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Evaluation of a novel double-layer biological aerated filter (BAF) for drinking water bio-pretreatment: comparison with a single-layer BAF

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ABSTRACT

Biological pre-treatment for drinking water production is becoming more crucial in developing countries, due to the polluted water resource and stringent water quality regulation. Comparison between a double-layer biological aerated filter (BAF) and a single-layer lava-based BAF had been carried out in terms of organic matter and ammonia removal, and maintenance strategies were discussed. Both the BAFs could achieve satisfactory removal of ammonia, and the former was better to cope with higher ammonia loading due to adsorption ability of clinoptilolite. Dissolved oxygen and pH monitoring demonstrated that desorption would happen when the feed ammonia concentration decreased. The two reactors had similar ability for removal of organic matter; however, the double-layer BAF apparently showed more economically well-controlled considering backwashing during the investigation period. This may be attributed to the special hydraulic flow status, that is, suspended and fluidic flow state in the lower layer, which could decrease the blockage of the light carrier. Moreover, both the BAFs presented a good removal of trace organic matter, such as odor and endocrine disrupting chemicals. Thanks to the superiority of the double-layer BAF, and it could be expected that it has a great potential to act as a bio-pretreatment reply to the problem from polluted source water and stringent water quality regulation.

Keywords: Light carrier; Clinoptilolite; Lava; Biological aerated filter; Drinking water bio-pretreatment

1. Introduction

Drinking water treatment lines need to be improved due to polluted source water and stringent water quality standard. Ammonia and organic matter removal has been becoming one of the main objectives in modern drinking water treatment [1,2], because they are difficult to be eliminated by conventional process of coagulation/sedimentation/sand filtration.

Biological removal of organic matter and ammonia has got a lot of interests because there are hardly by-products, and it could greatly reduce the formation

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potential of trihalomethanes by reducing the dosage of chlorine [3]. Therefore, effort has been made to apply biological methods for pre-treatment of polluted source water. Biological aerated filter (BAF) was one of the popular bioreactors for biological nutrient removal due to its low land requirements and simplicity of operation for domestic wastewater [4,5] and industrial wastewater treatment [6,7]. Moreover, BAF also could perform well with respect to trace organic matter removal [8]. Although BAF has been widely accepted for efficient treatment of wastewater, little was reported for drinking water production.

Recently, Hasan et al. [9] demonstrated that BAF performed well with respect to ammonia and manganese removal in Malaysia. Moreover, Lu et al. [10] found that BAF presented high removal of ammonia while pre-treating raw water containing high ammonia nitrogen. In China, many drinking water plants used biological filters to pre-treat source water, which could greatly reduce the impurities' loadings for the following processes. In a drinking water work located in South China, a double-layer BAF had been established as a novel pre-treatment process for polluted source water, and previous study [11] had demonstrated that double-layer BAF could perform well with polluted source water.

In this report, a single-layer BAF based on lava rock and double-layer BAF based on light carrier and clinoptilolite (a type of natural zeolite) were established. The objective of this study is to compare the two BAFs in terms of impurities removal and maintenance. Removal of ammonia was reported under steady-state and shock-loading conditions. Removal of dissolved organic matter and some chosen trace organic matter was also investigated, as well as the backwashing efficiency and frequency. The results could provide more ideas about the application of BAF for drinking water bio-pretreatment.

2. Experimental sections

2.1. BAF reactors systems

A schematic diagram of the BAF reactors used in the experiments is shown in Fig. 1. Each BAF was constructed of a plexiglass pipe with a diameter of 100 mm and total effective depth of 2,200 mm. For the single-layer BAF, lava was used as the packing material, and the media height was 1,800 mm. For the double-layer BAF, as seen from Fig. 1, the lower layer of the BAF was packed with polyethylene media, a kind of light carrier; the upper layer of the BAF was packed with clinoptilolite, a kind of zeolite. The total media height of the double-layer BAF was 2,200 mm, with the lower layer and upper layer at 1,000 mm and 800 mm, respectively. The BAFs were operated in an up-flow mode. Properties about the different media in terms of particle density, porosity, specific surface areas, and size were displayed in Table 1.

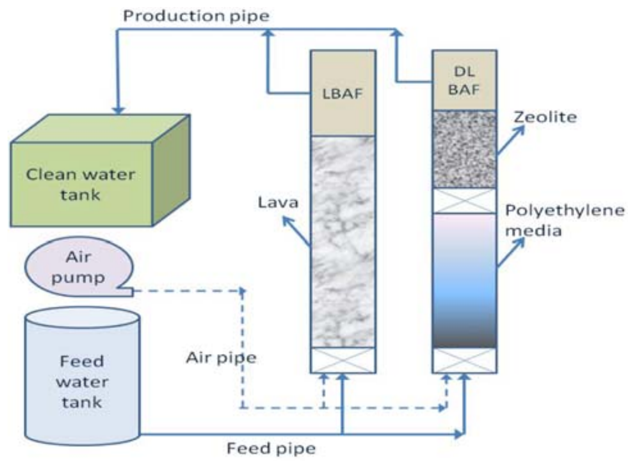

Fig. 1. Schematic diagram of the experimental set-up.

2.2. Polluted raw water

Comparison of two BAFs was carried out under varying conditions, and feed of the two reactors was always identical. Start-up period lasted for about 50 days. Approximately 60 days of stable operation was compared. Shock loadings were achieved by adding pre-calculated NH_4Cl into the feed water. The specific water quality was summarized in Table 2.

2.3. Operation conditions

Peristaltic pumps were used to feed the river water to the BAFs, and others provided backwashing. Compressed air was introduced into the BAF by air pump via air diffusers placed at the bottom of the BAF, with the air flow rate measured using an air flow meter. According to previous studies, hydraulic retention time was set at 0.5 h, and air to water ratio was 0.5:1. The hydraulic flow was 28 L/h, and the backwashing strategy was to combine air and water flushing as follows: air flushing for 3 min, then air and water flushing for 5 min, and then water flushing for 5–15 min. The aeration intensity and water intensity for flushing were 5 L/(m^2 s) and 5–10 L/(m^2 s), respectively. Sampling points were located along the height of the BAF column at 200, 500, 800, 1,400, and 1,800 mm.

2.4. Analytical methods

The influent and effluent of the BAFs were sampled and analyzed for chemical oxygen demand

Table 1
Properties of the filter media

	Lava rock	Light carrier	Clinoptilolite
Particle density (g/m^3)	1.12	–	1.35
Porosity (%)	58.33	91.12	41.23
Surface (m^2/g)	3.98	0.0065(m^2/one)	4.85
Size (mm)	1–3	Ø30 × 15	1–3

Table 2
Characteristics of the polluted source water

	Start-up period	Steady-state period	Shock-loading period
COD (mg/L)	5.73–9.44	5.76–8.98	6.12–6.89
NH_3-N (mg/L)	0.74–2.25	1.07–3.56	5.87–28.65
Turbidity (NTU)	58.9–83.3	21.4–69.2	22.8–46.3
pH	7.21–7.68	7.06–7.65	7.14–7.51
Temperature (℃)	30–34	20–30	20–25
DO (mg/L)	3.71–7.07	2.12–5.89	2.27–4.74

(COD), ammonia, nitrite, and turbidity. COD, ammonia, and nitrite were measured using standard methods, and turbidity was monitored by turbidity meter. Dissolved oxygen (DO), pH, and flow rates were also measured. Trace organic matters examined in this study were determined by liquid–liquid extraction by gas chromatography.

3. Results and discussion

3.1. Removal of ammonia

In order to completely remove ammonia, ammonia-oxidizing bacteria and nitrite-oxidizing bacteria were needed to simultaneously exist in the reactors [12]. Therefore, in the initial start-up period, performance of the reactors in ammonia removal increased gradually (data not shown) as accumulation and reproduction of bacteria went on in the reactors. The start-up duration lasted for about 10–15 days, and the test of this report was initiated when the reactors had been operated for about 50 days.

During the stable operation period, removal of ammonia in the two reactors was shown in Fig. 2. It could be seen that both the reactors were able to effectively remove ammonia when the loading rate was between 1.07 and 3.56 mg/L in the feed. Though ammonia increased gradually in the feed, two reactors always got satisfactory removal of ammonia, with average removal rates at 85.86 and 85.68%, for lava-based BAF and double-layer BAF, respectively. Note that effluents of the two BAFs were always below

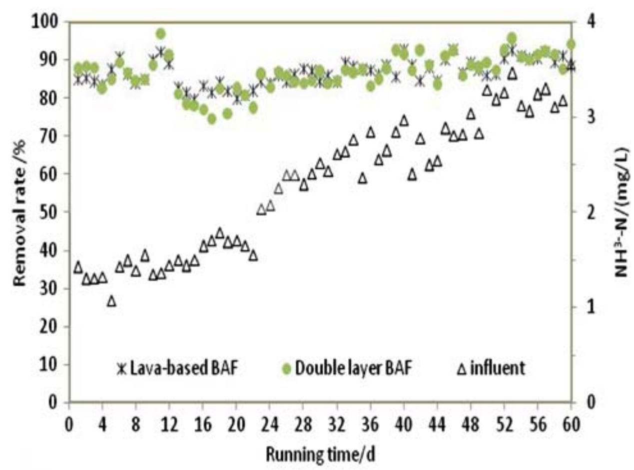

Fig. 2. Removal of ammonia by lava-based BAF and double-layer BAF.

0.5 mg/L, which was the standard limited value in China. Moreover, no accumulation of nitrite was observed during this period (data not shown).

In summer, storm water may aggravate the river water quality, especially the concentration of ammonia. Moreover, when some wastewater treatment plant cannot work well, the river water was possibly polluted heavily. Therefore, it was interesting to evaluate whether the BAF reactors was able to work well when ammonia increased suddenly. On day 70, an ammonia shock was carried out. As expected, when increasing the ammonia concentration to 28.65 mg/L, efficiencies of the two reactors apparently decreased to 20.47 and 67.85% (see Fig. 3). It was clear that double-layer BAF was greatly better at the beginning of the shock loading; this may be attributed to the adsorption ability of the zeolite in the double-layer BAF [13]. With time elapsing, adsorption gradually saturated, and removal rate of ammonia in double-layer BAF decreased gradually. While decreasing the influent concentration to 3.63 mg/L, desorption possibly happened in the upper layer of the double-layer BAF, because the removal rate of double-layer BAF was far lower than that of lava-based BAF.

In order to find out the mechanism of the ammonia variation, on day 75, DO and pH throughout the length of the double-layer BAF column were continuously determined for three times every 4 h, and the presented data in Figs. 4 and 5 were given as average values. It could be seen that DO and pH presented a relatively large drop at the point of 1,400 mm. This demonstrated that there was apparent nitrification in the clinoptilolite. However, the ammonia concentration did not decrease. That is, nitrification really decreased ammonia, but desorption of ammonia from clinoptilolite may offset the nitrification effect. Thus, ammonia concentration would not change.

The phenomena observed in this experiment demonstrated that double-layer BAF indeed had greater ability to cope with ammonia shock loadings. Moreover, clinoptilolite was also reported to have adsorption ability for Fe and Mn [14]; thus, clinoptilolite would act as a greatly potential application in drinking water production. But as subsequent desorption would affect the performance, a rapid regeneration strategy of zeolite was necessary for successful application of zeolite as the BAF media.

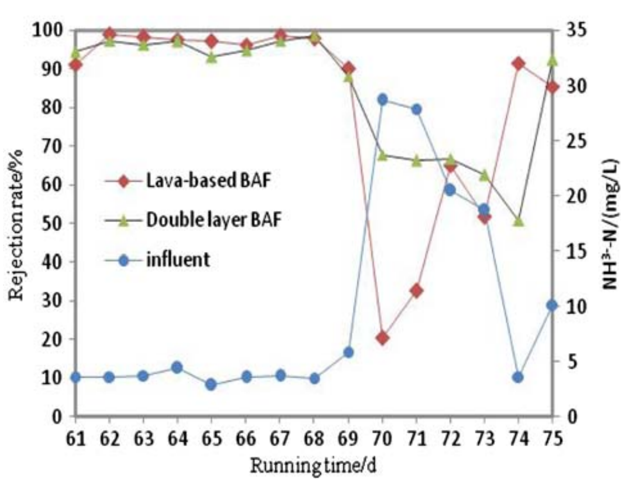

Fig. 3. Performance of the two BAFs in terms of ammonia under ammonia shock loadings.

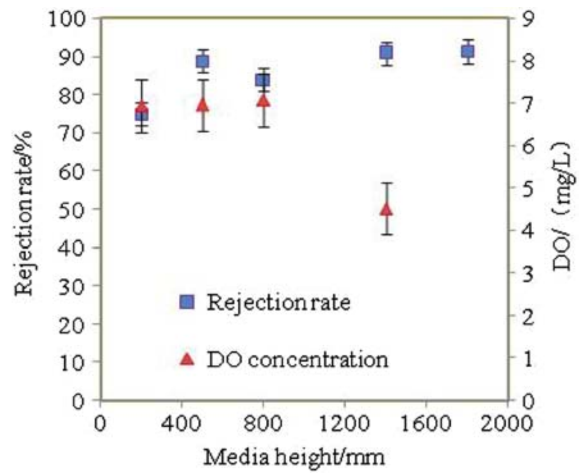

Fig. 4. Variation of ammonia rejection rate and DO concentration along the BAF column on day 75.

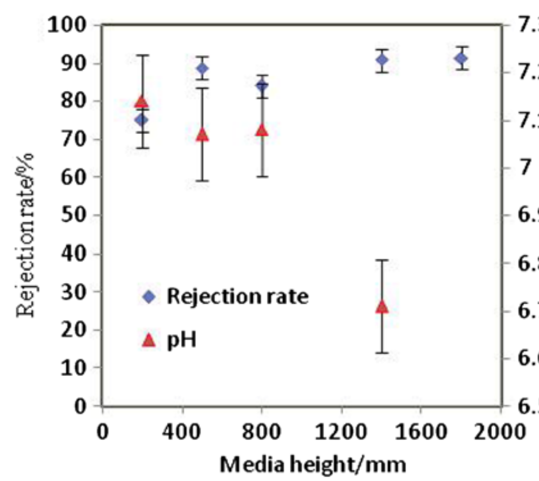

Fig. 5. Variation of ammonia rejection rate and pH along the BAF column on day 75.

3.2. Removal of organic matters

The organic matter did not have apparent seasonal fluctuation during the test period; the average feed concentration of COD was 7.11 mg/L. The average organic matter removal rate in the lava-based BAF and double-layer BAF was 23.11 and 19.6% (see Fig. 6), respectively. Though lava-based BAF acted a bit better than double-layer BAF, the two reactors presented unsatisfactory, limited, and fluctuated results of organic matter removal. However, some observed that the organic matter removed by biodegradation had great potential for disinfection by-products formation [15].

Odor and PAEs were also evaluated to investigate the feasibility of BAFs for trace organic matter. During

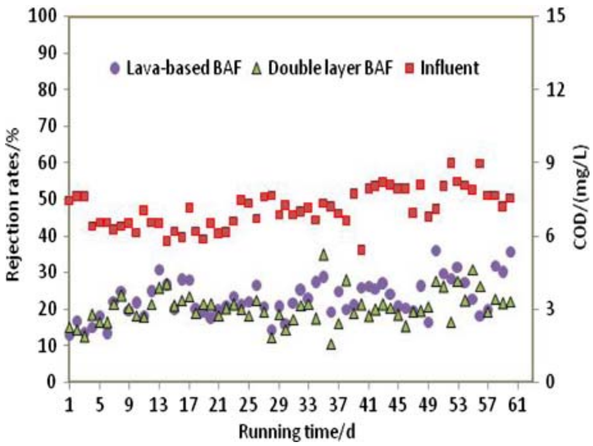

Fig. 6. Removal of organic matter during the experimental period.

the experiment period, the average concentration of geosmin and 2-MIB in the feed water was controlled at 124 and 114 ng/L by standard addition, respectively. Interestingly, as shown in Fig. 7, removal rates of geosmin and 2-MIB in lava-based BAF were 50.16% and 42.11%, respectively, and removal rates of geosmin and 2-MIB in double-layer BAF were 30.65 and 35.44%, respectively.

Moreover, endocrine disrupting chemicals (EDCs) were also kinds of trace organic matter receiving much attention [16]. Therefore, dibutyl phthalate (DBP), diethyl phthalate (DEP), and diethylhexyl phthalate (DEHP) were controlled at 66.2, 34.2, and 545 μg/L, respectively, in the feed by standard addition. It could be seen from Fig. 8 that lava-based BAF could remove 87.35% of DBP, 62.86% of DEHP, and 50.00% of DEP.

Though BAFs did not give ideal rejection of organic matter, it was significant to demonstrate that

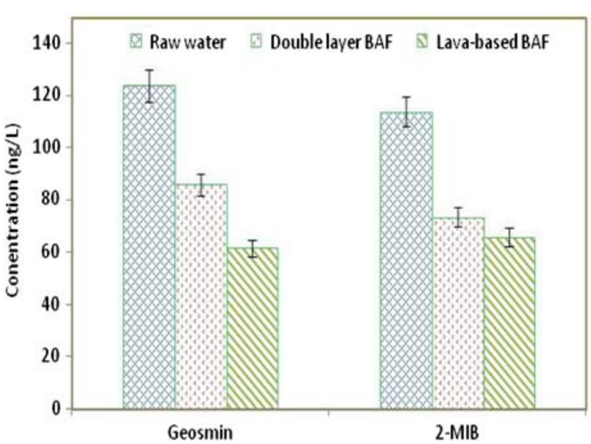

Fig. 7. Removal of geosmin and 2-MIB during the experimental period.

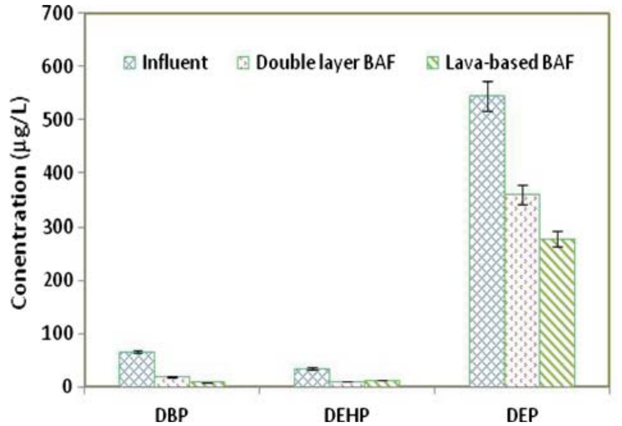

Fig. 8. Removal of EDCs during the experimental period.

both lava-based BAF and double-layer BAF could remove trace organic matter from drinking water resources.

3.3. Considering the operation and maintenance

After operation for a certain time, the filter may be clogged resulting in pressure drop and weak oxygen transfer. In order to guarantee the activity of the aerobic bacteria, it was suggested to backwash the BAF regularly [17]. During two year's operation, double-layer BAF needed to be backwashed every 15–45 days, depending on the feed water quality. Generally, 15 days and 45 days were appropriate for high-turbidity water in summer and low-turbidity water in winter, respectively. While for lava-based BAF, backwashing was more frequent. It was 7 days in summer and 15 days in winter.

Factually, the light carrier was suspended with a dynamic balance. It was observed that light carrier in the double-layer BAF was always suspended under the lift forces of aeration and hydrodynamics. Thanks to the middle support, and the light carrier was squeezed while filtration. As the biofilms grew gradually on the filter surface, mass of the filter media increased. Then the light carrier would be less squeezed. However, when the gravity of the filter media increased to some extent, some biofilms on the surface were observed to be brushed off. Thus, it could be seen that turbidity in the effluent of the lower layer was bigger than that in the influent between times (see Fig. 9).

Thick sludge cake would not easily accumulate and form. Therefore, it was relatively easy and simple to backwash the double-layer BAF. On the other hand, for the single-layer BAF, more and more sludge would accumulate, which resulted in difficult and frequent backwashing.

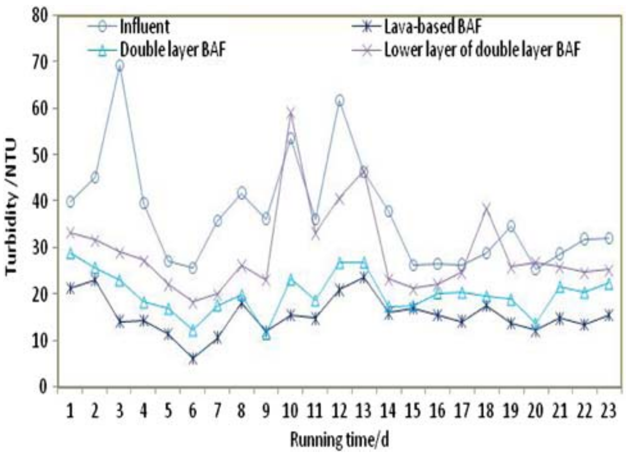

Fig. 9. Variation of turbidity during the test period.

4. Conclusion

- Elimination rates of ammonia would be greatly influenced by the feed concentration, and double-layer BAF presented a significant potential to cope with the shock loadings. Though adsorption by clinoptilolite would temporarily remove higher ammonia, desorption may be following as the feed ammonia decreased.
- Removal of dissolved organic matter may be not so satisfactory, but both the BAFs showed potential rejection of some trace organic matter, such as odor and EDCs.
- Considering the backwashing frequency, double-layer BAF was easier to be operated and managed than lava-based BAF.

As a result, there is a wide range of potential applications of BAFs for pre-treatment of polluted source water, and the proposed double-layer BAF may be a better solution for seasonal variation of impurities in the feed when compared with the single-layer BAF.

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