한국환경분석학회지 제8권 (제4호) 000~000, 2005
J. of the Korea Society for Environmental Analysis

Phytoremediation: Carbon Dioxide (CO_2) and Nutrient Removals by Aquatic Plant Treatment System (APTS)

Janjit Iamchaturapatr, Jae Seong Rhee†, and Su Won Yi

Water Environment and Remediation Center, Korea Institute of Science and Technology (KIST), Seoul 136-791, Kroea

The experiments were conducted to investigate the removal of nitrogen (N), phosphorus (P) and carbon dioxide (CO_2) by four selected plants. The plants were cultured in phyto-reactor. The reactors were examined by batch operation under certain light intensity and temperature. Results showed that more than 80% of nitrate as nitrogen (NO_3-N) can be removed for all phyto-reactors contained aquatic plants; only 35% of NO_3-N was removed by control reactor. Phosphate as phosphorus (PO_4-P) removal was 86% for control reactor and 90-96% for phyto-reactors contained aquatic plants. Increase of elevated CO_2 500-2,000 ppm enhances the CO_2 removal rate by those aquatic plants. More than 95% of CO_2 were removed by aquatic plants at elevated CO_2 of 2,000 ppm. No significant changes of CO_2 were observed by control reactor at every elevated CO_2 concentrations.

Key words : Aquatic Plant Treatment, Nutrient Removals, CO_2 Sequestration and Plant Species

1. Background

The rapid growth of industry and major agricultural activities to supply the human consumptions causes a destruction of ecosystems and addition of air and water pollutions. Excess nutrients resulted from discharge of untreated wastewater to water resources led to eutrophication phenomena. In addition, the role of carbon dioxide (CO_2) in climate changes is one of the most important environmental issues. Higher concentrations of CO_2 and other greenhouse gasses (GHG) reduce the ability of the Earth to radiate planetary heat through the atmosphere. Most scientists agree that the increase of CO_2 is a major cause in the observed trend of global climate warming[1]. It is therefore necessary to have available technology which minimizes the discharge of CO_2 into the atmosphere. One ecological method to treat polluted water contained high nutrients and to reduce the increase of CO_2 levels in the atmosphere is aquatic plant treatment systems (APTS). APTSs are treatment systems that combine physical, chemical, and biological processes in an engineered and managed system. In aquatic plant systems, wastewater contaied excess nutrients are treated principally by means of plant-bacterial metabolism and physical sedimentation process. Photosynthesis process withdraws CO_2 from the atmosphere by photosynthesis process. Carbon sequestered from the atmosphere is stored in plant fiber for extended periods of time. High atmospheric CO_2 levels enhanced plant productivity generally and, consequently, the rate at which CO_2 is removed from the atmosphere[2), 3)]. Successful performance of aquatic plants for the treatment of contaminated water and soil is being clearly acceptable by scientists and engineers. However, the use of phytoremediation for air pollution prevention is only at early stage of commercial and public developments.

2. Methodology

2.1. Design of Phyto-reactor

Phyto-batch reactors were made of acrylic and air-tight materials with a dimension of 230 mm × 230 mm × 600 mm. Top of reactor was connected with the CO_2

†To whom correspondence should be addressed.

Table 1. Raw wastewater characteristics

Parameters	Units	Quantity
pH	-	7.1-7.7
Dissolved Oxygen (DO)	mg O_2/L	4.0-5.0
Temperature	^oC	25.0
Nitrate Nitrogen (NO_3^--N)	mg/L	14.0-17.8
Phosphate (PO_4^{3-}-P)	mg/L	14.5-15.7

sensors (probe types) model GMP70 obtained from Vaisala Co., Ltd (Finland). Fig. 1 shows the phyto-reactor used for the experiments. The phyto-reactors were replaced of Ø10-15 mm of gravel and Ø0.6-2.4 mm of sand with approximate depth of 2 cm and 8 cm. Various kinds of aquatic plants; *Cyperus alternifolius Dracaena fragrans*, *Iris ensata*, and *Thalia dealbata* were planted into each phyto-reactor and filled up with 3.5 L of synthetic wastewater (Table 1). Water level of each reactor was remarked. An addition of de-ionized water to phyto-reactor is sometime necessary to maintain constant level of water-table from water loss by evaporation. High concentrated CO_2 gas (99% v/v) was diluted with ambient air and filled to the phyto-reactor by batch operations. The CO_2 concentrations of 500-2,000 ppm are distributed to the phyto-reactors for 8 hr/day. The light source used for the experiment was florescence lamp OSRAM FL40 provided light intensity at the top of PBR-surface by 55 ± 5 mmole/m^2/s. The temperature in the phyto-reactors is controlled at 25 ^oC. The effluent treated wastewater was sampled at the bottom of the phyto-reactors and analyzed for the main nutrient quality parameters such as NO_3-N, NH_4-N, NO_2-N and PO_4^3-P by spectrophotometric method. The

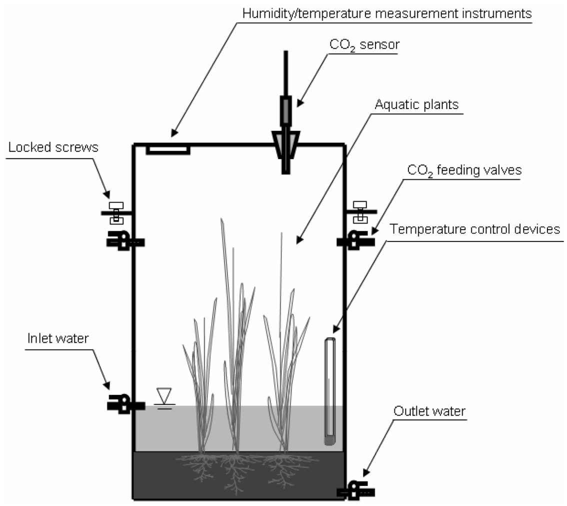

Fig. 1. Phyto-reactor.

test-kids used in the experiment were ECOtest obtained TECHCROSS Inc. The wavelengths (l) used by NO_2-N, NO_3-N, NH_4-N and PO_4^3-P were 450, 540, 600 and 660 nm. Fig. 2 shows the standard curves for nutrient analysis by ECOtest.

3. Results and discussion

3.1. pH and DO

The temperature was controlled at 25 ± 0.7^oC. No significant change of pH was observed in phyto-reactors and control reactor. The pH in phyto-reactors and control reactor was varied from 6.9-7.7 and it trends were increased. Dissolved oxygen (DO) concentration in phyto-reactors was fluctuated from 2.7-5.8 mg/L (Fig.

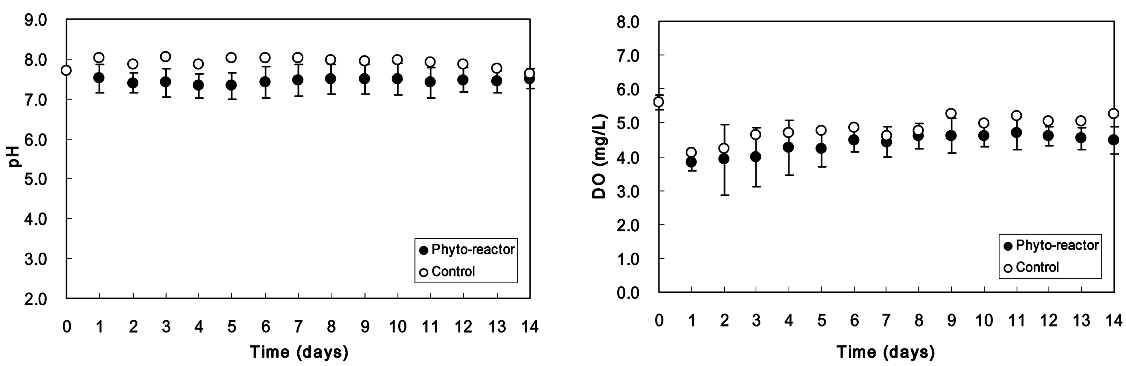

Fig. 2. N and P standard curves.

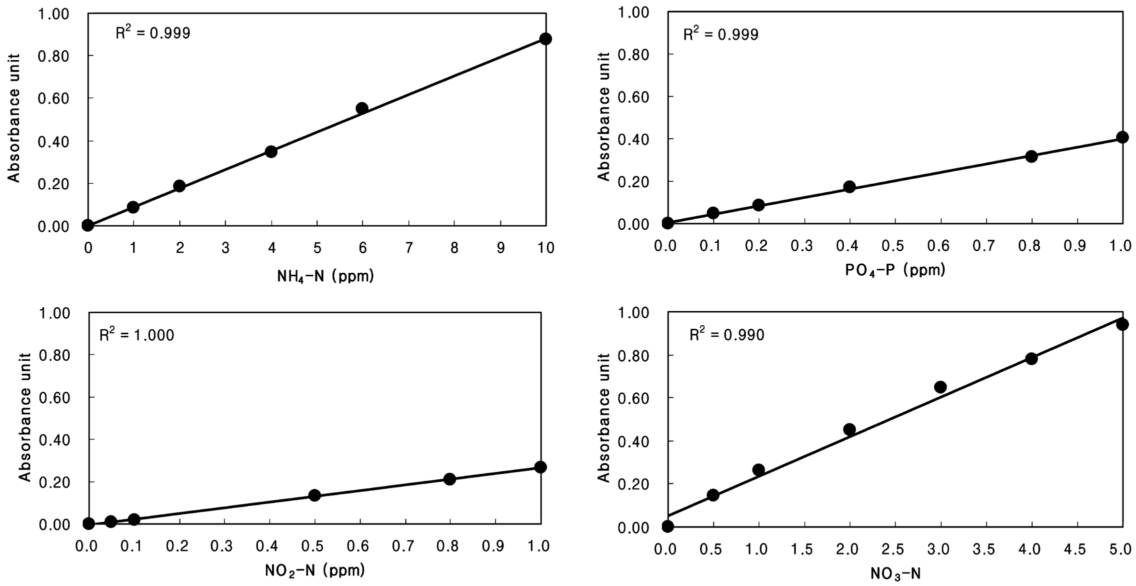

Fig. 3. Variation of pH and DO.

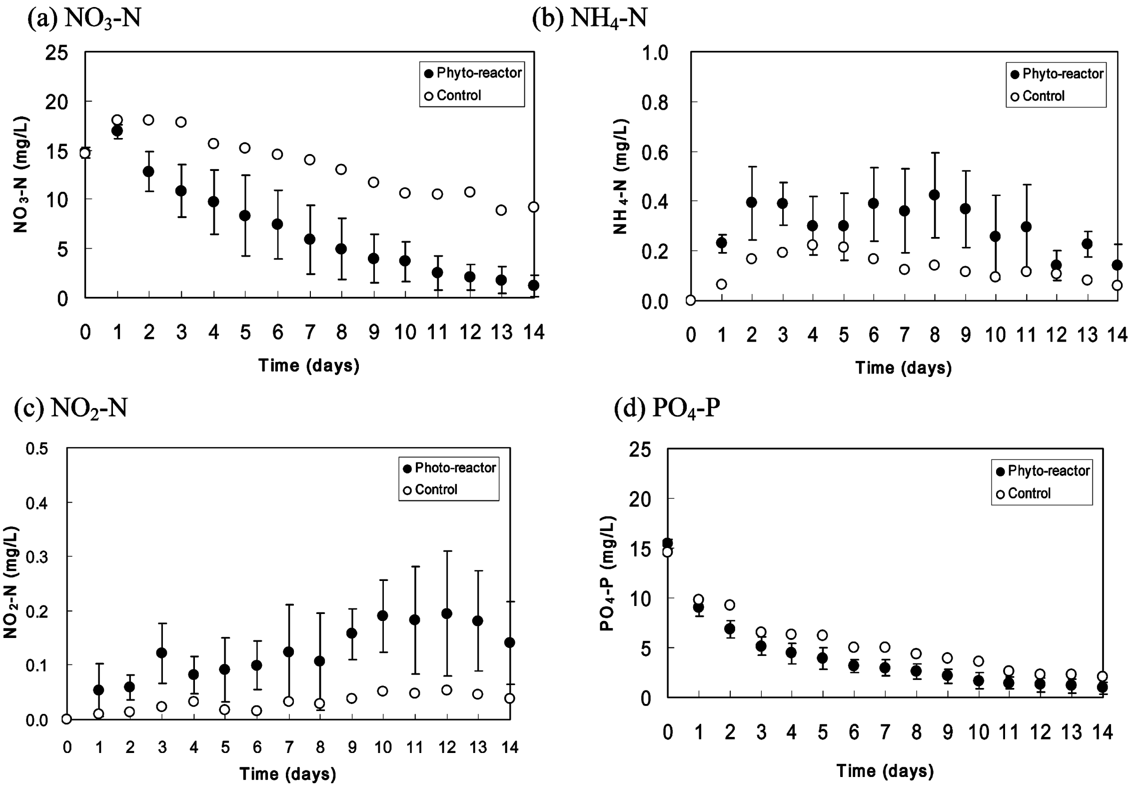

Fig. 4. Variations of nitrogen and phosphorus.

3). Data indicated that rapid reduction of DO in the phyto-reactors was at 1-2 days of the experiments. The reason might that the depletion of oxygen diffused through the soils under undrained condition and the remaining of organic matters in media beds coupled with the decaying of some death leaves of aquatic plants in phyto-reactors caused high oxygen demand during 1-2 days of the experiment. After day 3, the DO concentrations in PBRs were enhanced.

3.2. Effect of phyto-reactor on N and P removal

Fig. 4 shows the variation of N and P in the phyto-reactors (The points and bars indicate the average values ± SD, n = 4). The results showed that 86.6%, 80.8%, 95.1% and 96.9% of NO_3-N can be removed by phyto-reactors contained *C. alternifolius*, *D. fragrans*, *I. ensata*, and *T. dealbata*. Only 35.1% of NO_3-N was removed by control reactor. High PO_4-P removal was

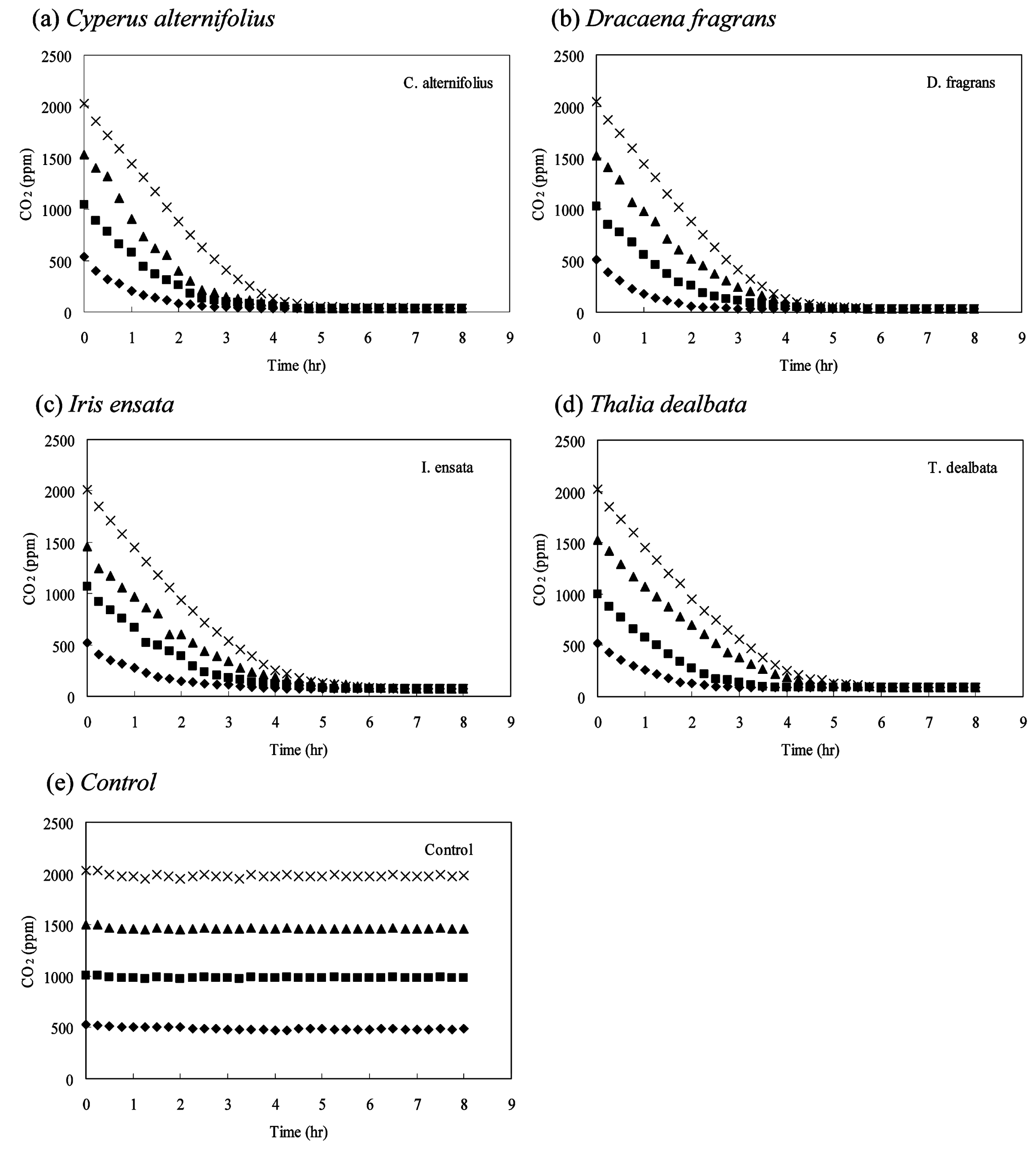

Fig. 5. Variation of CO_2 in phyto-batch reactor.

obtained by phyto-reactors and control reactor. The PO_4-P removal orderly was 86.0%, 96.4%, 90.3%, 90.0% and 98.2% for control and phyto-reactors contained *C. alternifolius*, *D. fragrans*, *I. ensata*, and *T. dealbata*s. During the experiments, the NH_4-N and NO_2-N were occurred in the phyto-reactors. NH_4-N concentrations were sharply increased during 2-3 days of the experiments and it was reduced by the end of the experiments, while NO_2-N concentrations were gradually increased during 14 days of the experiments. Several reasons explained the occurrences and changes of NH_4-N and NO_2-N were degradation of plant matters and remaining of organic N in the soils, ammonia volatilization, nitrification and denitrification processes[4,5] and physico-chemical properties of media beds used in PBR including chemical adsorption and precipitation on hydrous oxides of Fe, Al, Ca minerals in beds[6-8] were included.

3.3. Effect of phyto-reactor on CO_2 Removal

Fig. 5 shows the changes of CO_2 concentrations in the phyto-reactors. The graph illustrated that CO_2 concentrations in phyto-reactors were reduced by time function due to photosynthesis process. At 5 hours of the experiments, CO_2 concentration inside the reactors was less than 100 ppm for every phyto-reactors contained aquatic plants. No significant changes of CO_2 concentrations were observed in control reactor at elevated CO_2 of 500, 1,000, 1500 and 2,000 ppm.

Table 2 summarizes the performance of phyto-reactors for CO_2 removal. CO_2 removal by phyoto-reactors contained aquatic plants was ranged between 83-99% depending on type of aquatic plants and initial CO_2 concentrations. Increase of initial elevated CO_2

Table 2. CO_2 Utilization Rate Coefficients

Aquatic plants	Removal efficiency (%)
Control	<5
C. alternifolius	94-99
D. fragrans	94-99
I. ensata	87-97
T dealbata	83-96

The data represents at temperature 25°C and light intensity 55 ± 5 mmole/m²/s.

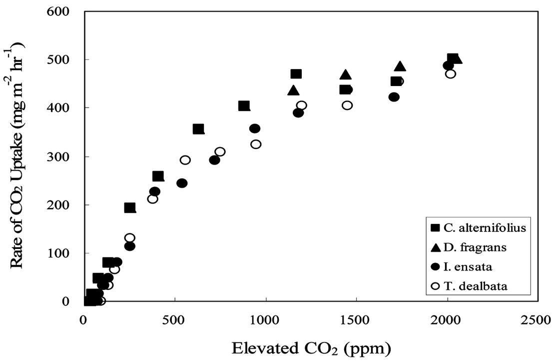

Fig. 6. Effect of initial elevated CO_2 on CO_2 utilization rate.

concentrations enhanced the CO_2 utilization rate of aquatic plants (Fig. 6). At CO_2 level of 2,000 ppm, CO_2 utilization rates of *C. alternifolius, D. fragrans, I. ensata and T. dealbata* were varied between 480 to 500 mg CO_2 m^{-2} hr^{-1}.

4. Conclusions

The use of *C. alternifolius, D. fragrans, I. ensata and T. dealbata* in the PBRs were able to remove approximately 81-97% of NO_3-N and 90-98% of PO_4-P, while control reactor had comparatively lower N removal efficiency. The pH and DO in PBRs were 6.9-7.7 mg/L. and 2.7-5.8 mg/L. The rapid reduction of DO was during 2-3 days of the experiments fro every PBRs contained plants. The experiments indicated that PBRs contained aquatic plants can remove CO_2 from indoor condition (500 ppm) to less than 90 ppm after 4 hrs of the experiemts. Increase of elevated CO_2 concentrations of 1,000, 1,500 and 2,000 encouraged the CO_2 utilization rate in the phyto-reactors compared with ambient CO_2 level (500 ppm), CO_2 utilization rates were increased 28%, 40% and 47% for *C. alternifolius*, 30%, 44% and 52% for *D. fragrans,* 43%, 64% 76% for *I. ensata* and 40%, 58% and 69% for *T. dealbata* at initial CO_2 levels of 1,000, 1,500 and 2,000 ppm.

References

1. IPCC, *"Intergovernmental Panel on Climate Change"*,

1995, 572 pp. Cambridge University Press, UK.

2. Schulze E.D., Schulze W., Kelliher F.M., Vygodskaya N.N., Ziegler W., Kobak K.L., Koch H., Arneth A., Kusnetsova W.A., Sogatchev A., Issajev A., Bauer G. and Hollinger D.Y., *Canadian journal of forest research*, **1995**, 25, 943–960.
3. Burton I., *Climate. Change*, **1997**, 36, 185-196.
6. Brix, H., "*Constructed Wetlands for Water Quality Improvement*", **1993**, pp. 9-22, Lewis Publishers, Boca Raton, USA.
7. Ingersoll, T., and Baker, L. *Water Research*, **1998**, 32. 677-684.
8. Sakadeven, K., Bavor, H.J., *Water. Research*, **1998**, 32, 393-399.
9. Arias, C.A., Bubba, M.D. and Brix, H., *Water Research,* **2001**, 35(5), 1159-1168.
10. Yang, L., Chang, H.T., and Huang, M.N., L., *Ecological Engineering*, **2001**, 18, 91-105.