INFLUENCE OF EFFECTIVE SIZE AND LEVEL OF SUPERNATANT LAYER IN SLOW SAND FILTER PERFORMANCE

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Abstract

Slow sand filtration has been admitted as an old method of water treatment and has been widely used in the world. This type of sand filter is prominent in its simplicity, low cost, and effectiveness. The term effectiveness refers to the performance on removing particulate matter and microorganisms. There are some significant factors should be considered in the system of slow sand filtration, such as grain size distribution of media, sand type, bed depth, operation mode of filter, and filtration rate. This study focuses on the influence of different effective size of media and operation mode in slow sand filtration especially on removing turbidity. Grain size distribution is represented by the effective size (d_{10}) and uniformity coefficient (C_u). In regard to the operation mode, both sizes were operated under intermittent operation mode and were compared in two different level of supernatant layer: decreasing level and constant level. Laboratory scale experiments were conducted using four filter columns. Two filter columns were filled up with Rhein sand in different effective size of d_{10} 0.075 mm and d10 0.50 mm. Uniformity coefficient C_u 2.5 and curvature coefficient C_c 1 were the same for both d_{10}. Every column was fed with the same concentration of artificial raw water. The artificial raw water was created from Heilerde (clay from Germany) which passed 0.063 mm sieve opening mixed with tap water. Fine grain size tends to be easier to be controlled in regard to filtration rate, and vice versa for the coarse grain size. Surprisingly, the coarse grain size was able to remove turbidity as good as the fine grain size. Permeability of column was also tested and it decreased along with the addition of Heilerde.

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1. Introduction

Slow sand filtration has been used since the beginning of 19^{th} century (Huisman and Wood, 1974). It is not only a simple and low cost water treatment method but also effective on water purifying. Visscher (1990) resumes the effect of slow sand filtration as follows: reduces turbidity to < 1 NTU; reduces fecal coliform up to 95-100% to 99-100%; reduces organic matter 60-75%; largely removes iron and manganese; and reduces 30-95% heavy metals. Moreover, the significant effect of slow sand filtration is the reduction of chlorine use.

Slow sand filtration performance is influenced by many factors, such as biological layer (schmutzdecke); grain size distribution of media; sand type; bed depth; filter operation mode; and filtration rate. Different condition of the combination of those factors will lead into different performance. As an example, sand which is not too coarse combined with certain thickness can provide very good purifying process (Hazen, 1908). However, Sadiq et al. (2004) proves that finer grain size combined with certain bed depth and filtration rate might produce low removal efficiency.

This study reports on the influence of different grain size distribution, represented by the effective size (d_{10}), and operation mode to the filter performance, especially on the different level of supernatant layer. There are four combinations: fine grain size with constant level supernatant layer; fine grain size with decreasing level supernatant layer; coarse grain size with constant level supernatant layer; and coarse grain size with decreasing level supernatant layer.

According to Crites and Tchobanoglous (1998) in Tyagi (2010), grain size distribution of media represented by effective size (d_{10}) and uniformity coefficient (C_u) has a significant role in the performance of slow sand filtration. Hazen (1931) as mentioned in Barrett et al. (1991) states that the fine grain size determine the characteristic of the sand filter and confirms that the finer the d_{10}, the higher the removal efficiency. Fine grain size can also avoid the deeper penetration into the bed that makes it difficult to be eliminated by surface scrapping (Hazen, 1908) (Huisman and Wood, 1974). Associated with head loss, Boller and Kavanaugh (1995) claim that the coarser the grain is, the larger the pores will be. Larger pores will lead into higher head loss. For slow sand filtration, Huisman and Wood (1974); Visscher (1990); and Environmental Protection Agency (1995) recommend the value of d_{10} 0.15 mm – 0.35 mm and C_u < 3. Hazen (1908) suggests that it will be better not to employ sand coarser than 0.35 mm. In the other hand, Bellamy et al. (1985) find out that coarser sand may have high percentage of bacteria removal.

Normally, filtration rate in slow sand filtration is in the range of 0.1 – 0.4 m/h (Huisman and Wood, 1974). Visscher (1990) recommends the value of 0.1 – 0.2 m/h for the filtration rate as the slow filtration rate would give satisfactory effluent. This statement is enhanced by Di Bernardo and Escobar Rivera (1996) who claim that higher filtration rate does not only produce worse result but also lower filtration period. In contrast, Muhammad et al. (1996) prove that the slow sand filter keeps giving reasonably good filtrate operated at higher filtration rate. The data of Sadiq et al. (2004) shows that the high filtration rate may produce better effluent.

Filtration rate, besides is affected by grain size distribution, it can be controlled by the way the filter is operated by controlling the level of the supernatant layer. Supernatant layer level can be kept constant or decreasing in the filtration process. Based on Di Bernardo and Alcócer Carrasco (1996), there is no significant influence on the filters during the ripening period for both conditions of supernatant level.

Based on the description above, many researches have been done and resulting in dualism of the influence of the factors in slow sand filtration. In this study, laboratory scale experiments were done in order to investigate the comparison of different grain size combined with different level of supernatant layer. Filtration rate and permeability of the filter were observed in regard to study the effect of different combination of filter. Turbidity was taken as a parameter on evaluating the performance of the filter.

2. Research Methodology

Four columns were employed in during the investigation. Two columns had coarse grain size distribution d_{10} 0.50 mm (Figure 1) and the other two had fine grain size distribution d_{10} 0.075 mm (Figure 2). Both grain size distributions had the same uniformity coefficient Cu 2.5 and curvature coefficient Cc 1.

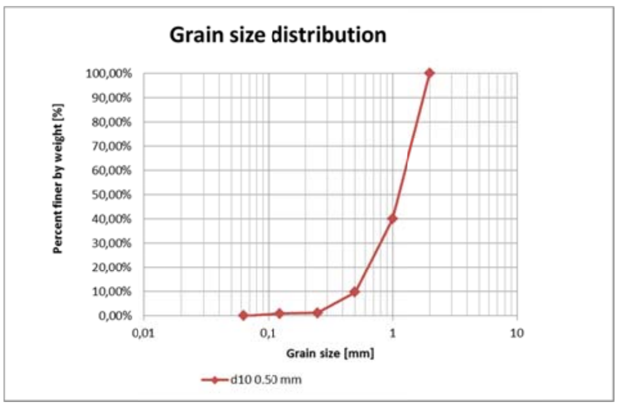

Figure 1. Grain size distribution d_{10} 0.50 mm

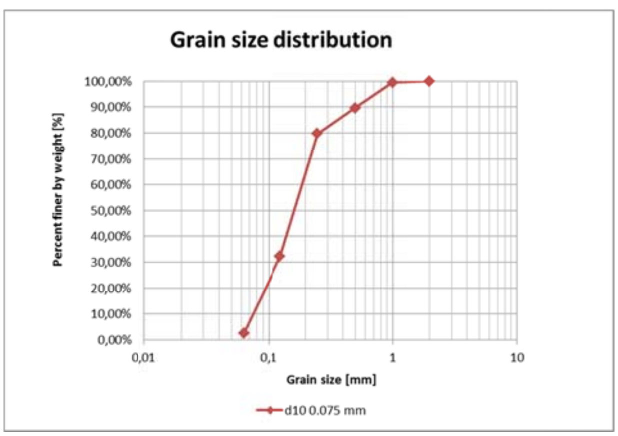

Figure 2. Grain size distribution d_{10} 0.075 mm

Filter columns had the same bed thickness. As can be seen in Figure 3, every column consisted of 5 cm gravel layer in the bottom of the column as supporting layer; 20 cm sand bed; and 2 cm gravel layer as a protection layer. The existence of protection layer was only to prevent any disturbances in the surface of sand bed. Gravel used in the columns was in the size of 2 – 6.3 mm.

Construction of columns was followed by set-up of filtration rate. Tap water was used in the set-up phase. The columns were filled with tap water by backfilling through the outlet. Backfilling was stopped after the water reached the upper surface of the protection layer. Water was then filled through the inlet of column. Then, using a stopwatch, the volume of water collection in every 15 minutes was measured after the position of outlet was set up. The outlet was set in the position that can give filtration rate of every column in the range of 0.15 – 0.2 m/h.

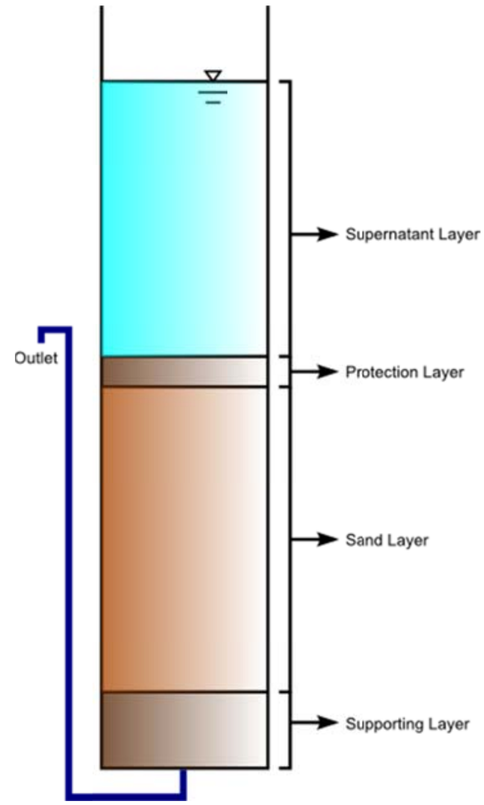

Figure 3. Sketch of filter column

After the filtration rate had been set up, artificial turbid water as the influent for the filter columns was prepared. It was a mixed of clay from Germany, well known as Heilerde, that passed 0.063 mm sieve opening and tap water. Influent water concentration was 1 g/L. Feeding of filter columns used the same concentration of mixture and the same amount of influent water.

All of the filter columns were operated under intermittent mode. However, each grain size distribution had two different level of supernatant layer. One was maintained constant and the other was with the decreasing level. In order to maintain the constant level of supernatant layer, a reservoir of influent water was added to the system. The reservoir would flow the influent water to the filter column to keep the level constant.

Raw water was flowed from the upper part of the column. During that process, outlet valve was closed until raw water reached the head position which gave the desired filtration rate. Then, all filters were operated by opening the outlet valve.

Filtration process for all filter columns would be stopped after the raw water of the decreasing supernatant columns reached certain head position in where the filtration rate dramatically changed. The time needed for raw water reaching that head position was recorded and the volume of water collected was measured. In that way, filtration rate could be calculated.

Turbidity measurement for filtrate water was always done after the filtration process. Furthermore, to evaluate the performance, inlet turbidity value was compared to the outlet turbidity value.

3. Results of Research

Performance of the filter was evaluated using some parameters such as filtration rate, permeability, and turbidity. Filtration rate as well as permeability decreased along the additional of clay particles. Figure 4 and Figure 5 showed the decreasing filtration rate for the fine grain size and coarse grain size respectively.

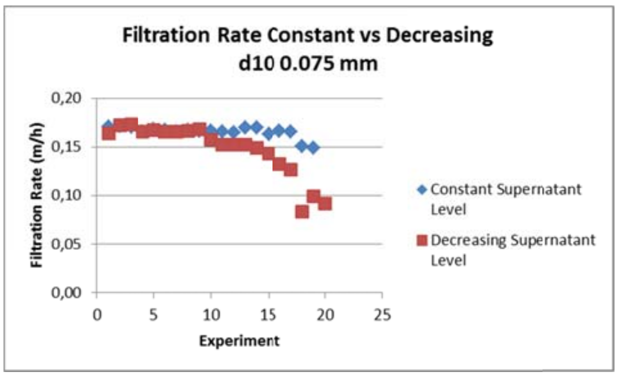

Figure 4. Filtration rate fine grain size distribution d10 0.075 mm

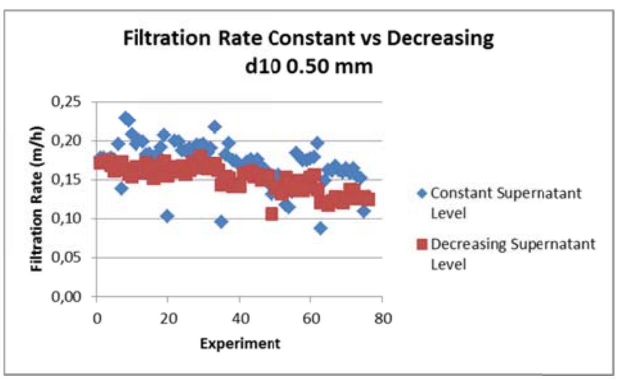

Figure 5. Filtration rate coarse grain size distribution d10 0.50 mm

Permeability measurement was conducted in order to test how ease the water flow through the media after the additional fine particles to the filter. The more particles were added, there would be more obstruction for the water to pass through the media, then the permeability value would decrease. Results of permeability measurement were shown in Figure 6. According to the graph, all filter columns had the same behavior. In addition to permeability measurement, porosity condition of filter media should be taken into account. An empirical calculation of porosity was done in order to find out the porosity of filter media. The porosity also decreased along with the increasing amount of particles as can be seen in Figure 7.

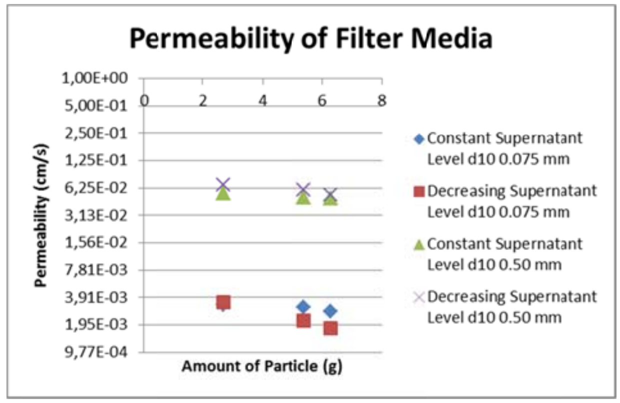

Figure 6. Permeability of four filter columns

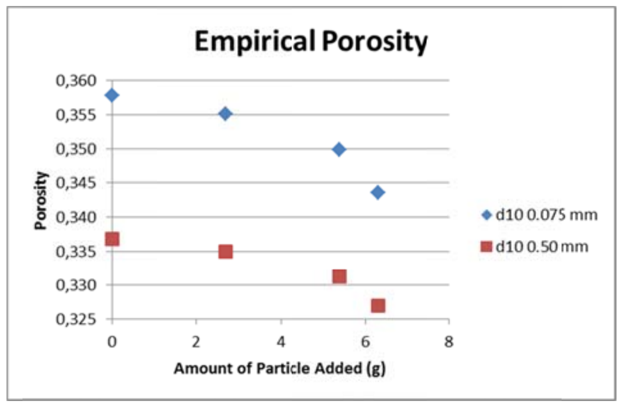

Figure 7. Empirical porosity of fine and coarse grain size distribution

Turbidity was evaluated in regard to find out the performance of the filter media on particle removal. Table 1 showed the data of turbidity for all filter columns. Surprisingly the coarse grain size distribution could reach high percentage of turbidity removal.

Table 1. Summary of turbidity data

Filter Column Characteristic	Influent Turbidity (NTU)	Average Effluent Turbidity (NTU)	Average % Removal
d10 0.075 mm Constant Supernatant Level	258	0.23	99.91
d10 0.075 mm Decreasing Supernatant Level	258	0.20	99.92
d10 0.50 mm Constant Supernatant Level	258	0.22	99.91
D10 0.50 mm Decreasing Supernatant Level	258	0.35	99.86

4. Discussion

During the experiment, decreasing filtration rate is shown along with the addition of clay particles. This phenomenon occurs in all filter columns as shown in the graphs in Figure 4 and Figure 5. As the more fine particles attached in the filter bed, the more difficult water flow through media. The difficulty of water to flow will lead into the clogging period of filter.

Filters with fine grain size distribution tend to have more constant filtration rate for both supernatant level compared to filters with coarse grain size distribution. This shows that the coarse grain size distribution will not be easy to be controlled compare to the one with fine grain size distribution. However, in regard to the clogging period, fine grain size tends to have faster clogging period compared to the coarse grain size distribution. According to Figure 4, fine grain size distribution with decreasing supernatant level has the tendency to clog faster than the one with constant supernatant level.

Together with the decrease of filtration rate, permeability which shows how ease the water flow through the media is also decreasing. Permeability is one of the parameter that is influenced by the fine particles of the media. The more the fine particles are added, the lower the permeability will be. Figure 6 shows how the decrease of the permeability after the additional fine particle.

Result of columns porosity calculation shows that additional fine particles reduce the pores. It is clear that fine particles will occupy the bigger pores. Then the pores will be reduced.

Turbidity removal for all columns is summarized in Table 1. Influent turbidity is always using the same value 258 NTU. Removal efficiency for the whole columns is higher than 99%. Surprisingly, there is no significant influence observed between filter with fine grain size and filter with coarse grain size. Many previous literatures mention that finer grain size will produce better effluent. However, in this experiment, filter with coarse grain size distribution performs as well as filter with fine grain size distribution.

Although filter column with coarse grain size distribution performs well, the penetration of fine particle is unknown. There is a possibility that in coarse grain size distribution, fine particles can infiltrate deeper into the media. Unfortunately, there are no sampling ports in certain layer of column that can be used to trace how deep the penetration of fine particles is. Another advantage of installing sampling ports is that the active layer, where the contaminant is mostly attached, can be detected. On the practical use, knowing the active layer will be important to decide the depth of filter bed in regard to operation and maintenance issue.

In regard to the different level of supernatant layer, the experiments strengthen the result of Di Bernardo and Alcócer Carrasco (1996) which states that there is no influence for both conditions. Constant supernatant layer and decreasing supernatant layer are able to deliver good quality in term of turbidity. In some tropical countries the issue of having constant supernatant layer may cause some problems when it is combined with continuous operation mode, such as the algae growth which will leads into the deterioration of effluent quality. In this case, intermittent mode can be a solution to prevent the algae growth.

5. Conclusion

1. Filtration rate and permeability will decrease along with the additional fine particles.
2. Clogging period is faster for the fine grain size distribution especially with the decreasing supernatant level mode.
3. There is no significant difference due to the different type of supernatant layer in regard to the turbidity removal.
4. Coarse grain size distribution performs as well as fine grain size distribution on turbidity removal.
5. Different filter configuration can provide different filter effluent.

Further research should consider the use of sampling ports in the filter as it will give more information on the removal of contaminant. It is also important to work on bacteria removal and compare different types of operation mode: intermittent and continuous.

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