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Effect of Temperature and Plants on the Removal Efficiency of a Constructed Wetland Treating Secondary Piggery Effluent

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Abstract: The water quality and biomass growth of a free water surface flow constructed wetland (CW) receiving secondary piggery effluent and stormwater runoff was monitored. The effects of plants and seasonal temperature changes on the removal efficiency of the CW were investigated. Average removal efficiency ranges were 30-35% for organic matters, 15-20% for nitrogen, and 30% for phosphorus. Based on the results, most of the pollutant removal efficiencies at temperature above 15°C were higher than at below 15°C. Among the water quality parameters, removal efficiencies of TKN, NH4-N and NO3-N indicated that differences in the two temperature ranges were significant. The mean proportion of biomass coverage to surface area of CW was from 0 to 10.8% during the macrophytes lifecycle. Since the plants that surrounded the cells of the CW were located outside the boundary of the water surface, low relationships between biomass and removal efficiency existed and therefore were not contributing much to the removal of pollutants.

Keywords: FWS constructed wetland; removal efficiency; temperature; biomass

1. Introduction

Plants and seasonal temperature changes are the two factors that greatly affect the pollutant retention in constructed wetland (CW). One factor that has proved highly influential in nearly all biological treatment processes is temperature. Increasing temperature generally increase treatment efficiency [1]. Wetlands are affected by solar radiation and ambient temperature, which cycle on an annual and daily basis. The influence of the lifecycle of plants in the processing of nutrients is also an important factor in evaluating the applicability of CW in treating livestock wastewater. It has been suggested that macrophyte species affect the pollutant removal efficiency in CWs, although differences in performance associated with different plant species are difficult to demonstrate due to inherent variation between studies and monitoring practices [2].

The influence of temperature and plants is important when effectiveness of a CW in treating pollutants is evaluated. This research is part of the on-going mon- itoring works being conducted in the FWS CW. The objective of this research is to examine the effect of temperature and plants on the removal of organic matter, nitrogen and phosphorus by a free water surface flow (FWS) CW in an effort to describe the function of systems under monsoon and temperate climate conditions.

2. Methods

2.1. Site Description and Constructed Wetland Design

The FWS CW was located in Nonsan City, South Chungcheong Province, Korea. The CW was built in 2007 by the MOE treating 110,000 m^2 catchment area which are mostly paved and has an urban type of land use. The CW was designed as the final stage of the piggery wastewater treatment plant (WTP) to treat low pollutant contents during dry days and stormwater runoff during wet days. Therefore, influent flowing through the CW is contaminated with organic matters, nutrients and pollutants coming from livestock waste and non-point sources.

The profile of the treatment cells in the CW is provided in Table 1. The influent flows from a channel equipped with a grid which removes large particles. Thereafter, the influent wastewater enters into the settling basin 1 and finally discharges into Geum River. Figure 1 shows the schematic layout and flow line of different cells of CW system with the dominant plant species. The CW cells were planted with two types of wetland plants (i.e., *Phragmites australis* and *Miscanthus sacchariflorus*), which play a role in sediment retention, nutrient uptake and pollutant removal.

2.2. Water Quality and Biomass Monitoring

Physical and chemical monitoring of influent and effluent water of the CW was performed from October 2008 to August 2010. Samples were analyzed for water quality parameters including temperature, dissolved oxygen

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Table 1. Specification of the constructed wetland.

Cell No.	Description	Surface area (m^2)	Storage volume (m^3)	Water depth (cm)	HRT for design flow (hr)	HRT for peak flow (hr)
Cell 1	settling basin	560	453	80.9	5.5	1.6
Cell 2	aeration pond	776	565	72.8	6.8	2.0
Cell 3	deep marsh	805	810	100.6	9.8	2.9
Cell 4	shallow marsh	527	280	53.1	3.4	1.0
Cell 5	deep marsh	1,474	1,626	110.3	19.6	5.8
Cell 6	settling basin	350	272	77.7	3.3	1.0
Total	-	4,492	4,006	-	48.4	14.3

(DO), pH and conductivity, which were all measured on site using portable meters. Samples were then transported to the laboratory for analysis of typical water quality parameters such as biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4-N), nitrate (NO_3-N), total phosphorus (TP) and phosphate (PO_4-P). Analyses were conducted in accordance with ASTM standard methods for the examination of water and wastewater. Meteorological data for study site were collected from Korea Meteorological Administration (KMA). Biomass measurements were carried out during the macrophytes lifecycle from May 2009 to July 2010. Two of the plant species were sampled within 30 x 30 cm quadrant from Cells 1 to 5 that is proximal and distal to the inflow and outflow to measure the weight of biomass per unit area. The collected plants were dried in an oven at 105 °C and the water content of the plant biomass was determined. Moreover, the concentration of N and P in plant tissues was measured using Kjeldahl method.

2.3. Data Analysis

The treatment efficiency was calculated as the percent removal R for each parameter, which was calculated by $R = (1- C_e)/C_i \times 100$, where C_i and C_e are the influent and effluent concentration in mg L^{-1}. All statistical analysis was performed using SYSTAT 9.0 software, including analysis of variance (one-way ANOVA). The differences were accepted as significant at the $p = 0.05$ level.

3. Results and Discussions

3.1. Water Quality and Removal Performance

Table 2 summarizes the parameters measured in the influent and effluent of the wetland and the estimated removal percentages. Of all the parameters, BOD achieved the highest removal percentage of 35.2 ± 16.0 %. BOD of wastewater typically decreases steeply once wastewaters are discharged to wetlands, as they provide suitable environments for sedimentation and filtration processes [3]. Nitrogen forms obtained relatively low removal percentage, having TN as the lowest with 16.3 ± 10.2 %. Reference [4] reported that TN removal via plant uptake accounts for a small fraction of the overall nitrogen removal as denitrification through anaerobic respiration remains the most effective procedure for nitrogen removal in heavily nitrified secondary wastewaters. All of the pollutant concentration was lower in the effluent water than in the influent. However, the mean concentration removal percentages were still below 50%. The magnitude of reductions depends on several factors including inflow concentrations, chemical form of the nutrients, water temperature, season, and DO [5].

Changes in values of the situ measured physico-chemical variables of water and air temperatures, DO and pH are presented between October 2008 and July 2010 in Fig. 2. The mean values of influent and effluent temperatures are 20.4 ± 7.5 °C and 20.1 ± 8.8 °C, respectively while the mean air temperature was 12.2 ± 9.7 °C. The monthly temperature in the influent and within the effluents of the CW was not significantly different. Seasonal fluctuations of the wetland water temperature could influence the processes of microbial transformation [6]. The pH is a fundamental factor for water quality, exerting a great influence over the aquatic system. The pH of the effluent increased slightly towards the end of the life cycle of the macrophytes, from 8.1 ± 0.5 to 8.2 ± 0.4. In general, pH showed no significantly change between the influent and effluent. The CW showed good efficiency to raise the DO concentration of the treated effluent that confirmed by the highly significant difference between inlet (3.5 ± 2.2 mg/L) and outlet (5.1 ± 3.1 mg/L) levels of DO. Moreover, the influent DO levels were increased from April to May, 2010. During January to April 2010, there was no influent to the CW from the piggery treatment plant; only stormwater runoff. It was observed that most of algae bloomed at the deep marsh in cell 5 especially during the spring season.

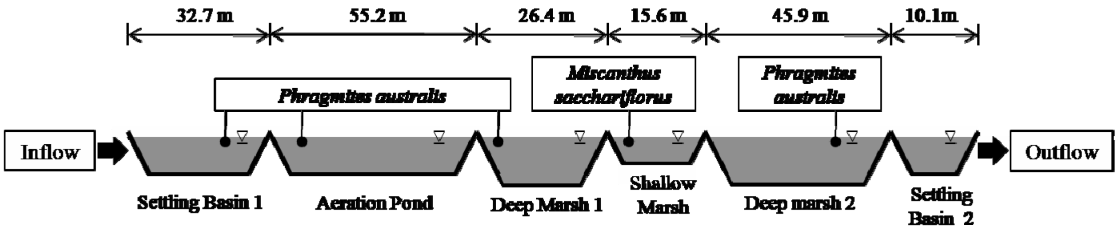


Figure 1. Schematic representation of the CW system with the dominant plant species.

Table 2. Influent, effluent and removal percentages (mean ± S.D.) in the constructed wetland (n=34).

Parameter (unit)	Influent concnetration (mg/L)	Effluent concentration (mg/L)	Removal efficiency (%)
BOD (mg/L)	51.8 ± 31.7	32.0 ± 19.5	35.2 ± 16.0
COD (mg/L)	209.3 ± 97.7	140.4 ± 63.4	30.0 ± 16.8
TN (mg/L)	139.0 ± 44.2	114.7 ± 34.2	16.3 ± 10.2
TKN (mg/L)	89.3 ± 29.8	70.9 ± 20.8	19.0 ± 12.0
NH_4-N (mg/L)	47.5 ± 21.7	37.0 ± 16.2	20.7 ± 11.7
NO_3-N (mg/L)	11.1 ± 2.6	8.9 ± 2.2	20.0 ± 12.4
TP (mg/L)	4.7 ± 1.8	3.3 ± 1.5	31.7 ± 14.3
PO_4-P (mg/L)	1.3 ± 0.9	0.9 ± 0.6	32.2 ± 19.3

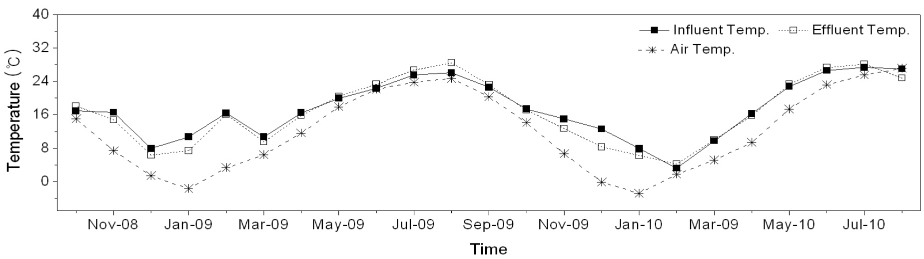
3.2. Effect of Temperature on the Removal Efficiency

The temperature of wetland waters influences both the physical and biological processes within a FWS CW. It can be observed that generally for all pollutants, lower removal efficiencies correspond to lower temperatures and the opposite. Figure 3 presents correlation charts of pollutant removals with influent temperature. The purpose of these graphs is to only show the trend of dependence of pollutant removal on temperature. For BOD and COD, the temperature dependence is not so significant, which implies that the removal of the organic matter is mostly a result of the microbial activity of aerobic and anaerobic bacteria [7], which function even in temperatures as low (5°C).

For nitrogen, the dependence of removal efficiency on temperature is significant (R^2≈0.3), because plant uptake plays a significant role on nitrogen removal [7], and the microorganisms responsible for nitrogen removal optimally in temperatures above 15°C [8]. Phosphorus removal efficiency did not show important dependence on temperature (R^2<0.05). Three years data for Linkoping, Sweden [9] showed no correlation of removal with temperature (R^2<0.05), over the temperature range -3 to 17 °C. The Orlando Easterly Florida wetlands also displayed no correlation (R^2<0.05) over the range 10 to 30 °C [10].

Table 2 shows the pollutant removal statistics for water temperatures below and above 15°C. The tem- perature value of 15°C was selected because below this neither the bacteria responsible for nitrogen removal nor the vegetation function properly [8]. Most of the pollutant removal efficiencies at temperature above 15°C were higher than at below 15°C. Regarding BOD and COD, ANOVA analysis in the two temperature ranges indicated that there was no statistically significant difference (BOD; p=0.491, COD; p=0.335).

For TN, it also seems that differences in removal in the two temperature ranges were not significant (p=0.238). Differences in removal in two temperature ranges were significant for TKN (p=0.013), NH_4-N (p=0.012), and NO_3-N (p=0.007). On the other hand, TP and PO_4-P removal efficiencies indicated that differences in the two temperature ranges were not significant (TP; p=0.691, PO_4-P; p=0.154).



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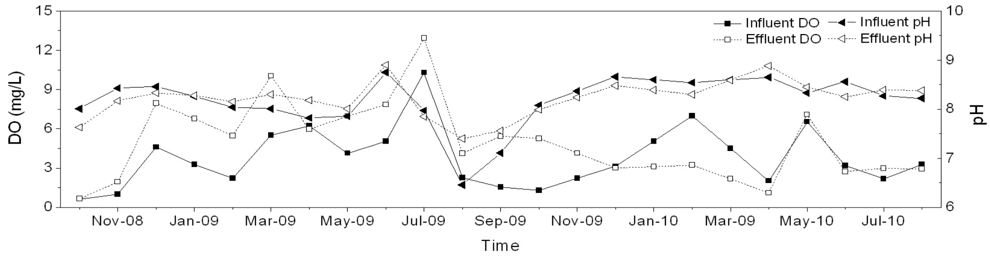

Figure 2. Distribution of (a) air and water temperature (b) pH and DO in the CW from October 2008 to August 2010.

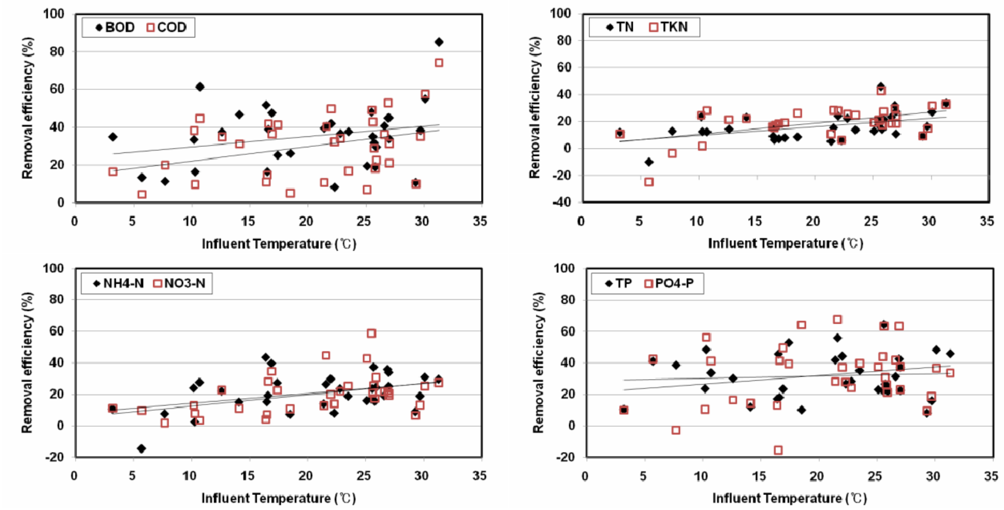

Figure 3. Temperature and removal efficiency correlation charts.

3.3. Effect of Plants on the Removal Efficiency

Figure 4 shows the monthly biomass changes of *Phragmites australis* (PA) and *Miscanthus sacchariflorus* (MS) during monitoring period. All the plants adapted themselves well into the CW and did not wither until the fall in 2009. The highest biomass rate of PA and MS in the first growing season both occurred in September with 8.09 kg/m^2 and 6.9 kg/m^2, respectively. In the second growing season, the highest biomass rate of PA and MS both occurred in June with 14.1 kg/m^2 and 6.0 kg/m^2, respectively. They grow during spring, become dormant during winter, and grow back during spring of the next growing season. Photosynthesis cycle and nutrient uptake plays a major role in the growth of plants in the CW. The increase of plant productivity is mainly due to the increase in availability of water, light and nutrients. The higher mean temperatures in spring and summer generally led to higher and earlier increase of biomass in the CW [11]. The mean proportion of biomass coverage to surface area of CW was from 0 to 10.8% (535 m^2) during the macrophytes lifecycle which suggests that the dependence of removal efficiency on plants is not so significant. Moreover, since the plants that surrounded the cells of the CW were located outside the boundary of the water surface, low relationships (R^2 = 0.04~0.31) between biomass and removal efficiency existed and therefore were not contributing much to the removal of pollutants.

Plant uptake has been found to be an important contributor to nutrient removal in most treatment wetlands. Nitrogen and phosphorus are the key nutrients in the life cycles of wetland plants. Therefore, the proper N and P availability are of principal concern in the growth of wetland plants in the CW. According to the data shown in Table 4, the mean N and P contents were 7986 ± 987 mg/kg and 57 ± 13 mg/kg in May 2010, 6917 ± 1499 mg/kg and 34 ± 6 mg/kg in June 2010, respectively. In temperate climates, macrophyte uptake is a spring-summer phenomenon. In the literature, there were many reviews on N and P concentrations in plant tissue as well as nitrogen standing stocks for plants found in natural stands and CWs. Aboveground N standing stock values were reported in the range of 0.6-72 g N m^{-2} [12] or 2-29 g N m^{-2} [13]. On the other hand, Aboveground P standing stock values were reported in the range of 0.1-6.8 g N m^{-2} [12] or 0.1-11 g N m^{-2} [14]. Obviously, active uptake and incorporation into plant tissue was a major factor responsible for the observed N and P removal in FWS CW.

Table 3. Mean ± standard deviation of removal efficiency for temperature below and above 15 °C.

Parameter	Temperature below 15 °C	Temperature above 15 °C
BOD (%)	31.8 ± 17.5	36.3 ± 15.8
COD (%)	24.9 ± 14.4	31.5 ± 17.4
TN (%)	12.6 ± 10.3	17.5 ± 10.0
TKN (%)	10.0 ± 18.1	21.7 ± 8.0
NH_4-N (%)	11.9 ± 13.7	23.4 ± 9.8
NO_3-N (%)	10.0 ± 6.4	23.0 ± 12.3
TP (%)	29.9 ± 13.6	32.3 ± 14.7
PO_4-P (%)	23.6 ± 20.5	34.8 ± 18.5

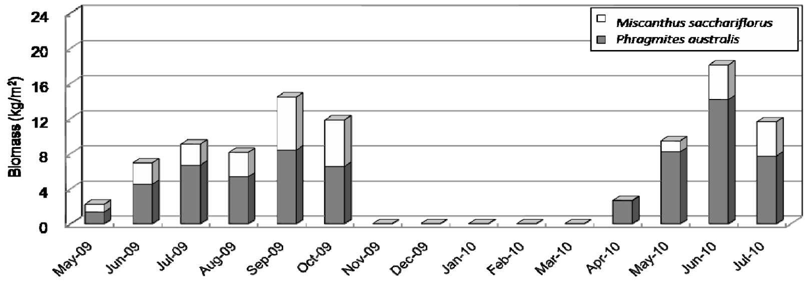

Figure 4. Growth of biomass Phragmites australis (PA) and Miscanthus sacchariflorus (MS).

Table 4. Nutrient contents of plants in the CW.

	May-2010				June-2010			
	TN (mg/kg)		TP (mg/kg)		TN (mg/kg)		TP (mg/kg)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Cell 1	7537	2362	43	16	7119	1297	32	5.0
Cell 2	9677	395	53	22	8581	1073	35	6.4
Cell 3	7601	1263	52	7.5	7495	1776	31	11
Cell 4	5793	622	53	1.5	4797	1248	36	5.0
Cell 5	9320	295	82	16	6594	2101	35	4.0
Mean	7986	987	57	13	6917	1499	34	6

4. Conclusions

This study was performed to investigate the treatment performance of the FWS CW. The results indicate that:

(1) Average removal efficiency ranges were 30-35% for organic matters, 15-20% for nitrogen, and 30% for phosphorus.

(2) Most of the pollutant removal efficiencies at temperature above 15°C were higher than at below 15°C, when the plants at temperature above 15 °C were growing and microbial activity was favored, nitrogen removal values were significantly higher than those on low temperature.

(3) The mean proportion of biomass coverage to surface area of CW was from 0 to 10.8% during the macrophytes lifecycle. Since the plants that surrounded the cells of the CW were located outside the boundary of the water surface, low relationships between biomass and removal efficiency existed and therefore were not contributing much to the removal of pollutants.

(4) Active uptake and incorporation into plant tissue was a major factor responsible for the observed N and P removal in the FWS CW.

Continuous monitoring will be performed especially to improve the removal efficiencies and to support further assessment of the CW system and design.

5. Acknowledgment

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