Study on optimal start-up time and water usage volume of blowdown residue discharge of mesh filter

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ABSTRACT

The water volume used for blowdown of a mesh filter is one of the important indicators to evaluate the economic benefit of a mesh filter. The amount of water used for drainage of the mesh filter can be controlled by setting the start-up time of the blowdown residue discharge of the mesh filter. Through the indoor prototype test, the sediment of the Manas riverbed in Xinjiang, China, was used as the filter medium to test the mesh filter and analyze the water usage volume at each stage. The test focused on the analysis of the trend of the pressure difference between the inlet and outlet of the mesh filter over the filtration time. The results showed that as the filtration time was prolonged, the inlet and outlet pressure difference of the mesh filter showed an S-shaped curve with time. The pressure difference between the inlet and outlet can be divided into four stages, i.e., the start of filtering to the first inflection point of the abrupt change in the pressure difference, the first inflection point of the abrupt pressure difference change to the median point of filtering, the median point of filtering to the second inflection point of the abrupt change in the pressure difference, and the second inflection point of the abrupt pressure difference change to the end of filtering. At the same time, the water usage volume for blowdown was calculated under various working conditions. This paper analyzed the start-up time of blowdown at three different time points, i.e., after the completion of the entire filtration cycle of the traditional mesh filter, at the first inflection point of pressure difference, and at the second inflection point of pressure difference. The tests were performed under the condition that the filtration cycle of the mesh filter was ten days. The results have shown that compared with the traditional screen filter that starts the blowdown at the end of the entire filtration cycle, starting the blowdown at the first inflection point of pressure difference can save 200–300 m³ of water resources for a single mesh filter, and starting the blowdown at the second inflection point of pressure difference can save 30–90 m³ of water resources for a single mesh filter. Meanwhile, the working conditions in the analyses in this paper were consistent with the actual engineering operating conditions. It is recommended that the mesh filter in the micro-irrigation system use the first inflection point of pressure difference to control the start-up time of the blowdown residue discharge, which can not only save water resources, but also ensure that the mesh filter runs at the optimal filtering conditions.

Key words | inflection point of inlet and outlet pressure difference, mesh filter, S-shaped growth, start-up time of blowdown residue discharge, water usage volume of blowdown residue discharge

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HIGHLIGHTS

- The study analyzed the change rule of the inlet and outlet pressure difference over time during the entire filtration stage of the mesh filter.
- The research focused on analyzing the water usage volume when the blowdown was started at different filtration time points.

GRAPHICAL ABSTRACT

PREFACE

Water resources are an irreplaceable basic element in agricultural development, but the current shortage of water resources restricts the sustainable development of agricultural production (Hamududu & Ngoma 2020; Kulmatov et al. 2020; Li et al. 2020). Water conservation and efficient use of water resources have become the common goal of the world’s agricultural development (de Vito et al. 2019). Micro-irrigation is an important technology for saving water resources for agricultural irrigation, and provides a strong technical prerequisite for the development of water-saving irrigation. As the core component of the micro-irrigation system, the filter mainly serves to remove mud particles and other suspended impurities from muddy water sources (Zong et al. 2015). Since the mesh filter has the advantages of good filtering effect, simple cleaning method and good cleaning effect, it has a wide range of applications. The studies on mesh filter have been focused on two key research directions, i.e., filtration process and cleaning process of mesh filters. Many scholars have studied the pressure difference of the filter during the filtration process, and the results have shown that the filter pressure difference is related to the inlet water flow, the sand content of the inlet water and the porosity of the filter mesh. In addition, the pressure difference between the inlet and outlet shows exponential change with time (Duran-Ros et al. 2010; Elbana et al. 2015; Bové et al. 2015; Bounoua et al. 2016). Secondly, models such as Gaussian process regression (GPR) have been applied to study the filters. The GPR model was used to establish a predictive model to predict the dissolved oxygen of the wastewater during the filtering process, analyze the turbidity of the effluent under different working conditions of the filter, and analyze the best parameters through regression (García–Nieto et al. 2020a, 2020b). Based on the artificial neural network (ANN), gene expression programming (GEP) and multivariable linear regression (MLR) models, Martí et al. used the test...
data of 769 filtration cycles to estimate dissolved oxygen content. The predicted results were consistent with the test results and the previously published results (Martí et al. 2013; García-Nieto et al. 2016). Mesquita et al. (2019) designed the diffuser and evaluated its hydraulic performance based on computational fluid dynamics (CFD) numerical simulation technology to maximize hydrodynamic efficiency (Mesquita et al. 2019). Meanwhile, research on backflush in the blowdown residue discharge stage is also a main research angle. The test method was used to measure the backflush time of the filter, and the backwashing process was studied by combining the backflush efficiency and the backflush pressure difference (Elbana et al. 2012; Zong et al. 2019). At the same time, some scholars proposed a hydraulic characterization method for the filter backflush process to evaluate the influence of sediment elements on filter design in micro-irrigation (de Deus et al. 2020). Many research results have been obtained on the mesh filter and have shown that the pressure difference between the inlet and outlet of the mesh filter has a consistent trend over time. However, there have been only few systematic theoretical studies on the trend of the pressure difference between the inlet and outlet of the mesh filter over time, the optimal start-up time of the filter’s blowdown, and the required water volume for blowdown. Furthermore, the relationship between the pressure difference of the mesh filter and the amount of clogged impurities in the pores has rarely been studied. The clogging of impurities further determines the water usage volume of the mesh filter during blowdown, which in turn determines the economic benefit of the filter. Therefore, this paper took a commonly used micro-irrigation mesh filter as the research object, focused on the trend of the pressure difference between the inlet and outlet over time under different working conditions, and studied the inflection point of the pressure difference curves. Moreover, the required water volume for blowdown residue discharge was studied under various operation conditions. The required water volumes for blowdown were compared and analyzed when the blowdown was applied at different time points (including traditionally at the end of the entire filtration cycle and at the inflection points). Based on the results, the optimal blowdown start-up time of the mesh filter was determined. At this optimal start-up time, the mesh filter can operate under the best economic efficiency and the optimal working conditions.

FILTER STRUCTURE AND WORKING PRINCIPLE

The mesh filter is mainly composed of filter housing, a filtering device, a blowdown device and a blowdown-starting control device. The working principle diagram is shown in Figure 1 within which, Figure 1(a) is the working principle diagram of a vertical mesh filter, and Figure 1(b) is the working principle diagram of a horizontal mesh filter. The filter design parameters are shown in Table 1. The apertures of the filters used in this test were 0.25 mm, 0.20 mm, and 0.16 mm. The working principle of the mesh filter is as follows: during the filtering process, the sand-containing water for irrigation enters the water inlet of the filter and is filtered from the inside to the outside through the filter. Large particles of silt impurities and organic impurities are intercepted by the filter. Impurity particles with a size smaller than the pore of the filter screen and filtered clean water enter the designated irrigation system. When the pressure difference between the inside and outside of the filter

Figure 1 | Working principle diagram of (a) the vertical mesh filter and (b) the horizontal mesh filter: ① fine filter; ② water inlet; ③ precision electronic pressure gauge; ④ water outlet; ⑤ filter housing; ⑥ coarse filter; ⑦ sewage outlet.
reaches the optimal start pressure difference for blowdown, the blowdown process is initiated to complete the filter cleaning work, and then the next filtration cycle is initiated. In the discharge process, the water carries the sediment impurities from the discharge pipe to the designated sedimentation system, and the mesh-filtered water continues to enter the irrigation water source for irrigation, avoiding the waste of water resources.

TEST DEVICE AND TEST METHOD

Test device

In this test, a universal micro-irrigation mesh filter produced by Shihezi Tianlu Water Saving Equipment Co., Ltd, Xinjiang, China, was used. The diagram of the test device is shown in Figure 2.

Test equipment

The test equipment is summarized in Table 2.

![Figure 2](http://iwaponline.com/ws/article-pdf/doi/10.2166/ws.2020.262/820818/ws2020262.pdf)

| Parameter category            | Specification (mm) |
|-------------------------------|--------------------|
| Inlet diameter                | 150                |
| Outlet diameter               | 150                |
| Filter housing diameter       | 420                |
| Filter mesh diameter          | 360                |
| Import and export height difference | 400            |

Test methods and steps

The test device was installed and debugged according to Figure 2. This experiment used the orthogonal experiment method to arrange the experiment groups. Each experiment was conducted twice, and the average of the two tests was taken as the experiment result. The optimal flow rate of the commonly used mesh filter is in the range of 180–220 m³/h. Thus, in this test, the inlet water flow rate was set to 180 m³/h, 200 m³/h, and 220 m³/h, respectively. In order to allow enough time for the test to take water samples without prolonging the test time, the influent sand contents were set to four values, which were 0.045 g/L, 0.068 g/L, 0.082 g/L, and 0.125 g/L, respectively. During the filtering process, the artificially mixed riverbed sand was uniformly added to the sedimentation tank, and the water samples were taken at the inlet and outlet of the filtration system every five minutes. The purpose of this test is to determine the change of the pressure difference between the inlet and the outlet after reaching the peak value, so the filtration time should be appropriately extended after the pressure difference reaches the peak value. The blowdown process was initiated immediately after the filtration process was completed. After the filter screen was cleaned, the next filtration process was initiated. After the filtration and blowdown processes were completed, the sand content of the connected water sample was measured to complete all the tests. In this test, a reservoir was used to store and supply water for the filter. The water source of the reservoir was obtained by extracting groundwater. The water source did not contain organic impurities or suspended impurities, and its turbidity was less than 0.3NTU. The sieved sediment impurities were added uniformly at the junction of the reservoir and the water inlet of the filter. This test mainly studies the working conditions in which the inlet water only contains sediment impurities, because in the actual project, organic impurities and suspended impurities can be filtered by first-level system filtering and do not enter the filter.

Gradation of sand particles in the test

Studies have shown that the physical properties of the filter media such as bulk density, actual density, porosity and...
sphericity have a certain impact on the performance of the filter. But the size and gradation of particles have more significant effect on the filter performance. Thus in this study, the riverbed sand of the Manas River Basin in Xinjiang Uygur Autonomous Region was used as the filter medium, and the particle gradation of the medium was analyzed. Through the particle size screening test, particles with a particle size smaller than 0.25 mm accounted for 30% of the total sediment, particles with a particle size smaller than 0.20 mm accounted for 25% of the total sediment, and particles with a particle size smaller than 0.16 mm accounted for 20% of the total sediment of the sand.

THEORETICAL ANALYSES OF PRESSURE DIFFERENCE AND WATER USAGE FOR BLOWDOWN

Theoretical analysis of pressure difference

The change of the pressure difference of the mesh filter with time was mainly affected by the filtration flow rate. The change of pressure difference was positively correlated with the quadratic square of the filtration flow rate. Filter clogging can be mainly divided into two stages, i.e., the clogging of the filter pores and the clogging of the inner surface of the filter. When the filter is completely clogged, the pressure difference between the inlet and outlet of the filter reaches the peak value. From analyzing the relevant results, the increase in pressure difference with filtration time during the filtration process is approximately exponentially increasing with time. When the pressure difference peak is reached, the filtration time is appropriately extended, and the change curve is approximately S-shaped. Origin was used to fit the pre-test multi-group test results, and the satisfied functional relationship is shown in Equation (1):

\[ f(x) = \frac{A_1 - A_2}{1 + e^{\alpha x}} + A_2 \]  

(1)

where \( A_1 \) is the initial value, \( A_2 \) is the final value, \( x_0 \) is the center, and \( dx \) is a constant.

The mathematical expression of the filter pressure difference of the mesh filter with the filter time can be shown in Equation (2):

\[ \Delta P = \frac{P_1 - P_2}{1 + e^{\alpha (t - t_0)}} + P_2 \]  

(2)

where \( P_1 \) is the initial value of the pressure difference (m), \( P_2 \) is the final value of the pressure difference (m), \( t_0 \) is the center (s), \( \alpha \) is a constant, \( \Delta P \) is the pressure drop of the filter (m), and \( t \) is the filtration time (s).

Analysis of required water volume for blowdown

The change in the pressure difference between the inlet and outlet of the mesh filter is mainly caused by the accumulation of impurities in the mesh. The clogging of the mesh can be divided into two main stages, i.e., clogging of the pores and clogging of the inner surface of the mesh. When the clogging on the surface of the mesh reached a certain thickness, the pressure difference between the inlet and outlet of the filter reached the peak value. Therefore, in the first stage, the pores of the mesh filter were blocked,
and only particles larger than the mesh were blocked inside the mesh surface. The interior of the mesh was calculated according to the principle of standard screening and mass conservation. The mathematical expression of the mass of the clogged impurities is shown in Equation (3):

\[
M_1 = S_1 \times Q_1 \times t_1 \times \gamma
\]  

where \(M_1\) is the amount of blocked sand in the filter screen during the clogging stage (kg), \(S_1\) is the influent sand content (g/L), \(Q_1\) is the influent filtration flow rate (m\(^3\)/h), and \(t_1\) is the time to reach an inflection point (s), and \(\gamma\) is the percentage of impurities greater than the pore size of the filter.

In the second stage, the clogging process was completed on the surface of the filter screen, that is, all particles were clogged inside the filter screen. The mathematical expression of the amount of clogged sand is shown in Equation (4):

\[
M_2 = S_1 \times Q_1 \times (t_1 - t_2)
\]  

where \(M_2\) is the amount of sand clogged inside the filter during the clogging stage (kg), and \(t_2\) is the time to complete the filtration (s).

The principle of the blowdown of the mesh filter is mainly to use water flow to discharge sediment. The calculation expression of the single discharge time is shown in Equation (5):

\[
t_2 = \frac{M}{S_1 Q_2}
\]  

where \(t_2\) is the single blowdown time (s), \(M\) is the total amount of clogged impurities (kg), \(S_1\) is the sediment carrying capability (g/L), and \(Q_2\) is the blowdown flow rate (m\(^3\)/h).

According to calculation of the sediment carrying capacity of the water in the pressure irrigation pipe, the sediment carrying capacity of the pressure irrigation pipe flow can be calculated by Equation (6):

\[
S_s = \frac{\lambda v^2}{0.000023 \omega \omega^2 \cdot 8g}
\]  

where \(v\) is the average flow velocity of the pipe flow (m/s), \(g\) is the acceleration of gravity (m/s\(^2\)), and \(\omega\) is the average sedimentation velocity of the sediment (mm/s).

The filter material is steel pipe or cast iron, and the drag coefficient along the pipeline can be calculated by Equation (7):

\[
\lambda = \frac{0.02164}{d^{0.1}}
\]  

where \(d\) is the pipe diameter (m).

The consumed water volume by the mesh filter is shown in Equation (8):

\[
V = Q_2 \times t_2 \times \beta
\]  

where \(\beta\) is the number of blowdowns in a filtration cycle.

**TEST RESULTS AND ANALYSIS**

**Test results**

Under various sandy soil conditions, the mesh filters with the apertures of 0.25 mm, 0.20 mm and 0.16 mm were tested. These filters are commonly used in field micro-irrigation. The trends of the pressure difference between the inlet and outlet (\(\Delta P\)) of the mesh filter over the filtration time (\(t\)) of four different sand content conditions were plotted, as shown in Figures 3, 4, and 5.

**Analysis of test results**

Through orthogonal test analysis, when the sediment content in the inlet water was constant, the pressure difference between the inlet and outlet changed with time in the same pattern, showing an S-shaped growth trend. Each curve can be divided into four parts, i.e., the beginning of the test to the first inflection point of the sudden change in the pressure difference, the first inflection point of the sudden change in pressure difference to the median point of filtering, the median point of filtering to the second inflection point of the sudden change in pressure difference, and the second inflection point of the sudden change in pressure.
difference to the end of filtering. In the first stage, the pressure difference between the inlet and outlet of the mesh filter basically remained unchanged. In the second stage, the pressure difference between the inlet and outlet of the mesh filter changed at an accelerating rate with time, and the pressure difference between the inlet and outlet increased sharply. In the third stage, the changing rate of the pressure difference between the inlet and outlet of the mesh filter slowed down, and the pressure difference increased slowly. In the fourth stage, the pressure difference increased slowly.
reached the peak value, and the pressure difference between the inlet and outlet of the mesh filter did not increase with time. Based on the analysis of the filtering principle of the mesh filter, the mesh filter clogging can be divided into two stages, i.e., clogging of the mesh filter pores and clogging of the mesh surface. Combining with the analysis of the curves in Figures 3–5, the clogging of the filter pores was almost completed at the first inflection point of the pressure difference, and it was difficult for the impurities of small particles to pass through the filter pores. Then the surface clogging of the filter started. When the second inflection point of the pressure difference was reached, the pores and the surface of the filter were completely clogged, and the contaminated water could not be filtered. At this time, the pressure difference of the filter screen reached the peak value. Origin was used to fit the raw data in each group using Equation (2), and the fitting correlation was higher than 99%. Therefore, it is considered that Equation (2) has a high correlation and can be used to calculate the pressure difference of similar types of network filters.

**Water usage analysis**

Under different working conditions, the water usage volumes by the mesh filter at three time points, i.e., the first inflection point of the pressure difference, the second inflection point of the pressure difference, and the start of blowdown residue discharge at the end of the filtration phase, were calculated based on the filtration test results. Taking a ten-day filtration cycle as the research object, the water usage in one filtration cycle was investigated at the flow rate of 180 m³/h. The analysis focused on the time of single blowdown (t₂), the total number of blowdowns (β), the total time of the blowdowns (T), and the cumulative water volume for all the blowdowns (V) over the ten-day test cycle. The predicted results are shown in Tables 3–5.

Tables 3–5 show that when the screen clogging stage starts, the total mass of clogged sediment impurities rapidly increases. In addition, the required water volume for blowdown increases with the increase of the total mass of clogged sediment impurities inside the screen. As the mesh number of the filter increased, that is, the impurities smaller than the pore size of the filter accounted for a higher portion, the amount of the clogged sand in the filter increased, and the filtration time was shortened. As a result, more blowdowns were needed in the entire filtration cycle of the filter and the required water volume for blowdown was increased. When the inlet water flow rate was 180 m³/h, the maximum water usage for blowdown was 1,476 m³ at the
first inflection point, 1,656 m³ at the second inflection point, and 1,698 m³ at the end of the filtration cycle. When the inlet water flow rate was 200 m³/h, the maximum water usage for blowdown was 1,641 m³ at the first inflection point, 1,888 m³ at the second inflection point, and 1,947 m³ at the end of the filtration cycle. When the inlet water flow rate was 220 m³/h, the maximum water usage for blowdown was 1,805 m³ at the first inflection point, 2,092 m³ at the second inflection point, and 2,129 m³ at the end of the filtration cycle. Therefore, when blowdown

Table 3 | Analysis of water usage for blowdown at the filter aperture of 0.25 mm in 10 days

| Q1 (m³/h) | S1 (g/L) | t1 (s) | t1 (s) | τ (s) | V (m³) | t2 (s) | t2 (s) | τ (s) | V (m³) | t3 (s) | t3 (s) | τ (s) | V (m³) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180 | 0.045 | 11.15 | 835 | 9,305 | 465 | 30.61 | 376 | 11,498 | 575 | 39.84 | 298 | 11,498 | 575 |
| 180 | 0.068 | 14.65 | 960 | 14,060 | 705 | 35.57 | 480 | 17,073 | 854 | 52.31 | 411 | 21,523 | 1,076 |
| 180 | 0.082 | 15.31 | 1,108 | 16,955 | 848 | 41.10 | 508 | 20,888 | 1,044 | 56.60 | 576 | 32,603 | 1,630 |
| 200 | 0.045 | 11.68 | 885 | 10,338 | 517 | 34.31 | 376 | 12,889 | 644 | 42.86 | 309 | 13,225 | 661 |
| 200 | 0.068 | 15.41 | 1,014 | 15,623 | 781 | 37.31 | 508 | 18,962 | 948 | 52.81 | 376 | 19,838 | 992 |
| 200 | 0.082 | 16.66 | 1,131 | 18,839 | 942 | 45.81 | 508 | 23,284 | 1,164 | 64.50 | 376 | 24,231 | 1,099 |
| 220 | 0.045 | 12.49 | 910 | 11,372 | 569 | 22.85 | 576 | 13,163 | 658 | 34.13 | 411 | 14,044 | 702 |
| 220 | 0.068 | 15.32 | 1,122 | 17,185 | 859 | 41.74 | 508 | 21,214 | 1,061 | 55.95 | 393 | 21,972 | 1,099 |
| 220 | 0.082 | 15.40 | 1,346 | 20,723 | 1,036 | 44.80 | 576 | 25,803 | 1,290 | 61.93 | 432 | 26,753 | 1,338 |
| 220 | 0.125 | 19.86 | 31,590 | 1,638 | 54.82 | 720 | 35,897 | 1,795 | 66.31 | 540 | 37,179 | 2,046 |

Table 4 | Analysis of water usage for blowdown at the filter aperture of 0.20 mm in ten days

| Q1 (m³/h) | S1 (g/L) | t1 (s) | t1 (s) | τ (s) | V (m³) | t2 (s) | t2 (s) | τ (s) | V (m³) | t3 (s) | t3 (s) | τ (s) | V (m³) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180 | 0.045 | 10.27 | 971 | 9,969 | 498 | 24.27 | 480 | 11,649 | 582 | 33.50 | 360 | 12,060 | 603 |
| 180 | 0.068 | 11.77 | 1,280 | 15,065 | 753 | 27.46 | 640 | 17,575 | 879 | 37.92 | 480 | 18,203 | 910 |
| 180 | 0.082 | 12.62 | 1,440 | 18,166 | 908 | 29.44 | 720 | 21,194 | 1,060 | 40.65 | 540 | 21,951 | 1,098 |
| 180 | 0.125 | 13.46 | 2,057 | 27,692 | 1,385 | 33.97 | 960 | 32,615 | 1,631 | 42.52 | 785 | 33,399 | 1,670 |
| 200 | 0.045 | 10.41 | 1,064 | 11,077 | 554 | 24.05 | 537 | 12,907 | 645 | 37.56 | 540 | 13,520 | 676 |
| 200 | 0.068 | 11.82 | 1,708 | 20,185 | 1,009 | 31.94 | 617 | 19,712 | 986 | 47.44 | 432 | 20,493 | 1,025 |
| 200 | 0.082 | 11.82 | 1,708 | 20,185 | 1,009 | 28.89 | 820 | 23,683 | 1,184 | 45.90 | 540 | 24,785 | 1,239 |
| 200 | 0.125 | 14.60 | 2,107 | 30,769 | 1,538 | 37.87 | 960 | 36,353 | 1,818 | 52.11 | 720 | 37,521 | 1,876 |
| 220 | 0.045 | 10.51 | 1,160 | 12,185 | 609 | 26.58 | 540 | 14,355 | 718 | 37.87 | 540 | 14,871 | 744 |
| 220 | 0.068 | 12.57 | 1,464 | 18,412 | 921 | 32.75 | 665 | 21,764 | 1,088 | 44.11 | 508 | 22,420 | 1,121 |
| 220 | 0.082 | 12.90 | 1,721 | 22,203 | 1,110 | 33.39 | 785 | 26,227 | 1,311 | 47.10 | 576 | 27,127 | 1,356 |
| 220 | 0.125 | 13.91 | 2,434 | 33,846 | 1,692 | 42.37 | 960 | 40,678 | 2,034 | 58.04 | 720 | 41,791 | 2,090 |
was started at the first inflection point of the pressure difference, although the number of blowdowns was increased, the overall water volume used for blowdown decreased by 200–300 m$^3$ in one filtration cycle. Considering the short duration of the filtration time, the total discharge of irrigation water is much larger than the total volume of backwashing water. Therefore, in the analysis of the water usage in the blowdown process, the relationship between the blowdown water usage and the total flow of irrigation water was not considered and the relationship should not affect the economy of the blowdown process. By converting the ten-day filtration cycle accordingly, the analysis in this paper can be applied to actual projects with different filtration cycles.

**DISCUSSIONS**

The pressure difference between the inlet and outlet of the mesh filter is mainly caused by the clogging of the pores and the inner surface of the filter. As the clogging continues, the pressure difference between the inside and outside of the filter gradually increases. When the filter is completely clogged, the pressure difference between the inlet and outlet of the filter screen reaches the peak value, and normal filtration cannot be performed. In the actual projects and in many studies, the starting point of the blowdown of the filters was set at the second inflection point of the pressure difference. In this study, the trend of the pressure difference between the inlet and outlet during filtration was used to control the network. The water usage for blowdown was analyzed when the filter was activated at the first inflection point of pressure difference and the second inflection point of pressure difference. Before the first inflection point of pressure difference, the pores of the mesh filter screen were gradually clogged. The sediment impurities entering the filter inlet did not completely accumulate on the inner surface of the filter. Instead, only impurities larger than the pore size of the filter accumulated on the inner surface of the filter. If blowdown was initiated at this time, due to the large particle size of the impurity particles and the small cohesion force, the required sand-carrying force for blowdown was small. Thus the impurities can be transported to the outside of the filter screen to complete the blowdown within a short time. The inner surface of the filter screen was mainly blocked between the first inflection point of pressure change and the second inflection point of pressure difference. During this period, the sediment entering the filter inlet accumulated on the inner surface of the filter, and impurities with a particle size

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**Table 5 | Analysis of water usage for blowdown at the filter aperture of 0.16 mm in ten days**

| $Q_1$ m$^3$/h | $S_1$ g/L | $t_1$ s | $s_1$ | $T_1$ s | $V_1$ m$^3$ | $Q_2$ m$^3$/h | $S_2$ g/L | $t_2$ s | $s_2$ | $T_2$ s | $V_2$ m$^3$ | $Q_3$ m$^3$/h | $S_3$ g/L | $t_3$ s | $s_3$ | $T_3$ s | $V_3$ m$^3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180 | 0.045 | 10.26 | 1,036 | 10,634 | 532 | 18.97 | 617 | 11,709 | 585 | 25.13 | 480 | 12,061 | 603 | 200 | 0.045 | 9.41 | 1,256 | 11,815 | 591 | 19.87 | 665 | 13,206 | 660 | 35.38 | 960 | 35,969 | 1,698 |
| 180 | 0.068 | 8.59 | 1,870 | 16,069 | 805 | 25.75 | 720 | 18,540 | 927 | 36.93 | 617 | 22,789 | 1,139 | 200 | 0.068 | 9.40 | 1,899 | 17,854 | 893 | 25.03 | 815 | 20,402 | 1,020 | 41.56 | 508 | 21,123 | 1,056 |
| 180 | 0.125 | 12.31 | 2,400 | 29,538 | 1,476 | 26.84 | 1,234 | 33,125 | 1,656 | 35.38 | 960 | 35,969 | 1,698 | 200 | 0.125 | 10.52 | 3,119 | 32,821 | 1,641 | 30.61 | 1,234 | 37,779 | 1,889 | 49.60 | 785 | 38,959 | 1,948 |
| 200 | 0.045 | 9.41 | 1,256 | 11,815 | 591 | 19.87 | 665 | 13,206 | 660 | 35.38 | 960 | 35,969 | 1,698 | 220 | 0.045 | 9.36 | 1,389 | 12,997 | 650 | 22.11 | 665 | 14,692 | 735 | 31.51 | 480 | 15,123 | 756 |
| 200 | 0.068 | 9.32 | 2,107 | 19,640 | 982 | 26.08 | 864 | 22,537 | 1,127 | 40.29 | 576 | 23,208 | 1,160 | 220 | 0.068 | 9.32 | 2,107 | 19,640 | 982 | 26.08 | 864 | 22,537 | 1,127 | 40.29 | 576 | 23,208 | 1,160 |
| 220 | 0.082 | 9.26 | 2,556 | 23,683 | 1,184 | 28.52 | 960 | 27,381 | 1,369 | 42.23 | 665 | 28,065 | 1,403 | 220 | 0.082 | 9.26 | 2,556 | 23,683 | 1,184 | 28.52 | 960 | 27,381 | 1,369 | 42.23 | 665 | 28,065 | 1,403 |
| 220 | 0.125 | 10.61 | 3,402 | 36,103 | 1,805 | 33.91 | 1,234 | 41,853 | 2,093 | 44.36 | 960 | 42,581 | 2,129 | 220 | 0.125 | 10.61 | 3,402 | 36,103 | 1,805 | 33.91 | 1,234 | 41,853 | 2,093 | 44.36 | 960 | 42,581 | 2,129 |
smaller than the pore size of the filter failed to pass through the filter. Due to the accumulation of smaller particles with higher viscosity on the inside of the filter screen, the adhesion of the impurities inside the filter screen was greatly increased. If blowdown was initiated at this time, the transport of impurities took a longer time. At the same time, the pressure difference and drainage characteristics of the filter in related studies are consistent with the conclusions of this article. Therefore, the water usage for the blowdown of the mesh filter can be calculated by Equation (8). Starting the blowdown of the mesh filter at the first inflection point of pressure difference can save water usage by the filter and ensure that the filter is running under the optimal filtering condition.

CONCLUSIONS

(1) The pressure difference between the inlet and outlet of the mesh filter showed a consistently S-shaped growth trend over time. Each curve can be divided into four stages, i.e., the beginning of the test to the first inflection point of the pressure difference, the first inflection point of pressure difference to the median of filtering, the median point of filtering to the second inflection point of pressure difference, and the second inflection point of pressure difference to the end of filtering. Equation (2) was used to fit and calculate the trend of the pressure difference between inlet and outlet over time with a fitting degree higher than 99%. Thus Equation (2) can be regarded as a highly accurate mathematical expression of the pressure difference of this mesh filter type.

(2) Through the analysis of the mass conservation principle and the variation law of the pressure difference between the inlet and the outlet, the mathematical expression of the water usage for the blowdown of the mesh filter was obtained. Equation (8) was used to calculate the number of blowdowns and the required water volume for blowdown under different conditions when the blowdown was started at three time points, i.e., the first inflection point of the pressure difference, the second inflection point of pressure difference, and the completion of the entire filtration cycle.

(3) When the blowdown was started at the first inflection point of pressure difference, the number of blowdowns increased but the overall water usage for blowdown decreased. Compared with starting blowdown after the entire filtration process was completed, the water usage volume was smaller when the blowdown was started at the first inflection point of pressure difference. Starting the blowdown at the first inflection point, a single filter can save 200–300 m$^3$ of water on average in each filtration cycle of ten days. Therefore, starting the blowdown at the first inflection point can ensure that the mesh filter saves water resources and always runs under optimal conditions.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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