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Research paper

Biofilters as Alternative Method for Ammonia Removal in Water Treatment Plant

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Abstract

High level of ammonia concentration in raw water have led to the temporary shutdown of water treatment plant at certain areas of Malaysia especially in Selangor state. The contamination occurred as a result of the impact of industrial activities, agricultural activities and disposal of rubbish into the river. This study was carried out to determine the performance of slow sand biofilters (BioSSF) as an alternative method for the ammonia removal in drinking water treatment plant. Two factors i.e., empty bed contact time (EBCT) (5 to 15 minutes) and ammonia concentration (3 to 5 mg/L) were investigated. The results showed the best ammonia removal percentage was at 15 minutes EBCT with removal percentage of 98.3%. Increasing the ammonia concentration in raw water reduced the BioSSF performance, but the ammonia removal was still below the regulated limits (< 1.5 mg/L). In addition, the BioSSF also have a capability to reduce the turbitidy, chemical oxygen demand, colour and suspended solid. Thus, it proved the BioSSF can be an alternative method for the current conventional water treatment specially to remove the ammonia.

Keywords: *Ammonia;Drinking Water Treatment; Slow Sand Biofilter; Turbidity*

1. Introduction

Clean water is essential to humans and other living because it is very important in life for human consumption source, industrial field and areas of agriculture. Before the water is pumped to the residential areas, it necessary to treat the water to ensure the quality of water is according to standard provided by Ministry of Health Malaysia. However, the river for clean drinking water production have been contaminated by the inorganic and organic pollutant such as chemical oxygen demand (COD) [1], ammonia and trihalomethanes [2,3]. Ammonia is an inorganic contaminant that results in odor and taste problems in water [4]. In Malaysia, the discharges from industrial and agricultural activities are caused of the contamination in the raw water such as surface and lake water.

Lately, water treatment plant in Malaysia often reported contaminated with ammonia such as in Johor, Negeri Sembilan and Selangor. The plant had be shut down temporarily because it received a high concentration of ammonia and led to shortage of water supply in the human population in certain areas [5,6]. Generally, the presence of ammonia with high concentrations causes toxicity to aquatic life and eutrophication. According to the National Drinking Water Quality Standard [7], the regulated concentration of ammonia for both raw water and drinking water are acceptable below than 1.5 mg/L.

Biological water treatment system can be used to remove high concentrations of organic and inorganic material and can produce high-quality effluent for reuse as various purposes such as plant watering, and use for car washing. The bacteria will be attached to the media filter as of biological layer and decompose all organic substances. According to Chaudhary et al. [8], biological system for water filtration also can reduce taste and odour of treated water [8]. The basic principle of sand filter is to physically filter out the suspended solid or particle from the water. The application of sand filter has become more abroad from year to years through the finding of its advantages in treating water by the researchers. The main advantage of sand filter is it not only can separate the suspended solid and particle from the water, but also other chemical; micropollutants [9], nitrogen compounds [10,11] and heavy metals [12].

This study was carried out to determine the feasibility of slow sand biofilter (BioSSF) as an alternative technology in water treatment plant (WTP). The main aim was to investigate the effect of empty bed contact time (EBCT) in removing ammonia in the contaminated drinking water source. In addition the variation of ammonia concentration in the influent of raw water was also investigated. Three levels of EBCT was studied i.e., 5, 10 and 15 minutes, while the variation of ammonia concentration in the range of 3 to 5 mg/L. Water sample was taken from Engineering Lake of Faculty of Engineering and Built Environment, UKM throughout this study.

2. Methodology

2.1. Experimental set-up

BioSSF was designed as alternative water treatment system to remove ammonia, turbidity, suspended solid, chemical oxygen demand (COD), and colour. This system was designed at a laboratory scale with a dimension of 65 cm height x 26 cm wide x 26 cm length as shown in Figure 1. Sand was used as filter media of BioSSF and was filled into the reactor until reached height of 40 cm.

Biofilm from tap water media filter in Environmental Laboratory, Faculty of Engineering and Built Environment was scratched and transferred into the BioSSF in order to develop the biological layer on the surface of the sand. Lake water sample taken from Engineering Lake, Faculty of Engineering and Built Environment, UKM , which contained carbon and other nutrient source, was fed into the BioSSF daily during the acclimatization process for the mature biofilm formation. Dependent on the biological content of raw water, the biological zone and biological layer on the media surface will basically develop within two to three weeks [13]. However, due to less quantity of biofilm obtained from the tap water media filter, the biofilm enhancement and formation in this study was conducted for 3 months.

There were two factors investigated i.e., EBCT and ammonia concentration in raw water. The EBCT was varied at 5, 10 and 15 minutes, while the ammonia concentration was varied at 3, 4 and 5 mg/L.

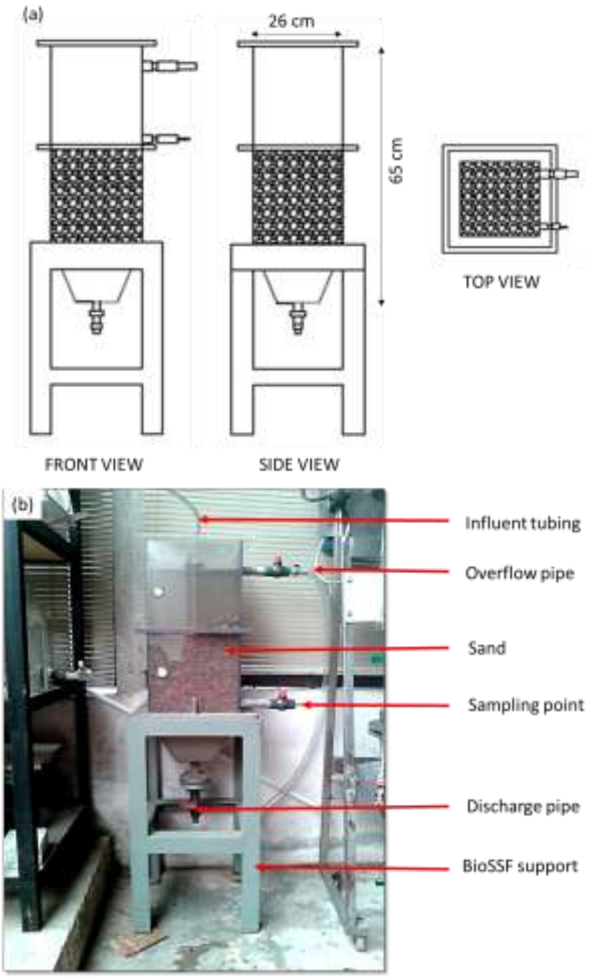

Fig. 1: BioSSF (a) schematic and (b) photo

2.2. Experimental procedure

The experiment was started by varying the EBCT at constant value of ammonia concentration was set at 4.5 mg/L. The EBCT was calculated using the following Equation (1):

$$EBCT = \frac{V_m}{Q} \quad (1)$$

Where, V_m was the working volume (L) and Q was the influent flowrate (L/min). From this experiment, the best EBCT was selected to investigate the effectiveness of BioSSF in removing the ammonia at different concentration of ammonia. For the first experiment (EBCT 5 minutes), the water sample with the constant ammonia concentration was fed into the BioSSF reactor at a flow rate of 8.8 L/min. For the EBCT 10 and 15 minutes, the flow rate of influent pump was adjusted to 4.4 and 2.9 L/min, respectively. The influent was flow from the influent tank to the BioSSF reactor and effluent of each EBCT was sampled five times. The sample effluent was analyzed according to the water quality analysis parameters. After the experiment of EBCT test, the best EBCT was chosen for the test with different concentration of ammonia. The influent of each sample with different ammonia concentration was flowed into the BioSSF reactor and effluent was sampled after the treatment.

2.3. Water quality analysis

Water quality analysis was conducted to determine the effectiveness of the BioSSF in treating the lake water sample. The parameters monitored in this study were pH, COD, color, turbidity and ammonia. The pH of each sample was measured using a pH meter (Model 215, Denver). The pH meter was calibrated by dipping the electrode into a container containing buffer pH 4 and pH 7 prior to the test on water samples. For determination of turbidity level, HF scientific DRT-15E Portable turbidity meter was used.

The concentration of ammonia in the water sample was measured using a spectrophotometer (HACH DR 2010, USA) at a wavelength of 425 nm. Three drops of mineral stabilizer and dispersing polyvinyl reagent, and 1 mL of Nessler reagent were added into 25 mL water sample prior to ammonia concentration measurement. The distilled water was used as a control.

The COD analysis was measured using a spectrophotometer (HACH DR2010, USA). Before the measurement, about 2 mL of distilled water and 2 mL of water sample is put into the COD reagent vials. Distilled water was used as control. The mixture was shaked to accelerate the reaction and then placed in the COD reactor (120-124 VAC reactor). The COD reactor was preheated to a temperature of 150 ˚C and then the mixture was heated for 2 hours. After 2 hours, the COD reagent was left until the temperature cool down. After temperature reached room temperature, the water COD was read at the wavelengths of 420 nm.

Color was measured using a spectrophotometer (HACH DR 2010, USA) at the wavelength of 455 nm. The color was measured in the unit of Pt-Co. Moreover, to determine the concentration of suspended solid (SS), initially filter paper 0.45 µm was heated for an hour and then allowed to cool at room temperature in desiccator. The weight of the filter paper (m_1, mg/L) was measured prior to filtration. About 20 mL of water sample (V, mL) was filtered using a vacuum pump. Then, the filter paper was reheated in the oven at 105 ˚C for an hour and was weighted afterward (m_2, mg/L). The concentration of SS was calculated using Equation (2):

$$SS = \frac{m_2 - m_1}{V} \tag{2}$$

2.4. Statistical analysis

The results were analyzed using a one-way analysis of variance (ANOVA) with a significant difference of $p < 0.05$. Statistical calculations were executed with SPSS software for Windows, version 16.0 (SPSS Inc. USA).

3. Result and discussion

3.1. Effect of empty bed contact time

3.1.1. Ammonia removal

Figure 2 shows the percentage removal of ammonia increased as the EBCT increased from 5 (77.0%) to 10 (93.6%) and 15 minutes (98.3%). In this experiment, the influent concentration of ammonia was constant at 4.53 mg/L. The longer the time taken for the EBCT, the higher the ammonia removal. The high level of EBCT gave sufficient time for the bacteria attached on the sand in the BioSSF reactor to degrade ammonia in the water sample as compared to the low level of EBCT. The pH value of the effluent (pH 8.5 to 9.0) was higher than influent sample (pH 6.5 to 7.0). However, it was still within the limit of treated water standards set by [14]. ANOVA analysis shows that there was significant different on the ammonia removal as increased the EBCT ($p < 0.05$).

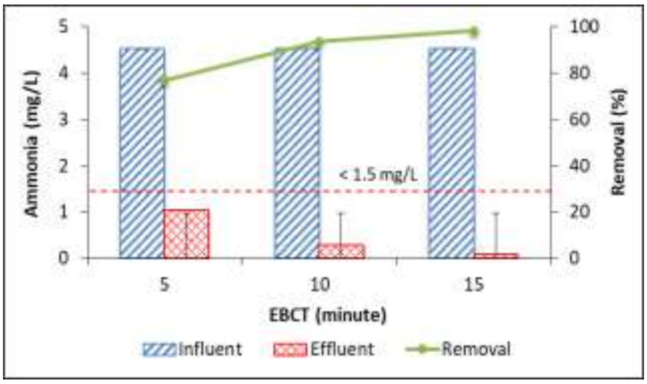

Fig. 2: Removal of ammonia at different EBCT

3.1.2. Turbidity removal

Figure 3 shows the percentage ammonia removal increased as the EBCT increased from 5 to 10 and 15 minutes. As can be seen, the turbidity of the lake water was treated to the below of standard limit (< 5 NTU) regulated by Ministry of Health, Malaysia [7]. The turbidity removal increased as the EBCT was increased from 5 (83.6%) to 10 (82.5%) and 15 minutes (87.5%). According to the statistical analysis, there was no significant difference ($p > 0.05$) between the three EBCTs on the turbidity removal.

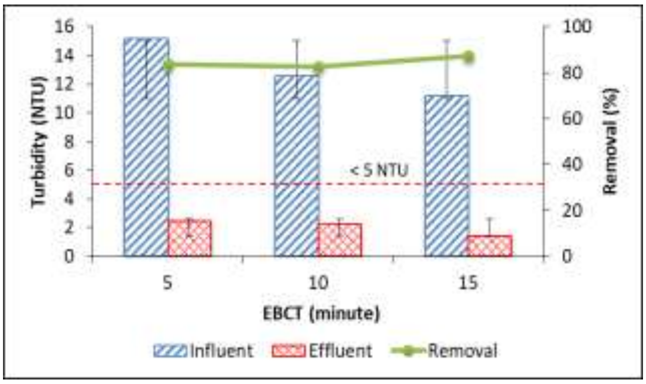

Fig. 3: Removal of turbidity at different EBCT

3.1.3. COD, SS and color removals

The BioSSF performed well in removing the COD where the percentage removal of COD for each EBCT rate were 100% as summarized in Table 1. This shows BioSSF can be an effective treatment system in reducing the COD in the water sample. The COD concentration in the influent water sample was 16 mg/L which higher than the permitted limits of 10 mg/L, but this contaminant parameter was totally removed. From the Table 1, the removal of SS also increased as the EBCT increased. However, the percentage removal of SS was less than 30%. In addition, the removal of color at EBCT of 5 minutes was 73.2%, and the removal increased to 79.2% and 84.4% at 10 and 15 minutes EBCT, respectively.

Table 1 Summary of BioSSF performance under the effect of EBCT

Water quality parameters	5 minutes	10 minutes	15 minutes
Ammonia removal (%)	77.0 ± 0.6	93.6 ± 1.3	98.3 ± 1.0
Turbidity removal (%)	83.6 ± 0.3	82.5 ± 1.6	87.5 ± 1.1
SS removal (%)	23.8 ± 4.4	28.3 ± 4.6	27.5 ± 4.6
Color removal (%)	73 ± 2.7	79 ± 3.0	84 ± 6.1
COD removal (%)	100	100	100

3.2. Effect of ammonia concentration in raw water

3.2.1. Ammonia removal

From the data obtained, the relationship between the ammonia concentration (mg/L) and the percentage removal of ammonia was shown in Figure 4. During this study, the EBCT was constant at 15 minutes. From the results, the percentage removal of ammonia decreased as the ammonia concentration increased from 3 mg/L to 5 mg/L, but the effluent concentrations were still below the permitted limit for treated drinking water (< 1.5 mg/L). By increasing the ammonia concentration, the bacteria in the BioSSF required more contact time to allow total degradation of ammonia occurs. Thus, a longer EBCT was required to remove high ammonia concentration in raw water. The pH value at these three conditions was in the range of 7.0 to 7.2 for raw water and 8.1 to 8.4 for treated water. In addition, ANOVA analysis found that increasing the ammonia concentration in the raw water had significantly decreased the ammonia removal.

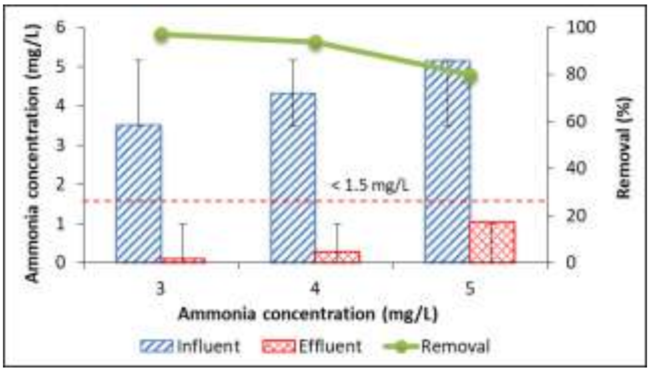

Fig. 4: Removal of ammonia at different ammonia concentration in raw water

3.2.2. Turbidity removal

Figure 5 shows the percentage removal of turbidity against the concentration of ammonia. This graph shows that there was a reduction in the turbidity of the three different concentrations of ammonia. At the ammonia concentration of 3 mg/L, the turbidity removal was 90%. The turbidity removal slightly decreased (83.1%) at ammonia concentration of 4 mg/L, but the percentage removal increased to 85.7% when the ammonia concentration was increased to 5 mg/L. It was found that the level of turbidity in the treated water at all ammonia concentrations were below than the limit of treated drinking water regulated by Ministry of Health Malaysia.

3.2.3. COD, SS and color removals

The summary of COD, SS and color removals under the effect of ammonia concentration were shown in Table 2. The removal of COD at all ammonia concentrations was 100%. Meanwhile the removal of SS at 3, 4 and 5 mg/L ammonia were 55.8, 46.9 and 45.8%, respectively. It was found that the SS removal percentages slightly decreased. Similar pattern to SS removal, the color removal also insignificantly decreased ($p > 0.05$) from 83% (3 mg/L ammonia) to 79% (4 mg/L ammonia) and 78% (5 mg/L ammonia).

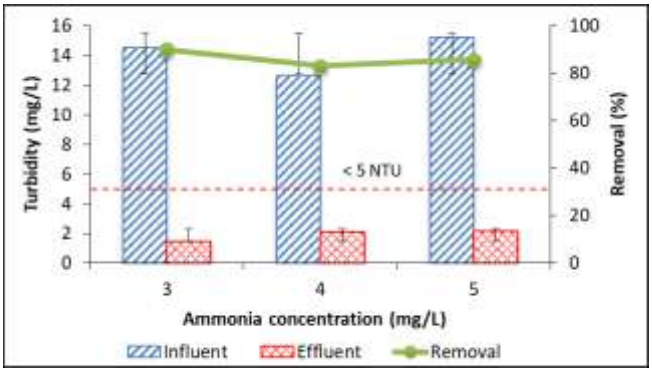

Fig. 5: Removal of turbidity at different ammonia concentration in raw water

Table 2: Summary of BioSSF performance under the effect of ammonia concentration

Water quality parameters	3 mg/L	4 mg/L	5 mg/L
Ammonia removal (%)	97.2 ± 0.9	93.7 ± 0.8	79.8 ± 0.5
Turbidity removal (%)	90.0 ± 0.6	83.1 ± 0.3	85.7 ± 0.3
SS removal (%)	55.8 ± 2.0	46.9 ± 3.4	45.8 ± 3.1
Color removal (%)	83 ± 2.0	79 ± 3.0	78 ± 2.0
COD removal (%)	100	100	100

3.3. Surface morphology of sand before and after the treatment

Figure 6 shows the micrograph of sand observed under the SEM at 20,000 magnification after the treatment. It can be seen the presence of microbial community in form of biofilm matrix on the sand surface that responsible for the water treatment especially for ammonia and COD degradation. The microbial morphologies were existed in mix colonies where bacillus and coccus were the main bacteria. According to Abu Hasan et al. [14], the biofilm structure contains bacterial colonies that presence in a complex form and have a rough surface. In addition, [15] found that the sand was accumulated by the bacteria attached on its surface.

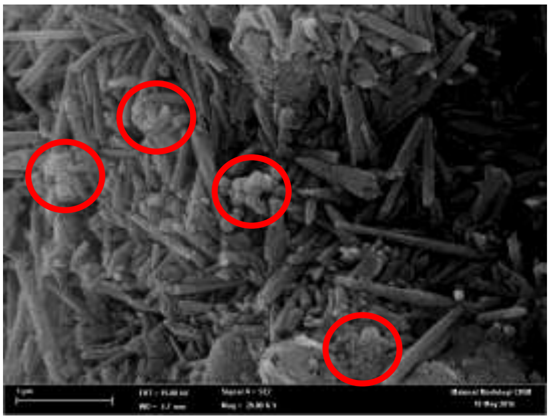

Fig. 6: Micrograph of sand surface after the treatment

3.4. Comparison with previous studies

Comparison with previous studies was conducted to evaluate the effectiveness of each technology in removing ammonia. All of the comparison of those treatment technology was conducted only for the water treatment such as surface water and tap water. There were six treatment technologies were summarized as tabulated in Table 3. The technologies covered BAC, trickling filter, sMBR, FBBR, BAF and MABR.

From Table 3, BAF reactor performed the highest ammonia removal with 98.4% followed by MABR (96.7%), sMBR (89.4%), trickling filter (80%), BAC (74%) and FBBR (50%). Instead of high ammonia removal showed by BAF, but the retention time for the ammonia removal using BAF was 24 hours which quite higher compared to the other treatment techniques. As can be seen in Table 3, low removal of ammonia using FBBR systems found by [16]. The phenomenon was due to the winter season where the studies was conducted. The winter season had affected the growth of the nitrifying bacteria thus, its affected to the ammonia removal performance.

Table 3: Comparison with previous studies

Treatment system	Source of water	Retention time (hour) or EBCT (minute)	Removal (%)	References
Biological activated carbon (BAC)	Surface water	10 minutes	74	[17]
Trickling filter	Tap water	-	80	[18]
Submerged Membrane Bioreactor (sMBR)	Raw water	30 minutes	89.4	[19]

Fluidized Bed Biofilm Reactor (FBBR)	Surface water	40 minutes	50	[16]
Membrane Aerated biofilm Reactor (MABR)	Surface water	30 minutes	96.7	[20]
Biological Aerated Filter (BAF)	Tap water	24 hours	98.4	[21]
Slow Sand Biofilter (BioSSF)	Lake water	15 minutes	98.3	This study (2018)

4. Conclusion

From the findings of the experiments that have been carried out, the study shows that BioSSF was effective in removing ammonia, COD turbidity, SS and colour in the lake water. From experiments, the EBCT 15 minutes was the best time in getting rid of ammonia. Ammonia was eliminated more than 90% and the concentration of ammonia in a sample of the water was less than permitted level of 1.5 mg/L. The presence of bacteria as a biocatalyst for decomposing ammonia was found attached on the sand surface. For the removal of turbidity, the removal percentage was high over 80% for each of EBCT and different concentrations of ammonia. Based on the analysis of water quality after the treatment, BioSSF can be considered as a potential alternative for the ammonia removal in water treatment plants, thus its can prevent the plant from periodically shutdown due to high level of ammonia in raw water.

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