Nitrification of Groundwater Contaminated with NH_4^+ Using a Novel Acryl-Resin Fiber for Biomass Attachment

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ABSTRACT

This study demonstrates the use of Biofill (BL), an inexpensive and durable acryl-resin fiber material, as a biomass retainer for the nitrification of ammonium polluted groundwater. The biomass retention capacity of BL for nitrifying activated sludge was determined to be 6,200 g-MLSS/m^3 and the effluent from the nitrifying reactor packed with BL material was free of SS. Results of continuous-flow experiments consistantly demonstrated a high rate of nitrification using the BL material. 30 mgNH_4-N/L was effectively nitrified with an efficiency of greater than 95% at a hydraulic retention time of 1 hour.

KEYWORDS

Groundwater, ammonium, nitrification, biomass carrier, acryl-resin, biofill

INTRODUCTION

Groundwater is used as the source for the public water supply system of Hanoi, which is distributed through eight major water treatment plants (WTPs) and a number of small water supply stations. The system has a capacity of about 450,000 m^3/d for a population of 1.4 million in urban districts (JICA, 1996). Over the last ten years, the population of Hanoi has increased rapidly to more than 4 million, thus straining the capacity of the system. In addition, in recent years ammonium contamination in the groundwater of Hanoi has become an increasing problem for water quality (Anderson *et al.*, 1998; HWBC, 2000; Takizawa *et al.*, 2001). The most heavily polluted areas are located mainly in the southern part of the city, where NH_4-N concentrations range from 20- 30 mg/L (Tran Hieu Nhue *et al*, 2001). Presently, all WTPs employ the same conventional water treatment process consisting of only iron removal and chlorination, thus the treated water is frequently in violation of both the Vietnamese drinking water standard and the WHO guideline for ammonium in drinking water of 1.5 mg-N/L. Analyses conducted by the Center for Environmental Engineering of Towns and Industrial Areas (CEETIA) in 2000 showed that at the WTPs where the source groundwater has high concentrations of ammonium and iron, efficiency of ammonium removal is very low (Tran Hieu Nhue *et al.*, 2001). Thus for effective treatment, it would be technically and economically favorable to develop a purification system including biological nitrification treatment.

Ammonium can be removed by nitrification involving bacteria (nitrifiers) which use ammonium as an electron donor to provide energy for growth. The ammonium is oxidized ultimately to nitrate which can than be biologically denitrified, i.e. reduced to dinitrogen gas. Biological treatment is relatively inexpensive and produces no unwanted by-products when taken to completion. However, nitrifies are slowly growing organisms and will thus be washed out of continuous-flow reactors unless they are effectively immobilized. A high cell concentration is possible with immobilized biomass, which enhances volumetric efficiency. This allows for relatively small reactors and often offers protection from toxic shocks and adverse temperatures which would help maintain stable treatment.

In this study, we focus on biological treatment of groundwater contaminated with ammonium and present the results of nitrification assays using a novel acryl-resin fiber material called Biofill (BL) as a biomass carrier. BL material was used because it is light in weight, inexpensive and durable. The objectives of the study were:

- To determine the maximum capacity of the BL material for retaining nitrifying activated sludge,
- To determine the maximum acceptable ammonium nitrogen loading capacity of a BL reactor,
- To determine the optimal influent iron concentration and evaluate the effects of pH and alkalinity on ammonium removal efficiency, and
- To evaluate the applicability of a biological nitrification process using acryl resin for ammonium removal from polluted groundwater in Hanoi.

MATERIALS AND METHODS

Biomass carrier

Two strips of the BL material each with a one-sided surface area of 300×450 mm and a weight of 32.7 g were used as biomass carriers in this study. With a width of 15 mm, the BL strips had a total effective volume of 4.05×10^{-3} m^3 and a bulk density of 16,000 g/m^3. The BL strips were folded in to 4 layers and set symmetrically on two sides of the reactor using aluminum frames (see Fig.1).

Seed sludge

The seed sludge was an activated sludge cultivated by fill and draw under total oxidation conditions for more than one year using a synthetic organic substrate containing peptone and meat extract (Furukawa *et al.*, 1998). The quantity of nitrifying biomass was estimated using mixed-liquor suspended solids (MLSS).

Synthetic groundwater

Based on Hanoi groundwater quality as reported in previous research (Tran Hieu Nhue *et al.*, 2001), the synthetic groundwater used in this study was prepared with the similar composition as the polluted groundwater of Hanoi and its' composition was as show in Table 1.

Reactor description and operation

Fig. 1 shows the schematic diagram of the experimental system. The 5-L reactor was made of PVC and the influent was fed by using a variable speed peristaltic pump. BL strips were set symmetrically in the reactor. Aeration at the base of the reactor kept the contents well mixed and oxygenated.

In order to investigate the maximum capacity of the BL material for retaining biomass, the reactor was seeded with nitrifying activated sludge at various initial MLSS concentrations ranging from 1,500 to 5,000 mg/L. The remaining, unattached MLSS was measured following 15, 30, 60,

Table1. Composition of the synthetic groundwater (mixed in tap water).

Composition	Concentration (mg/L)	Source
NH_4-N	30	NH_4Cl
NO_3-N	3.2	$NaNO_3$
TOC	3.2	$C_6H_{12}O_6$
SO_4^{2-}	2.8	tap water
SiO_2	30.9	tap water
Fe(II)	0~18	$FeCl_2$
Ca	25	$CaCl_2.2H_2O$
Mg	13	$MgCl_2.6H_2O$
Na	35	tap water
K	5.7	tap water
Alkalinity	100~250 (as $CaCO_3$)	$NaHCO_3$

90, 120 and 150 min and the decrease in MLSS concentration was used to estimate the extent of sludge attachment to the BL material.

To determine the maximum acceptable ammonium loading capacity, the reactor was initially inoculated with 15 g of nitrifying activated sludge. This seed sludge completely attached to the BL materials within 2 hours of gentle aeration. The influent NH_4-N concentration was maintained at 30 mg/L and the hydraulic retention time (HRT) was varied from 24h to 1h by adjusting the influent flow rate.

Operational conditions

The reactor was operated in the dark at room temperature. Influent alkalinity and the pH of the reactor contents were regulated by addition of a $NaHCO_3$ solution. The flow rate of the air supply was 0.5~ 1.5 L air/ min.

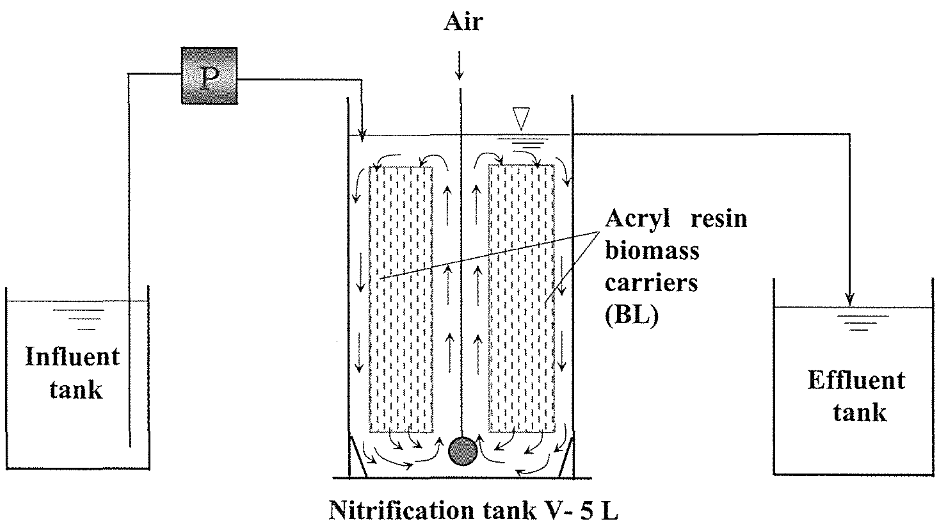

Figure 1. Schematic diagram of the experimental system used in this research.

Analyses

Flow rate, pH, DO and alkalinity were monitored every 2 days and SS, NH_4-N, NO_3-N and NO_2-N levels were determined in the effluent. The pH and DO were measured by using a Mettler Toledo-320 pH meter (Switzerland) and UC-12 Digital DO/ O_2/ Temp. Meter (TOA, Ltd., Japan), respectively. Analyses of NH_4-N, NO_3-N, NO_2-N, MLSS, SS and alkalinity were performed according to Japanese Industrial Standards (JIS, 1986).

RESULTS AND DISCUSSION

Sludge retention capacity

Time courses of sludge retention using the 2 strips of BL are shown in Fig. 2. The BL strips were dipped in various initial MLSS concentrations of activated sludge to investigate their sludge retention capacity. The decrease in MLSS concentration with the elapse of time indicates the rate of sludge attachment on BL. Almost all of the seeded sludge, when the initial concentration was below 5,000mg/L, was retained by BL within 2 hours of aeration. However, sludge seeded at initial concentrations above 5,000 mg/L did not attach completely within 2 hours. These results indicate that the maximum sludge retention capacity of BL is about 6,200g-MLSS/m^3.

Nitrification treatment efficiency

After attachment of sludge on the BL material, operation was started with an influent NH_4-N concentration of 30mg/L, iron of 18 mg/L, and alkalinity of 100 mg/L at a HRT of 24 hours. As shown in Fig. 3(c and d), the effluent NH_4-N concentration was high with only 30% of influent NH_4-N nitrified to NO_3-N and the pH dropped to 4.7. This may have been because of the low influent alkalinity (100 mg/L, see Fig.3(a)). The effluent iron concentration was close to 0 mg/L (data not shown) and the reactor was colored due to the precipitation of oxidized iron on the BL material. Subsequently, iron was eliminated from the influent and the alkalinity was increased to buffer the pH. After about 2 weeks more than 99% nitrification to NO_3-N was obtained and effluent

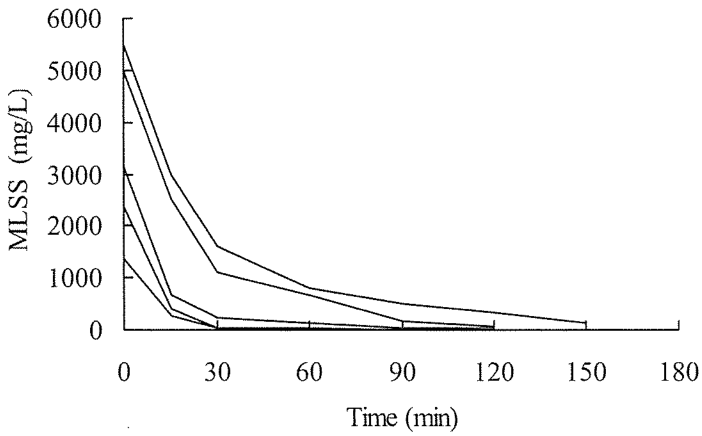

Figure 2. Time courses of sludge retention on BL material.

NO_2-N concentrations were close to 0 mg/L (Fig. 3(c)). Thereafter, the nitrogen volumetric loading rate (VLR) was increased stepwise by decreasing the HRT to 1 hour. The alkalinity of the influent was also increased stepwise and then maintained at approximately 230 mg/L to achieve a pH of 7± 0.2. As shown in Fig. 3(a, c and d), more than 95% nitrification efficiency occurred at each HRT. NO_2-N concentrations of about 5~ 8 mg/L were observed in the effluent at a HRT of 1 hour, which may have been due to the high loading rate associated with the short HRTs.

To support the activity of nitrifying bacteria attached on BL material, the reactor was aerated at an air flow rate of 0.5 L air/min, by which stable nitrification was maintained until the HRT was lowered to 3 hours corresponding to a nitrogenous VLR of 0.25 g-N/L.d. As shown in Fig. 3 (b), further increases in VLR were associated with a decrease in DO, which caused the nitrifying activity to become unstable. At a HRT of 1 hour (VLR of 0.75 g-N/L.d), the DO concentration was decreased to 0.5 mg/L and the nitrification efficiency dropped to 88%. At this point, the airflow rate was increased to 1.5 L air/min (on day 229), after which the DO concentration and nitrification efficiency recovered to 1 mg/L and 95%, respectively.

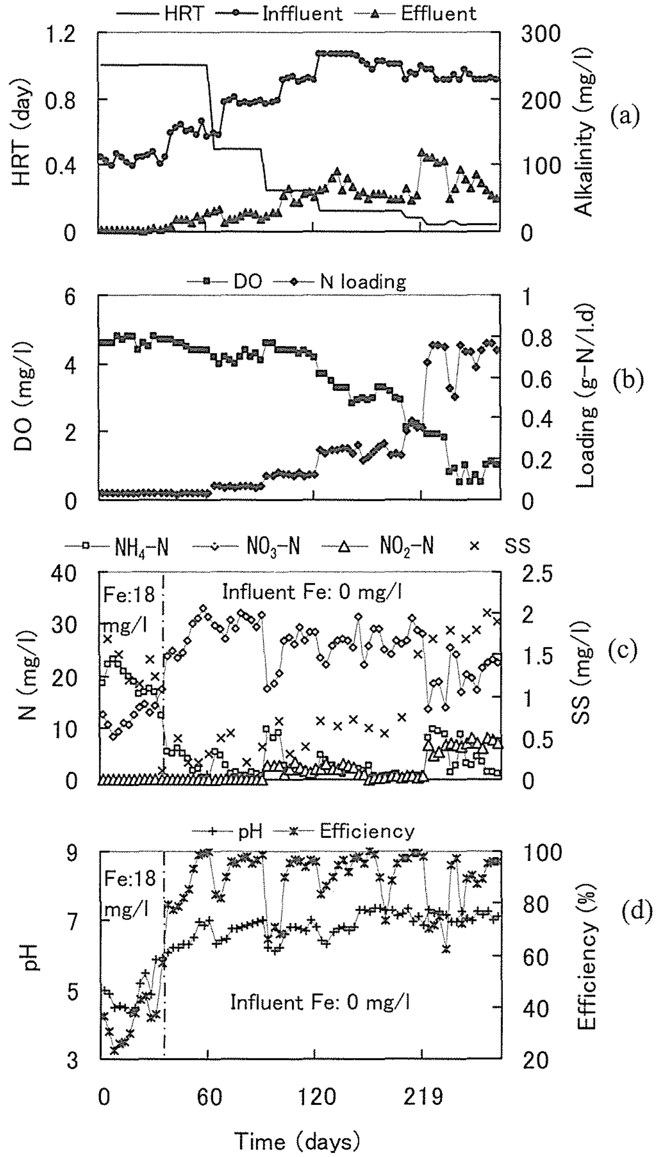

Figure 3. Time course of
(a) HRT, influent, effluent alkalinity;
(b) DO, nitrogen loading rate;
(c) Effluent NH_4-N, NO_3-N, NO_2-N, SS;
(d) pH and nitrification efficiency.

As shown in Fig. 3(c), the effluent from the reactor was exceptionally clear with SS less than 2 mg/L even when high precipitation of oxidized iron occurred in the reactor and when the airflow rate was increased. This aspect of low effluent SS is one of the main features of using acryl-resin fiber BL material. With such a system, use of a settling tank is not needed.

Fig. 4 summarized the relationship between the nitrogen volumetric loading rate and nitrification efficiency. As shown with use of acryl-resin fiber BL material, the reactor can maintain a high nitrification efficiency of more than 95% even when a short HRT of 1 hour corresponding to a VLR of 0.75 g-N/L.d.

CONCLUSIONS

Use of acryl-resin fiber BL material for nitrification treatment of NH_4-N polluted groundwater was demonstrated. With an influent alkalinity of about 230 mg/L, at a HRT of 1 hour, the reactor was able to nitrify over 95% of 30 mg-N/L applied ammonium. Thus the use of BL material as a biomass attachment medium has demonstrated potential for nitrification treatment. Considering the ammonium contaminated groundwater of Hanoi, such a system can play an effective role in providing safe drinking water.

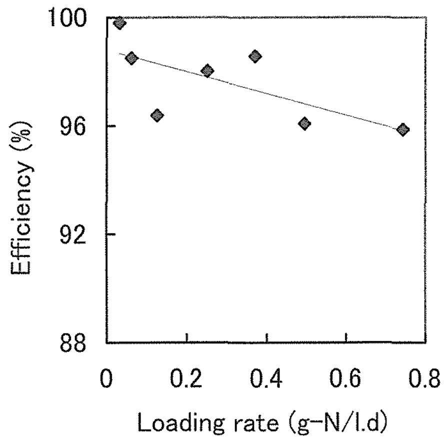

Figure 4. Relationship between nitrogen volumetric loading rate and nitrification efficiency

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