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Pollutants Transformation and Removal within Constructed Wetlands Hybrid Systems

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Abstract: - In Taiwan, constructed wetlands have received tremendous interests for water quality enhancement due to insufficient sewage treatment and groundwater deterioration. The main objectives of this study were to investigate pollutants removal mechanisms and efficiency within the field-scale natural purification hybrid systems. The systems included an oxidation pond, two serial surface flow wetlands with a cascade in between, and a subsurface flow wetland. These water purification systems received secondary treated dormitory sewage as their inflow. The macrophytes within the study system were submergent plants including cattails and reeds. The average SS, BOD and COD percent removal efficiency was approximately 90.4, 80.4 and 59.9%, respectively. The ratio of BOD to COD decreased from 0.64 in the initial aerobic compartment to 0.2 in anoxic parts of the systems, indicating most biological degradable materials were decomposed in the aerobic oxidation pond and surface flow wetlands. Effective phosphorus removal was not achieved while percentage removal was around 21.5%. Total Kjeldahl nitrogen (TKN) and ammonium decreased from 7.42 to 2.15 and 5.12 to 1.32 mg/L, respectively, while nitrate nitrogen increased from 2.21 to 5.56 mg/L within the aerobic oxidation pond and surface flow wetlands. This result demonstrated nitrification occurring within aerobic units. The nitrate nitrogen continued to decrease from 5.56 to 1.21 mg/L within the anoxic subsurface wetlands through denitrification transformation. Total nitrogen removal was from 10.95 to 3.80 mg/L, with the percentage removal of total nitrogen around 65.29%. The primary nitrogen removal and transformation mechanisms within the studied wetland systems were nitrification within aerobic followed by denitrificaiton within anaerobic systems. The submergent macrophytes enhance aeration through oxygen transferring that attributing the higher organic matter removal and nitrification rate. The wetland systems are viable options of pollutants transformation and removal in tropical countries, while tertiary wastewater systems are too costly or unable to operate. Effluent of the studied hybrid constructed wetland systems can comply with surface water criteria and water reuse standards.

Key-Words: - Hybrid constructed wetlands, suspended solids, phosphorus, nitrification, denitrification

1 Introduction

Hybrid constructed wetland systems have been demonstrated to be less labor intensive, low operational cost, and easy to maintain methods to enhance surface water quality. Constructed wetlands might be one of viable options to enhance the water quality and have been primarily employed for rural or sewage treatment in tropical regions while concrete treatment facilities are too costly to construct and operate. Different biological and physicochemical treatment processes have been applied to remove nitrogen nutrients from secondary treated sewage and each has its own technical and economical limitations. Conventional advanced wastewater treatment requires significant capital investments and consumes large amounts of energy. The wetland system possesses the merits of low-cost and less labor intensive while it is capable of removing various pollutants including heavy metals, organic matters, pathogenic indicators, and nutrients. Constructed wetlands are growing popularity as a natural and economical alternative for purifying contaminated water. Numerous studies have been conducted to research on the removal efficiency of pollutants including suspended solids (SS), organic matters, heavy metals, and nutrients within wetlands [1].

Discharging sewage effluent rich in pollutants into receiving water courses has problems including deteriorating water quality, inhibiting water reuse, impacting aquatic ecosystems and human health. Specifically, excess amounts of nutrients nitrogen discharge into rivers and streams, leading to eutrophiction and aquatic ecosystem impact due to low dissolved oxygen. In addition, elevated levels of nitrate in groundwater utilized for formula water might be concern about public health effects on humans especially infants while nitrate binds to hemoglobin and prevents its oxygen carrying inducing the blue baby syndrome.

In Taiwan, manure produced by concentrated swine operations is one of the primary pollution sources of watercourses. The wastewater generated is either untreated or poorly treated by anaerobic followed by aerobic pollutant removal processes. The effluent is then sprayed on fields or discharged in the surrounding waterways. If nutrients in the effluent are applied in excess of plant uptake rates, the nutrients may contaminate the surface or groundwater due to runoff and leaching. The recent monitoring data showed that elevated ammonium and nitrate levels were detected in groundwater in western Taiwan. One option for nutrient removal might employ constructed wetlands prior to land application or waterway discharge [2].

Nitrification-denitrification, microbial assimilation, plant uptake, ammonia volatilization, adsorption, organic accumulation and sedimentation are possible nitrogen removal mechanisms within constructed wetlands [3]. Nitrification- denitrification is the favorable mechanism for nitrogen removal by converting ammonia to nitrogen gases emitting to the atmosphere. Nitrate nitrogen reduction in wetland is through two processes including denitrification and nitrogen uptake by macrophytes. The latter process is important only if the plant is harvested [4]. Constructed wetlands are water purification systems that mimic the functions of natural wetlands by enhancing processes involving vegetation uptake, soil and associated microbial degradation. The role of vegetation within constructed wetlands also includes creating aerobic degradation environments around root zones via atmospheric diffusion [5].

Besides SS and organic pollutants removal, wetland systems can also be employed as a nitrogen removal alternative that occurs through a sequence of ammonification, nitrification, and denitrification. Effluent from the wetlands can be percolated slowly to supply the underlying aquifer while the wetlands employed as the nitrogen removal of groundwater quality enhancement in Taiwan. The aim of this research intended to study the reduction rates of various pollutants including SS, phosphorus, organic matters and nitrogen treated within the treatment wetlands. The research was carried out to demonstrate the constructed wetlands were viable options for further enhancing the quality of secondary treated sewage by reducing nitrogen nutrient and various pollutants.

2 Materials and Methods

Field-scale natural purification systems included a pretreatment oxidation pond, two serial surface flow wetlands with a cascade aeration part in between, followed by a subsurface wetland. The purified water was discharged into a percolation pond for water reuse and groundwater recharge. The hydraulic retention time, total areas, and inflow rate of the studied natural purification systems were 12 days, 800 m^2, and 140 CMD, respectively. The inflow water was sewage from campus treated by secondary biological processes. Two surface flow wetlands were planted to submergent macrophytes including cattails (*Typha latifolia*) and reeds (*Phragmites austrials*). Nitrogen removal investigations into the efficiency and fate of nitrogen were carried out by sampling and analyzing from the marked points within the system (Fig. 1). The concentrations of TKN, ammonium, nitrite, and nitrate were determined. Organic matters and water quality parameters such as pH, temperature, and dissolved oxygen were also monitored. All water samples were analyzed in accordance with the Standard Methods for Examination of Water and Wastewater.

3 Results and Discussions

The monitored results of various pollutants including SS, BOD, and COD are shown in Fig. 2, 3, and 4. The water quality of effluent in terms of BOD, COD, and SS was elevated due to the increased loadings of dormitory sewage discharge into secondary treatment facilities.

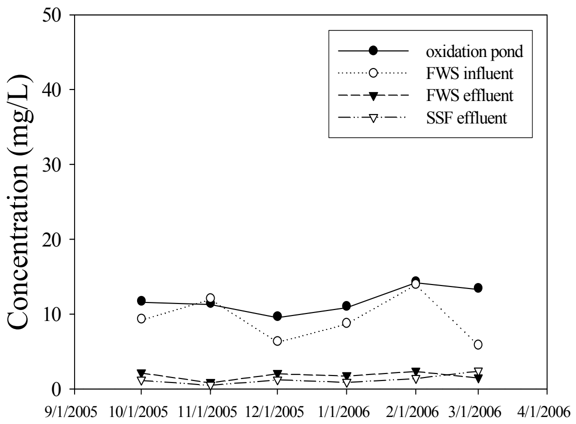

Fig. 2. Monthly average SS variations

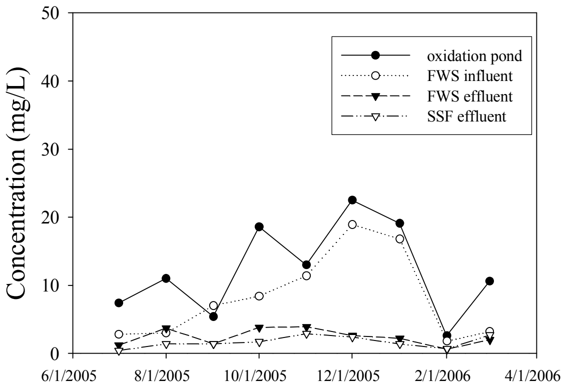

Fig. 3. Monthly average BOD variations

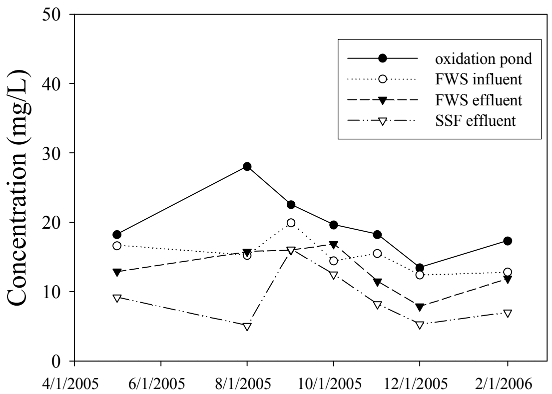

Fig.4. Monthly average COD variations

The significant percentage removal of SS, around 90.4%, was achieved within the studied system (Table 1). Most of SS removal occurred in oxidation ponds and surface flow wetlands while they provide quiescent conditions for particulate matters to settle. Phosphorus removal in wetlands might be induced by the plant uptake, accretion of wetland soils, microbial immobilization, retention by root bed media, and precipitation in the water column. In addition, phosphorus removal is less temperature inhibited because it is dominated by sediment adsorption as opposed to microbial and chemical transformations. Phosphorus removal in constructed wetlands found to be more limited than other pollutants due to an insufficient high capacity to bind phosphorus for a prolonged period. The adsorption capacity of wetland media was variable and may be rapidly exhausted. Researchers reported the Danish experience of phosphorus removal which was fairly low, typically 20-30%. The percentage reduction of total phosphorus was low, around 21.5%, in this study that is consistent with other researches [6, 7]. Effective phosphorus removal was not achieved.

The influent BOD and COD were 12.7 and 19.7 mg/L, respectively, while effluent BOD and COD were 1.6 and 7.9 mg/L, respectively (Table 2). The average BOD and COD percent removal efficiency in this study was approximately 87.4 and 59.9%, respectively. The BOD and COD removal efficiency were consistent with reported in other literatures [8, 9]. In Fig. 5, the ratio of BOD to COD decreased from 0.64 in the initial aerobic compartment to 0.2 in anoxic parts of the systems, indicating most biological degradable materials were decomposed in the aerobic oxidation pond and surface flow wetlands. Poor removal of organic matters might attribute to limiting oxygen availability within the anoxic subsurface flow system. Though, sedimentation and adsorption are also considered to be possible mechanisms for organic matter removal. BOD and COD are principally removed by microbiological activity. The high BOD removal efficiency shown in the surface flow wetlands planted cattail and reeds suggested that vegetation can enhance transporting extra oxygen for substrate attenuation. The performance of vegetated systems might be further enhanced if above ground biomass is harvested rather than allowed to decay within the wetlands. The effect of submergent vegetation in surface flow wetlands on shading algae and inhibiting algal activity might be the likely influence of organic matter removal. Oxidation pond and surface flow wetlands also provided quiescent conditions for settling SS and particulate BOD. This might be attributed to the higher organic matter removal in the aerobic components of the studied systems. Poor organic removal might be microbial breakdown of carbonaceous compounds being limited by low oxygen availability.

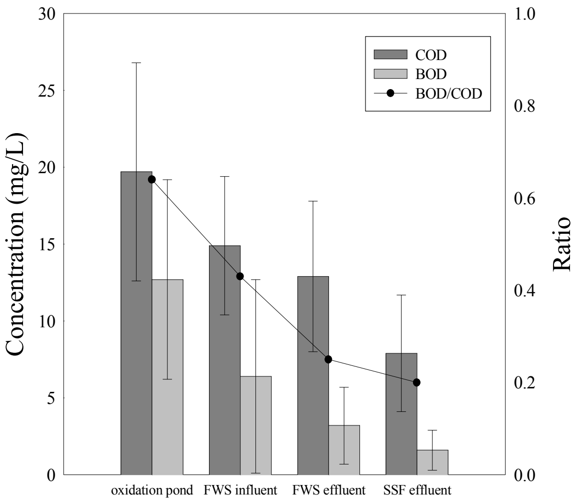

Fig. 5. Concentrations of BOD and COD(BOD/COD ratio)

Table 3 is a summary of nitrogen transformation data. Ammonium in the inflow water averaged 65 to 75% of TKN. The inflow water of the studied wetlands systems were ammonium dominated rather than organic nitrogen or nitrate. Ammonium inflow ranged from 5.01-6.73 mg/L (mean=5.12) while TKN ranged from 6.18-8.63 mg/L (mean=7.42). The outflow of ammonium and TKN ranged from 0.78-1.34 mg/L (mean=0.84) and 1.05-1.74 (mean=1.54), respectively. The wetland removed or stored approximately 80% of inflow TKN. The monitored data demonstrated seasonal oscillation with higher TKN and ammonium removal during summer months. This phenomenon might be due to increased photosynthetic activity which produced dissolved oxygen facilitating nitrification. Another explanation for this seasonal variation was likely the increasing macrophyte uptake of ammonium during the growing season. Further investigations of plant uptake will be carried out. In Fig. 6, TKN and ammonium decreased from 7.42 to 2.15 and 5.12 to 1.32 mg/L, respectively, while nitrate nitrogen increased from 2.21 to 5.56 mg/L within the aerobic oxidation pond and surface flow wetlands. The results demonstrated nitrification occurring within aerobic units. The nitrate nitrogen continued to decrease from 5.56 to 1.21 mg/L within the anoxic subsurface wetlands through denitrification transformation. Total nitrogen removal was from 10.95 to 3.80 mg/L. The percentage removal of total nitrogen concentration was around 65.29%, demonstrating that constructed wetlands in tropical areas might be a promising option to purify secondary treated sewage regarding nitrogen nutrient removal. The predominant decrease of total nitrogen was within the subsurface wetland compartment where denitrification occurred.

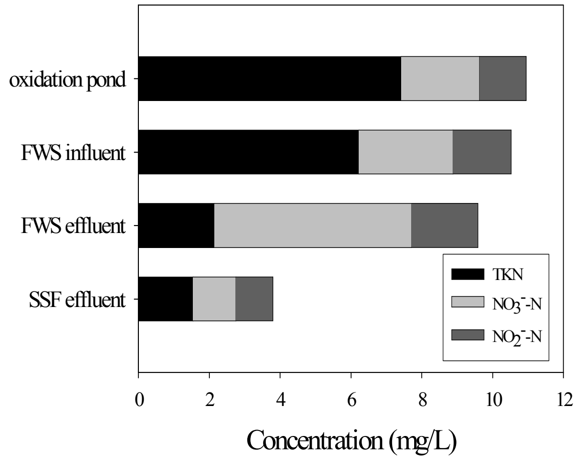

Fig. 6. Nitrogen species profiles within purification system

Nitrogen transformation in wetlands occurs by biological processes including ammonification, nitrification, denitrification, nitrogen fixation, and nitrogen assimilation. For secondary treated sewage, the predominant forms of nitrogen might be ammonium and nitrate depending on aeration levels in secondary treatment processes. Nitrification and denitrification are generally indicated as the principal processes for nitrogen reduction [10]. Macrophytes may remove some nutrients through direct uptake and provide environments for more intense microbial activities. The vegetation in constructed wetlands also creates quiescent conditions for sedimentation as well as oxidation conditions for organic matter decomposition and nutrient transformation through bacterial activities from microbes suspended in the water column and attached around the root zones. Preliminary results demonstrated that submergent macrophytes uptake approximately 1.95 % of total influent nitrogen (Table 4). These results are slightly below the average nitrogen removal levels, around 4-5%, reported in other researches [11; 12]. The discrepancy of these monitored results might be attributed to the maturity of the studied wetland systems.

Carbon availability might be the limiting factor for denitrification in the subsurface flow systems. However, the decomposition of macrophyte plants in the proceeding surface flow wetlands might yield sufficient carbon sources in the studied systems. Nitrification should be enhanced because it will increase the nitrate available or denitrification. The studied surface flow wetland systems are feasible for nitrification enhancement due to the permissive oxygen conditions with the assistance of submergent macrophyte and a cascade unit. Nitrification- denitrification was considered as the predominately nitrogen removal mechanism in this study.

The performance of hybrid wetland systems including surface flow followed by subsurface flow wetlands for significant removal of SS, organic matters and nitrogen was demonstrated in this study to be a prominent option to polish secondary treated sewage. Wetlands can serve an important role in low-tech water reuse systems while pollutants such as organic matters, SS, and nitrogen nutrients can be either removed or transformed.

4 Conclusions

Considerable potential by employing the treatment train natural purification systems for removing SS, organic matters and nitrogen nutrients was demonstrated in this study. Though, effective phosphorus removal was not achieved. The predominant forms of nitrogen are ammonium in the influent, nitrification and denitrification were the principal processes for nitrogen reduction.

In conclusion, constructed wetland systems are one of the viable options serving as environmentally sustainable, socially accepted and cost-effective nutrient purification processes. Constructed wetlands have emerged as alternatives for assisting to solve a wide range of environmental and water quality problems while the sewerage connection is fairly low in Taiwan. Wetland systems are particularly attractive alternatives for enhancing the secondary treated wastewater and groundwater quality enhancement due to their incorporating into the landscape plan and its operational simplicity and cost efficiency.

This research has showed that constructed wetlands can be designed to provide numerous pollutants transformation and removal by incorporating oxidation ponds, surface flow wetlands and subsurface flow wetlands into a treatment train. Results of this study will be useful for applying similar natural purification systems to purify secondary treated sewage in tropical regions while tertiary treatment are too costly or unable to operate.

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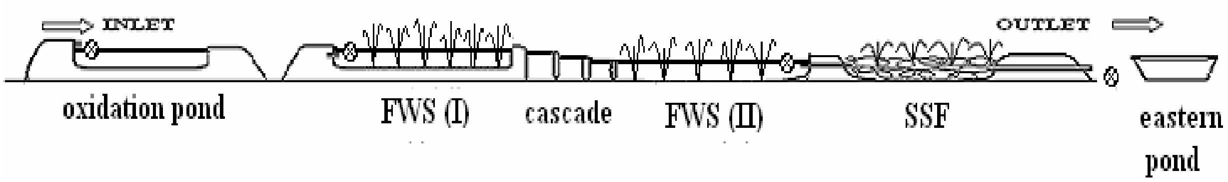

Fig. 1. Layout of filed scale purification systems

Table 1. Total phosphorus and suspended solids concentrations and removal rates

		Oxidation pond	FWS influent	FWS effluent	SSF effluent	Total removal rate (%)
TP	Concentration(mg/L)	1.58±0.76	1.54±0.71	1.35±0.67	1.24±0.60	21.52%
	Removal rate (%)	-	2.53%	12.34%	8.15%	
SS	Concentration (mg/L)	12.50±4.84	10.90±6.29	1.79±0.94	1.20±0.89	90.40%
	Removal rate (%)		12.8%	83.58%	32.96%	

Table 2. Concentrations and removal rates of organic pollutants in purification systems

Analytical parameters		Oxidation pond	FWS influent	FWS effluent	SSF effluent	Total removal rate (%)
BOD	concentration (mg/L)	12.7±6.5	6.4±6.3	3.2±2.5	1.6±1.3	87.40%
	Removal rate (%)		49.61%	25.20%	14.96%	
COD	concentration (mg/L)	19.7±7.1	14.9±4.5	12.9±4.9	7.9±3.8	59.90%
	Removal rate (%)		24.37%	10.15%	25.38%	
BOD/COD	ratio	0.64	0.43	0.25	0.2	

Table 3. Nitrogen species concentrations and removal rates

Analytical parameter		Oxidation pond	FWS influent	FWS effluent	SSF effluent	Total removal rate (%)
TN	concentration (mg/L)	10.95±1.87	10.53±1.31	9.59±1.13	3.80±0.74	65.29%
	Removal rate (%)	-	3.84%	8.58%	52.88	

TKN	**concentration (mg/L)**	**7.42±1.32**	**6.23±0.75**	**2.15±0.71**	**1.54±0.75**	**79.24%**
	Removal rate (%)	**-**	**16.04%**	**54.99%**	**8.22%**	
NH_4^+-N	**Concentration(mg/L)**	**5.12±1.08**	**4.12±0.75**	**1.32±0.75**	**0.84±0.32**	**83.59%**
	Removal rate (%)	**-**	**19.53%**	**54.69%**	**9.38%**	
NO_3^--N	**concentration (mg/L)**	**2.21±0.69**	**2.65±0.45**	**5.56±1.07**	**1.21±0.43**	-
NO_2^--N	**concentration (mg/L)**	**1.32±0.45**	**1.65±0.38**	**1.88±0.68**	**1.05±0.49**	

Table 4. Macrophyte nitrogen uptake levels

	Macrophyte growth rate($g/m^2/d$)	**Macrophyte nitrogen content(%)**	**Nitrogen uptake rate($g/m^2/d$)**	**Total nitrogen uptake rate($mg/m^2/d$)**	**Total nitrogen removal (%)**
Cattails	**1.83**	**1.82**	**33.3**	**64.2**	**1.95**
Reeds	**1.74**	**1.78**	**30.9**		