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Potential Use of the Constructed Wetland System as an Eco-technology for Wastewater Treatment in Resort

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Abstract

Tourism expansion can put pressure and deterioration on natural resources particularly in vulnerable riverside areas. Because of water pollution scenario could negatively impact the number of visitors, wastewater treatment before discharging becoming a necessary process for resort enterprises. However, lack of sewerage network and treatment system in Thailand poses the need to have an affordable and efficient onsite wastewater treatment system. In this study, a modified subsurface flow constructed wetland (MSF-CW) system was applied to treat a resort wastewater that had high and fluctuating organic contents. The system performance, investigated during 7 months, revealed that chemical oxygen demand (COD), biochemical oxygen demand (BOD), total kjeldahl nitrogen (TKN), total phosphorus (TP) and suspended solids (SS) removal efficiencies were 81%, 84%, 30%, 40% and 78%, respectively, and all meeting the Thai building effluent standards. The treated effluent qualities were also compared to the guidelines for water reuse, then applied for landscape irrigation at the resort to promote water conservation and sustainable use. Based on the analytical results, the hydraulic retention time (HRT) of this system should not be less than 5 days to maintain a satisfactory efficiency. From the long-term monitoring period, this system showed easy operation with low maintenance cost. The benefits of the MSF-CW application in this study are not only for wastewater treatment but also for green area creation, useful for the resort to promote eco-tourism and sustainability. The constructed wetland (CW) system is, therefore, strongly suggested as a facility for small or medium-size resorts, hotels and homestays to achieve water pollution abatement and promoting eco-sustainable tourism.

Keywords: Onsite wastewater treatment; Subsurface flow; Constructed wetland; Treated wastewater reuse; Green resort

1. Introduction

Water quality in Thailand and many countries has been deteriorated over the past decades, caused mainly by several activities such as expansion of residential areas, tourism, trading and services, agriculture (paddy fields, cropland, orchards, etc.), livestock and aquaculture activities. Surface water quality in many areas along the country varies from low to fair conditions (PCD, 2019). During the past decade, typical designs of wastewater treatment plants have been studied and applied mainly to urban areas; however, these infrastructures are not sufficient in terms of both quantity and quality. The government of Thailand had subsidized budget for building sewerage collecting system and municipal wastewater treatment plants, but this centralized system accommodated only 10% of total domestic wastewater generated from the Thai communities, while sewerage collection network served only 48% of urban households (World Bank, 2014). The studies reported that many centralized municipal wastewater treatment plants throughout Thailand did not function as well as expected (Chevakidagarn, 2006). Most of these wastewater treatment systems encountered with inadequate performance and operational problems (i.e. lack of personnel skills, shortage of operation and maintenance costs) which are indeed difficult for problem solving. The study of Moongkumglang, *et.al.* (2013) reported that a centralized wastewater treatment system is most appropriate for municipalities, but an on-site treatment system is suitable for sub-district administrative organizations or small communities. Therefore, an application of the on-site wastewater treatment concept that collects, treats, disposes/reuses treated wastewater at or near the generation source (or called build-as-you-go principal) is gaining more interests. In this respect, constructed wetlands (CWs) seem to be a promising technology in many aspects, especially in the context of the need for system performance, low cost, ease of maintenance which are considered as a sustainable wastewater treatment system for developing countries (Stefanakis, 2019). CWs have been successfully used to mitigate water pollution as they are potentially capable for removing various pollutants such as organic compounds, nutrients, suspended solids, heavy metals and pathogens (Gikas *et.al,* 2013; Zhang *et al.,* 2014). The CWs are also promoted as an appropriate technology according to its cost affordability, reliability, environmental-friendly and sustainability (Crites and Tchobanoglous, 1998; Wu *et al.,* 2011; Zhang *et al.,* 2014). Over the last decades, CWs have emerged and become a viable option for wastewater treatment at households, resorts, hotels and small-scale communities (Zhang *et al.,* 2014).

In this study, the potential uses of CWs for wastewater treatment and reuse were conducted at a resort in Amphawa District, Samut Songkram Province. This area was selected due to its well-known floating market, eco-tourism and homestay tourism, but does not have sewerage collection and treatment systems, resulting in large quantities of wastewater being discharged to the waterways without proper treatment. Therefore, the application of CWs in this area was considered an appropriate option to overcome this water pollution problem. The design criteria of CWs were based on daily wastewater quantity, available land area and BOD loading rate. The system performance including the effluent characteristics were evaluated and compared with the Thai building effluent standards (PCD, 2018).

2. Materials and methods

2.1 Experimental setup and operation

The modified sub-surface flow constructed wetland system (MSF-CW) was designed to treat domestic wastewater (a combination of grey water and kitchen wastewaters) at a resort, Amphawa district, Samut Songkram Province. The designed criteria were based on the guidelines of U.S. EPA. (1998) and Polprasert (2007). In general, as most resorts have limited land area, this constraint was also taken into consideration in the CW design. Table 1 shows the design and operational criteria used in this study.

The MSF-CW system was modified from the subsurface flow constructed wetland (SF-CW) concept in order to receive raw wastewater which was highly fluctuated in terms of its characteristics. Concept and schematic diagram of the MSF-CW system are illustrated in Figure 1, while Figure 2 shows overview photographs of the MSF-CW system during the study. Designed as a planting box in combination with an aeration chamber to lower the influent BOD, it consisted of four compartments as: (1) a retention chamber (for particles settling); (2) a semi-aerobic media chamber of 0.7 m^3 with plastic media and air pump (for partial treatment of organic matters); (3) a subsurface flow constructed wetland (for treating the remaining organic matters and nutrients; and 4) an effluent chamber (for collecting the treated water to be recycled or reused). The MSF-CW system (2 x 7m.) was designed to accommodate an organic loading rate of 100 kg/ha.day

(Crites and Tchobanoglous, 1998; Polprasert, 2007). The media used in the system were sand and gravel with void ratios of 0.384 and 0.475, respectively. As this system was installed at recreational area, emergent plants in this system were chosen based on both treatment performance and decorative aspects. The plant types used in this system included Indian shot (*Canna indica* L.), Bird of Paradise (*Strelitzia reginae* Ait.), Blue screw pine (*Pandanus tectorius* Pakinson ex Du Roi) and heart leaf Philodendron (*Philodendron cv.* Lemon Lime).

Grey water and kitchen wastewater from the resort were collected in the sump and overflowed to a retention chamber and a semi-aerobic media chamber, respectively. This combined wastewater was semi-continuously fed into the MSF-CW unit by a submersible pump (WP-5000, Zhognshan sobo electrical appliances Co.,Ltd., China) equipped with an electronic timer to achieve an average 5-day HRT. The treated water was kept in an effluent chamber and being reused for irrigation purpose in the resort.

Table 1. Design and operational criteria of the MSF-CW system at resort

Operational criteria	MSF-CW
Design organic loading rate (kg/ha.day)	100
Wastewater sources	Grey water and kitchen wastewater
BOD_5 (mg/L)	200
Surface area (m^2)	9.4
Media	Sand + Gravel
Media depth (m)	0.75
Average hydraulic retention time (days)	5
Slope	1:100
Types of constructed wetland	Baffle
Plants	Various types: Indian shot (*Canna indica* L.), Bird of Paradise (*Strelitzia reginae* Ait.), Blue screw pine (*Pandanus tectorius* Pakinson ex Du Roi) and Heart leaf Philodendron (*Philodendron cv.* Lemon Lime)

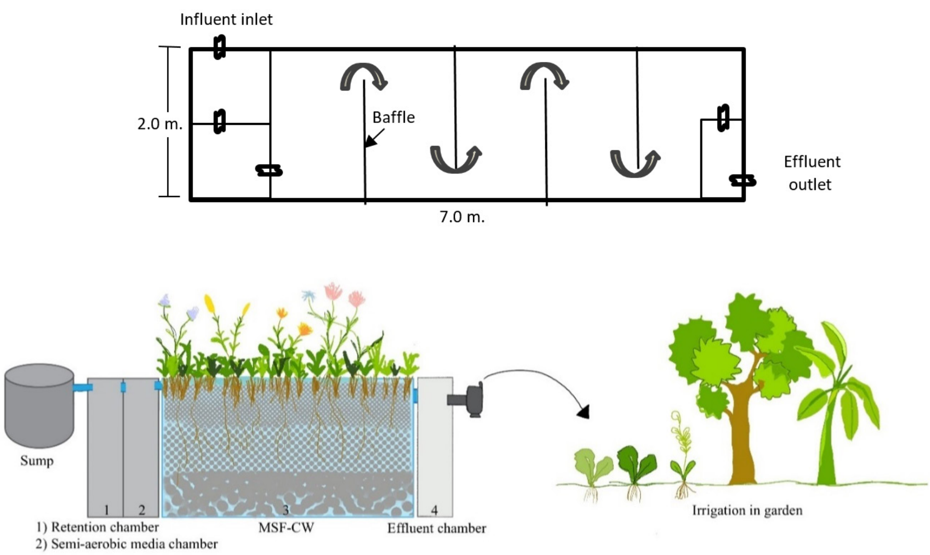

Figure 1. Concept and schematic diagram of the MSF-CW system

Figure 2. Overview photographs of the MSF-CW system at the resort

Laboratory and statistical analysis

During the operational period, influent and effluent samples were collected once a week from the MSF-CW unit. These samples were preserved at a temperature of 4-8 °C before being transported to the Central laboratory and Greenhouse Complex, Kasetsart University, Nakhon Pathom province, for analysis. Water samples were analyzed according to the Standard Methods for Examination of Water and Wastewater (APHA, AWWA, and WEF (2017): COD (close reflux); BOD (azide modification); TKN (digestion and distillation); total phosphorus (TP) (digestion and colorimetric); suspended solids (SS) (gravimetric); and total dissolved solids (TDS) (gravimetric). The pH meter of Mettler Toledo model S220, the electrical conductivity (EC) meter of Mettler Toledo model S30-k and the turbidity meter of Thermo Scientific model Eutech TN-100 were used to measure pH, conductivity, and turbidity throughout this study, respectively. The results were presented in terms of arithmetic mean ± standard deviation, and statistical analysis was performed using the Microsoft Excel.

3. Results and discussion

3.1 Wastewater characteristics

Influent wastewater to the MSF-CW system mainly came from cleaning and washing areas, laundry and cooking activities. The system performance was investigated weekly by analyzing the influent and effluent characteristics. The study period lasted about 7 months covering summer and rainy seasons. The first 4-week of operation was a start-up period to allow plant growth and fine tuning of the operational and environmental conditions. The influent characteristics of wastewater from the resort are presented in Table 2.

The wastewaters originated in this resort could be classified as medium strength wastewater (Mara, 2003). The relatively high BOD concentrations were probably due to some organic substances in the kitchen wastewater.

3.2 System performance

The pH, EC, COD, BOD, TKN, TP, SS and TDS concentrations were analyzed and compared with the Thai Building Standard, Type C (PCD, 2018). The analytical results are presented in Table 3. The MSF-CW system efficiencies identified as BOD, COD, TKN and SS parameters are illustrated in Figure 3.

Table 2. Influent characteristics of wastewater from the resort

Parameters	Unit	Values			
		Maximum	Minimum	Average	S.D.
pH	-	7.59	6.48	6.47	0.5
EC	mS/cm	2.24	0.66	1.35	0.5
COD	mg/L	630	281	519	257
BOD	mg/L	383	150	340	142
TKN	mg/L	26.5	5.1	19	6
TP	mg/L	4.6	0.4	3.3	1.2
SS	mg/L	113	38	92	42
TDS	mg/L	1,684	424	1,106	375

Table 3. Influent and effluent quality of constructed wetlands treating resort wastewater

Parameter	MSF-CW system			Effluent standard*
	Inlet	Outlet	Removal efficiency (%)	
pH	6.47 ± 0.5	7.62 ± 0.6	-	5 - 9
COD (mg/L)	519 ± 257	125 ± 95	75 ± 13	-
BOD (mg/L)	340 ± 142	78 ± 68	76 ± 17	< 40
TKN (mg/L)	19 ± 6	13 ± 4	30 ± 21	< 40
TP (mg/L)	3.3 ± 1.2	1.9 ± 1.0	40 ± 26	-
SS (mg/L)	92 ± 42	18 ± 11	78 ± 16	< 50
TDS (mg/L)	1,106 ± 375	1,067 ± 339	20 ± 20	-
Turbidity (NTU)	98 ± 61	49 ± 42	57 ± 31	-

Remarks: Average (± standard deviation) * Thai effluent standards for Building Type C, Effluent standard (PCD, 2018)

3.3 COD and BOD removal

As shown in Table 2, the COD and BOD concentrations in influent samples fluctuated depending on tourist numbers and their activities each day. The BOD concentrations in the influent varied from 150 to 383 mg/L. For almost 2 months during the start-up period, the BOD concentrations in effluent were fluctuated and above the standard at per interval week. The wide variation in influent organic loading in terms of BOD and flow rate resulted in the moderate efficiency of system performance during the start-up period. After continuing operation over 20 weeks, the system could reach the consistent and satisfactory treatment performance. The treated effluent was directly pumped out for watering the green areas in the resort.

This wastewater treatment system could remove BOD by 41-95% with the effluent BOD concentrations during the investigation period ranging from 18 to 312 mg/L (Figure 3a). The average BOD removal efficiency was 76%. The influent COD concentrations varied from 281 to 630 mg/L. The MSF-CW system removed COD by 45-94%, and the effluent concentrations ranged from 23 to 457 mg/L (Figure 3b). The average COD removal efficiency was 75%. The relative effluent concentration of COD and BOD implied that, at least half of the organic substances in the system could be biologically degraded. However, due to the influent flow rate and wastewater characteristic variation, the performance of the system in terms of COD and BOD removal efficiencies might vary as well. The average influent BOD concentrations (340 ± 142 mg/L) were greater than the design BOD (200 mg/L), resulting in an increase in organic loading rate of 1.7 times. The accumulation of organic matters in the retention chamber, which came mainly from the kitchen wastewater, was the major cause of poor removal efficiency attained during the startup period. Accordingly, a longer HRT of more than 5 days (or larger MSF-CW) is recommended for general uses to accommodate influent variation. However, in this study, due to land limitation, enhancement of COD/BOD degradation through pre-aeration was implemented to improve the removal efficiency. It was obvious that, after several operational weeks, the effluent COD and BOD concentrations were found comparatively lower than of the startup period and meeting the Thai building effluent standard, type C, which required BOD < 40 mg/L (PCD, 2018).

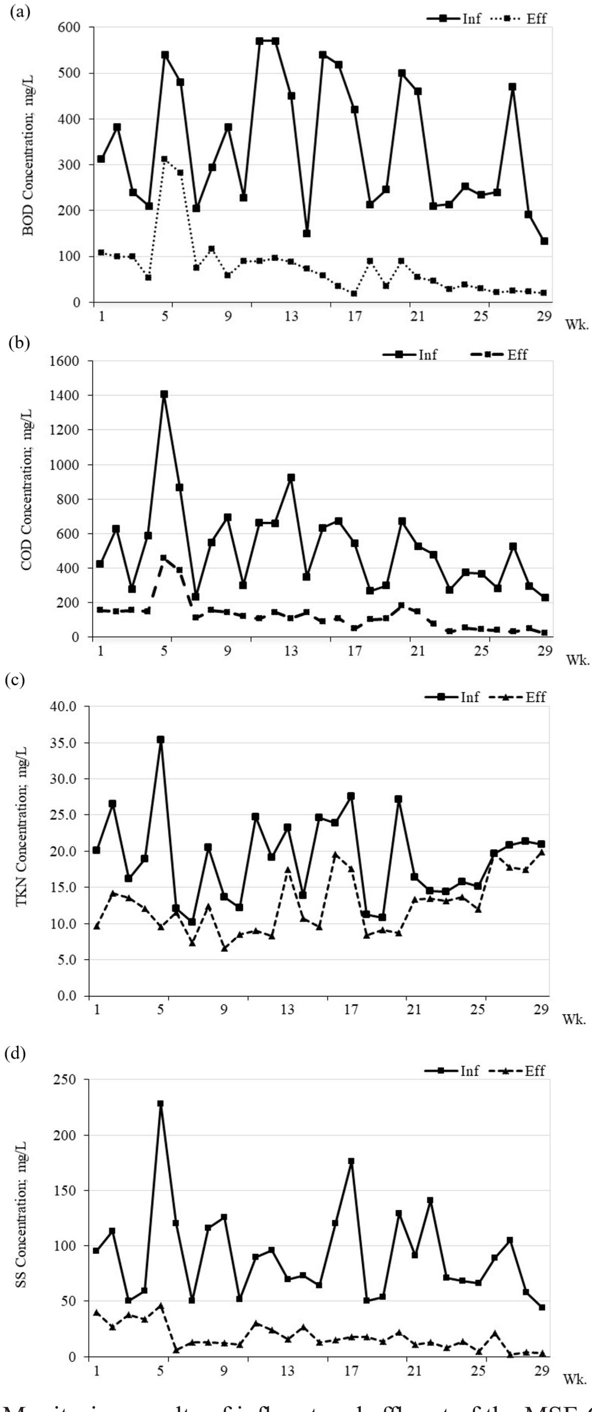

Figure 3. Monitoring results of influent and effluent of the MSF-CW system (a) Biochemical oxygen demand (BOD), (b) Chemical oxygen demand (COD) (c) Total Kjeldahl nitrogen (TKN), and (d) Suspended solids (SS).

The system efficiencies in this study were in accordance with the experiences of similar treatment systems of the other studies. For example, the study of Akhir, *et.al* (2017) reported the constructed wetland had COD and BOD removal efficiencies of 49.7% and 52.1%, respectively, at Frangipani resort, Langawi. The study of Sudarsan, *et.al* (2015) reported the COD and BOD removal efficiencies of 57.34% and 76.16%, respectively, for domestic wastewater treatment.

3.4 TKN, TP, and SS removal

The TKN concentration in the influent ranged between 5.1 - 26.5 mg/L. According to Figure 3C, the TKN removal efficiencies ranged from 5 - 73%, with an average of about 30%. The effluent TKN concentrations during the investigation period ranged from 6.6 to 19.9 mg/L, which are below the Thai building effluent standard, type C (TKN < 40 mg/L, PCD, 2018). TKN removal indicates some nitrifying bacteria activity in the CWs system, whereas no aeration was provided during the operation. The residual of nitrogen as TKN (Organic nitrogen + NH_4^+-N) in the effluent was safely reused in the resort garden. However, the NH_4^+-N and NO_3^--N concentrations should be further investigated to evaluate the efficacy of nitrification and denitrification processes.

An average TP removal efficiency of this system was 40 ± 26%, which corresponded to the average P removal in constructed wetlands with horizontal sub-surface flow in the Czech Republic of 45.7% (Vymazal, 2004). The main P removal mechanisms in the CW were sedimentation process, plant uptake and microbial assimilation (Vymazal, 2004; Sirianuntapiboon and Sohsalam, 2012).

SS removal efficiency ranged from 24 - 98%, with an average of 78%, which also corresponded with the average turbidity removal of 57%. The SS in influent was fluctuated as showed in Figure 3d, but the effluent was relatively low. This implied that the MSF-CW provided good settling and particle retaining conditions. It was assumed that suspended particles were captured within a dual media layer and partly settled in the MSF-CW. Typically, efficient removal of suspended solids can be observed for almost all types of constructed wetland used in treating wastewater. The SS was also reported at relatively low concentrations in the constructed wetland system (Sengorur and Ozdemir, 2006; Mustafa, 2013)

Based on the above results, the hydraulic retention time (HRT) of this system should not less than 5 days in order to maintain a satisfactorily efficiency. All of the treated effluents were applied for land irrigation in the resort based on the guidelines for water reuse (U.S.EPA, 2004) to promote water conservation and sustainable use. From the long-term monitoring period, this system showed an easiness in operation and low maintenance cost. If more stringent effluent standard is required, the system efficiency can be improved by the following adjustments, 1) a longer retention time or large land area may require, 2) an existing media (sand and gravel) may be replaced with more efficient materials like volcanic rocks or pumice rock. The study of Yammanas and Tuwicharanon (2016) suggested using volcanic rocks as media instead of typical rock to improve water quality in SFCWs and promoting the growth of biofilms in the MSF-CW chamber.

3.5 Other operational parameters

During the operational period, other parameters such as pH, EC, TDS, and turbidity, were investigated to ensure the satisfactory operation. According to Tables 2 and 3, the average pH, EC, and TDS were 6.47 ± 0.5, 1.35 ± 0.5 mS/cm, 1,106 ± 375 mg/L, respectively. The slightly low pH was probably due to accumulation of organic matters in the feed, causing septic condition in the sump and retention chamber, while TDS could not be efficiently removed by this system (20 ± 20%).

4. Conclusions

The MSF-CW system with ornamental emergence plants was employed as a prototype for wastewater treatment in small size resorts or homestays. The average removal efficiencies were 81% for COD, 84% for BOD, 30% for TKN, 40% for TP and 78% for SS, which met the Thai building effluent standard, Type C (PCD, 2018).

Due to organic substance fluctuation in influents, the HRT should not be less than 5 days for better or more consistent performance and in accordance with more stringent discharge or reuse standards. Therefore, implementing the MSF-CW system is considered to be a sustainable wastewater treatment technology, appropriate to resorts, particularly in tourism districts. Its function is not only for wastewater treatment, but also as a decorative planting box. Moreover, the further benefits of applying this system were reducing pollution to the nearby river and saving water supply by the use of treated effluent for irrigation. The results of this study suggested the MSF-CW system to be a suitable facility in the resorts, hotels and homestays in rural areas of Thailand and also of other developing countries.

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