SW002

Benefits of Using Biofiltration Process for Pre-Treatment of Polluted River Water as Raw Water for Drinking Water Supply

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Abstract

The polluted river water is often used as raw water for clean or drinking water supply in many areas of Indonesia. This leads to the increased water treatment costs as well as public health risks. An innovation of biofiltration process for pre-treatment of the polluted river water as raw water in a drinking water supply system can be considered as an effective solution. This research work aimed at evaluating the technical and financial benefits of applying this technology as a pre-treatment step prior to conventional coagulation/flocculation and chlorination processes. Research was carried out by using biofilters with quartz sand as filter media. The biofilters were operated in an upflow or downflow operation mode at various hydraulic retention time (HRT). It is obvious that pre-treatment of polluted water using biofiltration process could improve the quality of raw water that could lead to the improved quality of treated water, or increase the water treatment plant capacity. The biofilters demonstrated the ability to reduce organics, ammonium and physical pollutants such as total suspended solid/TSS, color and turbidity of the treated water, where the removal efficiency is depending on the applied HRT. The decrease in TSS or turbidity will reduce coagulant consumption in the subsequent water treatment processes. Furthermore, the ammonium removal will eventually reduce chlorine required for disinfection. The paper presents the performance of the biofiltration process for removal of TSS, turbidity, color, COD, and ammonium from river water as raw water in a drinking water supply system.

Keywords: Ammonium removal, biofiltration process, financial benefit, organics removal, polluted river water, quartz sand, raw water.

1. Introduction

Wastes from agriculture, livestock, fishery, trade, industry and housing are often discharged into the river that results in the river water pollution. This pollution disrupts the equilibrium of aquatic ecosystems, as well as disturbing aesthetics and increasing human health risks. Various programs and activities to control the pollution have been realized by the government, industry and non-governmental organizations, but the efforts have not been fully successful yet; even the pollution of river water is getting worse in some areas of Indonesia. The contaminated river water is often used as raw water in the provision of clean or drinking water supply. This condition causes the cost of water treatment to be expensive and public health risks increased.

Innovation of biofiltration technology can be the effective solution of the problem of clean or drinking water supply. The biofiltration process is a process that utilizes microorganism attached on a solid matrix surface and forms a biological layer (known as biofilm). This process can filter out pollutants physically, and also degrade pollutants through biological activity (Chaudhary et al., 2003). Many types of microorganisms (aerobic, anaerobic, and facultative bacteria, as well as protozoa) play an important role in degrading organic compounds in the raw water through metabolism to generate energy for their growth. In biofiltration system, various processes take place simultaneously such as oxidation, absorption, and filtration of pollutants by biofilms (Horan, 1990).

Biofilm process (the basic principles of biofiltration process) has been proven to be effective used for many purposes of water and wastewater treatment (Chaudhar et al., 2003; Jou and Huang, 2003; Sheth and Dave 2010). This system is suitable for removal of organic pollutants as well as nutrients from water and waste water (Haseborg et al., 2010). The advantages of biofilter for treatment of water and waste water are low investment and operational costs, stable over long periods of time, high degradation rate, no by-product, and simultaneous eliminating of organic and inorganic mixtures. The effectiveness of biofiltration process is strongly influenced by the type and characteristics of biofilter media. The more extensive the surface of a biofilter media the more biofilms can be attached on the media (Chaudhary et al., 2003; Vedova, 2008).

Performance of the biofiltration process is determined primarily by two parameters, namely the surface characteristics of the support material (matrix) and the biofilm thickness that affects the substrate and oxygen supply from the liquid phase (Bever et al., 1995; Banjenbruch, 1998; Malone and Pfiffer, 2006). In addition, the operating conditions also determine the performance of the process, such as contact time between microorganisms in biofilms with pollutants, type and concentration of pollutants, recirculation rate, and dissolved oxygen levels.

This research work was aimed at evaluating the process performance, and analyzing the benefits of biofiltration processes to eliminate pollutants of raw water. Particular attention is paid to the influence of HRT and the mode of operation (upflow or downflow). Both technical and financial benefits of using the biofiltration process are analyzed including the removal efficiency of various pollutants and the quality of treated water as well as the reduction in chemical costs (coagulant and chlorine) due to the improved water quality.

2. Materials and Methods

2.1 Materials and Equipment's

The materials used in this research are raw water from river, quartz sand as biofilter media, and chemicals for laboratory analysis. The equipment's used in this research are two biofilter units with quartz sand as medium, aerator for air supply into biofilter, control valve, pump, water tank, and piping system (Figure 1).

The biofilter units used for the experiments are made of a 4 inch diameter PVC pipe and 100 cm high. The total biofilter volume is 6.6 L consists of water volume of 3.2 L and quartz sand media volume of 3.4 L. There biofilter units are operated in upflow and downflow operation modes parallel. In the upflow biofilter, water flows from the bottom upwards, while in downflow biofilter water flows from the top downwards. Compressed air flows from the bottom of the biofilter for both modes of operation.

Equipment's or instrumentations used for physical and chemical analysis include microscope, spectrophotometer, distillation apparatus, COD reactor, pH meter, DO meter, sample bottle, as well as various glass tools such as Erlenmeyer, cup glass, kjedahl pumpkin, bulb, volumetric pipette, dropper, and other standard laboratory equipment's.

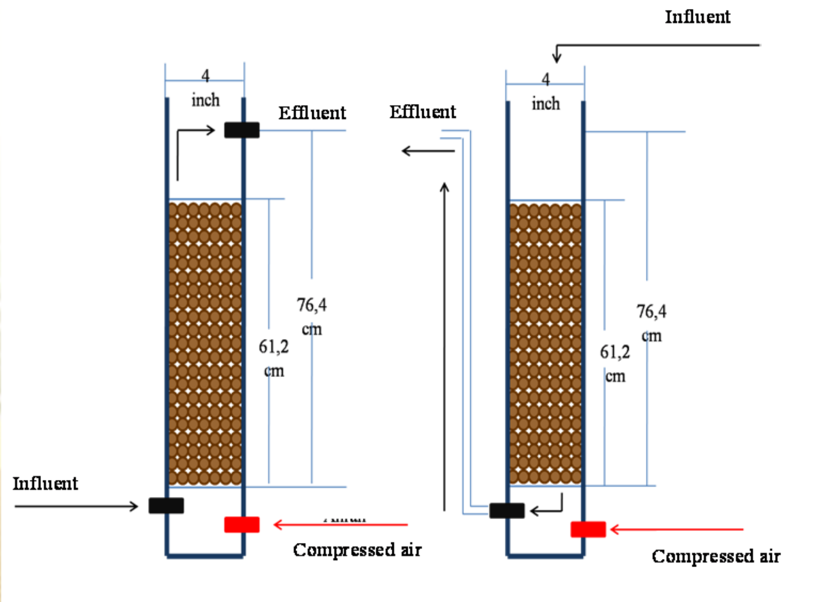

Figure 1 Schematic of upflow biofilter (left) and downflow biofilter (right).

2.2 Methods.

This research consists of several stages: preparation stage, acclimatization process, variation of HRT, biofilm observation, and technical and financial benefit analysis. Acclimatization process is done naturally by continuous flowing water into the biofilter systems that was filled with quartz sand. Acclimatization is realized with a HRT of 2 hours until the biofilm reaches pseudo-steady state. HRT is calculated based on EBRT (Empty Bed Retention Time). Performance of the biofiltration process during the acclimatization is determined by analyzing the physical water analysis parameters (TSS, turbidity, and color) for both influent and effluent. The test of the influence of HRT is performed after the biofilm reaching the pseudo-steady state condition. The HRT is set at 1, 2, 3, and 4 hours as treatment levels. The HRT variation is done by adjusting the input flow rate into the biofilter.

Laboratory analysis was performed according to standard method: color, turbidity, organic substances (expressed as chemical oxygen demand/COD), ammonium, and nitrate were performed acceding to APHA (2005). TSS was measured using spectrophotometry (HACH DR / 4000).

Financial benefits analysis is analyzed by calculating the decrease of required chemicals (coagulant and chlorine for disinfection) as a result of the better quality of raw water, i.e. the difference of TSS and ammonium concentrations in the influent and effluent.

3. Results and Discussion

3.1 Acclimatization process.

Acclimatization is done in order to allow an organism adapting physiologically to a new environment. In simpler term, it can be interpreted as an adaptation of organism to a new environment (Rittner and Bailey, 2005). In general, the concentrations of pollutants in the raw water decrease after being treated with biofilter. Figure 2 shows that turbidity, color, and TSS of influent and effluent as well as removal of the parameters during the acclimation process. The removal of physical parameters tends to increase with the increasing operation time. The end of the acclimatization process is characterized by the achievement of pseudo-steady state conditions, indicated by a stable level of pollutant removals. The longer the time of operation, the better the microorganisms getting adapted to its environment and thus the higher the rate of pollutants removal. As shown in Figure 2, the pseudo-steady state condition can be achieved at operating times of about three to four weeks.

3.2 Pollutant removal.

3.2.1 Physical parameters removal.

Figure 3 shows the turbidity, color and TSS removals at various HRTs. The raw water input has a turbidity of 6-12 FTU, color of 50-60 PtCo, and TSS of 5-9 mgL^{-1}. Upflow biofilter is able to reduce turbidity of 36-69%, depending on applied HRT. Downflow biofilter removes turbidity of 41-72%, slightly higher than upflow biofilter. At HRTs of 1-4 h, biofilter was able to decrease color of approx. 46-72% for upflow biofilter and 47-78% for downflow biofilter. Upflow biofilter decreases TSS of 30-57%, while downflow biofilter decrease TSS of 35-67%. The elimination of physical parameters, especially TSS and turbidity, is most likely due to the physical effects of sand filtration. However, the particles that are retained in the sand filter may be biologically degraded by bacterial or protozoal activity present in the biofilter system. This distinguishes the biofiltration process by the only physical filtration operation. From the figure it is seen that the physical parameter removal increases with the increased HRT, where the biofilter downflow performance is slightly better than the steam biofilter.

3.2.2 COD removal.

Figure 4 shows COD removal at various HRTs. COD inlet ranges from 50-110 mgL^{-1}. At HRT 1-4 hours, the biofilter was able to reduce COD between 39-60% for upflow biofilter, and 43-72% for downflow biofilter. The contact time influences the ability of microorganisms to degrade organic matter (Schnurer and Jarvis, 2009; Manahan, 2011), in which the COD removal increases with the increased HRT.

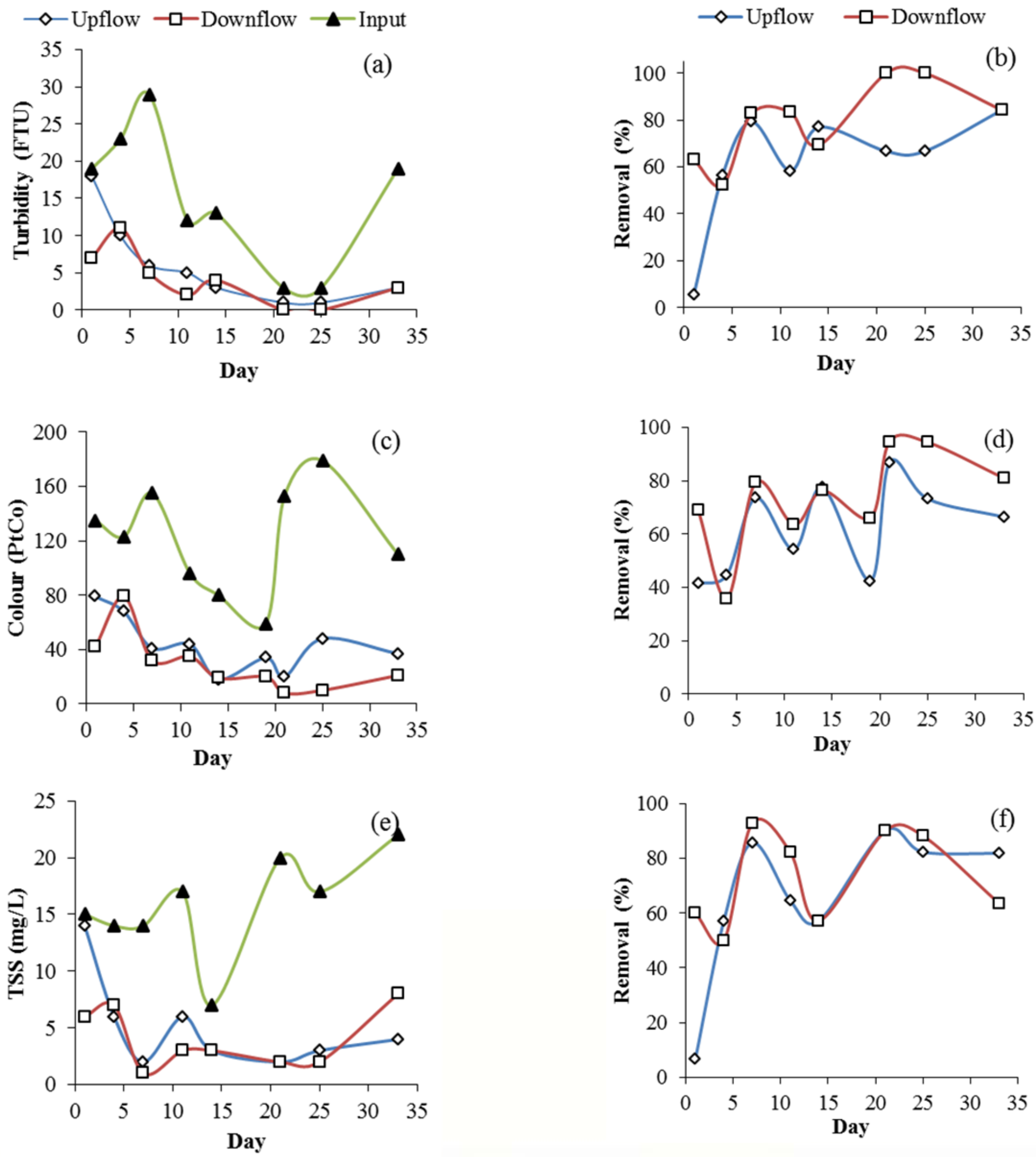

Figure 2 Turbidity, color, and TSS of influent and effluent as well as removal of the parameters during the acclimation process.

From Figure 4 it can be seen that the increased HRT leads to the higher COD removal by the biofilter. With the increased HRT the microorganisms have sufficient time to perform metabolism and utilize the dissolved organic substances contained in the water. In addition to oxygen supply, the introduced air also serves as mixing for improving mass transfer in the system.

Both upflow and downflow biofilters are able to reduce COD. The downflow biofilter has slightly higher removal efficiency than upflow biofilter because of the better mixing of air and liquid in this type of biofilter system. In downflow biofilter system air flows from the bottom opposite the direction of the water flow so that mixing and better mass transfer can take place better.

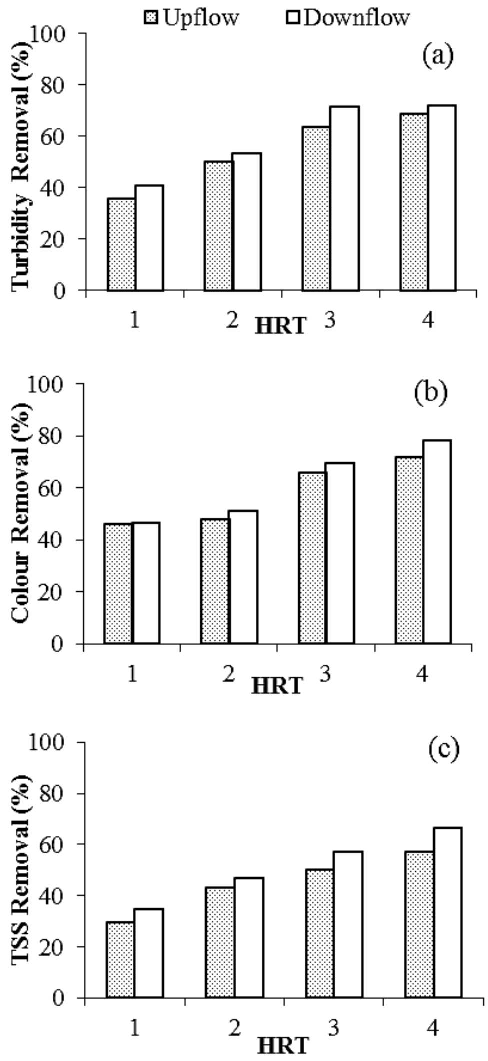

Figure 3 Turbidity, color, and TSS removal at various HRTs.

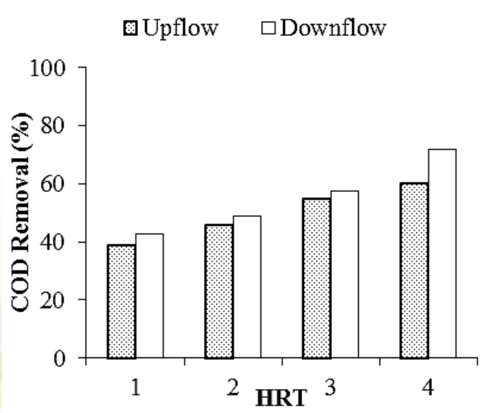

Figure 4 COD removal at various HRTs for upflow and downflow biofilters.

3.2.3 Ammonium removal.

Figure 5 shows the ammonium removal as function of HRT (upper). The raw water inlet contains ammonium 1.2-1.6 mgL^{-1}. Both upflow and downflow biofilters are able to reduce ammonium, where the higher HRT the higher is the ammonium removal. As in the case of physical and COD parameters, the rate of ammonium decrease in the biofilter downflow is generally slightly higher than in the upflow biofilter At HRT of 1-4 h, the biofilters remove ammonium of 25-47% for upflow biofilter, and 25-50% for downflow biofilter. The process of ammonium removal is called nitrification (Mahida, 1993).

The product of nitrification process is nitrate, so as a result the ammonium reduction is an increase in nitrate, as seen in Figure 5 (below). The nitrification process consists of two stages, namely ammonium is oxidized to nitrites by the bacteria *Nitrosomonas* and *Nitrosococcus*. Furthermore, nitrites are converted to nitrate by *Nitrobacter*. Both types of the bacteria are aerobic obligate bacteria, so the process requires the presence of dissolved O_2 in sufficient quantities (Manahan, 2011).

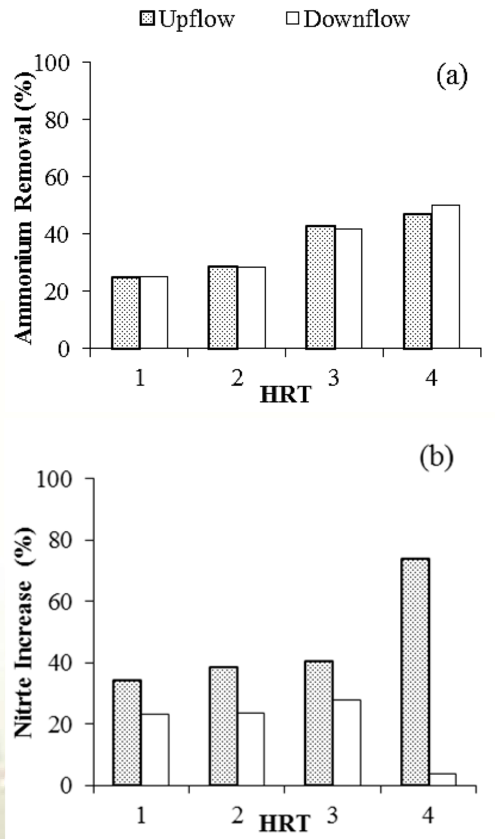

Figure 5 Ammonium removal and nitrate increase at various HRTs for upflow and downflow biofilters.

3.3 Financial Benefits Analysis.

The decrease of TSS (or turbidity) of raw water results decrease of coagulant requirement in the process of coagulation, for example coagulation with PAC (Poly

Aluminum Chloride) liquid with aluminum oxide content of 10.37%, as shown in Figure 6. Table 1 shows the relationship between physical characteristics (TSS, turbidity, color) of raw water with optimum PAC liquid dose for coagulation process. Basically, the higher the quality of raw water the lower is the required coagulant dose for the water treatment.

Table 1 Optimum PAC dose as function of raw water quality (TSS, turbidity, color).

TSS (mgL^{-1})	Turbidity (FTU)	Color (PtCo)	Optimum PAC dose (mLL^{-1})
23	39	189	0.0015
62	46	233	0.015
93	67	344	0.03
126	138	887	0.04

The coagulant requirement for coagulation process is directly proportional to the TSS of the raw water, which in this case may be expressed as.

$$Opt.PAC\ dose\ \left(\frac{mL}{L}\right) = 0.0003.TSS$$

where TSS is the concentration of suspended solids (mgL^{-1}). With the help of the equation, the decrease in PAC required can be estimated from the decrease in TSS resulting from pre-treatment of raw water with the biofilter. For example, decreasing of TSS from 12 to 3 mgL^{-1} is equivalent to a decrease in PAC requirement from 3.6 to 0.9 mLm^{-3} (a decrease in PAC requirement of 75%).

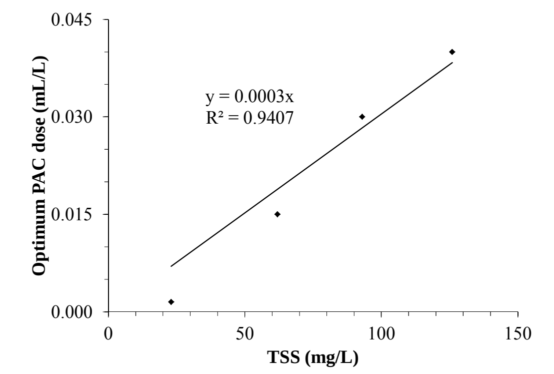

Figure 6 Optimum PAC dose as function of TSS in the water.

The ammonium (NH_4^+) in raw water can not be eliminated in a conventional water treatment system significantly, so that ammonium will remain in the treated water. Ammonium reacts with chlorine (Cl_2) added in the disinfection process according to the following reaction equation:

$$NH_4^+ + Cl_2 + 2HOCl \rightarrow NCl_3 + 2H^+ + Cl^- + 2H_2O$$

The ammonium in raw water can be oxidized to nitrate (nitrification) in the biofiltration process. A decrease in ammonium concentration also means decreasing of the chlorine requirement in the disinfection process. According to the reaction equation above, one mole (18 g) of ammonium reacts with one mole (71 g) of chlorine. For example, if the biofilter reduces ammonium from 2.5 to 0.5 mgL^{-1} can decrease the chlorine requirement from 9.9 mgL^{-1} to 2.0 mgL^{-1} (a decrease of 80%).

By knowing the price of these chemicals (PAC and chlorine), the financial benefits of improving the quality of raw water can be estimated for a certain amount of treated raw water. The technical and financial benefits can be considered for implementing the biofiltration system for the extension of existing water treatment systems. The application of biofiltration process as a pre-treatment of polluted raw water provides various benefits to the existing water treatment plant, such as improvements of treatment capacity and quality of processed products.

From the discussion above, it is obvious that pre-treatment of polluted water using biofiltration system could improve the quality of raw water and the quality of treated water, or improve the water treatment plant capacity. The biofiltration process could be implemented as pre-treatment of polluted river water as raw water in the clean or drinking water supply system. The addition of this unit to the existing water treatment plant will not interfere with the design and operation of the existing water treatment systems significantly.

4. Conclusion and Recommendation

4.1 Conclusion.

Biofiltration process using quartz sand as biofilter media can remove various pollutants in raw water significantly, such as turbidity, color, TSS, COD, and ammonium. Hydraulic residence time determines the efficiency of pollutant removal in raw water, where the downflow biofilter results in slightly better removal efficiency than the upflow biofilter. Besides technical benefits, the use of biofiltrations has been shown to result in cost saving due to reduced consumption of coagulant and chlorine.

4.2 Recommendation.

The biofiltration technology has enormous potential technical and financial benefits as pre-treatment of polluted river water in the water treatment system. Further research is needed for optimization of the biofiltration process, especially for the elimination of emerging pollutants derived from pharmaceuticals, shampoos, cosmetics, pharmaceuticals, chemical or synthetic fertilizers, herbicides, and pesticides.

5. Acknowledgements

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