Upflow Constructed Wetland for On-site Industrial Wastewater Treatment

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Abstract

Constructed wetlands are cost-effective wastewater treatment technology highly applicable to Asia region. Combination of anaerobic and aerobic processes can upgrade constructed wetlands to treat industrial wastewater containing less-degradable organic pollutants. Controllability of anaerobic and aerobic activities in a vertical constructed wetland was investigated with and without supplementary aeration. The ORP profile along the wetland bed showed clear distinguishes between the anaerobic and aerobic regions in the wetland with supplementary aeration. Supplementary aeration boosted the carbon removal and nitrification. The upflow constructed wetland with supplementary aeration was concluded to be highly promising for on-site industrial wastewater treatment system.

Introduction

A vast number of factories of various industries have been constructed especially in Southeast Asia and East Asia for the last several decades. These regions have been called “the world’s factory.” Such economic development and intensive human activities have been discharging domestic and industrial wastewater to the receiving aquatic environment. Effective wastewater treatment technology applicable to these regions should be developed and practiced to prevent water pollution and conservation of aquatic environment. The wastewater treatment technology should be cost-effective and can degrade so-called less-degradable organic pollutants such as dyes, aromatic and polyaromatic hydrocarbons, halogenated organic pollutants and so on.

Constructed wetlands have been widely used in treating various types of wastewater. According to the flow pattern and media applied, constructed wetlands are classified into two categories: surface flow (SF) and sub-surface flow (SSF). SF systems, in which water flows over the surface of the rooting media, have advantage of lower installation cost and simpler hydraulics. SF systems are frequently used to treat lightly polluted water such as polluted river or lake water for restoration, stormwater runoff from agricultural lands and secondary or tertiary treated sewage effluent. On the contrary, wastewater flows underneath and through the plant-rooting media in SSF systems. Hence, there are fewer problems arising from odors, insect vectors, or public exposure. Such advantages make SSF systems suitable to treat highly polluted water such as landfill leachate, farm wastewater (Kantawanichkul *et al*., 2001) and some industrial wastewater (Davies *et al*., 2005).

Biodegradation of less-degradable pollutants generally requires combination of anaerobic and aerobic processes. For example, azo dyes, sixty to seventy percent of dyes used in the textile industry, are mineralized aerobically only after the azo-linkage is broken anaerobically (Ong *et al*., 2005). To treat such pollutants with constructed wetlands, therefore, anaerobic and aerobic processes should properly incorporated to wetland systems. Vertical flow constructed wetland systems in which anaerobic and aerobic processes take place sequentially are the most promising options for this purpose. In other words, design and operating strategy to control anaerobic and aerobic activities in wetland system are the key technology to upgrade wetland system to treat industrial wastewater economically and effectively in Southeast Asia and East Asia.

The objective of the present article is to show the potentiality of upflow constructed wetland system to treat industrial wastewater. Supplementary aeration was carried out to enhance aerobic activity in the wetland system. Five wetland systems were investigated in terms of OPR profile, COD removal rate, COD and nitrogen concentration profiles, and overall wastewater treatment rate. The overall treatment capacity is then correlated with the DO profiles along the bed.

Materials and Methods

Figure 1 shows the schematic diagram of an upflow constructed wetland system. The wetland system consisted of a wetland column (18 cm in diameter and 70 cm in height), a wastewater reservoir, a roller pump and an effluent reservoir. The wetland column was filled with 5 mm glass beads to a depth of about 6 cm at the bottom as wastewater distributor, and round gravels, 5.7 mm in average diameter, was filled to a height of 60 cm above the glass beads bed. The bed height and water level in the reactor were almost the same. Three sampling taps were equipped along the column. The average porosity of the total bed was about 0.30.

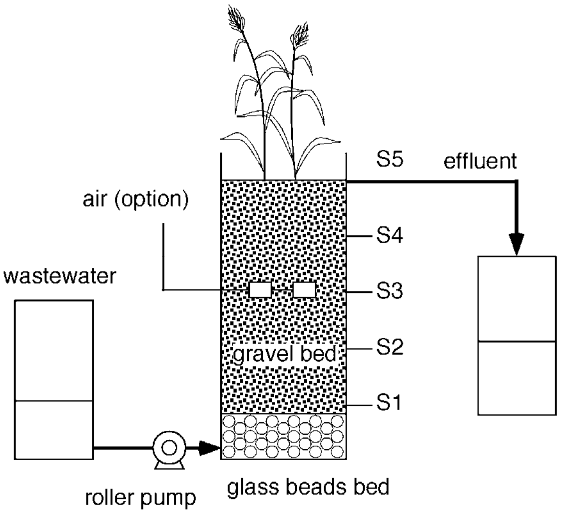

Figure 1. Schematic diagram of experimental setup.

Five wetland systems were operated with different conditions as summarized in Table 1. Reed (*Phragmites australis*) and Manchurian wild rice (*Zizania latifolia*) were used as model emergent plants. In a reactor D and E, supplementary air was introduce at 30 cm below the bed surface through four porous air spargers. The systems kept in an indoor area.

Table 1. Wetland conditions.

Reactor	Emergent plant	Aeration
A (control)	None	None
B	Manchurian wild rice	None
C	Reed	None
D	Reed	Aerated
E	None	Aerated

Synthetic wastewater wad fed to each reactor at a flow rate of 1.04 mL/min. The resultant hydraulic retention time of wastewater was kept at 3 d. The composition of wastewater was as follows: sodium bennzonate 107.1, sodium acetate 204.9, ammonium nitrate 36.7, sodium chloride 7.0, $MgCl_2 \cdot 6H_2O$ 3.4, and $CaCl_2 \cdot 62H_2O$ 4.0, in mg/L. The characteristics of the wastewater were as follows: COD_{Cr} 326 mg/L, T-N 62 mg/L, and T-P 5.0 mg/L. The column was inoculated with small amount of activated sludge prior to the wastewater treatment.
Wastewater samples were analyzed for COD, ammonia nitrogen, nitrite, nitrate, total nitrogen,

and total phosphorus. COD was determined using a HACH DR/890 portable colorimeter. Ammonia nitrogen, T-N, and T-P were determined by the standard method (JSWA, 1994). Nitrite and nitrate were measured using an ion chromatography. ORP was measured with an ORP meter (RM-20P, TOA-DKK, Japan).

Results and Discussion

ORP profile along the bed

Figure 2 shows the ORP profile along the bed at 11th Sep. In reactors A, B and C, without aeration, the ORP at the top was about 230 mV, and then sharply decreased to about -50 mV about 15 cm below the surface. Only top layer was aerobic in these reactors. The ORP at the bottom was about -150 mV, indicating anaerobic condition. There was little difference in the ORP distribution of reactors A, B and C. This suggests little contribution of emergent plants on oxygen supply into the gravel bed in macro-scale. On the other hand, the ORP at the aeration point is about 0 mV, and gradually increased to about 230 mV at the bed surface in the reactors D and E. The results show that almost half of the gravel bed was maintained aerobic with supplementary aeration.

The depth of aeration point and the conditions will be adjusted according to the characteristics of wastewater in practical application to give optimal aerobic and anaerobic ratio. Supplementary aeration will also contribute to the wetland performance to treat high-strength wastewater (Nivala *et al*., 2007).

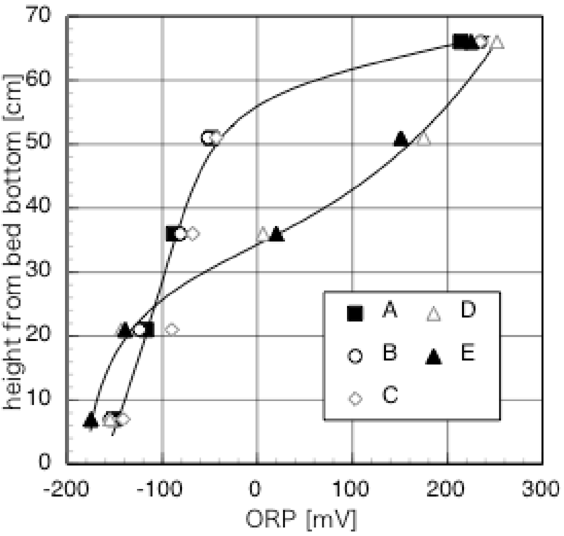

Figure. 2 ORP profile along the bed.

COD removal

The adsorption of pollutants on gravel was negligible from the preliminary test. Figure 3 shows the time course change in influent and effluent COD concentrations. The influent COD concentration was about 320 mg/L during the treatment. The effluent COD concentration of reactor A (control) gradually decreased to about 30 mg/L. Reactor B and C showed more rapid decrease in effluent COD concentration from 14th Aug. but the concentration was almost the same to that of reactor A from 3rd Sep. The effluent COD concentration of reactor D and E was below 50 mg/L from 27th Jul. and was about 20 mg/L from 10th Sep. The results were considered to be due to the supplementary aeration.

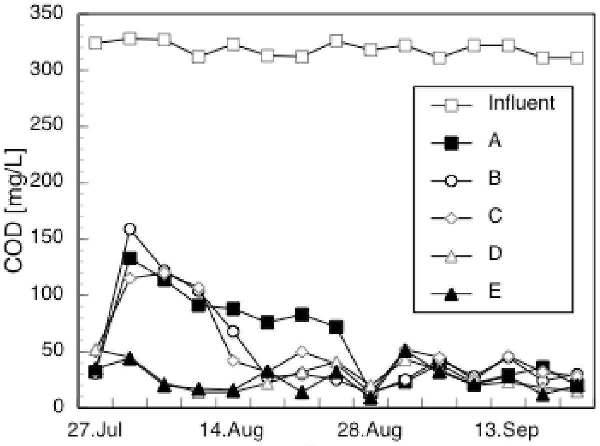

Figure 3. Time course change in effluent COD concentration.

Figure 4 shows the COD concentration profile within the gravel bed. The COD concentration of the reactor without aeration (A, B, C) sharply decreased above about 50 cm, while that of the reactor with supplementary aeration (D, E) was below 25 mg/L above 35 cm. These difference in COD concentration profile roughly corresponded with the ORP profile.

The supplementary aeration boosted the COD removal rate of the wetland system by increasing aerobic region, and shortens the startup period. These results indicate that supplementary aeration contributes to high COD removal performance and operational stability against loading fluctuation.

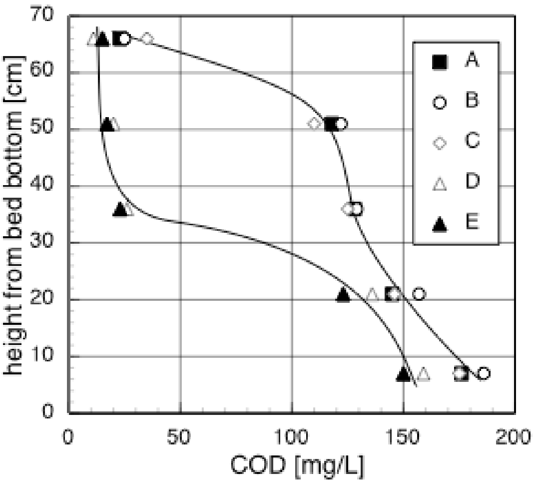

Figure 4. COD concentration profile.

Nitrogen removal

Nitrogen is biologically removed by two successive processes: nitrification and denirification. Figure 5 and 6 show the concentration profiles of NH_4-N and NO_3-N in the wetland. The NH_4-N concentration profiles of D and E were similar to the COD profile, indicating that nitrification proceeded in the upper aerobic beds. Gradual decrease in NH_4-N was observed in the anaerobic regions in the reactors A, B, C. The reason is not clear at the present. Further investigations, including microbial activity and biomass distribution, are needed to understand the nitrogen removal mechanism in this bed.

Nitrate was hardly detected in the reactors without aeration. Nitrate concentration increased in the reactors D and E, corresponding to the decreased in NH_4-N concentration. The higher nitrate concentration in D (with reed) may be resulted from the increased nitrifying biomass in the vicinity of the rhizome (Münch *et al.*, 2007). Little denitrification was observed in the aerobic regions of reactor D and E. The supplementary aeration would inhibit the

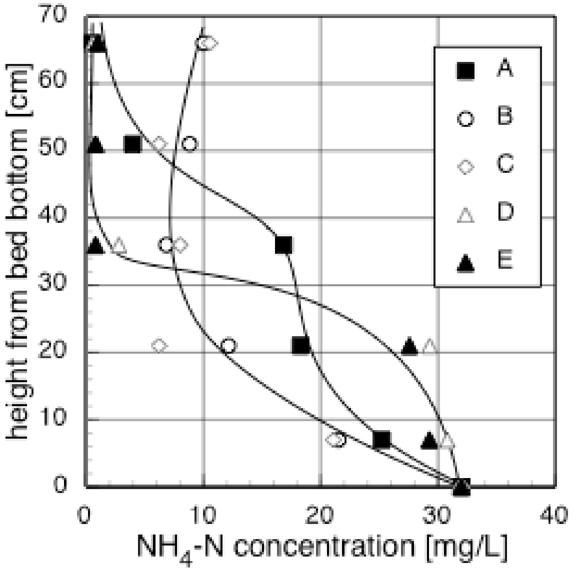

Fig. 5 NH_4-N concentration profile.

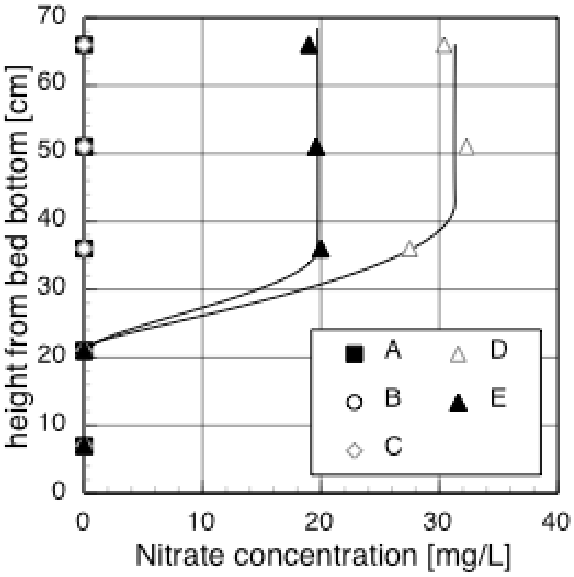

Fig. 6 NO_3-N concentration profile.

dentrification. Aeration conditions should be adjusted to provide suitable anaerobic and aerobic microbial reactions in the vertical wetland. Furthermore, combination of upflow vertical wetland, anaerobic condition followed by aerobic one, and downflow vertical wetland, aerobic condition followed by anaerobic one, would one of the most promising wetland configuration to treat less-degradable organic pollutants.

Conclusion

Upflow wetland systems with supplementary aeration could control the aerobic and anaerobic regions in the bed and treat high-strength wastewater. The present system will be one of the most promising wastewater treatment technologies to treat less-degradable industrial wastewater discharged in industrializing Asian regions.

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