Journal of Environmental Management 180 (2016) 384–389

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Optimization of operating parameters of hybrid vertical down-flow constructed wetland systems for domestic sewerage treatment

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ARTICLE INFO

Article history:
Received 21 December 2015
Received in revised form
22 May 2016
Accepted 25 May 2016
Available online 1 June 2016

Keywords:
Constructed wetland
Hydraulic loadings
Step-feeding ratio
Domestic sewage

ABSTRACT

In this work, three hybrid vertical down-flow constructed wetland (HVDF-CW) systems with different compound substrates were fed with domestic sewage and their pollutants removal performance under different hydraulic loading and step-feeding ratio was investigated. The results showed that the hydraulic loading and step-feeding ratio were two crucial factors determining the removal efficiency of most pollutants, while substrate types only significantly affected the removal of COD and NH_4^+-N. Generally, the lower the hydraulic loading, the better removal efficiency of all contaminants, except for TN. By contrast, the increase of step-feeding ratio would slightly reduce the removal rate of ammonium and TP but obviously promoted the TN removal. Therefore, the optimal operation of this CWs could be achieved with low hydraulic loading combined with 50% of step-feeding ratio when TN removal is the priority, whereas medium or low hydraulic loading without step-feeding would be suitable when TN removal is not taken into consideration. The obtained results in this study can provide us with a guideline for design and optimization of hybrid vertical flow constructed wetland systems to improve the pollutants removal from domestic sewage.

1. Introduction

Constructed wetlands (CWs), which is consisted of wetland plants, wetland substrate, micro-organisms and other constituent elements, are effective systems to treat wastewater through the complex combination of physical, chemical and biological processes (Cui et al., 2013; Dordio and Carvalho, 2013; Li et al., 2015; Liu et al., 2015). In a mature constructed wetland system, a large number of micro-organisms and substrates, plants and other organisms interconnected to form an independent ecosystem (Xu et al., 2015). When wastewater flows into the wetlands, suspended solids (SS) can be intercepted by substrates and plant roots, while dissolved organic pollutants can be removed by biofilm through adsorption, assimilation and dissimilation.

Vertical flow wetland system is a comprehensive integration of surface flow wetlands and subsurface flow wetlands, in which water flows through the packed bed vertically from the top to the bottom, is collected through the collection pipes laid at the bottom and discharged. Studies have shown that the vertical flow wetland beds are a reliable treatment system for wastewater purification with excellent oxygen transfer properties to treat water with high ammonia-nitrogen content such as sewage and urban wastewater (Cooper, 2005; Fan et al., 2013; Xu et al., 2015). However, the conventional vertical flow wetland system exhibits several disadvantages including pipeline blockage (clogging), which will lead to accumulation of water on the surface of the down-flow pool and decreased activity of aerobic microbes in the vertical flow. In addition, the low oxygenation capacity of the system could limit the total nitrogen (TN) removal efficiency, as carbon source is insufficient during the process of denitrification, the removal of nitrogen is further inhibited (Ding et al., 2012).

In our previous study, we have developed a series of hybrid constructed wetland systems, including re-circulated hybrid tidal flow CWs (Cui et al., 2012), hybrid baffled subsurface-flow CWs (Cui et al., 2013), and horizontal flow combined with vertical flow baffle hybrid CWs (Cui et al., 2015). How to further improve the oxygen enrichment ability and TN removal efficiency of the CW system is still a problem to be overcome. Based on this, in the present study, the removal efficiencies for TN, TP, COD, BOD_5, and NH_4^+-N by three adapted hybrid vertical down-flow constructed wetland (HVDF-CW) systems with different hydraulic loadings and step-feeding ratios were evaluated to examine the abilities of the three

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http://dx.doi.org/10.1016/j.jenvman.2016.05.060
0301-4797/

systems to treat domestic wastewater.

2. Materials and methods

2.1. HVDF-CW systems

Domestic wastewater was collected and fed to the primary sedimentation basin to remove large particles, and then run through the HVDF-CW system. HVDF-CW is composed of bed body and water distributors, the impermeable bed wall is made of cement plastered brick, and the bottom of the bed is made of concrete structure. Hybrid vertical down-flow constructed wetland system, The dimension of the Stage 1 units of HVDF-CW is 100 × 100 × 130 cm (length × width × height), that of the Stage 2 units is 100 × 100 × 110 cm (length × width × height). The water distributor of HVDF-CW are perforated PVC pipe located at about 10 cm below the top of the substrate surface, shown in Fig. S1 (Supporting Information). Wastewater is pumped to the HVDF-CW at the top of the Stage 1 unit via the primary water distributors, the down-flow of the wastewater through the Stage 1 unit mixes with the wastewater providing step-feeding ratio at the bottom, then flow into the Stage 2 unit for another vertically down-flow processing. Three different systems were constructed based on Table 1.

2.2. Substrate filling

In both the Stage 1 and Stage 2 units of HVDF-CW system, the bottom layer of the bed is filled with gravel with a diameter a 3–5 cm to a height of 10 cm, the height of the main substrate layer is 100 cm. The solid particles that fill the substrate layers in the first and second stage units of the three systems are presented in Table 1. The water distributors are located 10 cm below the top of the substrate layer, hence the valid height of the substrate layer in the Stage 1 unit is 90 cm, while that of the Stage 2 unit is 80 cm.

2.3. Operation and management

The system was operated on a 5: 2 wet-to-dry operating ratio (wastewater flowed through the system for five consecutive days then treatment was stopped and the system was dried for two days. 5: 2 wet-to-dry operating ratio is chosen as it is compatible with the work schedule of the operations managers), hydraulic load rates controlled by valves were 0.6 (low), 1.2 (medium) and 2.4 (high) $m^3/m^2 \cdot d$ at an effluent height of 80 cm, respectively. The primary water is introduced into the secondary tank as carbon source, and the flow ratio of primary water to secondary water was tuned at 0: 1, 1: 3 and 1: 1, that is, the step-feeding ratio is 0, 25% and 50%. The construction cost of a CW system in this study is about 600–700 RMB (~100 USD), and the average operation cost is 0.15 RMB/m^3 by considering the costs of electricity (0.08 RMB/m^3), manpower (0.04 RMB/m^3) and electro-mechanical equipment maintenance (0.03 RMB/m^3).

2.4. Water sampling and analysis

Dormitory wastewater from Guangzhou Iron and Steel Institute was pumped into HVDF-CW for treatment, the water quality parameters are shown in Table 2 below:

2.5. Statistical analysis

SAS8.1, SPSS 16.0 and Excel 2003 were used for data analysis including variance, correlation analysis, mean value, and standard deviation calculation. Duncan Multiple Range Test method (DMRT law, $P = 0.05$) was chosen for multiple comparisons by SAS. Multivariate and Repeated measures function were selected for general linear model (GLM) variation analysis of 3 factors (hydraulic loading, substrate types and step-feeding ratio) with three level on five indexes (removal rate of COD, BOD, Ammonium, TP and TN, respectively) by SPSS 16.0, and the results were displayed with significant values and observed mean values in supplementary tables. Correlations analysis of five indexes was conducted as well by utilizing the correlate (bivariate) function of SPSS.

3. Results

3.1. COD and BOD_5 removal

The COD removal by hybrid vertical down flow constructed wetlands (HVDF-CW) with different step-feeding ratio was shown in Fig. 1(a–c). Obviously, with the increasing of hydraulic loading rate, the purification effect of COD declined with different step-feeding ratio. Under low hydraulic loading rate (Fig. 1a), the COD removal efficiency of Systems IV1 and IV2 increased with increasing step-feeding ratio, and System IV3 showed the highest removal efficiency when the step-feeding ratio is 25%.

As observed in Fig. 1b, under medium hydraulic loading rate, the COD removal by System IV3 decreased with the increasing of step-feeding ratio, and Systems IV1and IV2 showed the highest removal efficiency when the step-feeding ratio is 25%. In System IV1, the substrate used for the Stage 2 is medium coarse sand with low surface area, which can intercept the pollutants. When step-feeding influent were pumped directly into the Stage 2 and reached a critical mass, organic matters intercepted by the substrate can not been degraded timely by the absorbed microorganism, resulted in the low efficiency of COD removal. When step-feeding influent was not pumped into the Stage 2 unit, the Stage 1 unit would play a crucial role in COD removal. With the increasing of step-feeding influent, the Stage 2 unit need to process more organic pollutants, hence System IV2 achieved a high COD removal efficiency. When the Stage 2 unit was supplied with 50% of step-feeding influent, the effect of the Stage 1 unit on COD removal attenuated, led to a low COD removal efficiency of System IV2. Under high hydraulic loading rate (Fig. 1c), the three hybrid CW systems showed the highest COD removal efficiency when the step-feeding ratio is 25%. Under medium and high hydraulic loading, with the increasing of step-feeding ratio, the Stage 1 of System IV3

Table 1
The specific structure of HVDF-CW systems.

System name	Cell body name	Types of substrate	Plant species
System IV1	Stage 1	Blast furnace slag	Windmill grass
	Stage 2	Medium coarse sand	*Canna indica*
System IV2	Stage 1	Pisolite	Windmill grass
	Stage 2	Blast furnace slag	*Canna indica*
System IV3	Stage 1	50%blast furnace slag&50% medium coarse sand	Windmill grass
	Stage 2	Coal ash	*Canna indica*

Table 2
Wastewater quality in this study (mg/L).

Parameter	COD_{Cr}	BOD_5	TN	TP	NH_4^+-N	NO_3^--N
Minimum	25.47	11.51	14.09	1.04	11.50	0.70
Maximum	343.33	44.70	62.82	5.07	38.46	8.60
Mean ± σ	83.56 ± 8.75	25.57 ± 1.25	34.10 ± 1.70	2.65 ± 0.14	24.51 ± 0.96	1.58 ± 0.24

Note: The sample number is 50.

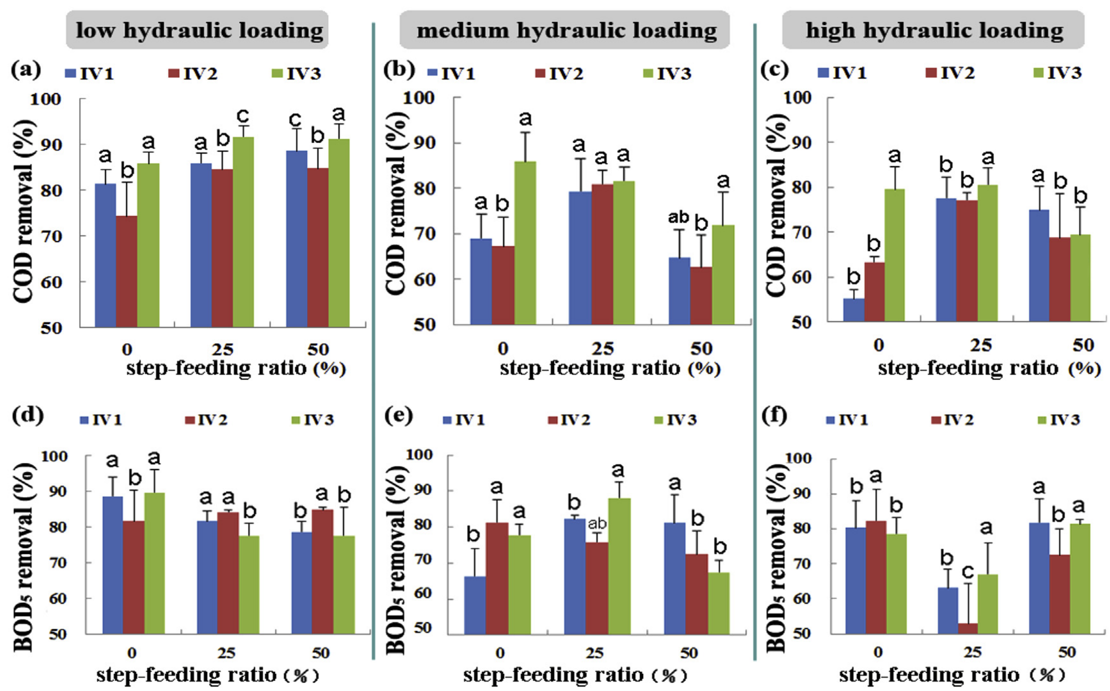

Fig. 1. Effect of step-feeding ratio on COD (a–c) and BOD_5 (d–f) removal under different hydraulic loading rates: (a, d) low hydraulic loading rate; (b, e) medium hydraulic loading rate; (c, f) high hydraulic loading rate.

play a more important role in the removal of COD. The CW substrate used for the Stage 2 of System IV3 is coal ash, with a large surface area and a strong adsorption capacity of pollutants (Cui et al., 2015). Generally, when step-feeding influent was supplied for the Stage 2 of the three systems, the COD values of the domestic sewage after treatment by each hybrid system were <50 mg/L (Table S1), which is up to the Chinese Standard (GB18918-2002) "Discharge standard of pollutants for municipal wastewater treatmentplant" Grade 1 A.

According to Fig. 1(d–f), the removal of BOD_5 by System IV1 decreased with the increase of influent content under low hydraulic loading rate. On the contrary, the removal by System IV2 increases with the elevation of influent content. When there was zero step-feeding influent content, the best removal rate of BOD_5 by System IV3 is 89.78% under low hydraulic loading rate; what's more, when the content of step-feeding ratio was 25%, the best removal rate of BOD_5 by System IV3 was 88.11% under medium hydraulic loading rate; Besides, when HVDF-CW system operated under high hydraulic load rate, the best removal rate of BOD_5 by System IV2 was 80.51% when no step-feeding influent was added. Most of the BOD_5 values (Table S2) of effluent (except with high hydraulic loading and 50% step feeding strategy) also meet the Grade 1 A standard (GB18918-2002) for wastewater (BOD5 < 10 mg/L).

3.2. NH_4^+-N and TN removal

As it can be seen in Fig. 2a, under low hydraulic loading rate, the NH_4^+-N removal rate by System IV2 is relatively stable high, and System IV1 and IV3 exhibited the lowest removal efficiency when the step-feeding ratio is 25%. When step-feeding influent was not pumped into the Stage 2 unit, the Stage 1 unit would play a major role in NH_4^+-N removal. Under low hydraulic loading rate, step-feeding ratio becomes the main factor determining NH_4^+-N removal by the Stage 2 unit of System IV2, because of the large diameter of the substrate material (pisolite) of the Stage 1 unit and the system's reoxygenation ability. The increasing of step-feeding influent for the Stage 2 unit made the removal capacity enhancement, as a result, the NH_4^+-N removal by System IV2 is relatively stable high. When step-feeding influent was not pumped into the Stage 2 (0%), under low hydraulic loading, the best removal of NH_4^+-N by System IV1 was 94.81%; under medium hydraulic loading rate, the best removal of NH_4^+-N by System IV1 was 91.11%; under high hydraulic loading rate, the best removal of NH_4^+-N by System IV2 was 81.14%. Under low, medium and high hydraulic loading rates (Zero amount of step-feeding ratio), NH_4^+-N concentration of 80% of the effluent after treatment was less than 8.0 mg/L (Table S3), which is up to Grade 1 A (GB18918-2002).

As can be witnessed in Fig. 2(d–f), when step-feeding influent was not pumped into the Stage 2 (Zero amount of step-feeding ratio), under low hydraulic loading, the best removal of TN by SystemIV3 was 39.39%; under high hydraulic loading, the best removal of TN by System IV3 was 56.17%. When the Stage 2 was supplied 50% step-feeding influent, under ultra-high hydraulic loading, the best removal of TN by System IV2 was 55.06%.

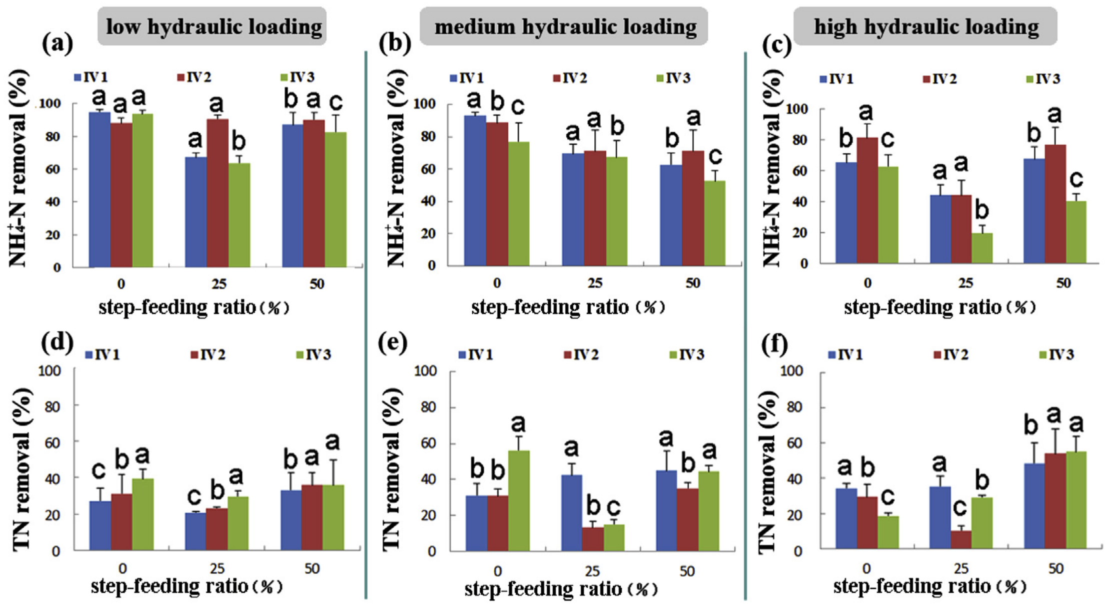

Fig. 2. Effect of step-feeding ratio on NH_4^+-N (a–c) and TN (d–f) removal under different hydraulic loading rates: (a, d) low hydraulic loading rate; (b, e) medium hydraulic loading rate; (c, f) high hydraulic loading rate.

3.3. *TP removal*

The TP concentration (Fig. 3) of domestic sewage after treatment by HVDF-CW system is less than 1.0 mg/L under low, medium and high hydraulic loading rates, which meet the standards of the level B of GB18918-2002. When there is zero step-feeding ratio, the best removal rate of TP conducted by the System IV2 is 94.82% under low hydraulic loading rate, 93.04% under medium hydraulic loading rate, and 93.31% under high hydraulic loading rate. Most of TP values (Table S5) meet the GB18918-2002 Grade 1 B standard (1.0 mg/L).

4. Discussions

4.1. *Effect of operating parameters on COD,BOD$_5$, NH_4^+-N, TN and TP removal*

General linear model analysis of variation between three factors and five indexes is shown in Fig. 4 and supplementary tables. Fig. 4 showed that both the hydraulic load and step-feeding ratio were two crucial factors determining the removal effect of most pollutants, while substrate material played a vital role in the removal of COD and NH_4^+-N. COD of domestic wastewater consist of soluble and insoluble COD, and the removal of COD by the substrate was mainly achieved by adsorption of insoluble COD. Removal of BOD by the substrate was not conspicuous as BOD is generally soluble COD. The removal of organic matters by constructed wetlands was primarily attributed to biodegradation, and extension of hydraulic retention time or smaller hydraulic load is beneficial for adsorption of insoluble COD by the substrate and microbial degradation of soluble COD/BOD (Vymazal and Kröpfelová, 2009). Different ratios of step-feeding can alter the hydraulic load of HVDF-CW systems, therefore affecting the adsorption of insoluble COD by the substrate. However, step-feeding ratio didn't have a significant impact on the removal of BOD as step-feeding influent only altered the distribution of carbon source instead of the total organic load of the system (Table S6). It was also shown that the three factors all played an essential role in the removal of NH_4^+-N, while only step-feeding ratio was primarily responsible for total nitrogen removal. The mechanisms of NH_4^+-N removal by constructed wetlands involves adsorption by the substrate and bio-nitration (Białowiec et al., 2012; Cui et al., 2015). The hydraulic

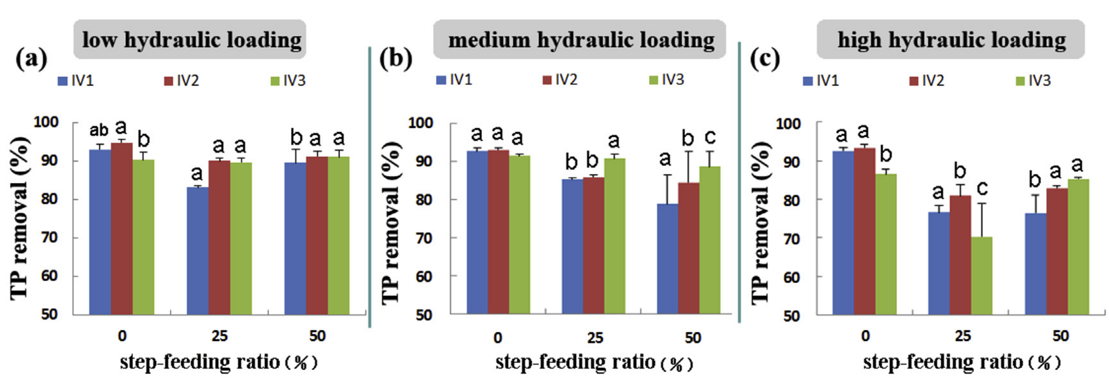

Fig. 3. Effect of step-feeding ratio on TP removal under different hydraulic loading rates: (a) low hydraulic loading rate; (b) medium hydraulic loading rate; (c) high hydraulic loading rate.

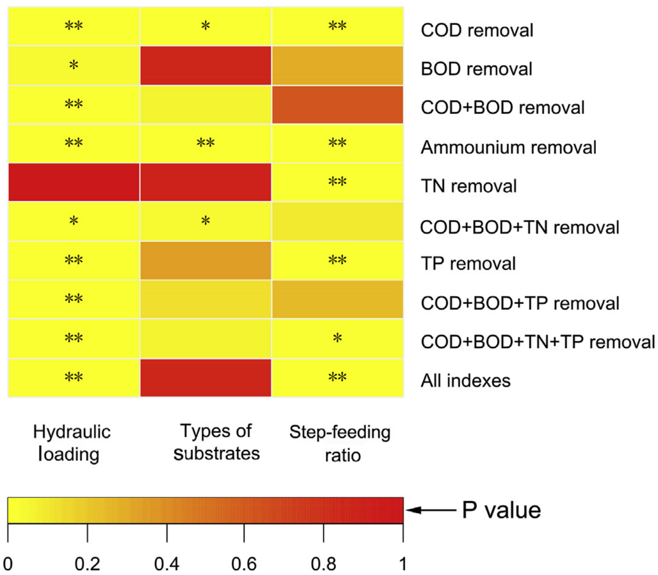

Fig. 4. Significance (P value) in general linear model analysis of variation between three factors and five indexes: **Correlation is significant at the 0.01 level, *Correlation is significant at the 0.05 level.

load and step-feeding ratio are both able to influence the hydraulic retention time so as to affect the adsorption of NH_4^+-N and the process of bio-nitration (Ouyang et al., 2011). The variations between wetlands with different substrate were probably due to the different adsorptive abilities the substrate (Cui et al., 2015). Table S7 showed that the substrate combination of System IV2 was superior to that of System IV3. As the step-feeding ratio increased, the removal efficiency of NH_4^+-N slightly declined, implying that affected the systemic nitration. When the step-feeding ratio = 0%, the entire constructed wetland was practically composed of two tandemly connected subsystems, which facilitated the separation of heterotrophic bacteria for removal of BOD and autotrophic nitrification bacteria for NH_4^+ oxidation (Cui et al., 2013; Fan et al., 2013; Hsueh et al., 2014). Most of the BOD would be removed by the Stage 1 subsystem, which was beneficial to nitrification in the Stage 2 subsystem. In contrast, when step-feeding ratio = 50%, the constructed wetland was a parallel of two subsystems, which was obviously superior to the constructed wetland with a step-feeding ratio = 0 when considering total nitrogen removal (Table S7). The reason for this may be that in the parallel system, the BOD entering the Stage 2 subsystem can provide carbon source to promote the denitrification of the nitrification products resulting from Stage 1 processing. Nevertheless, as the parallel system was less favorable for nitrification in comparison with the tandem system, the enhancement of total nitrogen removal by the parallel system was only marginal. The hydraulic load and the substrate didn't have a significant impact on total nitrogen removal, indicating that total nitrogen removal is heavily influence by denitrification process rather than substrate adsorption.

The above results showed that removal of total phosphorus by the constructed wetland was mainly through substrate adsorption (Fig. 4 and Table S8). Different substrate materials all exhibited satisfactory phosphorus removal efficiencies. Smaller hydraulic load and extension of hydraulic retention time could prominently improve the total phosphorus removal performance of the system. Other factors such as pH and ORP also affected the removal of total phosphorus apart from HRT and substrate types (Bezbaruah and Zhang, 2004; Dunne et al., 2015; Vymazal, 2014). When the step-feeding ratios changed, the hydraulic load and operation condition of the systems were also altered, which in turn affected total phosphorus removal. It was shown in Table S8 that the average total phosphorus removal efficiency was reduced as step-feeding ratio increased, suggesting that the tandem system exhibited better removal performance for phosphorus than the parallel system.

4.2. Optimization of operating parameters

The result (Fig. 4 and Table S6) showed that the hydraulic load, substrate type and step-feeding ratio were three crucial factors that determine the COD removal efficiency. Among these factors, lowering the hydraulic load exhibited the most prominent effect in improving the removal efficiency of COD. As for the removal of BOD, only the hydraulic load has a great impact on it, while the effects of substrate type and step-feeding ratio were insignificant. All things considered, the optimal operational parameters for the removal of both BOD and COD would be: low hydraulic load, System IV3 substrate and zero amount of step-feeding.

It was suggested that the three factors, including the hydraulic load, substrate type and step-feeding ratio, played a vital role in the removal of NH_4^+-N (Fig. 4 and Table S7). Low hydraulic load, System IV2 substrate and zero percent of step-feeding ratio were beneficial to higher removal rate of NH_4^+-N. However, raising the step-feeding ratio to 50% considerably improved the TN removal rate while hydraulic load and the substrate type had no effect on TN removal. It was therefore implied that there is a competitive relationship between NH_4^+-N and TN removal. Therefore, the hydraulic load and substrate type are both essential factors and should be taken into consideration to achieve higher COD and TN removal rate while the effect of step-feeding ratio is not significant (Table S7). The optimal operation parameters for efficient total nitrogen removal are as follows: low hydraulic load, System IV3 substrate and 50% of step-feeding ratio.

Alteration of hydraulic load and step-feeding ratio has a notable effect on TP removal (Fig. 4 and Table S8). Lowering the hydraulic load or reducing the step-feeding ratio led to enhanced TP removal. Low hydraulic load, System IV3 substrate and 25% of step-feeding ratio proved to be suitable for both COD and TP removal. In other words, for efficient removal of COD, TN and TP, the optimal operational parameters are: low hydraulic load, System IV3 substrate and 50% of step-feeding ratio.

4.3. Comparison of different CW systems

Table S9 compares the removal efficiency of pollutants from wastewaters by CWs between our (previous) study (Cui et al., 2015) and those studies. We found that the 3 types of CW systems reported in this study was superior in removal of pollutants than the CW systems constructed by other researchers. This could occur partially because different CW designs were used and partially because different CW plant species and substrates were employed between our study and other studies (Cui et al., 2015). However, the efficiency of the CW system in this study was outrun by the Baffle flow CW systems previously designed by our group (Cui et al., 2015). Nevertheless, it is worth noted that though the Baffle flow CW system demonstrated higher performance, it is easily clogged after long time operation.

5. Conclusions

The hydraulic load and step-feeding ratio had a significant impact on the removal of most pollution targets, while the selected substrate types in this study had limited influence on the removal of most pollutants except for COD and ammonia nitrogen removal. Lowering the hydraulic load was beneficial for the removal of ammonia nitrogen and total phosphorus whereas this did not significantly affect the total nitrogen removal efficiency. On the contrary, raising the step-feeding ratio resulted in better removal rate of total nitrogen, ammonia nitrogen and total phosphorus, but it had an inconspicuous effect on COD removal. Therefore, step-feeding should be adopted when the removal of total nitrogen is the priority. The optimal operational parameters for the HVDF-CW system are as follows: medium or low hydraulic load and 50% of step-feeding ratio when efficient total nitrogen removal is required; low hydraulic load and zero percent of step-feeding ratio when total nitrogen removal is not taken into consideration. The obtained results in this study offers a guideline for designing and optimizing of hybrid vertical flow constructed wetland systems to improve the pollutants removal from domestic sewage.

Acknowledgement

The study was supported by the National Natural Science Foundation of China (No.41071214, No.41271245, No. 51509093), the Engineering Research Center for Wastewater Ecological Treatment and Waterbody Remediation of Guangdong Higher Education Institutes (No.2012gczxA1004), the S&T Innovation Project of Water Conservancy of Guangdong Province (2015–15), the S&T Program of Guangzhou (156100027), the Project of Science and Technology of Guangdong Province (2012A020100003, 2014A020216034), the Dean Fund of College of Natural Resources and Environment of South China Agricultural University (ZHXY2014A04).

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2016.05.060.

References

Bezbaruah, A.N., Zhang, T.C., 2004. pH, redox, and oxygen microprofiles in rhizosphere of bulrush (*Scirpus validus*) in a constructed wetland treating municipal wastewater. Biotechnol. Bioeng. 88, 60–70.

Białowiec, A., Davies, L., Albuquerque, A., Randerson, P.F., 2012. Nitrogen removal from landfill leachate in constructed wetlands with reed and willow: redox potential in the root zone. J. Environ. Manag. 97, 22–27.

Cooper, P., 2005. The performance of vertical flow constructed wetland systems with special reference to the significance of oxygen transfer and hydraulic loading rates. Water Sci. Technol. 51, 81–90.

Cui, L.H., Feng, J.K., Ouyang, Y., Deng, P.W., 2012. Removal of nutrients from septic effluent with re-circulated hybrid tidal flow constructed wetland. Ecol. Eng. 46, 112–115.

Cui, L.H., Ouyang, Y., Gu, W.J., Yang, W.Z., Xu, Q.L., 2013. Evaluation of nutrient removal efficiency and microbial enzyme activity in a baffled subsurface-flow constructed wetland system. Bioresour. Technol. 146, 656–662.

Cui, L.H., Ouyang, Y., Yang, W.Z., Huang, Z.J., Xu, Q.L., Yu, G.W., 2015. Removal of nutrients from septic tank effluent with baffle subsurface-flow constructed wetlands. J. Environ. Manag. 153, 33–39.

Ding, Y., Song, X.S., Wang, Y.H., Yan, D.H., 2012. Effects of dissolved oxygen and influent COD/N ratios on nitrogen removal in horizontal subsurface flow constructed wetland. Ecol. Eng. 46, 107–111.

Dunne, E.J., Coveney, M.F., Hoge, V.R., Conrow, R., Naleway, R., Lowe, E.F., Battoe, L.E., Wang, Y., 2015. Phosphorus removal performance of a large-scale constructed treatment wetland receiving eutrophic lake water. Ecol. Eng. 79, 132–142.

Dordio, A., Carvalho, A.J.P., 2013. Constructed wetlands with light expanded clay aggregates for agricultural wastewater treatment. Sci. Total Environ. 463, 454–461.

Fan, J., Wang, W., Zhang, B., Guo, Y., Ngo, H.H., Guo, W., Zhang, J., Wu, H., 2013. Nitrogen removal in intermittently aerated vertical flow constructed wetlands: impact of influent COD/N ratios. Bioresour. Technol. 143, 461–466.

Hsueh, M.-L., Yang, L., Hsieh, L.-Y., Lin, H.-J., 2014. Nitrogen removal along the treatment cells of a free-water surface constructed wetland in subtropical Taiwan. Ecol. Eng. 73, 579–587.

Li, C.Y., Wu, S.B., Dong, R.J., 2015. Dynamics of organic matter, nitrogen and phosphorus removal and their interactions in a tidal operated constructed wetland. J. Environ. Manag. 151, 310–316.

Liu, R.B., Zhao, Y.Q., Doherty, L., Hu, Y.S., Hao, X.D., 2015. A review of incorporation of constructed wetland with other treatment processes. Chem. Eng. J. 279, 220–230.

Ouyang, Y., Luo, S.M., Cui, L.H., 2011. Estimation of nitrogen dynamics in a vertical-flow constructed wetland. Ecol. Eng. 37, 453–459.

Vymazal, J., 2014. Constructed wetlands for treatment of industrial wastewaters: a review. Ecol. Eng. 73, 724–751.

Vymazal, J., Kröpfelová, L., 2009. Removal of organics in constructed wetlands with horizontal sub-surface flow: a review of the field experience. Sci. Total Environ. 407, 3911–3922.

Xu, Q.L., Hunag, Z.J., Wang, X.M., Cui, L.H., 2015. *Pennisetum sinese Roxb* and *Pennisetum purpureum Schum.* as vertical-flow constructed wetland vegetation for removal of N and P from domestic sewage. Ecol. Eng. 83, 120–124.