Ecological Engineering 60 (2013) 271–275

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Short communication

The impact of influent mode on nitrogen removal in horizontal subsurface flow constructed wetlands: A simple analysis of hydraulic efficiency and nutrient distribution

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ARTICLE INFO

Article history:
Received 22 February 2013
Received in revised form 19 June 2013
Accepted 5 July 2013
Available online 15 August 2013

Keywords:
Constructed wetland
Influent mode
Nitrogen removal
Hydraulic efficiency
Carbon source distribution

ABSTRACT

Influent mode in constructed wetlands can cause changes of hydraulic efficiency and carbon source distribution. In this study, impacts of four influent modes on nitrogen removal were studied by hydraulic tracer test and nutrient distribution analysis. NH_4^+-N, TN and COD were sampled along the reactors in different layers. Results showed that diffusive inflow contributed highest NH_4^+-N and TN removal reaching 64.3% and 60.9%, respectively. It proved that diffusive inflow achieved higher effective volume ratio and hydraulic efficiency. Moreover, nutrient distribution analysis implied that diffusive inflow enhanced reaeration causing efficient NH_4^+-N reduction. Compared with other modes, diffusive inflow has also resulted in well-distributed carbon source for denitrification in bottom layer. In addition, ANOVA test analyzed the significance among influent modes indicating that diffusive inflow had obvious effects on enhancing nitrogen removal. The study documented the feasibility of using diffusive inflow to enhance the treatment by improving hydraulic conditions and carbon source distribution in CWs.

1. Introduction

Various applications have proved that constructed wetlands (CWs) are a convenient and cost-effective solution for domestic wastewater treatment (Vymazal, 2007, 2011). It offers advantages of simple operation and maintenance (Kadlec and Knight, 1996; Chang et al., 2012). Especially, the usage of horizontal sub-surface flow constructed wetlands (SFFCWs) has created a healthy and esthetic treatment (Ayaz and Akca, 2001). Owing to its considerable pollutant removal capability, SFFCWs have been reported to be an effective approach.

To improve nitrogen removal in SFFCWs, a large number of processes reliant on the hydraulic characteristics have been studied in the literature, i.e. control of water flow and change of in–outflow position. Among various factors affecting nitrogen removal, hydraulic efficiency is quite essential (Liu et al., 2010). Higher hydraulic efficiency has usually implied positive nitrogen removal in SFFCWs, high-lighting the importance of optimizing flow mode to achieve a better performance (Christopher and William, 2003). A proper hydraulic configuration has been proved to improve the denitrification by producing ideal nitrogen removal (Ye et al., 2012). One explanation for the positive hydraulic effects has been revealed by evaluating the hydraulic retention time (HRT) in relation to the removal rate (Konyha et al., 1995). Another intuitive explanation can be given by the evaluation of potential residence efficiency through tracer test. It has been found that the improvement of inlet ditch configuration can prevent or reduce “short-circuiting” and “dead zones” (Anna-Kaisa and Bjorn, 2008). Besides, the nutrient distribution could also be affected by the flow mode in relieving carbon source shortage especially in the rear of SFFCWs, optimizing the oxygen distribution, and enhancing denitrification processes (Ding, 2012). However, it poses a question on how inflow pattern could have impacts on nitrogen removal.

This study is a part of a research project aimed to determine the impacts of influent modes on nitrogen removal and indicate an effective configuration for practices. It is expected that the hydraulic efficiency and carbon source distribution can be optimized by adopting a suitable influent mode. For this purpose, sequential laboratory scale experiments were carried out. Analysis of hydraulic efficiency and nutrient distribution in terms of influent modes were made to reveal impacts on nitrogen removal. The remainder of this paper was organized as follows: Section 2 detailed the SFFCWs reactors, experiment preparation, testing and

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http://dx.doi.org/10.1016/j.ecoleng.2013.07.024

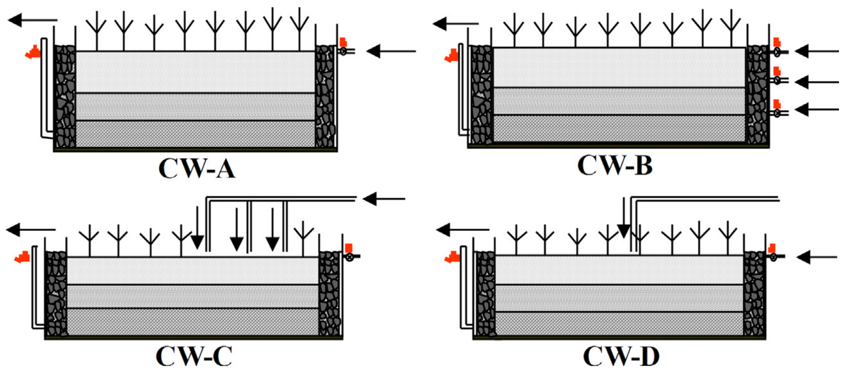

Fig. 1. Four influent modes used for comparison. The reactors were labeled as CW-A, CW-B, CW-C and CW-D.

evaluation method, and influent mode design. Section 3 presented the results, discussing possible effects on hydraulic efficiency and nutrient distribution. Finally, Section 4 summarized the conclusions.

2. Materials and methods

2.1. SFFCWs reactors

Four identical reactors were created. Dimension of each reactor was 1.6 m (L) × 0.5 m (W) × 0.7 m (H). The reactors were set up in the open air where temperature ranged from 20 to 38 °C. From bottom to surface, the reactors were uniformly stratified into 3 horizontal gravel layers filled with coarse gravel (φ: 10–30 mm, height: 15 cm), medium-size gravel (φ: 5–10 mm, height: 15 cm), and fine gravel (φ: 2–6 mm, height: 20 cm), respectively. The distribution and harvesting systems were symmetrical which were attached to both ends of each reactor in 20 cm width and filled with coarse gravel. Three inflow PVC pipes (Φ = 20 mm) were installed to the distribution system at 10 cm, 30 cm and 50 cm below the reactor; and four harvest pipes were attached at 10 cm, 30 cm, 45 cm and 55 cm in the height. Each reactor has three rows of sampling holes installed vertically at 7.5 cm, 22.5 cm and 42.5 cm above the bottom, the horizontal interval between each sampling hole is 20 cm (5 sampling holes in each row).

2.2. Inflow mode configuration

Four influent modes were configured. A PVC pipe distributor was prepared with holes (Φ = 0.4) for stable influent distribution. The inlet/flow patterns configurations were illustrated in Fig. 1. The reactors were respectively labeled as CW-A, CW-B, CW-C and CW-D for different inflow modes. CW-A was set as normal influent through top inflow pipe; CW-B used vertically distributed inflow mode. Three PVC pipes were vertically installed at 10 cm, 30 cm and 50 cm in the depth as multi-inflow-point; for CW-C, four horizontal inlets were set along the reactor, 0 cm, 40 cm, 60 cm and 80 cm downstream of the reactor. The inflow pattern could be regarded as horizontal diffusive inflow mode; for CW-D, two inlets were set. One was a horizontally single inflow set in the middle of the reactor. The other was set a normal influent through top inflow pipe. Inflow rate was controlled by the valves (Fig. 1).

2.3. Experiment preparation

The experiment took place from May to September in 2011. The SFFCWs were cultivated for a month using sludge obtained from Songjiang sewage treatment plant, Shanghai. *Phragmites australis* roots were planted on the top of each substrate with density of 20–25 stems m^{-2}. The *P. australis* were harvested in June and the roots were remained inside the beds. The experiment was started in July after stabilization. Peristaltic pump (BT600-2J) was used for steady influent. The water level was kept stable at 55 cm.

2.4. Influent water quality and testing method

Artificial wastewater was prepared using tap water, glucose, ammonium chloride and monopotassium phosphate. Influent water quality was daily sampled and recorded as COD: 487 ± 87 mg/L (HH-6 COD determinator), ammonia nitrogen (NH_4^+-N): 22.8 ± 49 mg/L (HANNA HI 93733 Ammonia ISM), total nitrogen (TN): 42.8 ± 67 mg/L (UV-2000 spectro-photometer), DO: 0.48 ± 0.23 mg/L (HANNA HI 9143), pH: 7.2 ± 0.2 mg/L (HANNA HI8424 NEW pH).

The hydraulic load was set to 0.72 $m^3 (m^2\,d)^{-1}$. Three duplicate samples were collected from effluent for TN and NH_4^+-N test. Tests were conducted every week and continued for 5 weeks (n = 5). N removal rates can be calculated as $(N_{out} - N_{in})/N_{in} \times 100\%$ during the sampling period. Standard testing methods were adopted that were: alkaline potassium persulfate-digestion-UV spectrophotometer method for TN and Nessler's reagent photometer HANNA HI 93733 Ammonia ISM for NH_4^+-N.

2.5. Tracer test for hydraulic efficiency

In order to co-analyze the relationship between hydraulic efficiency and nitrogen removal, peristaltic pump (BT600-2J) was used in the impulse tracer test and the hydraulic load was set to 4.8 and 5.9 $m^3 (m^2\,d)^{-1}$, respectively; NaCl solution (100 g/L) was prepared as tracer and effluent conductivity was tested. For each mode, five trials were carried out to obtain the mean value of hydraulic retention time distribution (RTD) curve. The tracer tests were started with an injection of NaCl solution (200 mL). Effluent conductivity was sampled at a 5-min time interval with a conductivity tester (HACH sensION + EC5 portable conductivity analyzer).

2.5.1. Hydraulic impact evaluation

To investigate the impacts of influent mode on nitrogen removal, breakthrough curves were analyzed from a classical RTD. In fluid reactor, the normalized RTD density $N(t)$ can be defined as $N(t) = C(t)(Q/M)$ where $N(t)$ means the normalized RTD, h^{-1}; Q is the effluent rate, m^3/h; M is the quantity of NaCl injection; $C(t)$ represents the NaCl concentration of effluent, g/m^3, which can be simply calculated by effluent electro-conductivity, written as:

$$C(t) = \frac{(E(t) - E_w)M_{\mathrm{NacI}}}{\lambda_{\mathrm{Na}} + \lambda_{\mathrm{Cl}}}$$