Study on hydraulic characteristics of mine dust-proof water supply network

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Abstract. In order to study the hydraulic characteristics of mine dust-proof water supply network and obtain the change rule of water consumption and water pressure, according to the similarity principle and the fluid continuity equation and energy equation, the similarity criterion of mine dust-proof water supply network is deduced, and a similar model of dust-proof water supply network is established based on the prototype of Kailuan Group, the characteristics of hydraulic parameters in water supply network are studied experimentally. The results show that water pressure at each point is a dynamic process, and there is a negative correlation between water pressure and water consumption. With the increase of water consumption, the pressure of water points show a decreasing trend. According to the structure of the pipe network and the location of the water point, the influence degree on the pressure of each point is different.

1. Introduction

Mine dust is one of the major disasters in coal mine, and mine dust control is mainly to rely on water at present. Mine water supply network system is one of the "three lines" of mine safety production guarantee. The water supply network provides important guarantee for mine safety production and rescue and relief work. With the continuous mining, the position of the mining face changes greatly, the mine water supply network is mostly tree-like extension, the dust-proof water consumption of each operating point is also changing. Water supply network as a dynamic system, any change will affect the hydraulic characteristics of the pipe network. In recent years, some scholars have done a lot of work on the similar model of water supply network [1-5]. It is very important to study the variation law of hydraulic characteristics by establishing a similar model of underground dust-proof water supply network, which is very meaningful for the daily pipe network and maintenance of underground dust-proof water supply network.

2. Derivation of Similar Criterion Number

As the mine down a few hundred meters deep underground, the general mine water supply rely on the ground reservoir as static pressure water supply, if necessary, the water pump pressurized supply should be used as auxiliary. The water supply power of the mine water supply network is mainly gravity, and when constructing a similar model, the gravity similarity criterion should be satisfied. The second is to meet the pressure similarity that is consistent with Euler similarity criterion [4,6]. According to the prototype flow and the experimental model flow between the gravitational similarities, the Froude similarity criteria number is equal. The calculation formula is shown as
formula (1) and (2).

\[ Fr = \frac{v^2}{lg} \]  

(1)

\[ Fr_p = Fr_m \]  

(2)

In the formula, \( Fr_p \) and \( Fr_m \) represent the Froude number of the prototype pipe network and the experimental pipe network respectively, \( v \) is the fluid velocity, \( l \) is the length of the pipe, and \( g \) is the acceleration of gravity. Substituting equation (1) into equation (2) could obtain equation (3).

\[ \frac{v_p^2}{l_p g_p} = \frac{v_m^2}{l_m g_m} \]  

(3)

Substituting \( \lambda_v = \frac{v_p}{v_m} \) and \( \lambda_l = \frac{l_p}{l_m} \) into equation (3) yields the similarity of the flow rate \( \lambda_v = \sqrt{\lambda_l} \).

According to the expression, \( Q = Av = \frac{\pi d^2}{4} v \), seeking flow similarity criterion number \( \lambda_Q = \frac{Q_p}{Q_m} = \lambda_d^2 \lambda_v = \lambda_d^2 \sqrt{\lambda_l} \).

According to the pressure similarity, that is consistent with Euler similar, the Euler similarity criteria number is equal. The calculation formula is shown as formula (4) and (5).

\[ E_u = \frac{\Delta p}{\rho v^2} \]  

(4)

\[ E_{u_p} = E_{u_m} \]  

(5)

In the formula, \( E_u \) and \( E_{u_m} \) represent the Euler number of the prototype pipe network and the experimental pipe network respectively, \( \Delta p \) is the pressure difference. Substituting equation (4) into equation (5) could obtain equation (6).

\[ \frac{\Delta p_p}{\rho_p v_p^2} = \frac{\Delta p_m}{\rho_m v_m^2} \]  

(6)

Substituting \( \lambda_{Ap} = \frac{\Delta p_p}{\Delta p_m} \) into equation (6) yields the similarity of the pressure difference \( \lambda_{Ap} = \lambda_v^2 = \lambda_l \).

Therefore, the mine dust-proof water supply network to determine the number of independent similar
criteria with $\lambda_l$, $\lambda_d$, $\lambda_v = \sqrt{\lambda_l}$, $\lambda_Q = \lambda_d^2 \sqrt{\lambda_l}$, $\lambda_p = \lambda_l$.

3. Establishment of Similar Experimental Model for Water Supply Network

The similar experimental model of water supply network is derived from the underground water supply network of a coal mine in Kailuan Group. After the water supply network is properly simplified, there are 28 nodes and 27 pipe sections, information map of underground water supply network system is shown in figure 1.

![Information map of underground water supply network system](image)

**Figure 1.** Information map of underground water supply network system

The mine dust-proof water supply network pipe length range from 5m to 780m, there are three diameter, φ159mm, φ108mm, φ60mm. According to the metamorphosis similarity, the similarity of the tube length is chosen $\lambda_l = 100$, the maximum length of the experiment is $l_{\text{max}} = 780/100 = 7.8$ m. Select the field diameter φ159mm, φ108mm, φ60mm corresponding to the experimental model diameter φ40mm, φ32mm, φ25mm, the average guideline similarity criterion is $\lambda_d = 3.25$. Then calculate flow rate similarity, $\lambda_v = 10$; flow similarity, $\lambda_Q = 105.6$; pressure difference similarity, $\lambda_p = 100$. Water supply network experimental model is shown in figure 2, water supply network experimental model Three-dimensional scene is shown in figure 3.
4. Experimental Results and Analysis

Based on the experimental model of water supply network, the water consumption and pressure of each point are studied. The change of water point parameters with time is analyzed. Specific experimental content is as follows.

(1) According to the water demand data of each water point in different periods of mine, the water demand is similar to the experimental flow rate, in the experimental pipe network model; the pressure value of each water point is changed with 24 hours a day.

(2) In order to study the influence of the change of water point on the pressure, select the normal water supply period; change the water pressure of some water points in the pipe network to get the change law of other water pressure values.

4.1 Results of Water Pressure and Water consumption with Time

The water consumption of different faces is not equal according to the operation process. Generally speaking, the water consumption of the fully mechanized face is larger than the heading face, and the water consumption of the heading face is higher than the development face. In addition, the water consumption in the same working face varies with time because of the different operating procedures. Based on production requirements, the 24-hour operation class is divided into two or three classes, in the maintenance class, the water consumption is small, and the working class uses the largest amount
of water. Actual water consumption of different working faces at 24 hours is shown in figure 4.

![Figure 4. Actual water consumption for different working faces at 24 hours](image)

The mine is divided into three classes every day, including a maintenance class and two operating classes, 0: 00 ~ 7: 00 for the maintenance class, 7: 00 ~ 15: 00 and 15: 00 ~ 23: 00 for the operating class. During the maintenance class, the amount of dust produced is very small; the water consumption is small, the water demand range from 0 to 3.26 m$^3$/h. During the operation class, the water consumption of the working face reach the peak value, and the water consumption of the development face is 5.65 m$^3$/h, the heading face is 11.72 m$^3$/h, fully mechanized face is 26.51 m$^3$/h. In the shift, there will be a short period of fluctuation in water consumption and the water consumption fluctuation during 6: 00 ~ 7: 00 and 15: 00 ~ 16: 00 will be obvious.

The similar flow rate is obtained after the actual water demand through the flow similarity. In the experimental model, the water pressure is measured at different time. In the course of the experiment, the similar flow rate is smaller; the pressure value of the water point is not obvious when the water consumption is adjusted. In order to study the change of the pressure value of each water point with time, the experiment shows that all the water consumption in the model experiment is increased by 10 times and has no effect on the result. In the experimental model, the similar water consumption of the development face is 0.535 m$^3$/h, and the heading face is 1.1 m$^3$/h, fully mechanized face is 2.51 m$^3$/h. In the experimental model, the pressure of each water point at different time is obtained, and the trend of water pressure at different time is shown in figure 5.
4.2 Experimental results of the effect of water consumption on pressure

In the experimental model, there are 10 water points, four development faces, four fully mechanized faces and two heading faces. Because there are more water points in the experimental model, a representative point of water is selected for research. In this experiment, 1# water point is selected as an example to study the normal water supply in the operation class. The influence of water pressure on the remaining operating points is studied by changing the water quantity of the water point. The variation curve of water pressure with the flow of 1# is shown in figure 6.

![Variation curve of water pressure with the flow of 1#](image)

Figure 6. The variation curve of water pressure with the flow of 1#
5. Conclusion

(1) Based on the similarity theory, combined with the actual situation and laboratory conditions, the similarity criterion number is determined and a similar experimental model of water supply network is established.

(2) In the maintenance class, the pressure value of each water point is the same as the static pressure, then, the water point pressure value is rapidly reduced with the various work. The pressure value produces small fluctuations that decrease after the first increase in the shift between two classes. The water pressure at each point is a dynamic process, and there is a negative correlation between water pressure and water consumption.

(3) With the increase of water consumption, the pressure of water points showed a decreasing trend. According to the structure of the pipe network and the location of the water point, the influence degree on the pressure of each point is different. With the change of water consumption, there is a larger impact of water pressure near the water point.

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