaluation of social benefits (such as the impact on the environment, the promotion of urban heating stability to social development, etc.) and economic benefits. Hydraulic balance regulation not only affects the economic benefits of heating enterprises, but also has a wide impact on society. For example, a good hydraulic balance can reduce energy consumption and, in turn, carbon emissions, which is good for the environment. At the same time, stable heat supply is very important for the life of urban residents and the normal operation of cities, but there is a lack of research on the unified quantitative analysis of these factors, and it is difficult to comprehensively evaluate the comprehensive value of hydraulic balance regulation.

5 THE RELATIONSHIP BETWEEN THE OPERATION OPTIMIZATION OF THE HEATING SYSTEM AND THE HYDRAULIC BALANCE

5.1 Research Questions

Optimizing the operating parameters of the heating system is essential to achieve hydraulic balance under different operating conditions. For example, under different outdoor temperature conditions, the heat load will change, and parameters such as water supply temperature, flow rate, etc., need to be adjusted accordingly. In the early and late cold periods when the heating load is low, the hydraulic balance can be maintained by appropriately reducing the water supply temperature and flow. In severe cold periods, heating parameters need to be improved. At the same time, different heating load distributions, such as changes in user occupancy rates, differences in heat demand in different regions, etc., also need to adjust the operating parameters to ensure hydraulic balance.

Hydraulic balance regulation has an important impact on the stability and reliability of the heating system. Reasonable hydraulic balance can avoid equipment failures caused by excessive or small local flow, such as pump overload, pipeline rupture, etc., and improve the stability of the system. At the same time, the stable hydraulic balance can ensure the heating quality of each user, reduce the system failure caused by heating problems, and improve reliability. The focus of research is how to further improve the overall operational performance of the system by optimizing the hydraulic balance, such as dynamically adjusting the hydraulic balancing equipment to adapt to changes in the system.

The application of intelligent technology in the operation optimization and hydraulic balance adjustment of heating system has broad prospects, but it also faces challenges. Intelligent technology can monitor the temperature, pressure, flow and other parameters of the system in real time, and automatically adjust the operating parameters and hydraulic balancing equipment through the control algorithm. However, it faces problems such as sensor accuracy, control algorithm accuracy, and system compatibility. For example, measurement errors in sensors can lead to incorrect control decisions that affect the effectiveness of hydraulic balancing.

5.2 Disputed Views

There are different views on the application of intelligent technology. Some scholars believe that intelligent technology is an inevitable trend in the future operation optimization and hydraulic balance adjustment of heating systems, and should be vigorously promoted and applied. They believe that intelligent technology can improve the accuracy and efficiency of adjustment, and better adapt to complex and changeable operating conditions. For example,The results show that compared with the traditional centralized computing method, the optimal control method under the distributed architecture can solve the problem of on-demand heating of the secondary pipe network in the district heating system under the fast convergence speed, and the energy consumption of transmission and distribution are low[7]. An intelligent control system based on big data and artificial intelligence can predict system changes based on historical data and real-time data, and make optimization adjustments in advance. However, other scholars believe that intelligent technology is not suitable for large-scale application due to its high cost and difficulty in retrofitting some old heating systems. They advocate starting with traditional operational optimization methods and gradually improving and upgrading. For example, for some areas with poor economic conditions and aging heating systems, the large-scale installation of intelligent equipment may increase the burden on enterprises, and may lead to operational problems due to the unskilled operation of new equipment by technicians.

5.3 Insufficient Research

There is insufficient research on the intelligent operation optimization and hydraulic balance adjustment strategies of different types and scales of heating systems under complex working conditions (such as extreme weather, sudden heating failure, etc.). Most of the existing studies focus on conventional working conditions, and there is a lack of in-depth discussion on coping strategies for special situations. For example, in the event of extreme cold weather, the heat load of the heating system increases sharply, and how to quickly adjust the hydraulic balance and operating parameters to ensure heat supply through intelligent technology is rarely studied. For sudden heating failures, such as pipeline leakage, pump failure, etc., the research on how to adjust the hydraulic balance in time to reduce the impact of the failure is also not perfect.

In the study of the application of intelligent technology, there is not enough research on its adaptability with the existing operation management system and personnel skill level. Intelligent systems need appropriate management and operation, but there is a lack of research on how to adapt the existing personnel and management mode of heating enterprises to intelligent regulation. For example, the maintenance of intelligent systems requires professional technicians, but heating companies may lack relevant talents. At the same time, the existing operation management system may not adapt to the real-time monitoring and rapid decision-making requirements of intelligent systems, and corresponding reforms need to be carried out, but the research in this area is still relatively weak.

6 CONCLUSION

The research on hydraulic balance of heating system has achieved certain results in many aspects, but there are still obvious research gaps. In terms of the causes of hydraulic imbalance, it is necessary to strengthen quantitative analysis and long-term dynamic research on complex influencing factors. For the hydraulic balance adjustment method, a unified evaluation standard should be established and the compatibility of the old and new equipment should be studied in depth. In the evaluation of the economic benefits of hydraulic balance, it is necessary to improve the whole life cycle model and comprehensively consider the social benefits. The research on the relationship between heating system operation optimization and hydraulic balance needs to be extended to complex working conditions and pay attention to the adaptability of intelligent technology. Through further in-depth study of these aspects, it is expected to improve the hydraulic balance level of the heating system, improve the quality and economic benefits of heating supply, and promote the sustainable development of the heating industry.

More interdisciplinary research methods and technological innovations are needed to fill the current research gap and provide more scientific guidance for the optimal design, operation and management of heating systems. Future research can be combined with computer simulation, big data analysis, intelligent technology and other means to further explore the hydraulic balance of heating system to meet the increasing demand for heating and energy efficiency.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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