Leakage Reduction of Water Distribution Network System Based on the Observation Data of Water Leakage and Pressure of Actual Water Distribution Network System

Peng Cheng
Liaoning Jianzhu Vocational University, Liaoning, China
*Corresponding author e-mail: 742592485@lnjz.edu.cn

Abstract. As the main way of urban water use, water supply system is an important urban infrastructure. It plays an important role in guaranteeing people's life and economic construction. In recent years, it has an overall and guiding influence on the city. The monitoring and leak detection of water supply network system has become one of the most important problems in the water supply network system. The purpose of this paper is to explore the leakage reduction of the water distribution network system under the observation data of water leakage and pressure based on the actual water distribution network system. This paper analyzes the different pipe diameter of pressure change on the influence of water leakage, and the effect of different decompression interval to reduce water leakage results show that the leakage and pipeline pressure changes exponentially, it changes with reduced pressure pipe installation of pipe diameter and valve for high same diameter of pipeline, decompression and leakage effect is more effective, for the decompression range of basically the same pipeline, pipe diameter, the greater the effect is more obvious. In this paper, we study a kind of based on the pressure signal and traffic signal of the existing urban water supply pipe network leakage recognition and positioning method, and carries on the simulation of urban pipeline leakage simulation test platform through test analysis, probes into the key technology of this method and improvement, to improve the accuracy and positioning precision of the method to detect leaks. The research results show that the simplest method can be realized and the best effect can be achieved through the summary analysis of existing studies. When the leakage coefficient is set as 1, the water leakage is about 600%, and the pressure value of the leakage node and the pressure monitoring point for 24h is shown. It is obvious that when the lowest pressure is 10h, the pressure value is 300%. Through the analysis and improvement of this method, it can realize the timely identification and positioning of leakage events, reduce economic losses, and guarantee people's normal life.

Keywords: Leak Identification And Location; Pipeline Pressure; Pressure Management; City Pipeline

1. Introduction
Fresh water resources on the earth are very limited. The water resources available for human direct use are mainly distributed in rivers, lakes, reservoirs and shallow groundwater, accounting for only 0.007% of the total water resources. China's total water resources amount to 324.661m cubic meters, ranking sixth in the world, according to the 2017 China Statistical Yearbook. However, due to the large population in China, the per capita water resource occupancy is only 2354.9 cubic meters, which is a typical country with a large total volume and a small per capita. It is listed as one of the 12 water-poor countries by the United Nations. At the same time, China's water resources are also facing a series of problems, such as prominent contradiction between supply and demand, uneven distribution of water resources, serious water pollution, serious damage to the water environment and excessive development and waste. This poses a severe challenge to us, so we need to make rational use of water resources and strengthen the management of water supply facilities from the perspective of our profession.

Urban water supply pipe network system, as the main way to transport urban water, is an important infrastructure to ensure the normal operation of the city. It has great significance in ensuring people's basic life and economic construction, and is one of the important guarantees for urban development and the improvement of comprehensive national strength.Kumar, a foreign scholar, believes that in the past decade, along with the continuous expansion and development of urban water supply network, some pipes with long service life and severe corrosion aging have been replaced, but there are still some pipes in service with varying degrees of corrosion and damage [1].Yang Jun, a domestic scholar, also believes that pipeline leakage and waste of water resources will occur in urban water supply network due to aging, excessive operating pressure, unqualified construction, ground settlement and other reasons. According to statistical results, the average leakage rate of water resources caused by pipeline leakage is 15.7% every year, and even in some areas, the leakage rate is up to 30%.The leaking water is treated water [2].

Paper, the observation data of water leakage and pressure in the actual water distribution network system are taken as the research object. Moreover, the water pressure and flow rate of water supply network are important parameters in the operation of water supply network, which reflects the service level of water supply units and provides a basis for the effective dispatching of urban water supply network. However, in general, the cost of flow monitoring equipment is much greater than that of pressure monitoring equipment. So given the realistic cost factor, a lot of times stress monitoring equipment is usually the first consideration. In the actual pipe network, it has a very large number of nodes, so it is not realistic to monitor the pressure of each node only from the economic consideration. Therefore, in order to reflect the actual operation of water supply network to the greatest extent, nodes with strong representativeness and small errors should be selected as far as possible to facilitate the solution of subsequent problems.

2. Based on the Observation Data of Water Leakage and Pressure of Actual Water Distribution Network System, the Technology research of Water Distribution Network System Leakage Reduction

2.1. Overview of research Methods for Pressure Monitoring
Pressure and flow rate are important state parameters in water supply network. The measurement of pressure and flow rate also plays an important role in many works of water supply network. However, in general, the flow measurement requires a higher cost, relatively speaking, the network pressure measurement costs less. Therefore, many times the first consideration is the installation of the pressure measuring device. In the actual pipe network, it has a very large number of nodes, so it is not practical to monitor the pressure of each node only from the economic consideration. It is very important to arrange the pressure monitoring points scientifically and reasonably. At present, the commonly used pressure monitoring point layout methods include optimization algorithm, cluster analysis and sensitivity analysis, etc. Based on the sensitivity matrix of water pressure, this paper conducts the optimal arrangement of pressure monitoring points in the water supply network [3].
2.2. Solution of Standardized Water Pressure Sensitivity Matrix

2.2.1. Hydraulic characteristics of pipe network
Hydraulic characteristics is the basis for the optimization of pressure measuring point location, the hydraulic characteristics can be achieved by the relevance of the pipe network pressure changes between each node to indicate a certain position in the water supply pipe network leakage occurs, can cause the change of cross section flow and node pressure the same leak location, different influence on each node pressure leakage is different, the same leakage and under different leakage location, different pressure change of each node is also different. In addition, under the same leakage loss, different nodes also have different degrees of pressure change. Therefore, several nodes with large pressure changes in the loss process may be the pressure monitoring points we need to select [4].

2.2.2. Solution of water pressure sensitivity matrix
We can assume that the number of nodes in a section of water supply network is $N$. Under a certain normal working condition, $H$ represents the water pressure value of node $i$. Assume that a leak with a loss of $\Delta Q_i$ occurs at a certain moment at node $J$. Affected by the loss of node $J$, the water pressure change of node $J$ is $\Delta H_J$, and the water pressure change of node $I$ is $\Delta H_I$, then the pressure change at node $I$ caused by the state change at node $J$ can be represented by $\Delta H_I / \Delta H_J$ [5]. $\Delta H_I / \Delta H_J$ represents the influence of the change of flow on the water pressure of the node. However, due to the dimensional difference between $\Delta H_I$ and $\Delta Q_j$, and the difference between the flows of each node, it is generally expressed by $\Delta H_i / \Delta H_j$. In other words, based on a certain normal working condition, the influence of the loss of node $J$ on the water pressure of node $I$ can be expressed by the following formula:

$$X(i, j) = \frac{H_i - H'_i}{H'_j - H'_j}$$

(1)

Actual pipe network, the flow rate of each node in the pipe network is constantly changing within 0-24h, that is, the working condition of the pipe network is constantly changing. Based on the expression method of pressure sensitive matrix in the above single working condition, the pressure sensitive matrix $M$ is constructed by using the average value of the pressure changes of other nodes caused by the loss of a node in each working condition for 0-24h, namely:

$$M(i, j) = \sum_{k=1}^{24} X(i, j)_k = \sum_{k=1}^{24} \left( \frac{H_i - H'_i}{H'_j - H'_j}_k \right)$$

(2)

Where, $\Delta H_I$ and $\Delta H_J$ respectively represent the water pressure values of node $I$ and $J$ under normal working conditions $K$. $H'_i$ and $H'_j$ respectively represent the water pressure values of node $I$ and $J$ when loss occurs in node $J$ based on working condition $K$; represents the pressure change degree of node $I$ caused by the loss of node $J$ under working condition $K$; $X(i, j)_k$ represents the average value of the pressure change degree of node $I$ caused by the loss of node $J$ during 0-24h [6].

2.2.3. Standardization of hydraulic sensitivity matrix
Z-score standardization is carried out for matrix $M$, and the expression is as follows
Min-max standardization is carried out for $M_1$ matrix, and the expression is as follows:

Domestic and foreign scholars have invested a lot of energy and made considerable progress in the research on monitoring and positioning methods of pipeline leakage pressure and flow signal [7]. At the same time, the emergence of various identification and positioning methods to a certain extent is helpful to solve the problem, but also to the future need to research and breakthrough direction have a relatively clear and clear understanding. As the mainstream water supply mode, water supply by water pump is also the water supply mode adopted by the leak monitoring simulation platform, which belongs to pressure water supply. In the pressure-type water supply network, the main forces of the internal medium in the pressurized pipe flow are pressure and resistance, and the effect of gravity, compared with the former two, has little influence on the pipe flow, which can be ignored [8-9]. Among them, the resistance is mainly reflected as viscous force, which depends on the roughness of the pipe material and the flow velocity of the internal medium. The similar model needs to be distinguished according to different pipeline running state. Therefore, the viscous force plays a major role in the motion state of the fluid, and the construction of the model should follow the viscous force similarity criterion. However, in the leakage state, the flow movement is mainly influenced by pressure, and in this case, the model construction needs to follow the pressure similarity criterion, which can be calculated through matrix formula [10].

3. Experimental Study on Leakage Reduction of Water Distribution Network System Based on the Observation Data of Water Leakage and Pressure of Actual Water Distribution Network System

3.1. Experimental Data
Test focuses on the variation characteristics of pipeline pressure and flow caused by the leakage event, based on which leakage identification and positioning are carried out, and the influence of data collection is also paid attention to. Maximum measurement range can be adjusted from $50m^3/h$ to $200m^3/h$. The focus is on the dynamic pressure change of pipeline as well as the changes of operating pressure and flow when the leakage event occurs. The three were measured by relative pressure sensor, absolute pressure sensor and flow meter respectively. By analyzing the data obtained, we obtained the relevant data about the leakage reduction of the actual water distribution network system under the observation data of water leakage and pressure.

3.2. Experimental Process
Experiment in this paper we aim at research of optimal placement of the pressure test points, based on the pressure sensitive matrix, combining FCM fuzzy clustering algorithm, and the rest of the nodes in the network impact of pressure fluctuations, solving the $0 \sim 24h$ each node corresponding to each node when the leakage occurred in the relative changes of average pressure, hydraulic pressure sensitive matrix is obtained; Then by standardizing the water pressure sensitivity matrix to eliminate the potential influence between different orders of magnitude, it lays a foundation for cluster analysis. Finally, FCM fuzzy clustering method is adopted to realize the optimal layout of monitoring points according to the actual number of selected clusters. Using this method to optimize the monitoring points can not only understand the pressure distribution in the pipe network, but also provide strong support to realize the leakage location of the pipe network.

4. Experimental Analysis of Water Distribution Network System Leakage Reduction Based on the Observation Data of Water Leakage and Pressure
4.1. Parameters and Variables Obtained in the Experiment

Relevant principles of leakage location of water supply network are clarified, a leakage location model is constructed, and the decision variables are solved by particle swarm optimization algorithm. Combined with the actual situation, the method feasibility study was carried out by calculating the example pipe network, and the leakage points at different locations in the selected pipe network were studied and analyzed in terms of the number of pressure monitoring points, the magnitude of leakage loss, the maximum number of leakage nodes and different working conditions. And it is applied to locate the leakage point in the experimental pipe network and the actual pipe network. Thus where there is leakage loss, greatly reducing labor costs and the amount of water waste. See Table 1 and Figure 1.

Table 1. Parameters and variables obtained in the experiment

| Number | Volume | Coefficient of variation | Q Volume | Pressure | Time |
|--------|--------|--------------------------|----------|----------|------|
| 1      | 5      | 22.94%                   | 22.94%   | 2.3      | 2    |
| 2      | 18     | 9.87%                    | 9.87%    | 4.4      | 3    |
| 3      | 15     | 65.60%                   | 65.60%   | 4.0      | 4    |
| 4      | 45     | 10.57%                   | 10.57%   | 8.15     | 5    |
| 5      | 20     | 23.05%                   | 23.05%   | 5.12     | 6    |
| 6      | 35     | 78.31%                   | 76.31%   | 7.32     | 7    |
| 7      | 15     | 74.67%                   | 61.11%   | 4.5      | 8    |
| 8      | 22     | 61.73%                   | 32.98%   | 6.2      | 9    |

Using mathematical tools, we can better promote and use this method to realize optimal layout of monitoring points. Secondly, the selected pressure monitoring points are distributed discretely on the water supply network, which can well reflect the pressure fluctuation of the water supply network and understand the operation of the network. Finally, with the increase of the number of clustering, namely the number of monitoring points, the distribution of the pressure monitoring points obtained will change, and the monitoring points obtained when the number of clustering is large do not necessarily contain the monitoring points obtained when the number of clustering is small.

4.2. Experimental Data

When the leakage coefficient is set as 1, the water leakage is about 600%, and the pressure value of the leakage node and the pressure monitoring point for 24h is shown. It is obvious that when the
lowest pressure is 10h, the pressure value is 300%. The highest pressure is at the moment when T is 3, and the pressure value is 800%. See Figure 2.

![Figure 2. Pressure value changes under different working conditions](image-url)

Seen from the figure that the change of the flowmeter is consistent with the change rule obtained from the theoretical analysis. The flow signal caused by the leakage event has the characteristic of typical reverse and reverse changes. This phenomenon has been verified in the simulation test. On the one hand, it can be shown that the flow parameter, as an auxiliary analysis signal for pipeline leakage identification, can achieve the expected effect very well. On the other hand, it can also prove the authenticity and reliability of the simulation test to a certain extent, and provide evidence from other angles for the analysis and conclusion mentioned above.

Simulation of leakage at a single node at different locations of the pipe network, when the maximum leakage coefficient is set as 1, that is, equal to the actual number of leakage nodes, the optimized node position and leakage coefficient are more accurate. At maximum leakage coefficient is set to 2, also can search to the leakage of node position, just leakage index value and the actual percentage, there is a certain gap could not be determined accurately, however, with the increase of number of monitoring stations, and more close to actual situation, and in most cases the scope of the leakage location significantly narrowed, leak positioning more accurate. At the same time, for the same node, when the leakage coefficient K value is changed, that is, when the leakage quantity is changed, the positioning result is more accurate when the leakage quantity is large. In the case of the same set maximum loss number, the same number of monitoring points and the same leakage coefficient, the positioning accuracy of different nodes in the pipe network is also different to some extent, which is related to their positions in the pipe network and their operation status in the pipe network. In a word, the leakage node or its area can be judged accurately through model optimization calculation, which is convenient for leakage detection of actual pipe network.

5. Conclusions

Leakage location of urban water supply network is taken as the target. On the basis of relevant studies at home and abroad, the weight of leakage factor is analyzed based on the improved analytic hierarchy process based on the three-scale, and the main influencing factors are sought to make a rough judgment of the leakage area. Considering the single leakage node, the node position and leakage coefficient obtained by optimization are more accurate when set as the actual number of leakage nodes. In the case of the same set maximum loss number, the same number of monitoring points and the same leakage coefficient, the positioning accuracy of different nodes in the pipe network is also different to some extent, which is related to their positions in the pipe network and their operation status in the pipe network. In the optimization solution process, the positioning analysis under three contrasting working conditions shows that the leakage positioning results are better when the user's water consumption is relatively small, and the node leakage has a greater impact on the whole pipe network.
References

[1] Kumar, N. Praveen, Charles, B. Stephen, Sumalatha, V..A Review on Leakage Power Reduction Techniques at 45nm Technology[J].Materials Today: Proceedings, 2015, 2(9): 4569-4574.

[2] Yang Jun, Liu Zhenglin, Liang Xingxin, Wang Jian, Cheng Qichao. Research on Friction Vibration of Marine Water Lubricated Rubber Bearing[J]. Tribology Online, 2018, 13(3): 108-118.

[3] Strm? nik, Ervin, Majdi?, Franc. Comparison of leakage level in water and oil hydraulics[J]. Advances in Mechanical Engineering, 2017, 9(11): 168781401773772.

[4] Wilson, Jason, Klein, James, Shanahan, Kirk, Korinko, Paul, Poore, Anita. Reduction of Glovebox Stripper System Water Loading[J]. Fusion Science and Technology, 2017, 71(4): 666-670.

[5] Akhavana, oakhavan@sharif.edu" title="E-mail the corresponding author, R. Azimiradb, H.T. Gholizadehb, F. Ghorbania. Hydrogen-rich water for green reduction of graphene oxide suspensions[J]. International Journal of Hydrogen Energy, 2015, 40(16): 5553-5560.

[6] Gui, Herong, Lin, Manli, Song, Xiaomei. Research on pore water and disaster prevention in China coalmines[J]. Water Practice and Technology, 2016, 11(3): 531-539.

[7] Zhu, Zicheng, Zhang, Xuejun, Wang, Qiang, Chu, Weijun. RESEARCH AND EXPERIMENT OF THERMAL WATER DE-ICING DEVICE[J]. Transactions of the Canadian Society for Mechanical Engineering, 2015, 39(4): 783-788.

[8] He, Zhen. A new era of Water Environment Research[J]. Water Environment Research, 2019, 91(1): 3-4.

[9] Colakoglu, Mert, Tanbay, Tayfun, Durmayaz, Ahmet, Sogut, Oguz Salim. Effect of heat leakage on the performance of a twin-spool turbofan engine[J]. International Journal of Exergy, 2016, 19(2): 173.

[10] Zhao, Yong, Zhu, Yongnan, Lin, Zhaoxui, Wang, Jianhua, He, Guohua, Li, Haihong, Li, Lei, Wang, Hao, Jiang, Shan, He, Fan, Zhai, Jiaqi, Wang, Lizhen, Wang, Qingming. Energy Reduction Effect of the South-to-North Water Diversion Project in China[J]. Scientific Reports, 2017, 7(1): 15956.