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Full Length Research Paper

Application of para-wood charcoal as the media of the vertical-flow constructed wetland for treatment of domestic wastewater

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The research aimed to observe the efficiency of vertical flow constructed wetland (VFCW) system using Para-wood charcoal as the media and *Typha* sp. as the cultivating plant to treat domestic wastewater. The removal efficiency was increased with the increase of HRT or decrease of hydraulic loading. And the size of Para-wood charcoal media (1, 3 and 5 cm in diameter) did not show any effect to the system efficiency under the lowest hydraulic loading of 0.05 m^3/m^2d. The microbial degradation of organic matter was promoted by the activity of the cultivated plant (*Typha* sp.) due to the transferring of oxygen from the atmosphere to the root system of cultivated plant. Nitrogen and phosphorus compounds of the wastewater were assimilated into the cultivated plant tissue with the highest level as 1.34 – 1.51 and 0.12 – 0.15 g/100 g plant tissue with the lowest plant-growth rate of 1.42 – 2.0 kg/m^2 under the lowest hydraulic loading of 0.05 m^3/m^2d. Para-wood charcoal was most suitable for using as the media due to the low reduction of infiltration rate of only 1.4% after 3 months operation. However, this VFCW system with small size media (1.5 cm in diameter) at lowest hydraulic loading of 0.05 m^3/m^2d showed the highest biological oxygen demand (BOD_5), total nitrogen (TN), total phosphate (TP) and suspended solids (SS) removal efficiencies of 95.5 ± 1.7, 92.1 ± 2.3, 95.5 ± 2.7 and 94.5 ± 1.6%, respectively.

Key words: Constructed wetlands, vertical flow, para-wood charcoal, *Typha* sp., domestic wastewater.

INTRODUCTION

Being low-cost and low-technology systems, eco-technological approaches like "constructed wetlands" (CWs) are now standing as potential alternatives or supplementary systems for the treatment of municipal, industrial, agricultural wastewaters, as well as storm water (Moshiri, 1993; Kadlec and Brix, 1995; Kadlec and Knight, 1996; Cooper et al., 1996; Vymazal et al.,1998; Haberl, 1999; Kivaisi, 2001). Since the 1950s, throughout the world, constructed wetlands have been used effect-tively for several purposes with different configurations, scales and designs. This was because of their nutrient capturing capacity, simplicity, low construction/ operation and maintenance cost, low energy consumption, process stability, little excess sludge production, effectiveness and potential for creating biodiversity (Haberl, 1999; Brix, 1997).

CW technology is more widespread in industrialized countries due to more stringent discharge standards, finance availability, change in tendency to use *on-site* technologies instead of centralized systems and to the existing pool of experience and knowledge based on science and practical work. Even though the potential for application of wetland technology in the developing world is enormous, the rate of adoption of wetlands technology for wastewater treatment in those countries has been slow (Kivaisi, 2001). Recently, as a result of the transfer of the knowledge, technical collaboration and co-operation by the developed countries, a variety of applications for CW technology for water quality improvement has also started to be implemented in developing countries like China, Kenya, Mexico, Nepal, Nicaragua, Tanzania, Uganda, India, Morocco, Iran, Thailand, and Egypt (Haberl, 1999; Haberl et al., 1995; Kivaisi, 2001). Similar to other developing countries, there is a great need for simpler, cheaper, and more reliable, effective and practical wastewater treatment alternatives. Therefore, implementing low-technology systems like CWs can also be appropriate solutions for treatment of different types of wastewater. In this regard,

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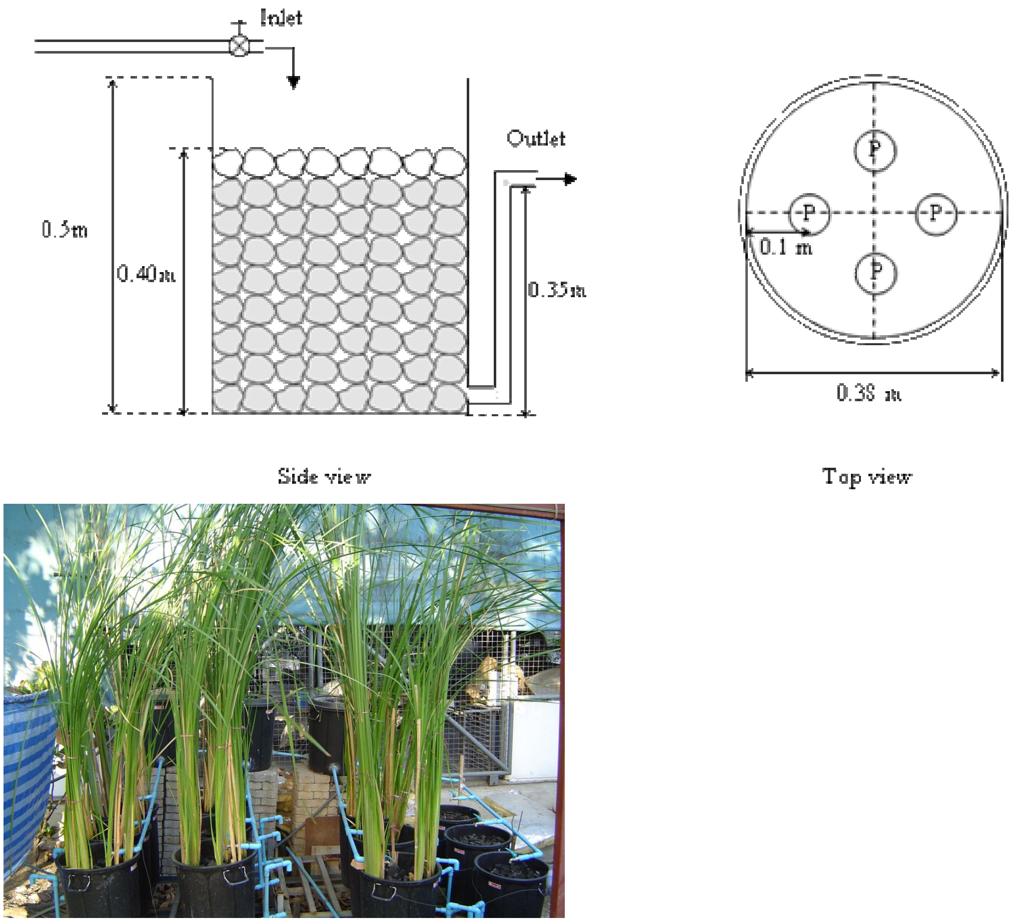


Figure 1. Schematic of VFCW, plantation position (P) in the bucket and photograph of complete set of VFCW system

to foster the practical development of CWs used for domestic wastewater treatment in Thailand, four parallel sets of the VF pilot-scale CWs (0.45 m^2 each) with identical design configurations, but with different size of filter media, were implemented on the King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand. The design and installation of the CW was based solely on utilizing the local resources. The main objective of this research was to quantify the effect of different size of Para-wood charcoal media (1, 2 and 3 cm in diameter) on the treatment performance of VFCW system in the prevailing climate of Thailand. In this paper, the short term removal performances of the identically operated VFCW system with various types of media under various HRT operations are presented.

MATERIALS AND METHODS

Sizing of the vertical flow constructed wetland (VFCW)

The VFCW system with dimensions of 0.38 m in diameter and 0.50 m in depth and surface areas of 0.45 m^2 (Figure 1), was constructed near the student dormitory's wastewater treatment plant of King Monkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand. The total volume of each VFCW cell was approximately 0.23 m^3. Para-wood charcoal with the diameters of 1.0, 3.0 and 5.0 cm were filled in each VFCW cell. The property of Para-wood charcoal media was shown in Table 1. A water pump transferred the raw wastewater (influent) from a storage tank to each VFCW cell and exceed flow was re-circulated to storage tank for homogeneous mixing. PVC pipes were used to distribute the wastewater onto each VFCW cell. The water level of each VFCW cell was maintained at 0.35 m depth. Each planted VFCW cell was planted with the shoots of *Typha* sp. which was harvested from the natural swamp and transplanted at a density of 17 shoots/m^2 (4 shoot/VFCW cell).

Operation of VFCW system

Using a submersible pump to transfer the raw wastewater was diverted from the nearest manhole of the student dormitory wastewater treatment plant to the storage tank of the VFCW system. The settled wastewater from the storage tank was distributed to each VFCW cell via spherical valves and PVC pipe as shown in Figure 1. The wastewater was fed down through the root zone as the vertical flow system. The chemical property of the wastewater was shown in Table 2. The operation program of the VFCW system was shown in Table 3. The VFCW systems were operated for 12 weeks.

Each VFCW cell was started up by feeding with the wastewater

Table 1. Size and properties of Para-wood charcoal media and the avoid volume of the media after packing in experimental chamber.

Properties					
Size of Charcoal media	Particle size (cm)		Surface area (m^2/g)	Porosity ($A^0 = 10^{-10}$ m)	Avoid Volume (%)
	Average	Range			
Small (S)	1.0	0.9-2.1	7.76	32.95	0.45
Medium (M)	3.0	2.8-3.4	7.76	32.95	0.48
Large (L)	5.0	4.9-5.5	7.76	32.95	0.50

Table 2. Chemical properties of KMUTT's dormitory wastewater

Chemistry properties	Concentration (Average ± SD)
pH	8.0±0.2
BOD_5 mg/L	118±17
COD, mg/L	142±18
SS, mg/L	38±7
TP, mg/L as phosphorus	6.8±1.3
TKN, mg/L	32.2±13.1
NH_4^+, mg/L	19.3±17.8
NO_3^-, mg/L	0.19±0.03

Table 3. Flow rate, hydraulic loading and organic loading of the VFCW system

Hydraulic Retention Time: HRT (days)	Flow rate (L/d)	Hydraulic loading rate (m^3/m^2-d)	Organic loading rate (g BOD_5/m^2-d)
3	5.2	0.05	7.5
2	7.9	0.08	12.0
1	15.7	0.16	24.0

at the lowest hydraulic loading of 0.05 m^3/m^2-d for a week. The cultivated plant grew well after 1 week acclimatization. And the effluent quality became steady after 2 weeks operation. The average temperature during operation (12 weeks cultivation) was 28.6 ± 4.8°C.

Monitoring and measurements

The influent and effluent of each VFCW cell was taken once a day to determine the chemical property. The samples were taken and brought to the Environmental Laboratory of the Department of Environmental Technology of KMUTT within 15 min. Chemical analyzes were performed on the same day according to the standard methods for water and wastewater analysis (APHA, AWWA, WPCF, 1998). The pH, suspended solids (SS), biochemical oxygen demand (BOD_5), ammonium (NH_4^+), nitrate (NO_3^-), total nitrogen (TN) and total phosphorus (TP) of both effluent and influent were analyzed. The media of each VFCW cell was collected before and after operation to determine the number of aerobic bacteria: bio-film (APHA, AWWA, WPCF, 1998). The cultivated plant (*Typha* sp.) was harvested before and after operation to determine biomass and relative growth rate (RGR). Plant height was measured weekly and the root depth was measured at the end of operation.

Sampling and data analysis for cultivated plant

The cultivated plant (*Typha* sp.) was analyzed before and after 12 weeks of cultivation to determine net biomass (APHA, AWWA, WPCF, 1998). The harvested plants were chopped and dried at 103°C for 24 h before measuring the dry weight biomass. The relative growth rate (RGR) of the plant was calculated by using the following equation (Beadle, 1982):

Where, W_1 and W_2 are the dry biomass values before (t_1) and after 12 weeks cultivation (t_2), respectively.

Statistical analysis

The experiments were repeated at least 3 times. All the data were subjected to two-way analyses of variance (ANOVA) using SAS Windows Version 6.12 (SAS Institute, 1996). Statistical significance was tested using least significant difference (LSD) at the $p < 0.05$ level. The results are shown as the mean± standard deviation.

RESULTS

Percentage of Infiltration Rate Loss (PIRL) on VFCW system

The small size charcoal media showed the interested

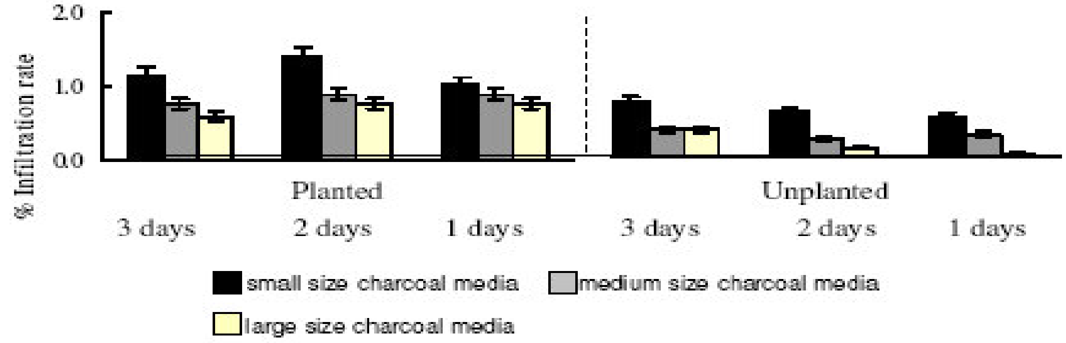
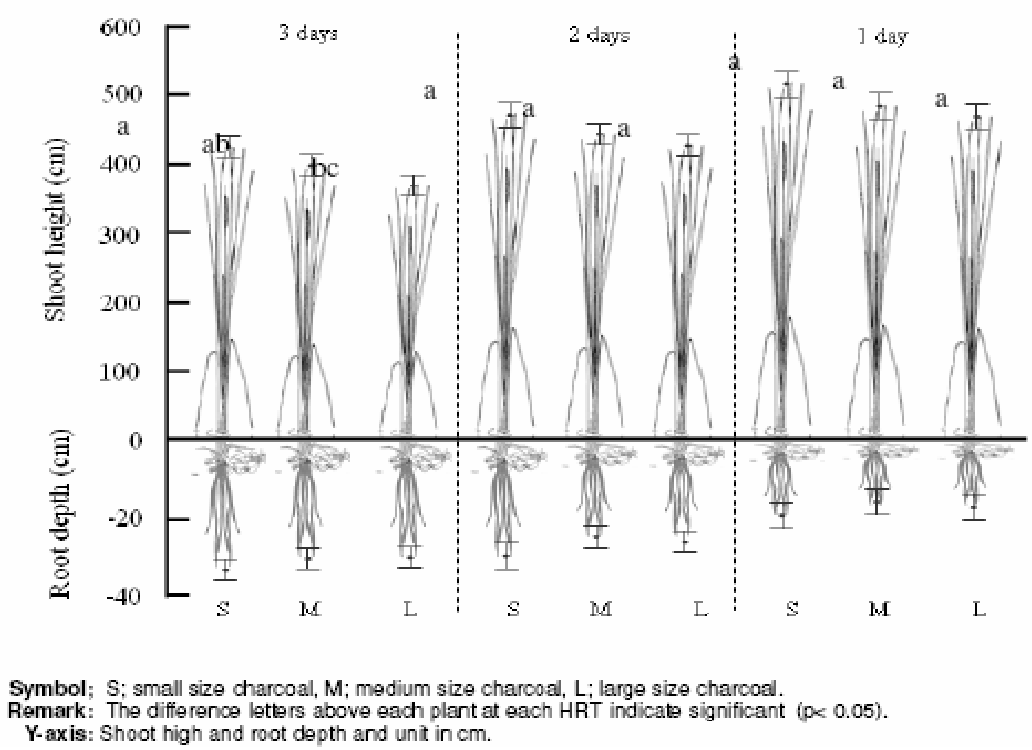


Figure 2. Percentage of infiltration rate loss in each bucket at HRTs of 3, 2 and 1 days after 3 months operation



Symbol; S; small size charcoal, M; medium size charcoal, L; large size charcoal.
Remark: The difference letters above each plant at each HRT indicate significant ($p < 0.05$).
Y-axis: Shoot high and root depth and unit in cm.

Figure 3. Shoot height (cm) and root depth (cm) at HRT of 3, 2 and 1 days.

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

results as shown in Figure 2. The reduction of infiltration rate of the planted and unplanted VFCW systems with small size media after operation was higher than that of the system with medium and large sizes media. And the PIRL of the planted VFCW system was higher than that of unplanted VFCW system in all HRT operations tested. PIRL of the unplanted VFCW system was less than 1.0 percentage after 3 months operation, while the PIRL of the planted VFCW system was highest of 1.4 % at HRT of 2 days or hydraulic loading of 0.08 m^3/m^2-d as shown in Figure 2. The medium and large sizes media showed almost same PIRL in planted VFCW system in all conditions tested.

Plant growth and relative growth rate (RGR)

The planted VFCW system was fed with domestic wastewater showed the rapidly growth of *Typha* sp. But the steam of the cultivated plant was shorter than that was cultivated in the natural swamp (the normally height of 1,500 - 2,000 cm) as shown in Figure 3. Reduction of HRT could promote the plant height. However, the size of

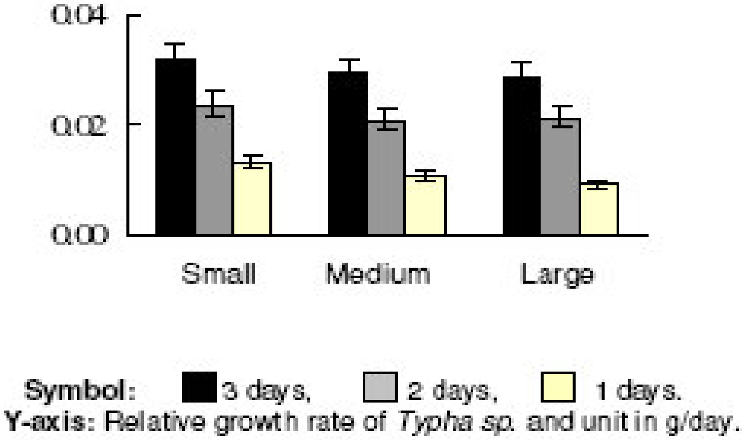


Figure 4. Relative growth rate (g /day) at HRTs of 3, 2 and 1 days

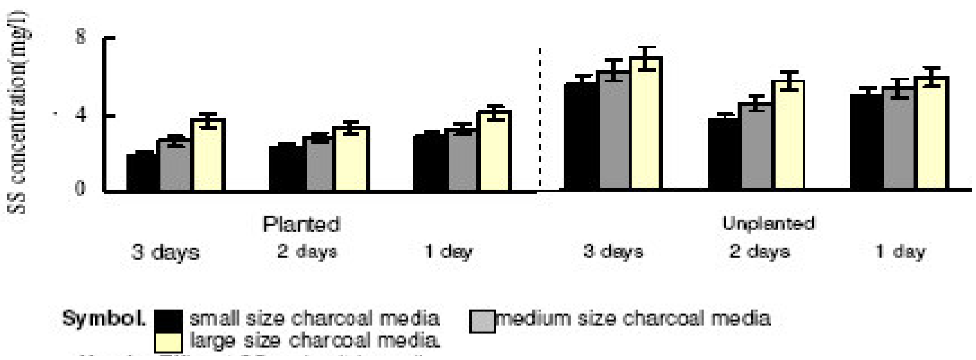


Figure 5. Suspended solid (SS) concentration (mg/L) in treated wastewater at HRTs of 3, 2 and 1 days

media did not have any significantly effect on the growth or height of the cultivated plant. The height of cultivated plant was in the range of 374 - 534 cm. In contrast, the reduction of HRT might affect the root depth, but size of media did not show any significantly effect to the root depth. The root depth was in the range of 16.5-33.5 cm. Reduction of HRT was affected the RGR value in all media sizes tested (Figure 3 and 4). The reduction of media size did not affect the RGR value. The RGR values were in the range of 0.028-0.032, 0.021-0.024 and 0.009-0.013 g/day under HRT operations of 3, 2 and 1 days, respectively.

SS removal efficiency

Planted VFCW system could enhance the SS removal efficiency as shown in Figure 5. Also, the reduction of media size promoted the SS removal efficiency. However, the reduction of HRT showed a slightly increase in SS removal efficiency in both planted and unplanted VFCW systems. The SS removal efficiencies of planted VFCW system with small, medium and large sizes media were 92-95, 91-93 and 89-90%, respectively. They were 87-91, 84-88 and 82-85% in unplanted VFCW system with small, medium and large sizes media, respectively.

BOD_5 removal efficiency

Reduction of HRT affected the BOD_5 removal efficiency in both planted and unplanted VFCW systems as shown in Figure 6. Effluent BOD_5 of the planted VFCW system with small size media was the lowest. However, the medium and large sizes media did not show any significant effect on BOD_5 removal efficiency in both planted and unplanted VFCW systems. BOD_5 removal efficiencies of planted VFCW system with small, medium and large sizes media were 82-96, 77-92 and 75-91%, respectively, while they were 70-85, 68-81 and 68-81% in unplanted VFCW system with small, medium and large sizes media, respectively.

TN removal efficiency

Reduction of HRT affected the TN removal efficiency of

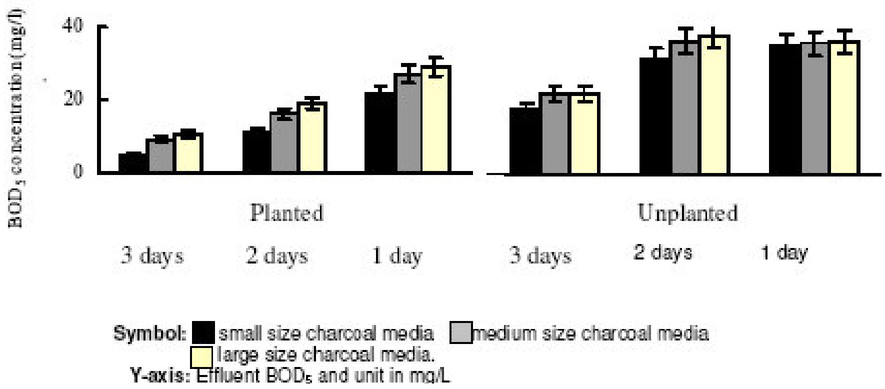


Figure 6. BODs concentration (mg/l) in treated wastewater at HRTs of 3, 2 and 1 days.

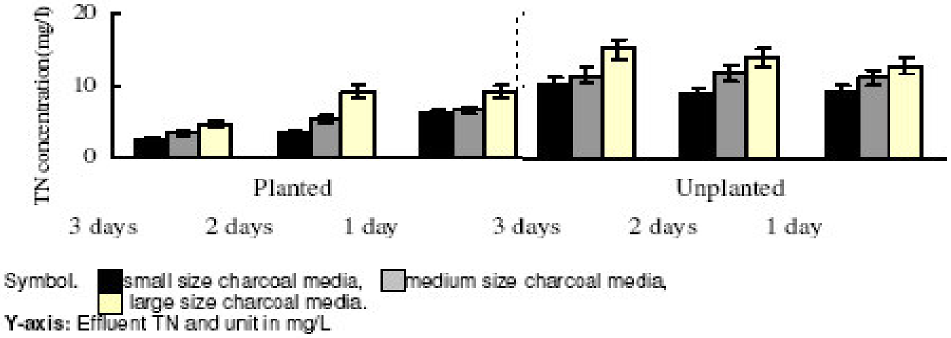


Figure 7. Total nitrogen (TN) concentration (mg/l) in treated wastewater at HRT OF 3, 2 and 1 day.

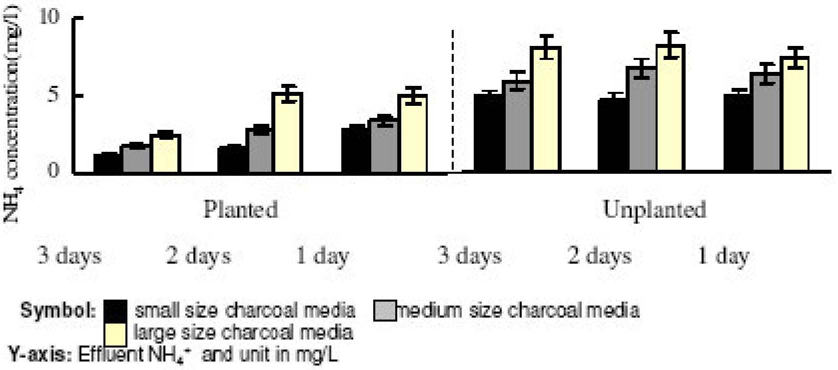


Figure 8. Ammonium (NH_4^+) concentration (mg/l) in treated wastewater at HRT of 3, 2 and 1 days.

both planted and unplanted VFCW systems as shown in Figure 7. The effluent TN decreased with the increase of HRT or decrease of hydraulic loading. However, the effluent TN of the unplanted VFCW system was still high at the level of 8 - 10 mg/L. TN removal efficiencies of planted VFCW system with small, medium and large sizes media were about 81-92, 80-89 and 71-86%, respecttively. While, they were 68-71, 63-65 and 53-60% in unplanted VFCW system with small, medium and large sizes media, respectively.

NH_4^+ removal efficiency

Reduction of HRT affected the ammonium removal efficiency of planted VFCW system (Figure 8), in turn; this was not affected in unplanted VFCW system. NH_4^+ remo-

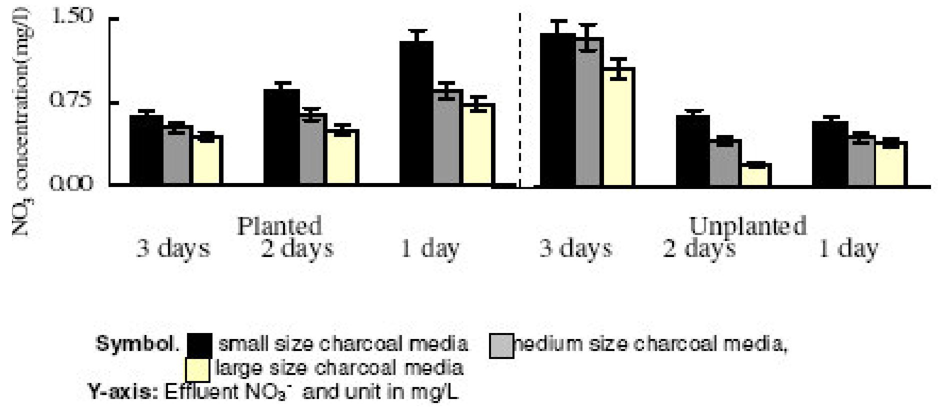


Figure 9. Nitrate (NO3) concentration (mg/l) in treated wastewater at HRT OF 3, 2 and 1 days.

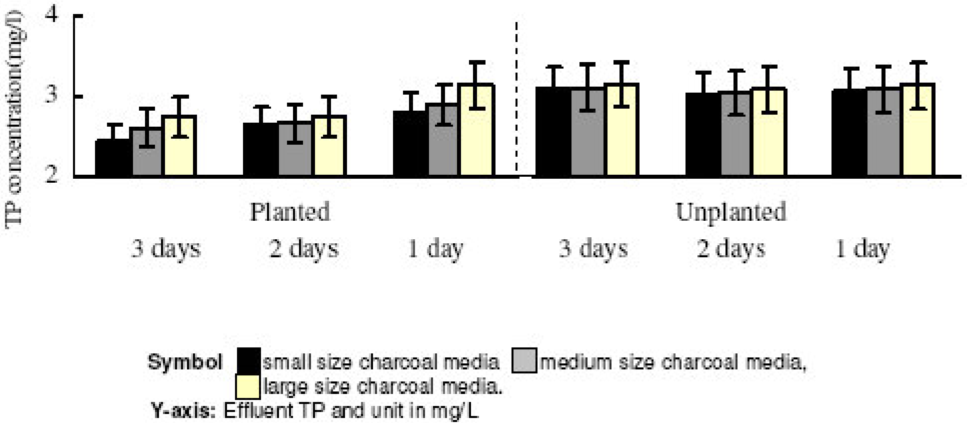


Figure 10. Total phosphorus (TP) concentration (mg/l) in treated wastewater at HRT OF 3, 2 and 1 days.

val efficiencies of planted VFCW system with small, medium and large sizes media were 86-94, 83-91 and 74-87%, respectively. While, they were 75-76, 66-70 and 58-62% in unplanted VFCW system with small, medium and large sizes media, respectively.

NO_3^- removal efficiency

Reduction of HRT influenced to nitrate removal efficiency of VFCW systems (Figure 9). Effluent nitrate concentration of planted VFCW system with small size media under HRT of 2 and 1 day was later high, but it was quite low under HRT of 3 days. However, the unplanted VFCW system showed good removal yield and low effluent nitrate concentration when the system was operated under HRT of 1 or 2 days. And the increasing of media size in the unplanted VFCW system would decrease nitrate removal efficiency. However, the effluent nitrate was still higher than influent nitrate for all HRT operations tested.

TP removal efficiency

Reduction of HRT did not affect the TP removal efficiency of unplanted VFCW systems as shown in Figure 10. The size of media did not show any effects on the TP removal efficiency of both planted and unplanted VFCW systems. TP removal efficiencies of planted VFCW system were 59-64, 57-62 and 54-59% with small, medium and large size media, respectively. While, they were 55-56, 55-56 and 54-55% in unplanted VFCW system with small, medium and large sizes media, respectively.

DISCUSSION

The infiltration rates of the VFCW systems reduced after operation because of the growth of the attached bacteria (bio-film) on the surface of charcoal media (Metcalf and Eddy, 1993; Brix, 1997). Also, PIRL of the system increased with the increase of HRT in both planted and unplanted VFCW systems because of the increasing of the influent flow rate (Kadlec and Knight, 1996; Metcalf and Eddy, 1993). However, PIRL of the planted systems was higher than that of the unplanted system. It might have affected of the root system of the cultivated plant after operation to increase both bio-film (attached bacteria) and the root mass resulted to reduce the avoid volume of the system.

Both of planted and unplanted VFCW systems could remove the organic matters (BOD_5, total nitrogen and total phosphorus) from the wastewater. And the removal efficiency increased with the increase of HRT or decrease of hydraulic loading (Sherwood et al., 1995). The removal efficiency of the planted VFCW system was higher than that of unplanted VFCW system because of the activity of both cultivated plant and microorganisms in the planted VFCW system while, there was only microbial removal in the case of unplanted VFCW system (Vymazal, 2002). However, the effluent SS of the planted VFCW system was about 30-50% lowers than that of unplanted VFCW system. This is resulted by the reducetion of the infiltration rate according to the root system of the cultivated plant. The root depth of the cultivated plant increased with the decrease of hydraulic loading. Then, the filtration rate of the system decreased also the activity and number of aerobe was increased with the increase of root depth which resulted to increase the oxygen supply. The effluent NH_4^+ and NO_3^- of the planted VFCW system was lower than that of the unplanted VFCW system. This might be the effect of both cultivated plant and attached microorganisms (bio-film) in the planted VFCW system (Reddy and Patrick, 1984). The number of attached bacteria (bio-film) of planted VFCW system was higher than that of the unplanted VFCW system resulted to increase the number of both nitrification and denitrification bacteria. However, the relevant data for population of nitrification and denitrification bacteria (data not shown). It is therefore recommended that further research regarding the bacterial population should be conducted to advance the understanding of population distribution of nitrification and denitrification bacteria. The phosphate removal efficiency of the planted VFCW system was about 8-12% higher than that of the unplanted VFCW system due to the activity of both microorganisms and cultivated plant of planted VFCW system (Plant et al., 2001; Lantzke et al., 1999; Zhu et al., 1997; Zhu et al., 2003). However, the phosphate removal efficiency by cultivated plant was only 8-12% of the total phosphate removal efficiency. It meant that the phosphate compounds were mainly removed by the microbial activity and adsorption onto the media (Brooks et al., 2000; Gruneberg and Kern, 2001; Sakadevan and Bavor, 1998; Mann and Bavor, 1993; Johansson, 1997). However, same with nitrification-denitrification process, the further research regarding the microbial-removal of phosphate and the phosphate adsorption by charcoal media have to be conducted to advance the understanding on the phosphate removal mechanism of the wetland system. It also found that the shoot height of the cultivated plant increased with the decrease of hydraulic loading or increase of HRT, because the decreasing of hydraulic loading resulting to increase the reaction time of the system (Metcalf and Eddy, 1993). In contrast, the root depth of cultivated plant increased with the decrease of hydraulic loading according to the increase of dissolved oxygen and decrease of organic matter in the wastewater (Kroon and Vesser, 1997; Tanner, 2001).

For application, the planted VFCW system operation under an HRT of 3.0 days (hydraulic loading of 0.05) was the most suitable system for treating domestic wastewater according to the highest removal efficiency under low growth rates of both aerobic bacteria and *Typha* sp. The other advantage of this system was the low PIRL during operation.

Conclusion

The study showed that VFCW system with Para-wood charcoal media and *Typha* sp. was suitable for treatment of domestic wastewater. The planted VFCW system showed higher removal efficiency than the unplanted VFCW system according to the activity of both microorganism and *Typha* sp. The removal efficiency of the system increased with the increase of HRT or decrease of hydraulic loading. However, the PIRL of the planted VFCW system was higher than that of unplanted VFCW system according to the root system of cultivated plant. The PIRL of the systems during operation was very low of only 1.4 percentage. For the optimal operation condition of the planted VFCW system, the system with small size Para-wood charcoal (1.0 cm in diameter) at lowest hydraulic loading of 0.05 m^3/m^2d showed the highest BOD_5, COD, TN, TP and SS removal efficiencies of 95.5 ± 1.7, 75.5 ± 2.5, 92.1 ± 2.3, 95.5 ± 2.7 and 94.5 ± 1.6%, respectively.

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