Available online at www.sciencedirect.com
ScienceDirect
Journal of Hazardous Materials 143 (2007) 291–295
Journal of Hazardous Materials
www.elsevier.com/locate/jhazmat

The performance of BAF using natural zeolite as filter media under conditions of low temperature and ammonium shock load

Sheng-Bing He[a,*], Gang Xue[b], Hai-Nan Kong[a]

[a] *School of Environmental Science and Engineering, Shanghai Jiaotong University, 800 Dongchuan Road, Shanghai 200240, PR China*
[b] *School of Environmental Science and Engineering, Donghua University, Shanghai 200051, PR China*

Received 16 March 2006; received in revised form 30 August 2006; accepted 8 September 2006
Available online 15 September 2006

Abstract

Natural zeolite and expanded clay were used as filter media for biological aerated filter (BAF) to treat municipal wastewater in parallel in whole three test stages. The stage one test results revealed that zeolite BAF and expanded clay BAF have COD and NH_3-N removals in the range of 84.63–93.11%, 85.74–96.26%, 82.34–93.71%, and 85.06–93.2%, respectively, under the conditions of water temperature of 20–25 °C and hydraulic load of 2–3 $m^3/(m^2\,h)$. At the following stage two, the influent NH_3-N concentration was increased to about double value of the stage one, and it was investigated that the effluent NH_3-N of expanded clay BAF increased significantly and then gradually restored to normal condition in 2 weeks, while the effluent NH_3-N of zeolite BAF kept stable. At stage three, the low reactor temperature has also different effects on these two BAFs, under conditions of water temperature of 7–10 °C, hydraulic load of 2–3 $m^3/(m^2\,h)$, zeolite BAF and expanded clay BAF have COD and NH_3-N removals in the range of 74.5–88.47% (average of 81.57%), 71.73–88.49% (average of 81.06%), 71.91–87.76% (average of 80.49%), and 38.41–77.17% (average of 65.42%), respectively. Three stages test results indicated that the zeolite BAF has a stronger adaptability to NH_3-N shock load and low temperature compared to expanded clay BAF. In addition, the detection of the amounts of heterobacteria and nitrobacteria of two biological aerated filters in three stages also showed the zeolite filter media was more suitable to the attached growth of nitrobacteria, which is helpful to the improvement of nitrification performance in zeolite BAF.

Keywords: BAF; Natural zeolite; Expanded clay; NH_3-N shock load; Low temperature

1. Introduction

Biological aerated filter (BAF) is flexible reactor, which provides a small footprint process option at various stages of wastewater treatment. BAF contains a granular media that provides a large surface area per unit volume for biofilm development. The media also allows the reactors to act as deep, submerged filters and incorporate suspended solids removal. As a fixed-film process, optimal conditions for the relevant micro-organisms can be maintained independently of hydraulic retention times. The process has therefore achieved high levels of nitrification, denitrification and phosphate uptake [1]. The selection of a suitable BAF media is critical in the design and operation of the process, to enable the required effluent standards to be reached. Superior substrate removal has been shown by BAF containing mineral media, such as expanded clay, compared to those using sand or plastic media with similar dimensions [2]. The selection of a suitable BAF media is critical in the design and operation of the process, to enable the required effluent standards to be reached. Superior substrate removal has been shown by BAF containing mineral media, such as expanded clay, compared to those using sand or plastic media with similar dimensions [2]. The size of a BAF medium also has a strong influence on process performance. Consequently, different sized media have been recommended for different applications [3]. A medium larger than 6 mm may be preferable for a roughing stage BAF prior to full secondary treatment. Meanwhile, it has been suggested that a tertiary treatment BAF should use a medium smaller than 3 mm. The intermediate size range of 3–6 mm has been designated suitable for secondary treatment BAFs.

Natural zeolite is a potential filter media for BAF. It is a nonmetallic mineral with the characteristics of high porosity and large specific surface area. In addition, it is one ion exchanger with a high affinity for ammonium ion [4,5], which is reported

---

* Corresponding author.
E-mail address: heshengbing@sina.com (S.-B. He).

0304-3894/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhazmat.2006.09.024

Table 1
Characteristics of the zeolite

Size range (mm)	3–5
Density (kg/m^3)	2316
Bulk density (kg/m^3)	1015
Porosity (%)	43.83
Specific surface area (m^2/g)	6.84
Silicon/aluminum ratio	4.1–5.7

to have a classical aluminosilicate cage like structure and therefore exhibits significant macroporosity [6]. Earlier studies have shown that clinoptilolite, and certain other natural zeolites can be effective in removing ammonia from wastewater [6–8], and has been used to enhance the nitrification of biofilter and equalize the ammonia peaks from secondary effluent [9–11]. However, it has not been found the reports on removing organic pollutants and ammonium nitrogen simultaneously from raw wastewater under the conditions of low temperature and ammonium shock load by using zeolite as filter media.

This paper reports the application of BAF for municipal wastewater treatment using natural zeolite as media. The wastewater from a municipal wastewater treatment plant was fed to upflow biofilters and the performance of biofilters with natural zeolite and expanded clay media under the conditions of low temperature and ammonium shock load was observed. For expanded clay is a common and superior filter media for BAF, and the aim of the study was to compare the efficiencies of these two media in removing organic pollutants and ammonium nitrogen simultaneously from raw wastewater under the conditions of low temperature and ammonium shock load.

2. Materials and methods

2.1. Reactor description

The test BAF was made of acrylic. The reactor diameter was 0.15 m and the height 2.5 m with an effective volume of 31.8 L. The air was introduced into the reactor with a micro-bubble air diffuser and the air flow rate was controlled with an air flowmeter. Under normal conditions, the air flow rate was set at 3.5 L/min. There were all two BAFs, of which one was run as control reactor packed with expanded clay and the other with zeolite media as test reactor. At the bottom of the filter, a gravel layer with height of 0.3 m was laid to support the filter media, and the heights of both filter media layers were 1.7 m. The natural zeolite was obtained from Jinyun, Zhejiang province, and its characteristics are shown in Table 1. Zeolite has a mean diameter of 3–5 mm which is similar to that of expanded clay used in control BAF, and the characteristics of expanded clay are shown in Table 2. The diameter of the column was nearly 50 times of that of the filter media to limit the wall effect [12]. The raw wastewater was pumped into two BAFs with influent pumps and flowed upward through the filter media layer, and the effluent was collected in a storage tank to provide backwash water. The BAFs were backwashed every 48 h. The backwash sequence included air scour (4 min), followed by combined air scour and water backwash (5 min). The water and air backwash application rate were set at 10 L/min and 12 L/min, respectively. The temperatures of the mixed liquid in two BAFs were both controlled with thermostats. A schematic of the experimental system is shown in Fig. 1.

Table 2
Characteristics of the expanded clay

Size range (mm)	3–5
Density (kg/m^3)	2260
Bulk density (kg/m^3)	975
Porosity (%)	45.27
Specific surface area (m^2/g)	4.57
Content of silicon dioxide (%)	65.33

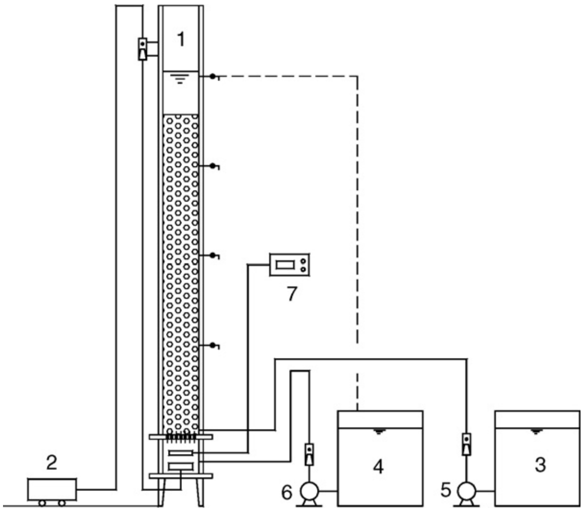

Fig. 1. Schematic of the BAF system: (1) BAF reactor; (2) air blower; (3) raw wastewater tank; (4) effluent storage tank (backwashing water tank); (5) influent pump; (6) backwashing pump; (7) thermostat.

2.2. Experimental raw wastewater

The test wastewater was collected from the outlet of grit tank in Shanghai Minhang wastewater treatment plant, and its characteristics are summarized in Table 3.

2.3. Operating conditions

The whole test was divided into three stages. During each test stage, the operating conditions of two BAFs are identical and summarized as follows:

Table 3
The characteristics of the test wastewater

Parameter	Range	Mean
pH	6.5–7.9	7.5
SS (mg/L)	121–211	175
COD (mg/L)	188–422	307
NH_3-N (mg/L)	22.3–41.6	29.8
TN (mg/L)	32.7–66.5	52.2
TP (mg/L)	2.1–5.2	3.2

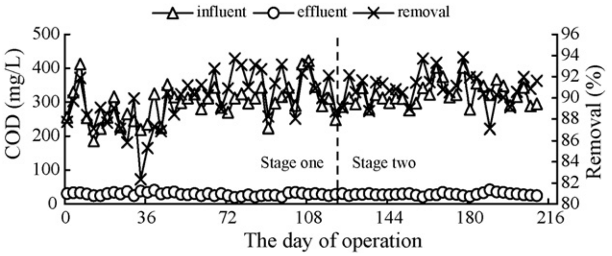

Fig. 2. Influent and effluent COD in zeolite BAF at the reactor temperature of 20–25 °C.

- *Stage one* (*120 days*). The temperature of mixed liquid was controlled at 20–25 °C, DO 1.5–2.0 mg/L, hydraulic load 2–3 $m^3/(m^2\ h)$, HRT 0.95–1.43 h.
- *Stage two* (*90 days*). The temperature of mixed liquid was controlled at 20–25 °C, DO 1.5–2.0 mg/L, hydraulic load 2–3 $m^3/(m^2\ h)$, HRT 0.95–1.43 h, and a certain quantity of NH_4Cl solution was added into raw wastewater and make the ammonium nitrogen in influent doubled.
- *Stage three* (*90 days*). The temperature of mixed liquor was controlled at 7–10 °C, DO 1.5–2.0 mg/L, hydraulic load 2–3 $m^3/(m^2\ h)$, HRT 0.95–1.43 h.

2.4. Analytical methods

The chemical oxygen demand (COD) and ammonium nitrogen (NH_4^+-N) were analyzed according to standard methods [13]. Additionally, the temperature, dissolved oxygen (DO) and pH were routinely monitored during the experimental period.

2.4.1. Counting of nitrifying bacterial population

Samples of media covered with biomass were collected at the middle section of the biofilters. A membrane filter method was used to count viable heterotrophic and nitrifying bacteria. To count heterotrophic bacteria, albumin agar medium was used. For nitrifying bacteria, Nitrobacteria, a medium containing the nitrite ion was used. These media and details of viable cell counting are described in literature [14].

3. Results and discussion

3.1. Start-up of BAFs

Seed sludge was inoculated from Shanghai Minhang wastewater treatment plant. The two BAFs operated under the conditions of stage one, and were backwashed once every 24 h, then reached steady state after 4 weeks' operation.

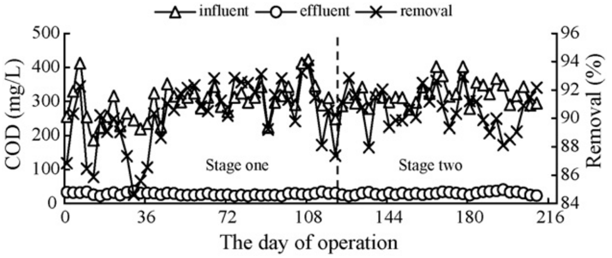

Fig. 3. Influent and effluent COD in expanded clay BAF at the reactor temperature of 20–25 °C.

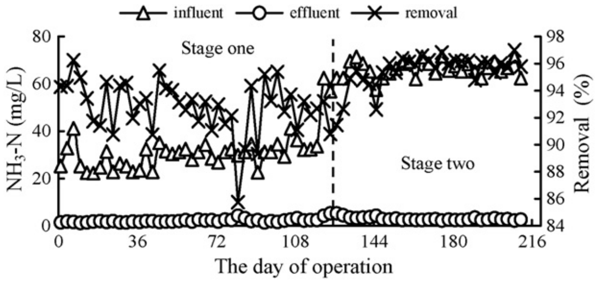

Fig. 4. Influent and effluent NH_3-N in zeolite BAF at the reactor temperature of 20–25 °C.

3.2. The influence of ammonium shock load on performances of two BAFs

The COD and NH_3-N of influent and effluent in two BAFs during stage one and two are presented in Figs. 2–5.

During the stage one of 120 days, two BAFs showed excellent removals for COD and NH_3-N. It was found that the COD in effluent of expanded clay BAF was in the range of 20–41 mg/L, and COD removal varied from 82.34% to 93.71% (average of 90.28%). As to zeolite BAF, there has a COD removal range of 82.34–93.71% (average of 89.86%) and effluent COD was in the range of 22–38 mg/L. For the removal of NH_3-N, it was investigated that the zeolite BAF has a slightly higher removal efficiency compared to the expanded clay BAF, the effluent NH_3-N was in the range of 1.3–3.3 mg/L (average removal of 89.27%) while the expanded clay BAF was in the range of 2.0–3.5 mg/L (average removal of 92.87%).

During the following stage two of 90 days, a certain quantity of NH_4Cl solution was added into the raw wastewater tank to make the influent ammonium nitrogen about doubled, and to investigate the effect of ammonium nitrogen shock load on the performances of two BAFs. At this stage, it was found that the NH_3-N shock load has no disadvantageous influence on COD removals of two BAFs, and the COD removals of zeolite BAF and expanded clay BAF were in the range of 87.98–92.95% and 87.09–93.84%, respectively. Whereas, there has a certain difference in NH_3-N removal for these two BAFs, zeolite BAF showed a strong adaptability to this shock load and the effluent NH_3-N kept almost stable in the range of 1.3–5.3 mg/L. However, a

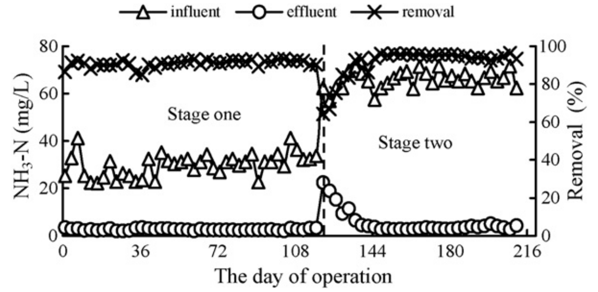

Fig. 5. Influent and effluent NH_3-N in expanded clay BAF at the reactor temperature of 20–25 °C.

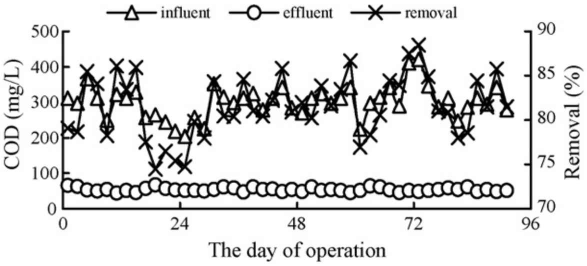

Fig. 6. Influent and effluent COD in zeolite BAF at the reactor temperature of 7–10 °C.

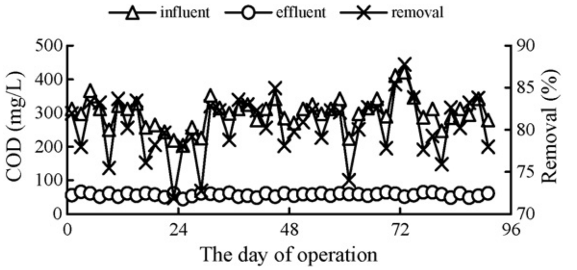

Fig. 7. Influent and effluent COD in expanded clay BAF at the reactor temperature of 7–10 °C.

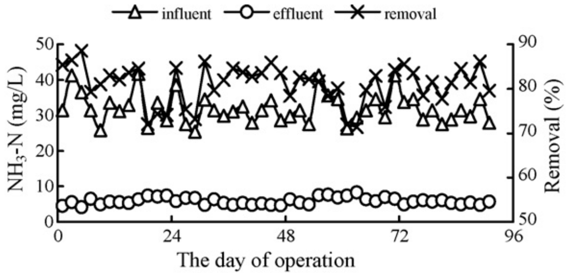

Fig. 8. Influent and effluent NH_3-N in zeolite BAF at the reactor temperature of 7–10 °C.

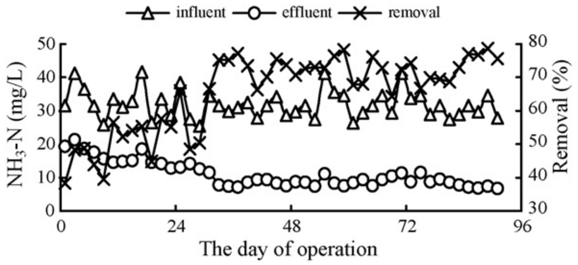

Fig. 9. Influent and effluent NH_3-N in expanded clay BAF at the reactor temperature of 7–10 °C.

high level NH_3-N of above 20 mg/L was observed in expanded clay BAF effluent and was gradually restored to normal level (2.6–6.4 mg/L) in 2 weeks. Through this test, it was showed that the adsorption of zeolite for NH_3-N is helpful to resist the NH_3-N shock load, which is similar to the result obtained in a zeolite added membrane bioreactor system [15].

3.3. The influence of low temperature on performances of two BAFs

At the stage three, the temperature of two BAFs was controlled at 7–10 °C to investigate the influence of low temperature on the performance of two BAFs, and the operational results are shown in Figs. 6–9.

According to operation result, a disadvantageous influence on COD and NH_3-N removal was found due to the low temperature, the COD removals for zeolite BAF and expanded clay BAF were decreased to the range of 74.5–88.47% (average of 81.57%) and 71.91–87.76% (average of 80.49%), respectively. Compare to COD removal, low temperature showed a more adverse influence on NH_3-N removal. At the initial of stage three, the effluent of expanded clay BAF has a NH_3-N concentration of about 20 mg/L (18.7–21.3 mg/L) and then kept stable at around 10 mg/L (6.8–11.5 mg/L) in 30 days, and the removal was in the range of 38.41–77.17% (average of 65.42%). For zeolite BAF, due to the combined effect of nitrification and adsorption of NH_3-N by zeolite [16], a low level of NH_3-N (4.3–8.5 mg/L) was observed in effluent during this period of 90 days, and the removal was in the range of 71.73–88.49% (average of 81.06%).

3.4. The detection of microorganism of two BAFs at three stages

At the whole three test stages, samples for viable cell counting of heterotrophic and nitrifying bacteria were taken at the same positions of the biofilter (1.0 m distance from the bottom). The results of cell counting are shown in Table 4.

It was found that there was no significant difference of heterotrophic bacteria amount in these two BAFs, whereas, a more distinct difference of nitrobacteria amount was observed, which showed the zeolite surface is more adaptive to the growth of nitrobacteria and more nitrobacteria was concentrated on the zeolite surface and thus enhance the nitrification ability of zeolite BAF, and the result was in line with the former research report [17]. In addition, a larger amount of nitrobacteria was detected in stage three than in stage one, whereas, a better nitrification performance was found in stage one than in stage three,

Table 4
The amounts of heterobacteria and nitrobacteria in two BAFs

Sample	Zeolite BAF		Expanded clay BAF	
	Heterobacteria (CFU/mL)	Nitrobacteria (CFU/mL)	Heterobacteria (CFU/mL)	Nitrobacteria (CFU/mL)
Stage one (day 80)	1.8×10^9	3.4×10^8	2.1×10^9	2.1×10^8
Stage two (day 180)	2.3×10^9	8.7×10^8	2.7×10^9	4.8×10^8
Stage three (day 60)	0.9×10^9	5.5×10^8	1.2×10^9	3.5×10^8

which substantiated the low temperature has an obvious disadvantageous effect on the activity of nitrobacteria.

4. Conclusions

Zeolite BAF and expanded clay BAF were used in parallel to treat municipal wastewater, and the results obtained are as follows:

(1) Zeolite BAF and expanded clay BAF have COD and NH_3-N removals in the range of 84.63–93.11%, 85.74–96.26%, 82.34–93.71%, 85.06–93.2%, respectively, under the conditions of temperature 20–25 °C, DO 1.5–2.0 mg/L, hydraulic load 2–3 $m^3/(m^2\,h)$, HRT 0.95–1.43 h.

(2) The operation performance of zeolite BAF was not influenced by the NH_3-N shock load, while a disadvantageous effect on NH_3-N removal was observed on expanded clay BAF and was restored to normal condition in 2 weeks.

(3) Low temperature (7–10 °C) showed a more significant influence on NH_3-N removal than COD removal for both zeolite BAF and expanded BAF. Stage three test results proved that the zeolite BAF has a stronger adaptability to low temperature for NH_3-N removal compared to expanded clay BAF.

(4) The detection of the amounts of heterobacteria and nitrobacteria in two BAFs in three stages indicated that a more favorable environment for nitrifying bacteria was provided in the biofilter with natural zeolite due to its ion exchange capacity, and therefore enhanced the ability of nitrification and resistance to the NH_3-N shock load.

Acknowledgement

This research was financially supported by Fok Ying Tung Education Foundation (no. 94004).

References

[1] R.F. Goncalves, F. Rogalla, Continuous biological phosphorus removal in a biofilm reactor, Water Sci. Technol. 26 (9–11) (1992) 2027–2030.

[2] R. Moore, J. Quarmby, T. Stephenson, Development of a novel lightweight media for biological aerated filters (BAFs), in: Proceedings of the Third International Symposium on Biological Aerated Filters, Cranfield, UK, 3 March, 1999, p. 7.

[3] L. Mendoza-Espinosa, T. Stephenson, A review of biological aerated filters (BAFs) for wastewater treatment, Environ. Eng. Sci. 16 (3) (1999) 201–216.

[4] M.J. Semmens, J. Klieve, D. Schnobrich, G. Tauxe, Modelling ammonium exchange and regeneration on clinoptilolite, Water Res. 15 (5) (1981) 655–666.

[5] K. Athanasiadis, B. Helmreich, Influence of chemical conditioning on the ion exchange capacity and on kinetic of zinc uptake by clinoptilolite, Water Res. 39 (8) (2005) 1527–1532.

[6] G.V. Tsitsishvili, T.G. Andronikashvili, G.N. Kirov, L.D. Filixova, Natural Zeolites, 1st ed., Ellis Horwood, London, 1992.

[7] M. Sarioglu, Removal of ammonium from municipal wastewater using natural Turkish (Dogantepe) zeolite, Separ. Purif. Technol. 41 (2005) 1–11.

[8] N.A. Booker, E.L. Cooney, A.J. Priestley, Ammonia removal from sewage using natural Australian zeolite, Water Sci. Technol. 34 (9) (1996) 17–24.

[9] M. Oldenburg, I. Sekoulov, Multipurpose filters with ion exchanger for the equalization of ammonia peaks, Water Sci. Technol. 32 (7) (1995) 199–206.

[10] B.B. Baykal, D.A. Guven, Performance of clinoptilolite alone and in combination with sand filters for the removal of ammonia peaks from domestic wastewater, Water Sci. Technol. 35 (7) (1997) 47–54.

[11] B.B. Baykal, Clinoptilolite and multipurpose filters for upgrading effluent ammonia quality under peak load, Water Sci. Technol. 37 (9) (1998) 235–242.

[12] R. Moore, J. Quarmby, T. Stephenson, The effect of medium size on the performance of biological aerated filters, Water Res. 35 (10) (2001) 2514–2522.

[13] APHA/AWWA/AWEF, Standard Methods for the Examination of Water and Wastewater, 19th ed., APHA/AWWA/AWEF, Washington, DC, 1995.

[14] H.J. Benson, Microbiological Applications—A Laboratory Manual in General Microbiology, 5th ed., Wm. C. Brown, IA, 1990.

[15] S.B. He, G. Xue, H.N. Kong, Zeolite powder addition to improve the performance of submerged gravitation-filtration membrane bioreactor, J. Environ. Sci. 18 (2) (2006) 242–247.

[16] S.J. Park, J.W. Oh, T.I. Yoon, The role of powdered zeolite and activated carbon carriers on nitrification in activated sludge with inhibitory materials, Process Biochem. 39 (2003) 211–219.

[17] W.S. Chang, S.W. Hong, J. Park, Effect of zeolite media for the treatment of textile wastewater in a biological aerated filter, Process Biochem. 37 (2002) 693–698.