Ecological Engineering 82 (2015) 643–648

Contents lists available at ScienceDirect

Ecological Engineering

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

Response of a tidal operated constructed wetland to sudden organic and ammonium loading changes in treating high strength artificial wastewater

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ARTICLE INFO

Article history:
Received 16 January 2015
Received in revised form 6 May 2015
Accepted 30 May 2015
Available online 19 June 2015

Keywords:
Tidal operated constructed wetlands
Influent sudden loading
High strength wastewater
Buffering capacity

ABSTRACT

The knowledge on the response of tidal-operated constructed wetlands (CWs) to suddenly changed influent characteristics, such as ammonium and organic matter concentrations, remains unclear. This study set up a pilot-scale tidal-operated CW and examined its response to various sudden organic matter and ammonium loading changes under constant hydraulic loading rate and retention time. Results showed an oxidative condition in the wetland bed with a high oxygen transfer rate induced by tidal operation. Effluent ammonium fluctuated from 0.5 mg/L to 62 mg/L when the ammonium pulse loadings were adopted, indicating the limited buffering capacity of tidal-operated CWs to influent ammonium pulse loadings because of the short contact time. No negative influence from influent COD pulse loadings to nitrification was observed, even when the influent COD concentration increased up to 1200 mg/L. The average constant effluent COD concentrations of 47 mg/L and high removal efficiencies of 93% under various pulse loadings (300–1200 mg/L) strongly indicated the high buffering capacity of tidal-operated CWs to suddenly changed organic matter loadings as well as its high degradation capacity driven by the enhanced oxygen transfer rate of tidal operation.

1. Introduction

Water eutrophication caused by nutrient discharge in improperly treated wastewater has become an important water quality issue that affects many aquatic environments (Vymazal, 2013). Constructed wetlands (CWs) are ecological alternatives for wastewater treatment that attempt to reproduce the conditions existing in natural wetlands and use their advantage of the natural depuration characteristics (Lv et al., 2013). Various pollutants can be removed when wastewater flows through wetland beds under multi-functioning substrate, microorganisms, and wetland plants. The use of CWs has become increasingly popular worldwide in the recent years, particularly in areas that lack public sewage systems and in economically undeveloped countries, because of its cost-effective operation and maintenance. Moreover, their application significantly expanded from the treatment of secondary and/or tertiary domestic sewage to various strength industrial effluents (Calheiros et al., 2012; Mbuligwe, 2005; Shehzadi et al., 2014).

Oxygen transfer and distribution in wetlands possess an important function in CW performance. Moreover, the degradation of organic matter and ammonium is closely related to oxygen availability (Metcalf et al., 2003; Tanner and Kadlec, 2003). In most applied traditional horizontal subsurface flow CWs and vertical flow CWs, the oxygen transfer capacity is often limited, which constrains the overall treatment performance, particularly for treatment of high-strength wastewaters (Garcia et al., 2010; Kadlec and Wallace, 2008). Large land area is often required to meet the discharge standards. However, the availability of large land area is increasingly limited for the establishment of large-scale CWs (Cooper, 2005). Therefore, operational strategies for performance intensifications with additional energy inputs to overcome oxygen transfer limitations have been increasingly applied, but should be under the consideration of balanced net savings of the reduced wetland area size to the lifecycle cost of energy inputs (Cooper, 2005; Fan et al., 2013).

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http://dx.doi.org/10.1016/j.ecoleng.2015.05.040
0925-8574/

Wu et al. (2014) reviewed the development of CWs in performance intensifications for wastewater treatment with various new designs, configurations, and technology combinations. Among the reported intensifying strategies, tidal operation characterized by multiple periodical flood and drain cycles per day can draw significant atmosphere oxygen into the soil pores and rapidly oxygenates the bio- and remaining waterfilms (Chan et al., 2008; Wu et al., 2011). The application potential of this technology has been demonstrated in multiple studies (Abou-Elela and Hellal, 2012; Zhao et al., 2004; Chan et al., 2008). However, their studies were conducted under isolated steady-state conditions, which may not be able to reveal the behavior of this technology in response to specific conditions with suddenly influent loading change. This investigation is especially important for the application of tidal-operated CWs on treatment of effluents from small agglomerations and industries where flow and concentrations can exhibit strong daily variations.

Septic tanks are often used as pretreatment units before the wastewater flows into CWs and can provide equalization effect of suddenly changed flow and pollutant concentrations, but complete equalization also seems to be practically impossible (Galvão and Matos, 2012). Although traditional horizontal subsurface flow CWs are often assumed to have a high buffering capacity, information on the buffering capacity of tidal-operated CWs is not well documented and may not be sufficient to maintain treatment performance when sudden changes occur in influent characteristics (Haberl et al., 2003). Moreover, the interactions of microbial transformations of carbon and nitrogen to these sudden changes in tidal-operated CWs are also not clearly elucidated and should be further investigated.

This study aimed to examine the response of pilot-scale tidal-operated CWs to various sudden organic matter and ammonium loading changes under constant hydraulic loading rate and retention time. The buffering capacity and the interactions of microbial transformations of carbon and nitrogen to these sudden changes were also evaluated.

2. Materials and methods

2.1. Pilot-scale tidal operated CW

The laboratory-scale tidal flow CW was made of poly vinyl chloride (PVC) column with height and diameter of 1800 and 1200 mm, respectively. The PVC column was filled with gravel (ϕ10 mm to 50 mm) to a depth of 400 mm to create a bottom drain layer with an average porosity of 75%. The column was also filled with coarse sand (ϕ5 mm to 10 mm) to a depth of 1000 mm to generate a main filter layer with an average porosity of 41% above the drain layer. The gravel drain layer at the bottom of the column was designed to enhance the negative pressure that would facilitate air intake into the matrix. The wetland was planted with *Juncus effusus* during the experimental period and then maintained in an indoor area at the BioEnergy Engineering and Low Carbon Technology Laboratory of China Agricultural University.

Tidal operation was generated by a peristaltic pump and an automatic drain valve controlled by a timer. The flood period started when wastewater filled the wetland, and the drain period started when the pore water of the wetland bed was completely discharged. Tidal operation was set to have a flooded to drained time ratio of 3 h:3 h, and four cycles daily. The pore volume of the bed was 200 L, and 160 L/d synthetic wastewater was added into the wetland, resulting in hydraulic loading rate of 98 L/m^2 d. Effluent was recycled to influent with a ratio of 1:4. The operating conditions of this tidal-operated CW are summarized in Table 1.

Table 1
Operating conditions.

Parameters	TFCW
Flooded/drained (h)	3:3
Cycle times per day	4
Influent volume (L/cycle)	40
Recycling effluent volume (L/cycle)	160
Influent flow rate (m3/m2 d)	0.39

2.2. Experimental conditions

Synthetic wastewater containing ammonium, organic matter, and phosphate was used in this study to minimize additional variability in the experiment. Influent artificial wastewater was prepared using $C_6H_{12}O_6{\cdot}H_2O$, NH_4Cl, and $K_2HPO_4{\cdot}3H_2O$ dissolved in deionized water according to the required concentrations. In all cases, a trace mineral solution (Wu et al., 2012) containing EDTA-Na (0.100 g/L), $FeSO_4{\cdot}7H_2O$ (0.100 g/L), $MnCl_2{\cdot}4H_2O$ (0.100 g/L), $CoCl_2{\cdot}5H_2O$ (0.170 g/L), $CaCl_2{\cdot}6H_2O$ (0.100 g/L), $ZnCl_2$ (0.100 g/L), $CuCl_2{\cdot}5H_2O$ (0.020 g/L), $NiCl_2{\cdot}6H_2O$ (0.030 g/L), H_3BO_3 (0.010 g/L), $Na_2MoO_4{\cdot}2H_2O$ (0.010 g/L), and H_2SeO_3 (0.001 g/L) was added to the artificial wastewater (1 mL/L).

The entire experiment was divided into two main sections with pulse organic matter loadings and pulse ammonium loadings to better understand the influence of sudden influent organic matter and ammonium loading change to the treatment performance of tidal-operated CWs, respectively. In the organic matter pulse loading section, the influent ammonium concentration was maintained at 60.0 mg/L, and the influent COD pulse loading varied at 300.0–1200.0 mg/L. Similarly, the influent COD was maintained at 300.0 mg/L and the influent ammonium pulse loading varied at 30.0–120.0 mg/L in the ammonium pulse loading section. Pulsed feeding was conducted twice for each concentration. Each pulse loading lasted for 1 week, followed by rest for 1 week. The influent pulse loading experimental arrangement is illustrated in Fig. 1.

2.3. Sampling and analysis

The wastewater samples were collected three times a week from 2013.8 to 2014.7 in triplicate from both the influent and effluent of the bed at 9:00 a.m. The pH value, redox potential (Maehlum et al., 1995), and dissolved oxygen (DO) concentration were immediately measured using a portable Orion 5-Star DO/pH/Eh meter with a DO electrode (ORION, 86.030MD), a pH electrode (ORION, 9172BNWP), and an Eh electrode (ORION, 9179BNMD). Nitrate was analyzed using continuous flow colorimetry (SEAL Auto-Analyzer3, UK). After adding corresponding standard pretreatment and reagent according to standard methods (AWWA and WEF, 1998), concentrations of ammonium (NH_4^+/4500-NH_3 F; phenate method), nitrite (NO_2^-/4500-NO_2^- B; colorimetric method), and phosphate (PO_4^{3-}/4500-P E; ascorbic acid method) were measured using ultraviolet and visible spectrophotometers (Gold S54T; Lengguang Tech, China). Total nitrogen (TN) was calculated by the sum of ammonium, nitrite and nitrate.

3. Results

The dynamics of influent and effluent pH, DO, and ORP under NH_4^+ pulse loadings and COD pulse loadings are given in Fig. 2. The pH of the artificially prepared influent wastewater varied from 5.95 to 8.13 with an average of 7.20. The effluent pH was slightly lower than the influent, which ranged from 4.02 to 6.62 with an average of 5.56. The influent DO averaged at 3.9 mg/L under NH_4^+