Improving Turbidity Removal Efficiency in Slow Sand Filter during the Occurrence of High Turbidity Levels in Surface Water

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Abstract: *The prominent drinking water treatment process practised to eliminate turbidity from surface water, especially during high turbidity occurrence in the surface water, is coagulation, sedimentation and rapid sand filtration for many years. However, the possibility of turbidity removal using a slow sand filter (SSF) was not extensively studied in the case of high turbidity occurrence in the surface water. This study aimed to evaluate the performance of SSF in terms of turbidity removal in surface water, when pre-adding poly-aluminium chloride (PACl) as a coagulant chemical along with the pre-treatment by roughing filter. One per cent of PACl is prepared and dosed at the rate of 20 mg/L with raw water into the water intake chamber before it reaches the SSF. The raw and treated water samples were collected every six-hour intervals. The raw water samples whose turbidity level more than 50 NTU were considered and analysed from 174 nos of trails. Turbidity level of raw water and filtered water was observed in the range of 50-313 NTU and 0.31-5.5 NTU respectively. The turbidity of treated water by SSF was observed to be well below the SLS 614;2013 acceptable limit of 2 NTU in 98.8% of the treated samples. It is observed the turbidity removal efficiency increases when the raw water turbidity level increases. The result shows turbidity of treated water from SSF was complying with the requirement in 98.5% of the trails, which enable the proper function of treatment plant during the high raw water turbidity by complying with SLS 614-2013 when adopting this methodology.*

Keywords: *Drinking water, Poly-aluminium chloride, Surface water treatment, Turbidity removal*

1. Introduction

There are many natural resources on the planet and water is one of them. Water is one of the basic needs not only for humans but also for plants, wildlife and other animals. In addition, the requirement of water as raw material is inevitable for all sorts of products in the industrial era. Hence, the contribution made by water to a country's economic development is huge in the present context. Though water is a basic human right, people over 785 million do not have access to basic drinking water facilities. Globally, it is estimated that over 2,000 million people consume drinking water from the faeces' contaminated water sources. Further, it is forecasted half of the world's population will be in water stress regions in another 5 years according to World Health Organization (World Health Organization, 2017).

There are many levels of water treatment available and practised at present. Household-level, community level and domestic level are the types of water treatment systems commonly available systems. The slow sand treatment method is adopted on all levels and this method can be applied even in the household level water treatment. A slow sand filter (SSF) was originally established by John Gibb, in Scotland (Ellis, 1987). The main advantages of SSF over the other filters are less energy requirement and cost- effective, which can be functioned well with minimal or no dependency on workman force and chemicals. SSF is one of the sustainable water treatment processes. In general, the physical, biological and chemical processes function together in the removal of contaminants and other impurities from the raw water. Many developed countries such as Japan, Scotland and Netherlands are using SSF as a solution to treat water (Anggraini and Fuchs, 2019).

The extent to which suspended solids in water scattered or absorbed the light is termed turbidity. Nevertheless, the relationship between suspended solids and turbidity in terms of quantitative is not yet proven. The sunlight penetration is resisted by the high turbidity existence in water, which affects the process of photosynthesis. The clarity of water can be discussed in terms of the turbidity level. The transparency or clarity of the water is affected by the suspended solids and colour presence of water. There are many reasons for the suspended solid existence in water such as decayed vegetation, fungi, slit, and algae, which lead to delivering high turbidity in water. The quality of drinking water is judged by various parameters and turbidity is one of them (Agrawal, Sharma and Sharma, 2020). The famous treatment process practised to eliminate or reduce turbidity is coagulation, sedimentation and rapid sand filtration, by the water supply engineers. Many SSF pilot studies have been done by researchers using plastic and concrete materials for the frame and different graded gravel and sand as filter media in layers in the past. There are several factors mainly, water source features, temperature, hydraulic retention time, surface area, filtration rate, and filter media size influencing the design and the performance of the SSF. However, filter media grain size and depth control the efficiency of the water treatment (Anderson et al., 2009).

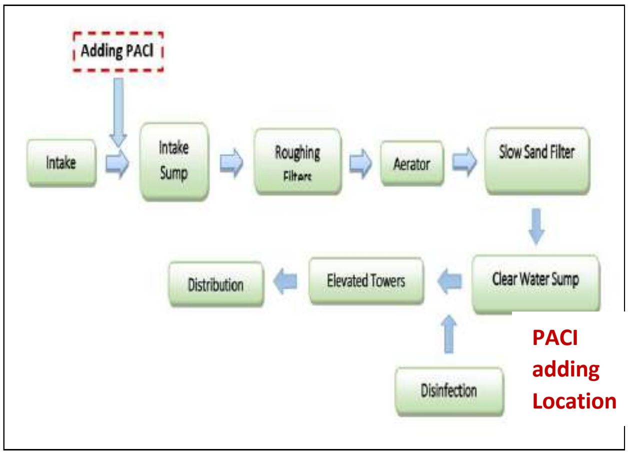

Figure 1. WTP layout and PACl mixing location

Different types of filter operations such as slow filter operation and fast filter operation were used with fine and coarse sand filter media by Ellis during his study in 1985. It was recorded that 60-65% removal of suspended solids and 70-75% removal of BOD5 in the study when using slow filter media (Ellis, 1987). Many finding suggests the SSF method can be used to treat different type of water and wastewater. In addition, drinking and wastewater treatment efficiencies of SSF have been about 99% for of removal of turbidity, pathogens and suspended solids up to 99% is recorded as the efficiency of wastewater and drinking water SSF (Haarhoff and Cleasby, 1991). The prominent drinking water treatment process practised to eliminate turbidity from surface water, especially during high turbidity occurrence in the surface water, is coagulation, sedimentation and rapid sand filtration for many years. The efficiency and the function of SSF to treat drinking water, in the case of high turbidity occurrence in the surface water, when adding the pre-oxidation chemical have not been thoroughly studied, even though there was advanced development in the SSF techniques. Hence, the objective of the present study is to evaluate the performance of SSF in terms of turbidity removal from raw water when adding coagulant chemicals.

2. Materials and Methods

The water intake, PACl mixing point and treatment process are exhibited in Figure 1. Figure 2 shows that when the amount of rain exceeds the threshold limit, turbidity shows an upward trend and when the amount of rainfall decreases, turbidity decreases. Right after the 60 mm/hr heavy rain on 25th November 2020, turbidity level of 111 NTU was recorded. The follwoing day turbidity increases to 280 NTU. After the heavy rainfall of 90 mm/hr on 6th December 2020 turbidity level of 350 NTU was recorded. No rainfall occurred between December 8 and 12, hence the turbidity levels decreased to 55 NTU. It was found by analysis the existing data, there is a clear correlation between rainfall and turbidity of the Dry Aru.

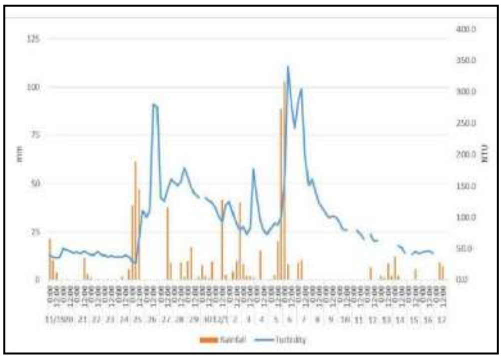

Figure 2. Rainfall vs Raw water turbidity level

The turbidity level of raw water generally satisfies this condition in the dry season. However, the record shows, that the turbidity of raw water increases to 100-350 NTU in the Kilinochchi water treatment plant during the rainy season, which resulted in stopping the plant's efficient operations. The treatment process of the Kilinochchi water treatment plant in Sri Lanka is pumping water from the intake to roughing filter to the aerator to SSF and finally to clear water ground sump. However, a new methodology was adapted and tested to the existing treatment process, by keeping the process as it is, encountering the threat of a higher level of turbidity in the raw water arises especially during the rainy season.

As per the WTP operation manual, raw water turbidity must be less than 30 NTU before entering into the slow sand filter to prevent clogging of the filter media of SSF (NWSDB, 1989). Therefore the methodology used was adding Poly Aluminium Chloride (PACl) as the coagulant chemical to activate the coagulation process from which the suspended solid particle can efficiently form clogs within a short period and be removed through the various filtration process.

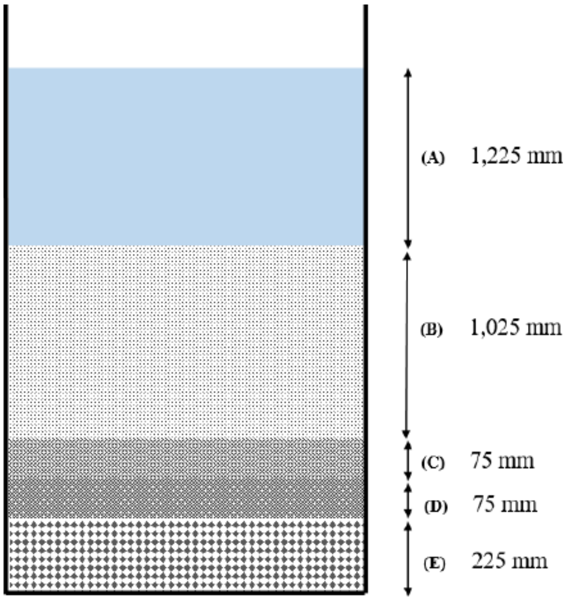

Figure 3. Cross-section of SSF

Where;

(A) Water column over the filter media

(B) Filter media sand layer

(C) Filter gravel layer 1

(D) Filter gravel layer 2

(E) Filter gravel layer 3

Figure 4: Fine aggregates and gravels as filter media

A jar test conducted to choose the suitable chemical coagulant among alum and poly-aluminium chloride and to estimate minimum coagulant dose required to achieve certain water quality goals. Based on the findings from the jar test, one per cent (1%) of PACl was prepared and dosed at the rate of 20mg/L. The prepared solution was mixed with raw water into the water intake chamber before it reaches the roughing filter as shown in Figure 1. In addition, the inlet structure of roughing filter was modified to improve the mixing of PACl with raw water. The experiment was carried out for the water inflow rate maximum of 2000 m3/day. The filter media in SSF placed were 1025 mm thick layer of fine sand with a uniform coefficient of 1.78 and effective size of 0.32 along with gravel with various particle sizes of 5-9 mm, 5-16 mm, and 9-62 mm with a layer thickness of 75, 75, and 225 mm respectively as shown in Figure 3 (not to scale). The water depth over the filter media was 1,225 mm approximately.

Figure 4 shows the coarse and fine aggregates which have been placed in SSF as the filter media. The turbidity level of raw water and the treated water from SSF were measured every six-hour intervals for one year. The turbidity is measured and analysed for 174 nos of trails. Turbidity was measured by a 2100Q turbidity meter at the site laboratory located in the water treatment plant site.

3. Results and Discussion

As representative test results, Figure 5 shows turbidity in raw water and treated water from a slow sand filter (SSF) when adding PACl as the coagulant agent in the intake chamber, with elapsed time obtained when the raw water turbidity exceeds the limit of 50 NTU. The raw water, before sending to SSF, generally be less than 30 NTU to prevent clogging of slow sand filter media (NJS Consultants Co., 2019)

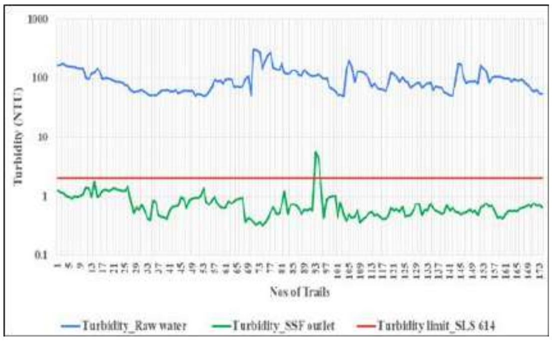

Figure 5. Comparison of turbidity in raw water and treated water

The result illustrates that the turbidity is removed significantly by the proposed methodology of with pre addition of PACl with raw water and with the pre-treatment and filtration by SSF. The turbidity of treated water by SSF was observed to be well below the SLS 614;2013 (SLSI, 2013) acceptable limit of 2 NTU in 98.8% of the treated samples when applying this method. Turbidity of raw water during the testing period by varying in the range of 50-313 NTU, whereas turbidity of the filtered water from SSF was observed between 0.31-5.5 NTU. The turbidity removal efficiency was calculated by using equation 1.

$$\text{Effeciency } (\%) = \frac{(\text{Influent Concentration} - \text{Effluent Concentration})}{\text{Influent Concentration}} \times 100 \qquad (1)$$

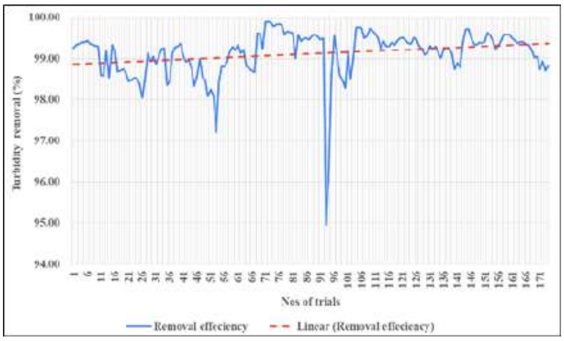

Figure 6. Turbidity removal efficiency vs trails

Figure 6 indicates that 171 out of 174 samples were observed to be above 98.5% efficiency in removing the turbidity. Further, there is a correlation observed between the time and the turbidity removal efficiency, where the efficiency increase with the days of operation. In a previous study, the same methodology was assessed through a prototype model of the same water treatment plant and turbidity removal efficiency found to be 82% and it was increasing with the increasing turbidity of the inlet water to the SSF. Consequently, the present study records the average turbidity removal efficiency of SSF as 98.5%.

In addition, it was recorded in a previous study that, a long operation of water treatment plant increased the turbidity removal efficiency (Jenkins, Tiwari and Darby, 2011). Further, it is also recorded that, drinking and wastewater treatment efficiencies of SSF have been about 99% for of removal of turbidity, pathogens and suspended solids up to 99% is recorded as the efficiency of wastewater and drinking water SSF (Haarhoff and Cleasby, 1991) and the findings are very much closer to the findings of the present study.

The turbidity removal efficiency by using this method was compared against the turbidity level of the raw water and plotted in figure 7. A positive correlation was observed between removal efficiency and turbidity level of raw water. The turbidity removal efficiency increases when the raw water turbidity level increases.

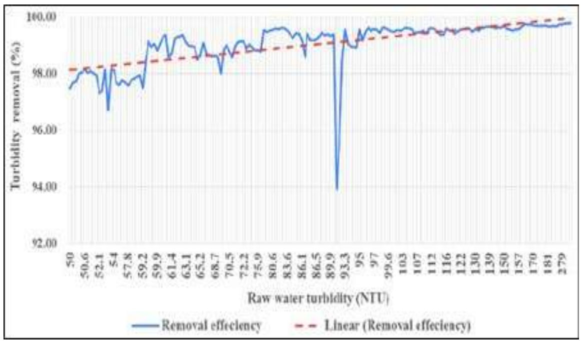

Figure 7. Turbidity removal efficiency vs raw water turbidity level

4. Conclusion

The research objective was to evaluate the performance of slow sand filter (SSF) in terms of turbidity removal when pre-adding poly-aluminium chloride (PACl) as coagulating chemical for treating the surface water to supply potable water. The past year's records show the WTP stops its operation when raw water turbidity is high, especially during the rainy season. The result illustrates that the turbidity is removed significantly by adopting this methodology. It can be observed that the treated turbidity level is well below the threshold limit of 2 NTU, specified in SLS 614;2013 for drinking water, in most of the trails when using this method. The turbidity removal efficiency was observed to be increased with the days of operation. Further, the efficiency in turbidity removal by SSF increases when the raw water turbidity level increases. This method is very efficient and shall be applied as the solution for turbidty treatment for the higher turbidity issues in surface water in any potable water supply system.

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