Turbidity Removal of Landscape Water by Filtration Bed with Suspended Media

B H Zhang¹, Y X Ren¹*, H Liu², D Guo¹ and Y H Shao¹

¹School of Environment and Municipal Engineering, Xi’an University of Architecture and Technology, Xi’an, China
²College of Architecture, Xi’an University of Architecture and Technology, Xi’an, China
ryx@xauat.edu.cn

Abstract. High turbidity seriously affects the landscape effect of urban landscape water. In order to explore the turbidity removal effect of filtration bed with suspended media materials on landscape water, a filtration test was carried out with Xinhua river in Fengxi new city. The results showed that the filter bed had an effective and reliable removal performance on turbidity and suspended solids in landscape water. The turbidity removal rates were 44.50%-77.24%, and the suspended solid removal rates were 50.37%-78.85%. The use of expanded polystyrene filter media material and upward flow direction got higher remove effect of the turbidity. Suspended solid particles with size less than 100 μm is the limiting factor affecting the treatment effect of the filter bed, and the expanded polystyrene filter material had a better removal effect on the particulate matter in this range. On the premise of ensuring the treatment effect, the filter bed with suspended media has the advantages of low backwash energy consumption and long filtration period, therefore, it is suitable to be used as the pre-treatment unit of landscape water treatment project.

1. Introduction

Recently, landscape water has become an important part of urban water environment. However, in some areas, the landscape water represented by river water contains lots of sediment, which leads to the increase of turbidity and the deterioration of transparency of water body, and the reduction of landscape function.

Sedimentation and filtration are common methods to remove turbidity in water. The settlement method can achieve a good turbidity removal effect in the case of coagulant, but it also has limited efficiency and generally covers a large area. Hence, it is hard to treat a continuous flow of water or landscape water body on a large scale. As a widely-used and effective water treatment technology, filtration can satisfy the demands of landscape water turbidity removal reliably, but it also has the disadvantages of complex structure, difficult management and high energy consumption of backwashing.

Suspended filter technology overcomes above issue to some extent, because it uses a lightweight filter material that can be suspended in water. In such a filter bed, the filter media materials are compressed by buoyancy and stacked together to form a filtering layer, which has a similar internal characteristic compare with filtering layers of heavy material that formed by gravity[1]. The smaller filter material density reduces the energy consumption of filter media material flushing and the operation difficulty of the filtration process. Tian[2] applied suspended filter materials in surface water...
plants, and the turbidity of effluent was 0.5-2.0 NTU. Yin[3] used self-made light ceramsite as suspension filter material and Guangzhou LiuXi River water as raw water, the turbidity removal rate reached 31.5%-40.5%. The application cases of suspended filter media material filtration are increasing gradually in recent years.

2. Materials and methods

2.1. Suspended filtering media
The density of the filter material should be controlled below 0.8g/cm³ to ensure that the filter layer can still be suspended in water after retaining certain solid particles. In this experiment, two types of filter material are used, namely expanded polystyrene (EPS) and light ceramsite (Table 1).

| Diameter (mm) | Density (g/cm³) | Other characteristics                           |
|---------------|-----------------|-------------------------------------------------|
| EPS           | 3~5             | 0.02~0.05                                       | Hydrophobic, corrosion resistant, impact resistant |
| Ceramsite     | 3~5             | 0.6~0.8                                         | Rough surface, high hardness, large specific surface area, good microbial compatibility |

2.2. Experimental device.
Figure 1 shows the experimental device. The device is made by PMAA (500mm×200mm×700mm) with inlet valve F1, outlet valve F2 F3 and backwash valve F4. By opening and closing the valve and adjusting the cover plate up and down, the device can change the inlet direction and the suspension height of the filter layer to carry out horizontal-flow or up-flow filtration. When the valve F1 and F3 are opened and F2 is closed, the device is a horizontal-flow filter bed with a filter layer thickness of 400mm, as shown in figure 1(a). When the valve F1 and F2 are open and F3 is closed, the device is an up-flow filter bed with a filter layer thickness of 200mm, as shown in figure 1(b). Raw water from river water is used for backwashing, which is injected through a perforated distribution pipe above the filter layer, and the sludge is discharged by valve F4.

![Figure 1. Experimental device schematic](image)
2.3. Raw water quality

The water used for the test was Xinhe River in Fengxi new city, and the water quality during the test was shown in table 2. Due to the intake of sewage plant tail water and a small amount of coastal sewage, the water quality of the river is generally poor. In addition to high turbidity and suspended particulate matter concentration, it also contains certain organic pollutants. During the rainy season and flood season, the turbidity and SS of the river will further increase.

|          | Turbidity / NTU | SS / mg/L | COD / mg/L | TP / mg/L | TN / mg/L |
|----------|-----------------|-----------|------------|-----------|-----------|
| Normal   | 5.72-55.74      | 10.56     | 50.2-238.5 | 0.31-0.75 | 5.86-10.99|
| Mean     | 35.65           | 21.32     | 141.66     | 0.49      | 8.34      |
| Flood season | >100       | >100      | >150       | >1.5      | >20       |

When the device is running, the river water is first lifted to the high-level water tank by the submersible sewage pump in the riverbed, and then controlled by the ball valve and the rotor flowmeter to enter the small test device with a constant flow. The effective volume of the water tank is 200 L, which is equipped with hydraulic stirring device and water level monitoring probe to control the opening and closing of a water pump. The outlet water sampling interval was 4-6 hours.

3. Results and discussion

3.1. Factors affecting the effect of turbidity and SS removals

The turbidity removal rate of the filter bed is between 44.50% and 77.24%, and the SS removal rate is between 50.37% and 78.85%, as shown in figure 2, the effluent turbidity of the filter bed is less than 10 NTU, and the removal effect of the filter bed was significantly affected by the type of filter material, the direction of the water flow and the filtration rate. The filter bed with up-flow filtration showed better results in the removal of turbidity, and the use of EPS as filter material can intercept more suspended solids in raw water. Besides, it can be seen that the filtration rate of the filter bed is negatively related to its turbidity and SS removal effect generally.
The difference in the density of the filter material is the main factor that affected the turbidity removal rate. EPS is made of small polystyrene granules foamed at high temperature. Thus, it has only 1/50-1/20 the density of water, the resultant force in the vertical direction it receives is greater. This makes the filtering layer have a smaller voidage, which effectively improves the layer's turbidity removal ability[4]. In contrast, the ceramsite has a density far higher than that of the EPS, and the filtering layer has a larger voidage under the same conditions. It can only effectively filter large-diameter suspended particles at the initial stage of filtration. Therefore, the filter bed with EPS filter material has lower turbidity and SS concentration of the effluent. The flow direction also affected the turbidity removal rate of the filter bed. In horizontal-flow filter bed, there is a horizontal thrust of water in the filtering layer, which causes friction between the filter materials. As a result, suspended particles that have been trapped in the horizontal-flow filter bed may detach from the surface of the filter material under the action of flow shear force. Moreover, high filtration rate limited the removal rate of the filter bed similarly. It not only allows the filter bed to accept more suspended particles per unit time but also aggravates the shear force of the water flow. Hence, filter breakthrough occurred more frequently while the filter bed was running with a high filtration rate.

3.2. Suspended solid size distribution

The change of particle size is the microscopic reflection of the suspended solids removal, for which it is necessary to analyze the suspended solid size distribution of the filter bed inlet and outlet water. There are five Xinhe river water samples were collected at different times during the experiment, and their analysis results are shown in table 3.

| Particle size/μm | 1# | 2# | 3# | 4# | 5# |
|------------------|----|----|----|----|----|
| <10              | 4.84 | 14.6 | 2.49 | 4.23 | 10.29 |
| 10~25            | 33.61 | 44.35 | 15.64 | 26.87 | 39.04 |
| 25~45            | 30.45 | 22.43 | 17.74 | 28.58 | 25.69 |
| 45~100           | 24.75 | 14.2 | 43.15 | 33.95 | 18.21 |
| 100~300          | 4.72 | 3.64 | 20.76 | 6.23 | 5.92 |
| >300             | 1.63 | 0.78 | 0.22 | 0.14 | 0.85 |

Although the particle size distribution in the Xinhe river water fluctuated greatly, the particles with particle size less than 100 μm accounted for 80%-90% for all five samples. In other words, the turbidity removal effect of the filter bed is mainly determined by its ability to intercept suspended particles that size is in this range. In order to intuitively verify the intercept effect of particles, the particle size distribution results can be analyzed according to formula (1), which combined with the removal rate of SS to calculate the removal rate of particles in each little size range.

\[
\eta_i = 1 - (1 - \eta) \frac{r_{i-out}}{r_{i-in}}
\]

Where \( \eta \) is the particle removal rate of the \( i \) th particle size interval, \( \eta \) is suspended solids removal rate, \( r_{i-in} \) and \( r_{i-out} \) are the percentages of the \( i \) th particle size interval in influent and effluent.

The removal rates of suspended solid in different conditions show that up-flow filter bed had the largest suspended particle removal interval, which is between 3 and 250 μm, as seen in figure 3. In contrast, horizontal-flow filter bed had a smaller one, which is only 5-180 μm, and the removal rate with a size greater than 100 μm decreased with the increase of the particle size. Moreover, the removal rates of filter bed with EPS filter materials were significantly higher than that with ceramsite filter material. Overall, the up-flow filter bed with EPS filter materials showed a better removal effect on suspended solid particles in the Xinhe river body.
3.3. Head loss.

The growth rate of head loss directly determines the filtration period of the filter bed. During the experiment, the increase of head loss of up-flow filter bed is displayed in figure 4. The relationship between head loss and time was like a quadratic curve, which stayed steady at the beginning, then increased sharply at the end of the period until the filter bed is blocked. The filtration period of the light ceramsite filter bed at 10 m/h and 15 m/h filtration rate is about 185 hours and 152 hours respectively, which is much longer than the 120 hours and 107 hours of the EPS filter bed.

The change of head loss growth rate of filter bed was mainly due to the change of internal microstructure of filtering layer. In the initial stage of filtration, the internal voids of the filtering layer were relatively large, suspended solids with smaller particle sizes were less likely to be intercepted, therefore, the variation of the internal voidage of the filtering layer is limited. Then, as more and more particles adhere to the surface of the filter media material, the voidage inside the filtering layer decreased gradually, causing more complex the boundary shape of the gap, and the “inner wall” of the filter became rough. On the one hand, it directly consumed more and more energy when the water flow through the filtering layer, on the other hand, it improved the probability of the suspended solids particles being intercepted. They promoted each other and made the head loss of the filter bed grow faster and faster.

For the light ceramsite filter material, because of the smaller upward resultant force and worse uniformity in water, the filter layer formed by the combination has a larger voidage, the change process of the internal structure of the filtering layer is slower than that of the EPS filter material. Hence, there is a longer filtration period for filter bed with ceramsite media material, and a lower growth rate for its head loss.
3.4. Backwash
At the end of each filtration period, there was a backwash process for filter bed. The backwashing water was the raw water of the Xinhe river in the high-level tank, and the backwash velocity was controlled by rotameter and valve. Figure 5 and figure 6 illustrate the SS concentration of filter bed effluent during the backwash process.

When the backwash time lasted for 10 minutes, the SS concentration in the effluent decreased sharply to less than 10% of the highest, and then maintained between 20-50 mg/L, which just was basically consistent with the SS concentration in the high-level tank. Moreover, the higher the backwash velocity was, the higher the SS concentration of effluent in the initial stage of backwash process was. Because of smaller density and poor compatibility with inorganic materials for EPS, the SS concentration of backwash effluent for EPS filter bed decreased more quickly. The smaller the density, the smaller the mechanical energy needed to clean the EPS media material, and the stronger disturbance can be produced under the same backwash rate. Furthermore, the poor compatibility with inorganic matters endowed the suspended particles attached on the filter material more easily to separate[5].

The figure area of SS curve and X-axis in figure 5 and figure 6 can reflect the amount of suspended solids separated from the filtering layer in the backwash process to a certain extent. So, it can be found that when the backwash intensity of EPS filter bed was 6 L/(s·m²), the total SS washed out of the filter bed is obviously less than 18 L/(s·m²) and 12 L/(s·m²). This means that while backwashing the filter bed with a small flushing intensity, although the SS concentration of the filter bed effluent could remain stable in the end of the filtration period, there are still suspended substances mixed in the filtering layer and were not completely removed.

![Figure 5](image1)
![Figure 6](image2)

Figure 5. SS concentration of backwash effluent with EPS filter media material
Figure 6. SS concentration of backwash effluent with light ceramsite filter media material

4. Conclusions
The turbidity removal rates of the filter bed with suspended media were 44.50%-77.24%, and the removal rates of SS were 50.37%~78.85%. The effluent turbidity of the filter bed is less than 10 NTU, which satisfied the current relevant landscape water standards. The turbidity removal effectiveness was affected by many factors. Filtration rate was negatively correlated with turbidity removal effect, and it was feasible to operate with a high filtration rate (15 m/h or above). Using expanded polystyrene as suspended media material and adopting upward flow direction can achieve better results. Suspended solid particles with size less than 100 μm are the limiting factors influencing the treatment effect of filter bed, and EPS filtering layer can remove particles of this size effectively. The filter bed had a long filtration period, which can reach 107-185 hours under different operating conditions. The filter bed can be cleaned in a short time by backwashing with raw water at 12 L/(s·m²) or higher flushing rates.
Suspended media filter bed is suitable for the removal of turbidity in landscape water, and has the advantages of reliable, low energy consumption and long filtration period. Therefore, it can be used as a treatment unit of landscape water treatment project.

Acknowledgements
This research was supported by the founds of Xinhe River Ecological Landscape Project of Research and Development of Black-odorous Water Treatment Technology and Pilot Study, Fengxi New City, Shaanxi Xixian New Area (20180619).

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