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Short communication

Removal of nutrients from septic effluent with re-circulated hybrid tidal flow constructed wetland

Lihua Cui[a,*], Jingkun Feng[a], Ying Ouyang[b], Peiwen Deng[c]

[a] College of Natural Resource & Environment, South China Agricultural University, Guangzhou 510642, PR China
[b] USDA Forest Service, 100 Stone Blvd., Thompson Hall, Room 309, Mississippi State, MS 39762, USA
[c] Shenzhen-Hongkong Institution of Industry, Education & Research Environmental Technique Center, Shenzhen 518057, PR China

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ABSTRACT

Hybrid tidal flow constructed wetland (CW) with recirculation is an improved biological and engineering technique for removal of excess nutrients and certain pollutants from wastewater. This study investigated the removal efficiency of total phosphorus (TP), ammonia-nitrogen (NH_3-N), and total nitrogen (TN) from septic tank effluent with the hybrid tidal flow CW system. Results showed that the removal of TP and NH_3-N decreased as the hydraulic loading rate (HLR) increased, while the removal of TN increased and then decreased as the transition of HLR from 0.5 to 1.5 $m^3/m^2/d$. The removal of TN was maximized at the HLR of 1.0 $m^3/m^2/d$. The overall removal ranges of TP, NH_3-N, and TN were 35.55–77.68%, 33.30–72.71%, and 16.25–53.17%, respectively. In general, an increase in recirculation frequency could increase the treatment volume of the effluent. This study suggests that the recirculation hybrid tidal flow CW has better performance in removal of nutrients than that of the traditional vertical flow CW.

1. Introduction

Constructed wetland (CW) is a promising technique for removal of excess nutrients and certain pollutants from wastewaters. This technique utilizes the natural resources involving wetland vegetation, soil, substrate, and their associated microbial assemblages to assist in treating wastewater (Kadlec et al., 2000; Vymazal, 2007). With increasingly gaining acceptance, CW is now used for many other types of wastewater treatments, including industrial and agricultural wastewater, landfill leachate, and storm water runoff (Vymazal, 2005; Tam et al., 2009).

Based on the water flow regime, there are primarily three types of CWs: (1) surface-flow wetlands, (2) subsurface-flow wetlands (i.e. horizontal-flow and vertical-flow wetlands), and (3) hybrid systems that incorporate surface and subsurface-flow wetlands. Among these, the vertical-flow CWs are gaining popularity due to their greater oxygen transfer capacity and small in wetland size. When these CWs are used to treat wastewater with high concentrations of ammonia-nitrogen, the removal efficiency is often restricted by poor wastewater distribution on the wetland surface and by a low oxygen transfer rate (Sun et al., 2003). To circumvent the obstacles, a new type of CW, i.e. the tidal flow CW, has been introduced.

The concept of the tidal flow CW was put forward by the University of Birmingham in last decade (Sun et al., 1999). The term “tidal flow” refers to an operation that repeatedly allows wetland matrices to be filled with wastewater and then to be completely drained. In the filling phase, the air in the wetland bed is gradually being squeezed out and consumed, and the matrices are gradually being flooded. Fresh air is brought into the system in the draining phase. Therefore, water functions as a piston air compressor. Research shows that the oxygen consumption rate reaches highest level in the draining phase (Xu et al., 2001), thus the fresh air brought in by draining is regarded as an oxygen source in the CW system. With this circulation process of wastewater and air, supply and consumption of oxygen are greatly improved and the removal efficiency of organic pollutants in the CW system is significantly optimized. Additionally, sewage could have full accessed to matrices in the tidal flow CW, which both optimizes the utilization of wetland system and overcomes the uneven water distribution in the CW (Sun et al., 1999). With flood-tide and ebb-tide takes place by turn repeatedly, the nitrification and denitrification processes are intensified, which is favorable to maximize the removal efficiency of total nitrogen (TN) (Chan et al., 2008). However, little effort has been devoted to applying the tidal flow CW, especially the hybrid circulatory tidal flow CWs, for sewage treatments.

* Corresponding author.
E-mail address: lihcui@scau.edu.cn (L. Cui).

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Table 1
Method of operation of the tidal flow constructed wetland.

Hydraulic loading rate ($m^3/m^2/d$)	Phase duration (h)					
	Filling wastewater phase			drainagin wastewater phase		
	Without recycling	One time cycling	Two times cycling	Without recycling	One time cycling	Two times cycling
0.5	3	3.5	4	21	20.5	20
1	3.5	5	6.5	20.5	19	17.5
1.5	4	6.5	10.5	20	17.5	13.5

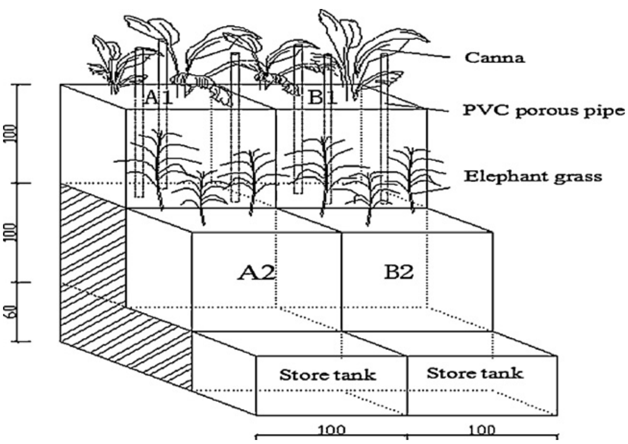

Fig. 1. Diagram of hybrid tidal flow constructed wetland. The unit for those values in the diagram is mm.

In this study, we investigated the removal of total phosphorus (TP), ammonia-nitrogen (NH_3-N), and TN from septic tank effluent using the hybrid tidal flow CW system. The objectives of this study were to: (1) estimate the effects of recirculation times and HLRs on TP, NH_3-N, and TN removals from the effluent, and (2) determine the performance of recirculation hybrid tidal flow CW system on effluent treatment.

2. Materials and methods

2.1. System description

The hybrid tidal flow CW used in this study was a three-stairs like system, which consisted of two independent subsystems (A and B) (Fig. 1). Each subsystem was made up by three units, namely the primary tidal flow CW (A1 and B1), secondary tidal flow CW (A2 and B2), and storage tank (from top to bottom). The primary tidal flow unit used five polyvinylchloride (PVC) porous pipes to achieve even water distribution, increase the contact area between matrices and air, and enhance reoxygenation from the atmosphere. The secondary tidal flow unit was kept flooded with a 30-cm water depth when the system was not in operation, and drained before the system functioned, thus it created an anaerobic environment. There were altitude differences among each stair in order to form an artesian flow. Effluent gathered in the storage tank could be pumped back to the primary treatment unit for a retreatment.

Each tidal flow unit was made of a concrete cube with 1.0 m on each side, while the storage tank was built with 1.0 m length × 1.0 m width × 0.6 m depth. Our previous studies showed that blast furnace slag as matrices can be very effective for TP removal. However, it would cause high effluent pH level, increase matrices hardiness, and add to the operational cost. Therefore, in this study we used 50% blast furnace slag and 50% medium-coarse sand mixture as the matrices of system A, while the blast furnace slag was filled up in the system B as the supporting medium for reference. The porosities of system A and system B were 44.77% and 55.56%, respectively. Plants were introduced into the system to imitate the main components of constructed wetland. Clumps of whole plants of the *Canna indica* were planted into the primary tidal flow CW unit with a density of 9 plant/m^2 and the *Pennisetum purpureum* Schum (Elephant grass) were planted into the secondary tidal flow unit with the same density.

2.2. System operation and analysis

The hybrid tidal flow CW was operated with a cycle of 24 h from September 2006 to April 2007. The system was operated with three different recycling methods and three different HLR alternately. Table 1 shows the method of operation of the system and each method was conducted with triplicates. The influent contains 15.06 mg/L TP, 219.84 mg/L TN, and 186.98 mg/L NH_3-N, which is 2–3 times higher than those from the general municipal sewage.

The NH_3-N, TP, and TN contents of wastewater were analyzed in the laboratory with standard methods (APHA, 1998). Removal efficiencies were obtained by calculating the percentages of nutrient removal from the influent concentrations. Correlation analysis and comparisons of the differences of nutrient levels were performed using DUNCAN statistics with SAS 8.1.

3. Results and discussion

3.1. Impact of HLR on TP

The HLR is the rate of wastewater entered into the hybrid tidal flow CW system. Impact of the HLR on TP removal from the hybrid tidal flow CW system is shown in Fig. 2A. This figure shows a decreasing TP removal trend with increasing HLR without circulation. For a HLR at 0.5 $m^3/m^2/d$, the average removal efficiencies for TP by the systems A and B were 68.88% and 74.08%, respectively. For a HLR at 1.5 $m^3/m^2/d$, the average removal efficiencies for TP by systems A and B were 35.55% and 46.49%, respectively. Fig. 2A further reveals that the performance of system B on TP removal was better than that of system A for all of the three HLRs. A statistical analysis shows that removal of TP among the three HLRs was significantly different ($p = 0.0021 < 0.05$) by System A and was not significantly different ($p = 0.0505 > 0.05$) by System B. This was mainly due to the fact that the 50% blast furnace slag and 50% medium-coarse sand mixture were used as the matrices in System A, while the 100% blast furnace slag was selected as the matrices in System B. The blast furnace is well-known for its excellent P adsorption capacity.

3.2. Impact of recirculation on TP

Recirculation of wastewater enhanced the TP removal in both Systems A and B by about 1–4% for a HLR at 0.5 $m^3/m^2/d$ (Table 2). For a HLR at 1.0 $m^3/m^2/d$, the TP removal in both systems dropped by 1–2% when the CW was first re-circulated, which could be a result of the P release due to washing. The removal of TP increased

Table 2
TP removal efficiency with different HLR and recirculation frequency.

System unit	Operation method	Hydraulic loading rate ($m^3/m^2/d$)		
		0.5 Percentage of removal ± standard deviation	1 Percentage of removal ± standard deviation	1.5 Percentage of removal ± standard deviation
TP				
A	Without recycling	68.88 ± 4.13	56.20 ± 1.16	35.55 ± 2.68
	One-time cycling	69.15 ± 4.68	54.52 ± 8.38	57.05 ± 5.96
	Two-time cycling	73.01 ± 1.64	59.76 ± 3.98	68.28 ± 3.25
B	Without recycling	74.80 ± 5.64	65.42 ± 6.17	46.49 ± 0.96
	One-time cycling	74.76 ± 1.44	63.56 ± 2.81	63.42 ± 0.90
	Two-time cycling	77.68 ± 2.08	71.93 ± 2.36	73.17 ± 0.28
TN				
A	Without recycling	18.73 ± 0.89	28.76 ± 7.24	26.98 ± 8.48
	One-time cycling	48.81 ± 3.22	39.07 ± 10.02	24.27 ± 5.32
	Two-time cycling	52.23 ± 3.69	48.76 ± 4.92	26.37 ± 2.37
B	Without recycling	16.25 ± 0.67	31.93 ± 8.03	22.80 ± 9.28
	One-time cycling	39.25 ± 2.64	33.83 ± 14.14	23.27 ± 0.29
	Two-time cycling	53.17 ± 0.85	33.99 ± 4.13	24.54 ± 4.21
NH_3-N				
A	Without recycling	59.76 ± 6.26	36.57 ± 8.27	33.30 ± 3.73
	One-time cycling	64.57 ± 1.03	47.42 ± 1.60	50.33 ± 5.29
	Two-time cycling	69.95 ± 2.28	54.50 ± 4.77	59.30 ± 1.01
B	Without recycling	71.02 ± 3.77	43.26 ± 5.24	40.96 ± 5.48
	One-time cycling	61.55 ± 5.59	52.80 ± 1.86	54.85 ± 2.19
	Two-time cycling	76.03 ± 0.93	72.71 ± 4.55	66.94 ± 3.88

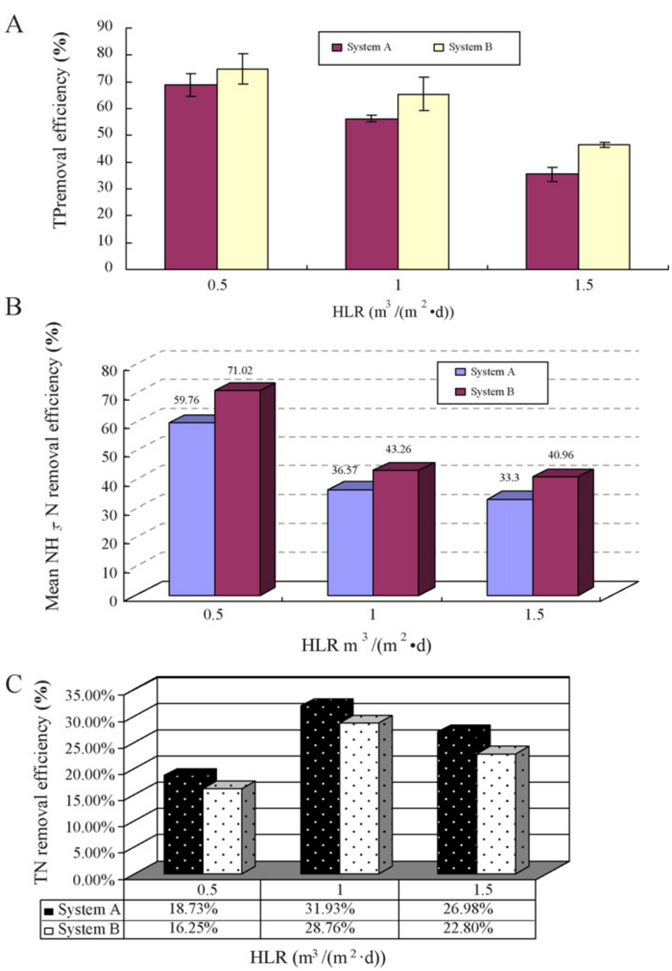

Fig. 2. TP (A), NH3-N (B), and TN (C) removal efficiencies with different hydraulic loading rates (HLRs).

by 3.5% and 6.5%, respectively, for Systems A and B after the CW had a second recirculation. For a HLR at 1.5 $m^3/m^2/d$, the TP removal in System A increased 21.5% with one time of recirculation and 32.7% with two times of recirculation. Similar result was found in System B (increased by 16.93% and 26.68%). Results indicated that the removal of TP increases with HLR and recirculation frequency. Two times recirculation with a HLR at 1.5 $m^3/m^2/d$ could achieve a similar TP removal efficiency as compared to one time recirculation with a HLR at 0.5 $m^3/m^2/d$. In other words, an increase in recirculation frequency could increase the treatment efficiency of the effluent.

3.3. Impact of HLR on NH_3-N

Fig. 2B shows that the performance of the hybrid tidal flow CW system on NH_3-N removal with a decreasing removal trend as the HLR increased without circulation. For a HLR at 0.5 $m^3/m^2/d$, the average removal efficiencies of NH_3-N by System A and B were 59.76% and 71.02%, respectively; for a HLR at 1.0 $m^3/m^2/d$, the average removal efficiencies of NH_3-N by System A and B were 36.57% and 43.26%, respectively; and for a HLR at 1.5 $m^3/m^2/d$, the average removal efficiencies of NH_3-N by systems A and B were 33.30% and 40.96%, respectively. The performance of System B on the NH_3-N removal efficiency was better than that of System A for all of the three HLRs. The removal of NH_3-N by System A was not significantly different ($p = 0.1252 > 0.05$) while the removal of System B was significantly different at different HLRs ($p = 0.0184 < 0.05$), which implied that System B was a preferable nitrification system. This was mainly because the porosity of System A (44.77%) was lower than System B (55.56%). The higher porosity increased the aerobic nitrification process.

3.4. Impact of recirculation on NH_3-N

For a HLR at 0.5 $m^3/m^2/d$, recirculation was favorable to the NH_3-N removal for both systems (Table 2), but this removal was not significantly different. For a HLR of 1.0 $m^3/m^2/d$, one and two times of recirculation, respectively, contributed to 10.85% and 17.93%

increase in NH_3-N removal for System A and to 9.54% and 29.45% increase in NH_3-N removal for System B. For a HLR at 1.5 $m^3/m^2/d$, one and two times of recirculation, respectively, contributed to 17.03% and 26.00% increase in NH_3-N removal for System A and to 13.89% and 25.98% increase in NH_3-N removal for System B. This concluded that the removal efficiency of NH_3-N increased with the HLR and recirculation frequency.

3.5. Impact of HLR on TN

The performance of the hybrid tidal flow system on TN removal increased and then decreased as the transition of HLR from 0.5 to 1.5 $m^3/m^2/d$ without circulation (Fig. 2C). Under the HLR at 0.5 $m^3/m^2/d$, the average removal efficiencies for TN by Systems A and B were 18.73% and 16.25%, respectively. For a HLR at 1.0 $m^3/m^2/d$, the average removal efficiencies for TN by Systems A and B were 31.93% and 28.76%, respectively. For a HLR at 1.5 $m^3/m^2/d$, the average removal efficiencies for TN by Systems A and B were 26.98% and 22.80%, respectively. The removal efficiency of TN was maximized for a HLR at 1.0 $m^3/m^2/d$. The performance of System A on the TN removal was better than that of System B for all of the three HLRs. This occurred because the porosity of the System A (44.77%) was lower than that of System B (55.56%). The lower porosity was favorable to denitrification process. Removal of TN was not significantly different ($p = 0.4643 > 0.05$) by System A and was significantly different by System B ($p = 0.02813 < 0.05$) for all of the three HLRs, which indicated that System B was greatly affected by the HLRs.

3.6. Impact of recirculation on TN

Under the HLR at 0.5 $m^3/m^2/d$, recirculation was favorable to TN removal for both systems in the tidal flow CW system. One and two times of recirculation, respectively, contributed to 30.08% and 33.50% increase in TN removal for System A and to 23.00% and 36.92% increase in TN removal for System B (Table 2). The impact of recirculation frequency on removal efficiency of TN for both systems was significantly different ($p = 0.0006 < 0.01$ for System A and $p = 0.0001 < 0.01$ for System B). For a HLR at 1.0 $m^3/m^2/d$, one and two times of recirculation, respectively, contributed to10.31% and 20.00% increase in TN removal for System A and to only 2% increase in TN removal for System B. In addition, the impact of recirculation frequency on TN removal for System A was significantly different and was not significant difference for System B. Under the HLR at 1.5 $m^3/m^2/d$, one and two times of recirculation only contributed to 1–2% increase in TN removal for both systems, which implied that as the HLR increased, more times of recirculation were required to improve the TN removal efficiency.

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