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Nitrogen removal in intermittently aerated vertical flow constructed wetlands: Impact of influent COD/N ratios

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HIGHLIGHTS

- Intermittent aeration was effective in treatment of high COD/N ratio rural sewage.
- Intermittent aeration changed the impact of COD/N ratios on performance of VFCWs.
- Influent with COD/N ratio of 10 resulted in high COD and nitrogen removal.

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ABSTRACT

The performance response of eight vertical flow constructed wetlands (VFCWs) to different influent COD/N ratios and intermittent aeration in domestic wastewater treatment was investigated. Almost complete nitrification was obtained by intermittent aeration, which well developed alternate anaerobic and aerobic conditions for nitrification and denitrification. Sufficient carbon source supply resulted from influent COD/N ratio of 10 simultaneously obtained high removals of COD (96%), ammonia nitrogen (99%) and total nitrogen (90%) in intermittently aerated VFCWs. In all non-aerated VFCWs, poor nitrification was observed due to oxygen deficiency whilst high COD/N ratios further led to lower COD and nitrogen removal efficiency. The results suggest that intermittent aeration combined with high influent COD/N ratios could achieve high nitrogen removal in VFCWs.

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1. Introduction

Vertical flow constructed wetlands (VFCWs) have been widely used for purification of various wastewaters owing to the advantages of small footprint, low construction and maintenance costs (Vymazal, 2002; Stefanakis and Tsihrintzis, 2009). Intensive studies focused on the application of VFCWs provided a natural alternative to traditional methods of wastewater treatment (Denny, 1997; Brix and Arias, 2005; Seo et al., 2005).

The treatment performance in VFCWs can be influenced by various operational factors, of which influent COD/N ratios always play a crucial role (Xia et al., 2008). Biological nitrogen removal in conventional wetlands is often restricted by lack of organic carbon source. External carbon addition was then adopted to enhance the influent water COD/N ratios in some studies to support denitrification (Ingersoll and Baker, 1998; Lu et al., 2009). Zhao et al. (2010) found that conventional VFCWs obtained total nitrogen (TN) removal efficiency of 25–62% when COD/N ratios changed from 2.5 to 10 and highest TN removal rates were observed at COD/N ratio of 2.5–5. However, another research study by Zhao et al. (2012) obtained better TN removal (62–87%) in hybrid VFCWs at COD/N ratios of 5–10 although the influent TN concentration was almost similar between the two studies. Ding et al. (2012) investigated the effect of dissolved oxygen (DO) and influent COD/N ratios on N removal performance in horizontal subsurface flow CWs and found that TN removal efficiency (21–54%) increased with COD/N ratios (0–9). Various N removal performances were observed at different optimal influent COD/N ratios in conventional CWs. In fact, nitrification was always the limiting step for N removal in conventional CWs. Complete TN removal relies firstly on efficient nitrification for ammonia nitrogen (NH_4-N) removal, and then requires sufficient organic carbon source in denitrification to eliminate nitrate permanently.

Intermittent aeration has been proved to be an effective method to enhance nitrification (Fan et al., 2013a). What is more, alternate aerobic and anaerobic conditions can be well developed by intermittent aeration which is favorable for nitrification and denitrification.

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Consequently, the presence of intermittent aeration may greatly change the redox environment in VFCWs, which leads to quite different impact of influent COD/N ratios on nitrogen removal. In particular, when dealing with wastewaters with appropriate influent COD/N ratios, intermittent aeration may simultaneously elevate NH_4-N and TN removal. The high DO during aeration enhances nitrification and the sufficient carbon source supply leads to high-efficiency denitrification when aeration is off. However, research on influent COD/N ratios on the treatment performance of VFCWs in the presence of intermittent aeration is not found.

To address this problem, eight batch-operated VFCWs with different designs were applied to treat simulated domestic wastewater in the present study. The effects of various influent COD/N ratios, especially the combination of influent COD/N ratios and intermittent aeration on the simultaneous transformations of COD, NH_4-N and TN were investigated. It aimed to determine how treatment performance responded to different influent C/N ratios in the presence of intermittent aeration.

2. Methods

2.1. Characterization of microcosm wetlands

Eight parallel microcosm VFCWs were constructed outdoors. The VFCWs were 65 cm in height and 20 cm in diameter. Multi-dimensional gradation of the substrate was adopted in this experiment according to former studies (Fan et al., 2013a), giving an average gravel bed porosity of 40%. A vertical perforated PVC pipe (65 cm in length and 3 cm in diameter) was inserted into the substrate in the middle of VFCWs to measure various physical and chemical parameters in situ. There were porous air spargers installed at the bottom of four reactors for oxygen supply. The emergent plants employed in VFCWs were *Phragmites australis* at a density of 6–8 rhizomes per unit. After planting, units were flooded for 30 d with tap water before introduction of influent water. The experiment then began and lasted for 150 d.

2.2. Experimental procedure

For comparison of the parallel experiments, the influent COD/N ratios was manipulated by adding sucrose to create four COD/N ratios (2.5:1, 5:1, 10:1 and 20:1). Synthetic wastewater composed of 96.7, 193.4, 386.8, 773.6 mg L^{-1} sucrose, 188 mg L^{-1} $(NH_4)_2SO_4$, 17.5 mg L^{-1} KH_2PO_4, 10 mg L^{-1} $MgSO_4$, 10 mg L^{-1} $FeSO_4$, and 10 mg L^{-1} $CaCl_2$ was used in this study. The composition of the influents from each experimental operation is shown in Table 1. The eight VFCWs were divided into four groups. Every two VFCWs were operated with the same COD/N ratio, one of which was intermittently aerated with an airflow rate of 1.5 L min^{-1} for 4 h (hours 0–1, 6–7, 12–13 and 18–19) each day. Batch operation strategy was used for influent mode. The hydraulic retention time (HRT) was 72 h according to previous experiments (Fan et al., 2013a). At about 8:00 am on the first day of each cycle, the influent was supplied within 5 min with a hydraulic load of 0.21 m^3 m^{-2} - $batch^{-1}$. Effluent was discharged from the outlets at the bottom of the VFCWs.

2.3. Water sampling and analysis

Influent and effluent at different time intervals of the VFCWs were sampled to evaluate the transformations of organics and nitrogen. Laboratory analysis was performed on the water samples for NH_4-N, NO_3-N, NO_2-N and TN. All the parameters mentioned above were determined according to standard methods (APHA, 2001). COD was measured by a HACH DR 2800TM Spectrophotometer, USA. DO and pH were measured in situ using a dissolved oxygen/pH Meter (HQ30d 53LEDTM, HACH, USA).

3. Results and discussion

3.1. Effect of intermittent aeration on DO distribution

Cyclic DO distribution in aerated and non-aerated VFCWs is illustrated in Fig. 1. Anaerobic and aerobic regions can be well distinguished by means of the DO profile. Sharp decrease of DO concentration was observed immediately after inflow in both aerated wetland VFCWs and non-aerated wetland VFCWs. For non-aerated wetland VFCWs, fast exhaustion of DO mainly occurred during the first 4 h and then DO concentration almost remained unchanged before drainage. As shown in Table. 2, the average effluent DO concentrations in non-aerated VFCWs were below 0.61 (±0.26) mg L^{-1} and most time in the cycle was therefore under anaerobic conditions. The effluent DO level decreased as the COD/N ratios increased from 2.5 to 20, which was mainly due to the degradation of excessive organic matters. Intermittent aeration was adopted to markedly enhance oxygen supply to the substrate. The oxygen was diffused from the bottom to the surface of the VFCWs and was utilized gradually. Cyclic anaerobic and aerobic conditions were alternately developed within the substrate. The average effluent DO concentration was much higher than that in non-aerated CWs.

There is always a contradiction among the removal of organic matters, NH_4-N and TN in conventional CWs mainly because of competition for limited oxygen supply (Saeed and Sun, 2011). The oxygen availability was therefore considered as one of the main rate-limiting factors for organics degradation and nitrification. The alternate anaerobic and aerobic conditions developed by intermittent aeration may simultaneously promote the activity of microbes in biodegradation of organic matter, nitrification and denitrification. Furthermore, with various influent COD/N ratios in the present study, the favorable DO distributions caused by intermittent aeration may produce distinct impact on the treatment performance especially when COD concentration significantly increased from 112.88 (±6.20) to 836.40 (±16.79) mg L^{-1}.

Table. 1
Characteristics of influents (Mean ± SD, *n* = 25).

COD/N control	2.5	5	10	20
COD (mg/L)	112.88 ± 6.20	217.25 ± 13.37	429.34 ± 14.17	836.40 ± 16.79
NH_4-N (mg/L)	40.22 ± 0.43	39.89 ± 0.86	40.18 ± 0.37	40.07 ± 0.41
NO_3-N (mg/L)	3.37 ± 0.61	3.38 ± 0.63	3.38 ± 0.61	3.45 ± 0.57
TN (mg/L)	44.73 ± 0.75	44.48 ± 0.97	44.69 ± 0.82	44.69 ± 0.28
TP (mg/L)	3.88 ± 0.32	3.94 ± 0.39	3.92 ± 0.34	3.92 ± 0.35
pH	7.45 ± 0.20	7.40 ± 0.20	7.41 ± 0.20	7.36 ± 0.24
DO (mg/L)	7.97 ± 0.50	7.95 ± 0.36	8.01 ± 0.31	8.12 ± 0.35
COD/N	2.59 ± 0.17	4.86 ± 0.38	9.74 ± 0.36	19.05 ± 0.45

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