ISSN 1001—0742
Journal of Environmental Sciences Vol. 18, No. 4, pp. 665—669, 2006 CN 11—2629/X

Article ID: 1001-0742(2006)04-0665-05 **CLC number**: X703 **Document code**: A

Performance of hybrid constructed wetland systems for treating septic tank effluent

CUI Li-hua[1], LIU Wen[1], ZHU Xi-zhen[1], MA Mei[2], HUANG Xi-hua[1], XIA Yan-yang[1]
(1. Department of Environmental Science and Engineering, South China Agricultural University, Guangzhou 510642, China. E-mail: lihcui@scau.edu.cn; 2. Coast to Coast Analytical Specialists, Garland, TX 75081, USA)

Abstract: The integrated wetland systems were constructed by combining horizontal-flow and vertical-flow bed, and their purification efficiencies for septic tank effluent were detected when the hydraulic retention time (HRT) was 1 d, 3 d, 5 d under different seasons. The results showed that the removal efficiencies of the organics, phosphorus were steady in the hybrid systems, but the removal efficiency of total nitrogen was not steady due to high total nitrogen concentration in the septic tank effluent. The average removal rates of COD (chemical oxygen demand) were 89%, 87%, 83%, and 86% in summer, autumn, winter and spring, respectively, and it was up to 88%, 85%, 73%, and 74% for BOD_5 (5 d biochemical oxygen demand) removal rate in four seasons. The average removal rates of TP (total phosphorous) could reach up to 97%, 98%, 95%, 98% in four seasons, but the removal rate of TN (total nitrogen) was very low. The results of this study also indicated that the capability of purification was the worst in winter. Cultivating with plants could improve the treated effluent quality from the hybrid systems. The results of the operation of the horizontal-flow and vertical-flow cells (hybrid systems) showed that the removal efficiencies of the organics, TP and TN in horizontal-flow and vertical-flow cells were improved significantly with the extension of HRT under the same season. The removal rate of 3 d HRT was obviously higher than that of 1 d HRT, and the removal rate of 5 d HRT was better than that of 3 d HRT, but the removal efficiency was not very obvious with the increment of HRT. Therefore, 3 d HRT might be recommended in the actual operation of the hybrid systems for economic and technical reasons.
Keywords: constructed wetlands; hybrid system; horizontal-flow; vertical-flow; removal efficiency; septic tank effluent

Introduction

As a new type of ecological technology for wastewater treatments, constructed wetlands are getting more popular in the world. According to water flow directions, constructed wetlands can be further divided into surface flow wetlands (SFW), subsurface flow wetlands (SSFW), and vertical flow wetlands (VFW). Since this technology has many advantages such as high quality of effluent, low capital investment, low treatment cost, and easy operation and maintenance, it is suitable for the treatment of sewage in small towns and villages.

The hybrid system of horizontal-flow (HF) and vertical-flow constructed wetlands (VFCW) is a new wastewater treatment system and many efforts have devoted to estimating the feasibility of this system in recent years (Cooper, 1999; Laber *et al.*, 1999; Luederitz and Eckert, 2001; Murray-Gulde *et al.*, 2005). However, the technical parameters for constructed wetland design and the optimal operations for the treatment of septic tank effluent with high nitrogen and phosphorus contents are rarely reported (Liu *et al.*, 2004; Cui *et al.*, 2003). The removal efficiencies of the TN and TP were often affected by many factors such as climate, plant species and hydraulic load (Breen and Chick, 1995). The nitrification and denitrification in constructed wetlands are best process of nitrogen removal mechanisms, and nitration process is that NH_4^+-N and NO_2^--N transforms for NO_3^--N. So the difference of removal rate of NH_4^+-N and NO_2^--N can be reflected by the denitrification intensity (Wang *et al.*, 2006). Since the hybrid system is composed of SSFW and VFW, nitrogen can be nitrified completely in vertical-flow cells, and denitrified in horizontal-flow cells by returning nitrates from vertical-flow cells back to the entrance of horizontal-flow cells. Plant species such as *Canna indica* L., *Edychium coronarium Koenig*, *Schoenoplectus lacustrwas*, and *Cyperus alternifolius* can be cultivated to determine the effects of the hybrid system on the improvement of effluent quality under different the hydraulic retention time (HRT) and different seasons. The objects of this study were to: (1) estimate the effectiveness of the hybrid system for the removal efficiencies of TN, TP, COD, and BOD_5 under different HRT and different seasons, and (2) to establish a practical and economic way for village sewage treatment in the developing countries such as China.

1 Materials and methods

1.1 Flow diagram

The technological processes of the hybrid system of horizontal-flow and vertical-flow constructed wetlands used in this study are given as follows:

Septic tank → Pump → Hihg-level tank →
HFCW → VFCW → Clarifying basin → Discharge
↑ Pump |

Foundation item: The National Natural Science Foundation of China (No. 40571074); the Natural Science Foundation of Guangdong Province (No. 04020599) and the Key Project of Guangdong Province (No. 2003C32912)

where HFCW is horizontal-flow constructed wetlands; VFCW is vertial-flow constructed wetlands.

1.2 Design of the hybrid systems

The hybrid systems were composed of horizontal-flow and vertical-flow constructed wetlands. Horizontal-flow constructed wetlands consisted of three cells and were designed to operate in parallel, each cell was 2 m long, 1 m wide, and 0.82 m deep. Vertical-flow constructed wetland cells also consisted of three cells and were designed to operate in parallel, each cell was 1 m long, 1 m wide, and 1.2 m deep. In addition, a clarifying basin, built at the outlet of vertical-flow cells, was used to take samples and collect nitrified effluent from vertical-flow cells, and the effluent was then pumped to the entrance of horizontal-flow cells by using organics (BOD_5) from sewage as carbon source to complete the process of denitrification (Laber *et al.*, 1997). This technology was called preanoxic process (A/O) for biological nitrogen removal. In the horizontal-flow cells, construction materials such as marble gravels and granite gravels were added to the bottom layer with 70 cm thick, 5 cm thick sands were filled in the upper layer. In the vertical-flow cells, 15 cm thick gravel was set for supporting layer, and then slag with 95 cm thick, and 5 cm thick soil layer was filled on the top of cell. Vegetation was planted in two hybrid systems, and one hybrid system was left unplanted as control (Table 1).

Table 1 Design of the hybrid systems and their operational regime

Hybrid systems[a]	Vegetation	t^b_{HRT}, d	Running time per day, h/d
HF1-VF1	*Cyperus alternifolius*–*Hedychium coronarium* Koen	1, 3, 5	12
HF2-VF2	*Schoenoplectus lacustrwas* – *Canna Indica* L.	1, 3, 5	12
HF0-VF0	Unplanted	1, 3, 5	12

Notes: a. HF0: horizontal-flow cell as control; HF1: HF cell with *Cyperus alternifolius*; HF2: HF cell with *Schoenoplectus lacustrwas*; VF0: vertical flow cell as control; VF1: VF cell with *Hedychium coronarium* Koen; VF2: VF cell with *Canna indica* L.; b. hydraulic retention time;

1.3 Vegetation

After these hybrid systems were operated for three months, the vegetation shown in Table 1 was planted in those cells. *Cyperus alternifolius* was planted in the horizontal flow cell (HF1), *Schoenoplectus lacustrwas* was planted in the horizontal flow cell (HF2). *Hedychium coronarium* Koen was planted in the vertical flow cell (VF1), *C. indica* L. was planted in the vertical flow cell (VF2), HF0 and VF0 were left unplanted as the controlled hybrid systems (HF1+VF1= HV1, HF2+VF2= HV2, HF0+VF0= HV0).

1.4 Characteristics of sewage used for experiment

Sewage used for experiment came from three-step septic tank effluent of public toilets in College of Natural Resource and Environmental Science, South China Agricultural University, China. The effluent had been monitoring during the experimental period (Table 2).

Table 2 Characteristics of sewage used for experiments (mg/L)

Seasons	COD	BOD_5	SS	NH_4^+-N	TN	TP	pH
Spring	228—555	94—146	15—67	102—108	53—187	6—18	7.71—7.99
Summer	74—141	35—147	18—39	43—97	28—104	4—14	7.21—7.66
Autumn	111—215	58—254	16—60	45—111	81—116	5—15	7.12—7.82
Winter	194—387	49—133	15—259	24—143	117—146	6—18	7.37—8.23

1.5 Analyses

COD was determined using the dichromatic reduction method; biological oxygen BOD_5 was determined using dilution and inoculation method; TN was analyzed using potassium-persulfate decomposition and UV/Vis spectrometric method; TP was determined using potassium-persulfate decomposition and colorimetric with molybdenum blue.

2 Results and discussion

2.1 Removal efficiency of COD by the hybrid systems

The removal efficiency of COD had significant positive correlation with HRT in these hybrid systems. HRT and the influent concentration of COD are two important parameters for running these hybrid systems and both of them were measured for regulating operational conditions of these hybrid systems in four seasons. The average removal rate of COD declined gradually with the decrease of HRT (Fig.1). In those treatments (i.e., HV0, HV1, and HV2), the removal rate of COD increased with the increment of HRT by the order 5 d > 3 d > 1 d. Since there were some organics left in the treatment wetland, which was input from effluent and could not be immediately degraded by the biological films of the surface of wetland substrates, the concentration of COD in the treated effluent increased with the decrease of HRT. Therefore, the removal rate of COD declined with the decrease of HRT. Plantation was found to improve the effluent quality with HRT extended from 1, 3 to 5 d. The removal efficiency of COD was higher in the planted cells than that in the unplanted ones. The removal efficiency of COD was higher in the hybrid system of HV2 than that in the hybrid system of HV1, and the removal rate of COD could be up to 90% for 5 d HRT.

The removal efficiency of COD in these wetland

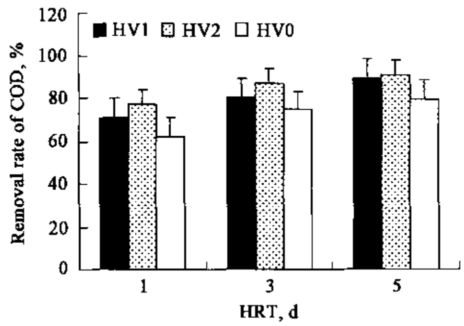

Fig.1 Effect of different HRT and plant on the removal rate of COD

cells was significantly affected by season change. The removal rate of COD was higher in autumn and spring than that in winter (Fig.2). This occurred due to higher temperature in autumn and spring in the subtropical areas, and nutrient was propitious to enhance the population and activities of microbes and the growth of vegetation, thus the removal rate of organics increased. And in winter, the population and activities of microbes were restrained by low temperature and the growth of vegetation and oxygen transfer were also slowed down in the low temperature, thus resulting in obvious decrease of the removal rate of COD. The removal rate of COD was lower in summer than that in winter (Fig.2), for the time of those systems running was too short and the vegetation effect could not yet shown.

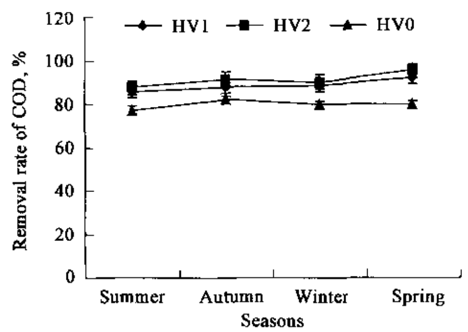

Fig.2 Effect of season change on the removal rate of COD under 5 d HRT

2.2 Removal efficiency of BOD_5 by the hybrid systems

The removal efficiency of BOD_5 was also positively correlated with HRT in these hybrid systems. The removal efficiency of BOD_5 increased with the increment of HRT (Fig.3). When HRT was only 1 d, the removal efficiency of BOD_5 was the worst among the three HRT, the removal rates of BOD_5 by these hybrid systems of HV1, HV2 and HV0 were only 58.55%, 70.83% and 52.83%, respectively. When HRT was 3 d, the removal efficiency of BOD_5 was enhanced by 4.02%, 13.29%, and 7.86% more than that of 1 d HRT for these hybrid systems of HV1, HV2 and HV0. The removal efficiency of BOD_5 of 5 d HRT was the best among the three HRT. The removal rate was up to 85% in these planted systems, the removal efficiency of BOD_5 was also up to 70% even in the controlled system.

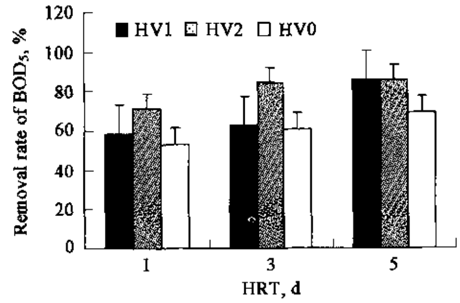

Fig.3 Effect of different HRT and plant on the removal rate of BOD_5

Season changes had significant impact on the removal efficiency of BOD_5 in these hybrid systems (Fig.4). Among four seasons, the removal efficiency of BOD_5 was the best in summer, and the average removal rate was up to 88.41%. In autumn and spring, the removal efficiency of BOD_5 was inferior to that in summer. The removal efficiency of BOD_5 was the worst in winter. The reason could be that the growth of vegetation and the activities and population of microbes might be restricted by low temperature in winter. Among these factors affected on the removal efficiency of BOD_5, it had been proved that planting was beneficial to improve the removal efficiency of BOD_5.

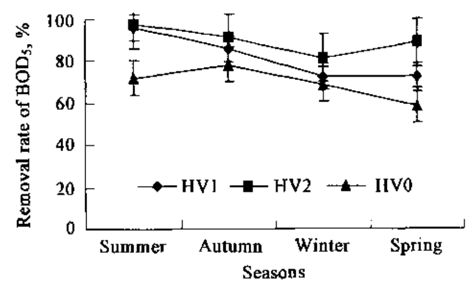

Fig.4 Effect of season change on the removal rate of BOD_5 under 5 d HRT

2.3 Removal efficiency of TP by the hybrid systems

The mechanisms of total phosphorus (TP) removal in wetland system included: physical action, chemical action of substrate, microbes assimilation and plant uptake (Brix, 1996). Effect of HRT on the removal efficiency of TP was very important (Fig.5). When HRT was too short, it was easy for the constructed wetland to form anaerobic condition which led the release of phosphorus, thus resulting in declining of the removal efficiency of TP, while phosphorus was excessively absorbed under the

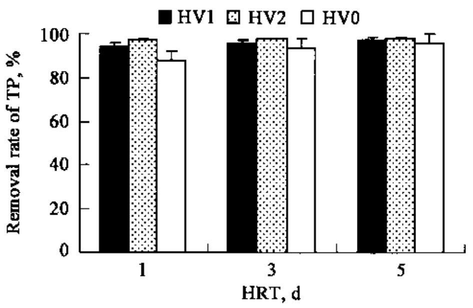

Fig.5 Effect of different HRT and plant on the removal rate of TP

interchangeable condition of anaerobic-anoxic-aerobic. Meanwhile, the velocity of sewage flow was too quick, and the action of hydraulic wash was also vigorous, therefore, phosphorus, even those parts fixed or absorbed in the surface of filling materials and rhizosphere of wetland systems, could be washed away from wetland systems. The average removal rates of TP were up to 93.94%, 97.38%, and 88.1% for 1 d HRT by these hybrid systems of HV1, HV2, and HV0, respectively. When HRT was 3 d and 5 d, the average removal rates of TP were increased by 1.72%, 0.36%, 5.68% and 2.99%, 0.59%, 7.63% more than that of 1 d HRT, but the increasing magnitude was not obvious. The reason is that slag was a kind of high phosphorus-adsorbed substrate in the vertical-flow constructed wetland system. When the wetland system was in operation at the early stage, substrate adsorption was main removal process for phosphorus in wetland system. Therefore, the effect of HRT and vegetation on the removal rate of TP did not obviously show up.

Under the same HRT (5 d), the removal efficiency of TP was the best in summer among four seasons (Fig.6), and the average removal rate of TP was up to 98%. Although the removal efficiency of TP dropped in winter compared to the other three seasons, the average removal rate of TP in winter still could keep up by 94%. It has been further proved that if the design and operation of the hybrid systems was reasonable and scientific, the better removal efficiency of TP would be gained in the subtropical areas even in winter (Sun and Fidler, 1996).

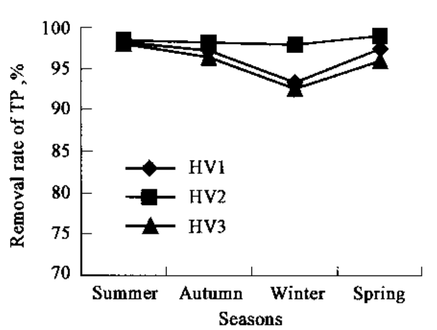

Fig.6 Effect of season change on the removal rate of TP under 5 d HRT

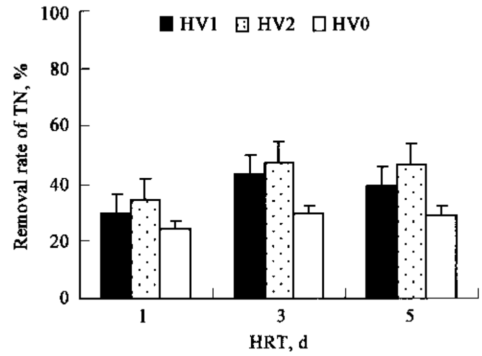

Fig.7 Effect of different HRT and plants on the rate of TN

2.4 Removal efficiency of TN by the hybrid systems

The removal rate of TN increased with the increment of HRT in these hybrid systems (Fig.7). The removal rates of TN in these hybrid systems were quite high, and the effluent concentration of TN of 5 d HRT were relatively low without being affected by the influent concentration of TN. Although the effluent concentration of TN for 3 d HRT began to fluctuate with the changes in influent concentration of TN, obvious decrease of the removal efficiency of TN was not observed. The removal efficiency of TN of 3 d HRT was nearly the same as that of 5 d HRT. The removal efficiency of TN was the worst under 1 d HRT, and the removal rates of TN for these hybrid systems of HV1, HV2, and HV0 were 29.87% , 34.52%, and 24.13%, respectively. Although other study showed that the removal efficiency of total nitrogen in a hybrid system was high, while microbes made nitrification and denitrification occur completely with the increment of HRT (Cooper *et al.*, 1999), the experimental results of this study showed that the removal efficiency of TN had a peak point, and the removal efficiency of TN was not getting better with extended HRT, therefore, the removal rate of TN for 5 d HRT could remain the highest in these hybrid systems. The removal rate of TN for 3 d HRT was obviously higher than that for 1 d HRT, and the removal rate of 5 d HRT was better than that of 3 d HRT, but the removal efficiency of TN was not significantly improved with the increment of HRT. Therefore, 3 d HRT might be recommended in actual operation of the hybrid systems for economic and technical reasons.

The removal efficiency of TN for these hybrid wetland cells was significantly affected by season change (Fig.8). Under the same HRT (5 d), the removal rate of TN was better in the hybrid systems of HV1 and HV2 than that in the hybrid system of HV0. The removal efficiency of TN for the three hybrid systems (HV1, HV2 and HV0) in autumn was the best among four seasons, and the removal rate of TN was up to 50.12%, 53.06, and 41.24%, respectively, but the average removal rate of TN declined rapidly by about 20% in winter. The reason was that the low temperature had impact on purifying function of plant uptake, microbe assimilation, nitrificaion and denitrification. Therefore, the removal rates of TN by these hybrid systems were low during winter. In order to improve the removal rate of TN, nitrified effluent from vertical-flow cells should be returned back to the entrance of horizontal-flow cells to use sewage as carbon source and complete the process of denitrification in horizontal-flow cells. It was found that the removal efficiency of total nitrogen was affected obviously by different recirculation rates, but the effect of recirculation rates on the treatment of organics, TP and SS was not significant. The results of this study also indicated that the removal rate of TN with nitrified effluent recirculation rates 50% and 100% of the effluent quantity was higher than that without recirculation. For economy and effluent quality considered, the recirculation rate was kept 50% of the effluent quantity might be the best choice in the actual running hybrid system.

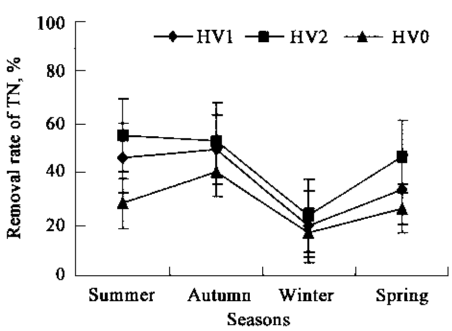

Fig.8 Effect of season change on the removal rate of TN under 5 d HRT

3 Conclusions

The operational results of these hybrid systems showed that the removal efficiencies of COD, BOD_5, TP and TN in horizontal-flow and vertical-flow cells were improved significantly with the extension of HRT under the same season. The removal rates of these indices of effluent quality for 3 d HRT were obviously higher than that for 1 d HRT, and the removal rates of 5 d HRT was better than that of 3 d HRT, but the difference of the removal rates between 3 d HRT and 5 d HRT was not very obvious. Therefore, 3 d HRT might be recommended in the actual operation of hybrid systems for economic and technological reasons.

The removal efficiencies of COD, BOD_5 and phosphorus were steady in the combination systems. The average removal rate of COD was 89%, 87%, 83%, and 86% in summer, autumn, winter and spring, respectively, and the removal rate of BOD_5 was up to 88%, 85%, 73%, and 74% accordingly. The average removal rate of TP could reach up to 97%, 98%, 95%, and 98% in summer, autumn, winter and spring, respectively, but the removal rate of TN was very low. Therefore, the removal rate of total nitrogen needs to be studied further in the future.

The results of this study also indicated that planting in these hybrid systems could improve the treated effluent quality, and enhanced the removal rates of total nitrogen and total phosphorus by plant uptake as well.

References:

Breen P F, Chick A J, 1995. Root zone dynamics in constructed wetlands receiving wastewater: A comparison of vertical and horizontal flow systems [J]. Water Science and Technology, 32 (3): 281—290.

Brix H, 1996. Functions of macrophytes in constructed wetlands [J]. Water Science and Technology, 29(4): 71—78.

Cooper P, 1999. A review of the design and performance of vertical-flow and hybrid reed bed treatment systems [J]. Water Science and Technology, 40(3): 1—9.

Cooper P, Griffin P, Humphries S *et al*., 1999. Design of a hybrid reed bed system to achieve complete nitrification and denitrification of domestic sewage [J]. Water Science and Technology, 40(3): 283—289.

Cui L H, Luo S M, Zhu X Z *et al*., 2003. Treatment and utilization of septic tank effluent using vertical-flow constructed wetlands and vegetable hydroponics[J]. Journal of Environmental Sciences, 15 (1): 75—82.

Laber J, Perfler R, Haberl R, 1997. Two-strategies for advanced nitrogen elimination in vertical flow constructed wetlands [J]. Water Science and Technology, 35(5): 71—77.

Laber J, Haberl R, Shrestha R, 1999. Two-stage constructed wetlands for treating hospital wastewater in Nepal [J]. Water Science and Technology, 40(3): 317—324.

Liu W, Cui L H, Zhu X Z *et al*., 2004. Purification efficiency of wastewater by constructed wetland treatment system based on the combination of horizontal-flow and vertical-flow [J]. Journal of Agricultural Environmental Science, 23(3): 604—606.

Luederitz V, Eckert E, 2001. Nutrient removal efficiency and resource economics of vertical flow and horizontal flow constructed wetlands[J]. Ecological Engineering, 18(2): 157—171.

Murray-Gulde C L, Bearrr J, Rodgers J H, 2005, Evaluation of a constructed wetland treatment system specifically designed to decrease bioavailable copper in a waste stream[J]. Ecotoxicology and Environmental Safety, 61(1): 60—73.

Sun Y, Fidler J K, 1996. Structure generation of current-mode two integrator loop dual output-OTA grounded capacitor filters [J]. IEEE Trans, 43(9): 659—663.

Wang X J, Zhang R S, 2006. Study on intensity of microorganism nitrification and denitrification in contructed wetlands [J]. Acta Scientiae Circumstantiae, 26(2): 225—229.

(Received for review September 5, 2005. Accepted March 10, 2006)