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INFLUENCE OF GRAVEL AS PROTECTION LAYER ON THE FILTER RUN TIME

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Abstract: Since the beginning of the usage of slow sand filter (SSF) as one of the water treat-ment technologies, studies on how to enhance the performance have been conducted to date. One of the limitations in the current knowledge is regarding the method to increase the filter run time. The addition of protection layer may extend the filter run time. This paper focuses on the influence of gravel as the protection layer to the filter run time and turbidity removal. Gravel was chosen as the material of protection layer because of its low-cost and availability. A system-atic investigation by comparing only one different factor within the filter, which was protection layer, was conducted under the laboratory scale. The experiment consisted of two filter columns namely K1 and K2. Both filters were constructed using the same filter depth, type of sand, and grain size distribution. The protection layer was added to filter K1, but not to filter K2. The sol-ids penetration and the increase of filter head loss was used to evaluate the filter run time. A sta-tistical analysis was also carried out to examine the difference on the turbidity removal from both filters. The findings showed that by adding the protection layer, the filter run time could be extended up to 70%. Regarding to the turbidity removal, there was insignificant difference be-tween two filters.

Keywords: protection layer, filter run time, clogging, sand filtration, filter performance

INTRODUCTION

Slow sand filtration (SSF) which was founded in the 19th century may be considered as the earliest water treatment technology. It is well known for its low cost, simplicity, and effectivity. Due to its feature, SSF has been admitted as the suitable technology for water treatment in rural areas (Guchi, 2015). However, SSF is also still being used in several regions in developed countries such as the Netherlands and Japan (Yamamura, 2014; Wubbels *et al.*, 2014).

Research concerning SSF has been conducted since the beginning of its discovery. Yet, there are still many limitations found in the current knowledge. One of several gaps is the technique to increase the filtration rate and filter run time (Graham and Collins, 2014). This paper focuses on the method to increase filter run time by considering the removal mechanism of SSF, especially on the accumulation of dirt on the filter surface.

Filter surface has a dominant role in the removal mechanism of SSF system (Gimbel *et al.*, 2008). Suspended solids and microorganisms are collected or retained on the surface of the filter bed, forming a dirt layer so called *Schmutzdecke* or filter cake (Mälzer and Gimbel, 2006). The existence of this layer may not only enhance the cleaning process (Pfannes *et al.*, 2015) but also trigger the increase of head loss (Aronino *et al.*, 2009). If the head loss is high, the hydraulic conductivity will decrease and the clogging, which is resulted from the combination of mechanical, chemical, and biological processes, occurs (Le Coustumer *et al.*, 2012; Kandra *et al.*, 2014). Clogging influences the filter performance and at the worst may cause a breakthrough in the filter bed (Kandra *et al.*, 2010).

Clogging in SSF has been deemed as a surface phenomenon where the pore spaces were declined by the dirt layer (Leverenz *et al.*, 2009). The development of clogging layer at the beginning of the filter run is influenced by the sand grain size (Elisson, 2002). The clogging intensity is influenced by the filtration rate and the turbidity of raw water (Wubbels *et al.*, 2014; Mercado *et al.*, 2015).

Considering the prolongation of the filter run time, the growth of filter cake or the clogging on the filter surface should be retarded. In 2006, (Mälzer and Gimbel) studied a method to extend the filter run time by adding a protection layer to the filter bed. Three different materials i.e. gravel (3.1 – 5.6 mm), pumice stone (1.0 – 4.0 mm), and coconut fibers (2 mm × 0.9 mm), were used as the protection layer. Evaluation on the ability of protection layer to prolong the filter run time was conducted by assessing the pressure drop. The findings showed that the use of protection layer could extend the filter run time.

In this paper, the performance of gravel as the protection layer was assessed by conducting the analysis of solids penetration to the filter bed. Gravel was chosen as the material for the protection layer because of its low-cost and availability. A systematic investigation was carried out during the study. The term systematic here means that the variation during the laboratory scale experiment was only in the existence of protection layer. Other variables such as raw water quality, sand type, initial media grain size, initial filter depth, and the operation mode were controlled to be the same. Since attention was given to the removal of suspended solids, the term of filter cake to represent the dirt layer in this paper was preferable. Parameters such as turbidity removal and the normalization of head loss were also used to monitor the protection layer performance.

MATERIAL AND METHODS

Raw Water

Following the systematic investigation, the raw water quality was controlled so that it has the same concentration of suspended solids. Silica powder (*Millisil W12*) was used as the suspended solids. The raw water was created from the mixing of tap water and silica powder with the concentration of 220 mg/L (100 ± 10 NTU). Feeding of artificial raw water was done for seven weeks. Each day, 1000 mL of raw water was fed to the filter.

Filter column

Two filter columns, i.e. K1 and K2, were constructed using the same type of sand. Both filter columns had the diameter of 60 mm. Each filter consisted of 30 mm gravel layer as the supporting layer and 200 mm of sand layer. Gravel layer to protect the filter bed with the depth of 20 mm was added only to the filter K1 (see Figure 1).

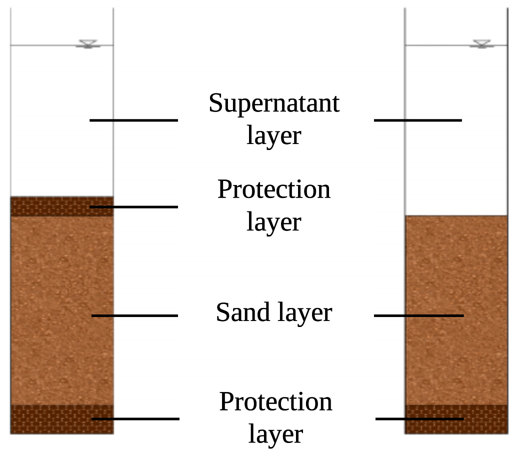

Figure 1. Sketch of filter columns K1 (left) and K2 (right)

The size of gravel used for supporting and protection layers were 2-6.3 mm. The grain size distribution of sand layer was represented by d_{10} of 0.26 mm and C_u of 2.5 (see). Since the ratio of filter column diameter to the d_{10} was higher than 50, the wall effect to the flow could be neglected (Lang *et al.*, 1993).

Operation of Filter Column

For seven weeks, both filter columns were in operation under intermittent condition. Every day, filter K1 and K2 were fed with the same amount and concentration of raw water. The same hydraulic loading rate of 0.20 ± 0.05 m/h was applied to both filters. Since the hydraulic loading rate decreased along with the growth of filter cake, the outlet position was always adjusted to control the same rate. Changing of head loss was observed to evaluate the performance of protection layer.

Evaluation on Filter performance

The main objective of the experiment was to investigate the ability of protection layer to prolong the filter run time. Performance of gravel as the protection layer was evaluated based on the normalized head loss and solids penetration were used to assess the filter run time. Turbidity removal was another parameter which was considered.

To calculate the normalized head loss, the equation of Nakamoto(1992) as cited by Sugimoto(2014) was used. The value of normalized head loss depends on the head loss, flow rate, and the normalized flow rate. In this study the normalized flow rate was at 0.20 m/h. The head loss value of each column will be comparable by converting it into normalized head loss.

The method of Ellis and Aydin(1995) on the solids penetration analysis was adapted in this study. Scraping every 10 mm of filter bed was done to analyze the solids penetration. After the scraping, each sand sample was put into a flask and diluted by adding 100 mL of distilled water. The flask was then shaken for 40 minutes. Afterwards, the mixture was rested for 5 minutes so that the sand grains could be sedimented. The turbidity of the supernatant water was measured to investigate the solids penetration. Turbidity removal was used to evaluate the ability of both filters to enhance the raw water quality.

RESULTS AND DISCUSSION

Previous study by Mälzer and Gimbel (2006) has proven that the existence of protection layer above the surface of filter media is able to prevent the premature clogging. In this study, the solids penetration analysis and the development of normalized head loss may provide broader understanding on the performance of protection layer. The characteristics of filter K1 and K2 are listed in Table 1.

Table 1. Characteristics of filter columns

Parameters	K1	K2
Initial hydraulic conductivity (m/s)	3.17×10^{-4}	2.73×10^{-4}
Initial Δh (mm)	47	48

Regarding the initial hydraulic conductivity, K1 had a higher value compared to K2. The same grain size, bed depth, and sand mass did not necessarily ensure the same values of initial hydraulic conductivity. Uncontrollable factors such as the arrangement of grains and voids could lead into different value of initial hydraulic conductivity.

Due to the different initial hydraulic conductivity, to achieve the same hydraulic loading rate, the initial Δh was set. The Δh of K1 is lower than of K2. During the operation, the filter cake was developed causing the hydraulic conductivity to decrease. Then, to maintain the constant flow rate, the Δh was gradually adjusted.

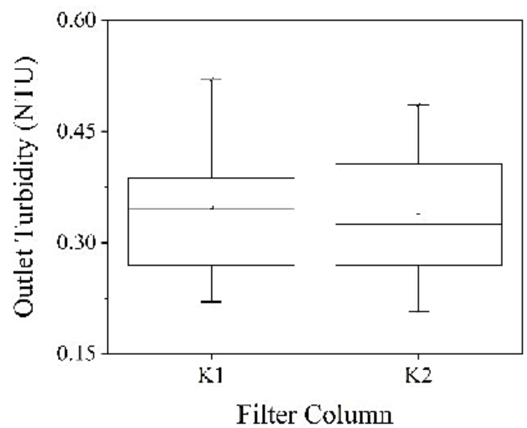

Figure 2. Outlet turbidity of filter K1 and K2

Concerning the turbidity removal, both K1 and K2 performed satisfactorily. Average turbidity removal of K1 and K2 was 99.67% and 99.68% respectively (Figure 2). One-way ANOVA was used to evaluate whether there were any differences between the outlet turbidity of K1 and K2. According to the statistical analysis, the p-value was higher than the alpha of 0.05. The result of ANOVA test indicated that the outlet turbidity of K1 significantly equaled to the ones of K2. Hence, the protection layer had no influence on the turbidity removal.

In this experiment, the hydraulic conductivity of filter K1 and K2 dropped to 26% and 89% respectively (see Figure 3) after 7 weeks of operation. Both filter columns were deemed to be clogged based on the consideration of Mercado et al. (2015) which stated that clogging has occurred when the outflow decreased to 15-20% of its initial.

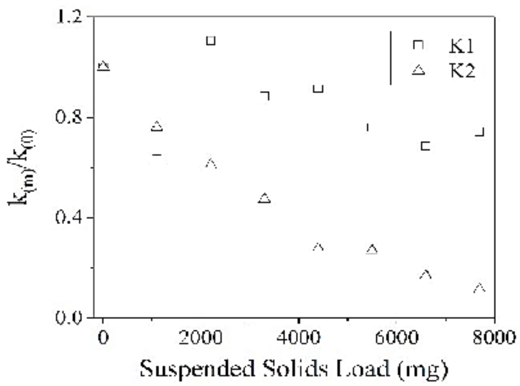

Figure 3. Development of relative hydraulic conductivity

Figure 3 shows that filter K2 clogs more than three times faster compared to filter K1. This graph indicates that the additional of protection layer may postpone the clogging period and increase the filter run time.

The performance of protection layer may be evaluated also based on the penetration of suspended solids. Total load of suspended solids during 7 weeks of operation was 7700 mg.

Scraping analysis demonstrated that the solids accumulated on the surface of filter bed for the filter without protection layer (see Figure 4). The accumulation is indicated by the high value of turbidity on the 0 cm of the filter bed depth. This solid accumulation formed filter cake which became the main cause of the decrease of hydraulic conductivity.

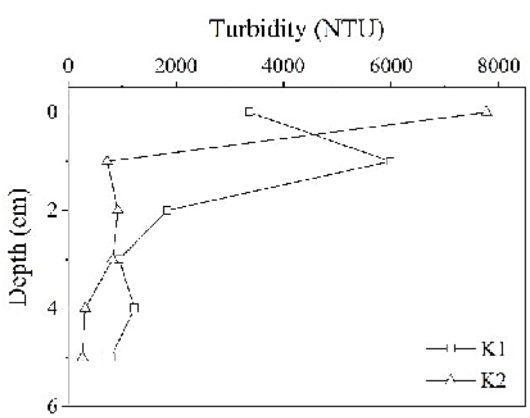

Figure 4. Analysis of solids penetration in the filter bed

In the filter column with protection layer, the solids were restrained by the gravel. As can be seen in Figure 4, the turbidity of the first 1 cm layer of the filter bed was not as high as of the filter K2. Hence, without the surface clogging, the filter run time of the filter with protection layer may be prolonged.

CONCLUSION AND OUTLOOK

The results above demonstrate the ability of gravel as protection layer to prolong the filter run time. Assessment was conducted based on the decrease on the hydraulic conductivity and the solids penetration. It has been proven that the filter with protection layer may prolong its run time three times longer than the filter without protection layer.

Further research may focus on the removal of microorganisms by using a filter with protection layer. The growth of Schmutzdecke in the protection layer should be another interest. Moreover, the characteristics of protection layer material can be another focus.

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