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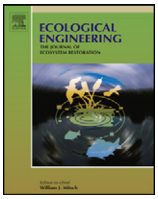

Characteristics and mechanisms of the hydroponic bio-filter method for purification of eutrophic surface water

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ABSTRACT

The hydroponic bio-filter method (HBFM) was adopted to purify eutrophic surface water. The average removal efficiency of total nitrogen (TN) and total phosphorus (TP) was 16.8% and 30.8%, respectively, at the hydraulic loading rate (HLR) of 3.0 $m^3 (m^2 d)^{-1}$. The mass removal rate of TN and TP accordingly reached 1.0 and 0.1 $g (m^2 d)^{-1}$ separately. The sedimentation of particulate nitrogen and phosphorus played a major role in removal of nitrogen and phosphorus, which contribute 62.2% and 75.9%, respectively. The optimal HLR of HBFM ranged from 3.0 to 4.0 $m^3 (m^2 d)^{-1}$. The sediment in midstream reached a maximum nitrification potential of 4.76×10^{-6} $g (g h)^{-1}$, while upstream it reached a maximum denitrification potential of 8.1×10^{-7} $g (g h)^{-1}$. The distribution of nitrification potential corresponded to the ammonium-oxidizing bacteria density. The key for improving nitrogen removal efficacy of HBFM system consisted of changing the nitrification/denitrification region distribution and accordingly enhancing the denitrification process. The sum of dissolved nitrogen removed by denitrification and plant assimilation was nearly equal to the amount released by sediment. Secateur length of *Nasturtium officinale* had some effect on its uptake rate. The length of cut should be less than 10 cm at a time. The harvesting frequency of once a month for *N. officinale* had no influence on nitrogen and phosphorus removal.

1. Introduction

The main reason for eutrophication is that nitrogen and phosphorus discharged to a water body cannot be removed effectively (Smith et al., 1999; Paerl et al., 2004). With regard to all point source pollution, the treatment process for removal of nutrients such as nitrogen and phosphorus has been developed (van Veldhuizen et al., 1999; Oehmen et al., 2007). But the traditional treatment process is not suitable for eutrophic lakes and rivers, which have a lower nutrient concentration and larger cubage compared to wastewater. So for eutrophic water, it is essential to develop a new purifying technique with a larger processing capacity, higher efficiency and lower cost.

As a sustainable technique for nutrient removal from lake and river water, ecological engineering has come to our attention (D'Angelo and Reddy, 1994; Michal et al., 1995; Annadotter et al., 1999; Mitsch et al., 2000, 2005; Coveney et al., 2002; Li et al., 2008). For example, surface and subsurface flow constructed wetlands (CWs) are widely used at present (Vymazal, 2005; Kovacic et al., 2006; He et al., 2007; Iamchaturapatr et al., 2007). But the effect of the former treatment is worse, and the latter, with lower hydraulic loading, clogs too easily and requires a higher cost (Gopal, 1999; Gervin and Brix, 2001; Langergraber et al., 2003; Vymazal, 2005).

Hydroponic plants have been widely used in wastewater treatment systems because they can efficiently absorb dissolved compounds in the wastewater as nutrients for plant growth (Rababah and Ashbolt, 2000; Adler et al., 2003; Elless et al., 2005). Furthermore, hydroponic approaches such as the nutrient film technique (NFT) have shown great potential for removing suspended solids from wastewater (Vaillant et al., 2003). The hydroponic bio-filter method (HBFM) was first developed by Aizaki and Nakazato (1995, 1997) for purification of hyper-eutrophic lake water. The characteristic of HBFM is that there is no medium filling in the filter bed, and the suspended pollutants and algae can be removed efficiently by a filter mat formed from aquatic plants with growing stems or root systems while organic matter and nutrients in the sediment can be removed through plant absorption and microorganism decomposition. All of the above makes an effective ecological purifying system composed of hydrophytes, aquatic animals and microorganisms. We can also clear away sediment in timely fashion to shift organic matter out of the water body.

Previous studies have established the construction method of HBFM, screened out the suitable plant species, and evaluated the purification efficacy of HBFM at a specific hydraulic loading rate

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of 1.0 $m^3 (m^2 d)^{-1}$ (Aizaki and Nakazato, 1995, 1997). Many studies suggest that the performance of eco-technology such as CWs is generally a function of hydraulic loading rate (HLR). So, for maximum nutrient remova1, selection of proper HLR is required for the application of HBFM. Furthermore, in order to realize the recycling of nitrogen and phosphorus and avoid the secondary pollution, the management of the aquatic plant in HBFM is important. Furthermore, harvesting edible aquatic plants is able to yield economic profit. The objectives of this research were to study the impact of hydraulic loading rate and plant harvesting on water purification, and quantitatively analyze both the nitrification and denitrification processes, as well as the removal pathway of nitrogen and phosphorus.

2. Methods

2.1. Experiment set-up

The experimental equipment of HBFM was made of a heated plastic membrane covered with light frothy material, 15 m × 1.0 m ×0.3 m ($L \times W \times D$), with a gradient of 1%. The water inlet was set at the front and the collecting channel was laid to the rear. To make the best use of the compact, reticular root mat system of hydrophytes as well as to clear away the sediment more conveniently, there was no filling material in the equipment and the flow was kept horizontal.

There were eight test-channels in all. *Nasturtium officinale*, a kind of aquatic vegetable that can live through the winter was planted compactly in channels nos. 1–6. *N. officinale*, commonly called watercress, is a perennial herb of the family Cruciferae (mustard family) that grows in and around water. Normally, it is commercialized in fresh and consumed in salads, soups and other recipes (Cruz et al., 2006), and is considered an excellent functional food for the prevention of cancer and related diseases (Engelen-Eigles et al., 2006). Also, *N. officinale* has been proved capable of growing well in HBFM (Aizaki and Nakazato, 1997). Furthermore, *N. officinale* is widely cultivated in China. Test-channel No. 7 was set for harvest and No. 8 was a blank control test-channel without aquatic plants. Fig. 1 shows the test equipment.

2.2. Operating conditions

The raw water was taken from a small lake and the water quality is presented in Table 1. The raw water was lifted by a submersible pump passing through the test-channel continuously, and the flux could be adjusted by a valve set at the influent pipe. The experiment lasted one whole year from August to the next September.

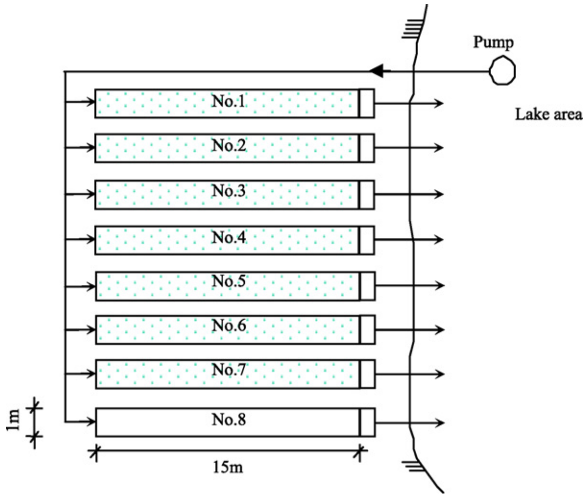

Fig. 1. Schematic diagram of hydroponic bio-filtration system.

Table 1
The raw water quality [$mg L^{-1}$].

TN	1.24–2.89
DTN	0.678–1.566
NH_4-N	0.143–0.348
TP	0.04–0.21
DTP	0.008–0.027
SS	27.6–40.6
Chl-a	45.1–70.5

2.3. Experiment of HLR

The HLRs of test-channels nos. 1–6 were set at 0.5, 2, 3, 4, 5, and 6 $m^3 (m^2 d)^{-1}$, respectively, by adjusting the influent flux.

2.4. Investigation on the nitrification and denitrification potential of the sediment

In the present study, nitrification potential is defined as gram NO_x-N produced per gram of sediment per hour and denitrification potential is defined as gram NO_3-N vanished per gram of sediment per hour.

2.4.1. Collection of sediment sample

In July of the following year, after 11 months of stable operation, three sediment samples were collected in channel No. 1 at upstream, midstream and downstream, located along the flow direction at 1.0 m (Point *a*), 7.5 m (Point *b*) and 14 m (Point *c*), respectively. The influent was stopped and the residual water in the test-channel was emptied before collecting samples. A sediment sample of 20 cm × 20 cm area and about 6 cm thick was obtained from each point by a collecting container. The construction of the sediment was kept standing as much as possible when sampling.

2.4.2. Test of nitrification potential

After sampling, the bottom of the collection container was sealed, and then added exactly by 3000 mL reaction solution that was confected by de-ionized water and NH_4Cl with NH_4-N concentration of 4 $mg L^{-1}$. The water above the interface of sediment was about 5 cm deep, nearly the same as the actual water depth in channel no. 1. A spherical porcelain air diffuser connected to compressed air was adopted for aeration and the DO concentration was controlled at about 6 $mg L^{-1}$ in accord with that in the actual measurement. The experiment was carried out in a thermotank of 20 °C and water samples were taken out at designated intervals to analyze the concentration of NH_4-N, NO_2-N and NO_3-N. To avoid affecting nitrification, pH was leveled off at 7.5 by monitoring and adding concentrated liquid of sodium hydroxide to compensate for the alkalinity consumption. The total volume of concentrated sodium hydroxide solution was less than 2 mL.

2.4.3. Test of denitrification potential

The bottom of the collection container was sealed after sampling and then 2995 mL de-ionized water was accurately added. The water was purged with pure N_2 until the DO reached zero, and then increased by 5 mL $NaNO_3$ solution resulting in a NO_3-N concentration of about 4 $mg L^{-1}$. Afterward, liquid paraffin was poured on the water surface, forming a cere 5 mm thick to separate water from air. DO was monitored throughout the test to make sure it keeps at zero all the time. The experiments were also performed in a thermotank of 20 °C and water samples were collected at des-