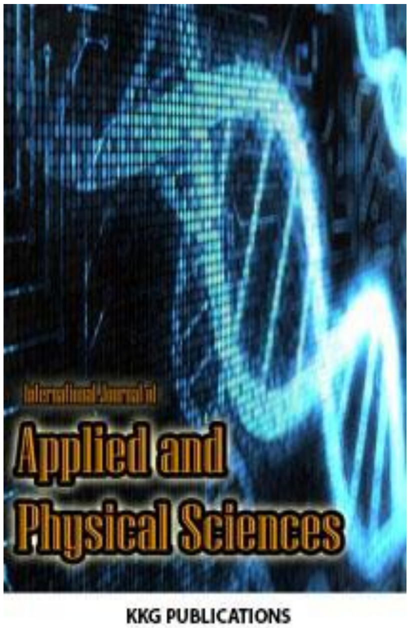

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Effect of Plant Density in Constructed Wetland on Domestic Wastewater Treating Efficiency

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EFFECT OF PLANT DENSITY IN CONSTRUCTED WETLAND ON DOMESTIC WASTEWATER TREATING EFFICIENCY

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Abstract. The constructed wetland was applied for initiating the domestic wastewater treatment process. Variation of plant density and Hydraulic Retention Time (HRT) were observed. Domestic treatment performance was improved by increasing plant density and HRT, but only HRT of 4 days could be achieved. Thailand's effluent discharge standard was studied. Vegetation or non-vegetation wetland could remove total suspended solid due to physical mechanisms (filtration, sedimentation, and adsorption), while Chemical Oxygen Demand (COD) and ammonium were removed by plants and microorganisms attached at the root zone and wetland media. Using constructed wetland for thermal transfer reduction and sewage treatment purposes could be applied at a plant density of 20 plants/m2 and HRT of 4 days. Moreover, increasing plant density could reduce heat transfer to houses because of rising relative humidity around the wetland area and nearby atmosphere.

INTRODUCTION

Constructed wastelands are immensely applied for various sources of wastewater e.g. agriculture, municipal, heavy industry or intensive freshwater aquaculture [1]. The main purpose of the constructed wetlands application was standing for wastewater treatment and ecological conservation [2]. Various parameters for optimization such as wet land design, sedimentation type and plant assemblage were studied and researched [3], [4], [5], [6]. In domestic area, housing wastewater was approximately produced up to 200 liter/person for the daily consumptions. Urban areas tend to have higher water usage than rural areas and according to Thailand's regulation, wastewater treatment unit should be installed into each residential house which costs 15,000 baht/unit (4 persons per house). The constructed wetland could be counted as low-cost and eco-friendly wastewater treatment process and also provides a beautiful landscape [7]. In this research, the constructed wetlands were applied for domestic wastewater treatment with *Canna indica* L. as the high pollutants removal efficiency vegetation [8]. The effect of plant density and Hydraulic retention time on treatment efficiency were investigated [21].

MATERIALS AND METHODS

Synthetic Wastewater and Feeding System

Synthetic wastewater was used instead of domestic wastewater due to precision of component composition. The synthetic wastewater consisted of 170 mg/l of Biochemical Oxygen Demand (BOD_5), 100 mg of total suspended solids (TSS) and 50 mg/l of ammonia which are prepared by mixing tapioca starch and urea dissolved into nearby water source (canal water). Synthetic wastewater was kept in 2 m^3 storage tank and connected with 0.5 HP pump as shown in the fig 1. Flow rate will be adjusted to 6.25 and 12.5 l/day for HRT of 2 and 4 days.

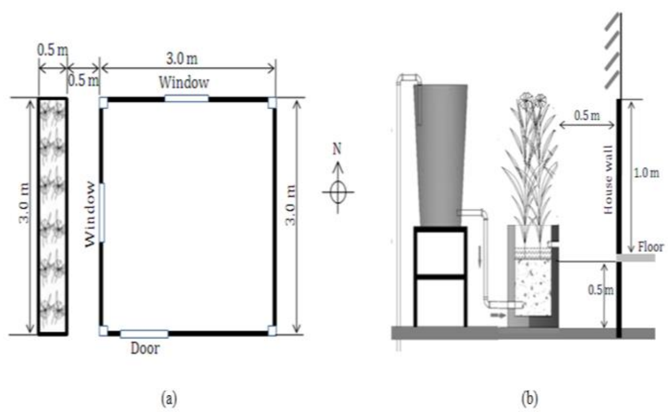

Fig. 1. Constructed wetland system and model house schematic

Constructed Wetland Installation

Constructed wetlands in this experiment were constructed by using square steel beam as external structure with the dimension of 2.0 x 0.5 x 0.7 m (length x width x height). covered inner wall with 100 micron HDPE plastic sheet. 40 mm crushed Rocks were used as wetland media at 0.5 m media height.

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The effluent tube was installed 0.6 m above the ground level to maintain the water level at 0.1 m above the wetland media as free water flow. *Canna indica* L. (1 m height in average) were used as vegetation with the density of 15, 20 and 25 plants/m^2. Plant density and HRT were varied and operated for 14 days for each condition. The experiment was set up at Kasetsart University, Khamphaeng Saen Campus, Nakhon Pathom, Thailand (14.023473N, 99.974945E).

Model House

The model house had 9 m^2 floor areas (3x3 m), the height of the ceiling was 2.5 m, the distance from ceiling to roof ridge was 1 m and roof eave was 50 cm. The wall was 9 mm thick with single layer gypsum board and the floor was 16 mm thick plywood. Louvers windows were installed in western and southern walls with the window with dimensions of 0.70 m width and 1.2 m height and the lower frame of the window was 1.0 m above the house floor. The model house was raised above the ground surface for 50 [20].

Water Quality Analysis

Influent and effluent of constructed wetland system were collected every 2 days in each set of an experiment. Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), ammonium and Dissolved Oxygen were analyzed following the APHA standard method for water and wastewater examination (2005) [9].

Statistical Analysis

Data was presented as mean and significant letter at $p<0.05$. Statistical comparisons were performed using SPSS 16.0 by SPSS Inc. The significant difference in each condition was tested using a One-way ANOVA with a Duncan's Multiple Range Test (DMRT). A $p<0.05$ was considered statistically significant.

RESULTS

Optimum HRT on Constructed Wetland Treatment Performance

Referring to previous work, the effect of vegetation and Hydraulic Retention Time (HRT) of constructed wetlands has been studied [10], [21].

The BOD, TSS and ammonia removing performance has been determined and compared to find the optimization. Constructed wetland with vegetation is shown in fig 2.

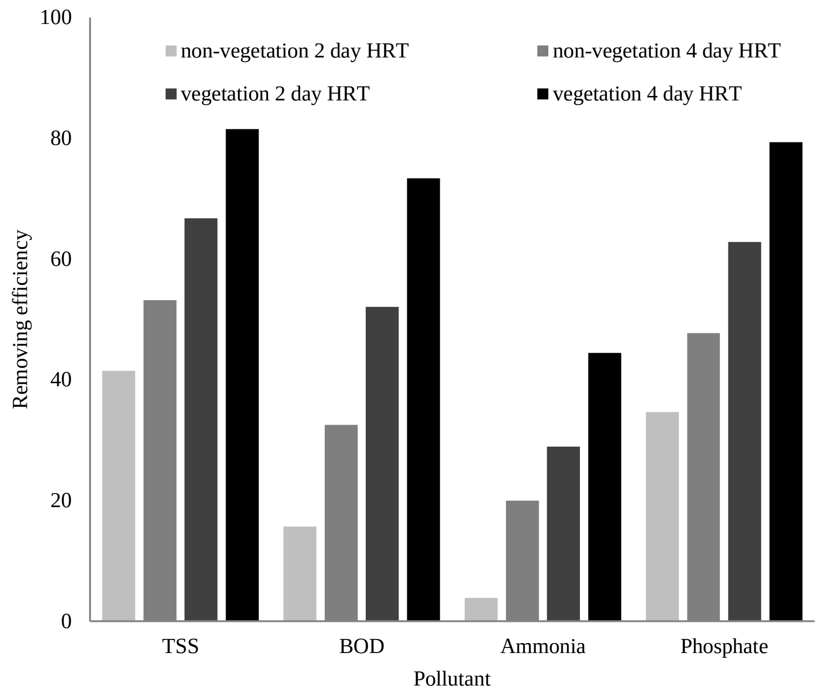

Fig. 2. Pollutant removing efficiency of various conditions [10]

According to Fig. 2, the results showed that the constructed wetland at 4-day HRT with Canna indica L. gave highest pollutant removing efficiency for treating TSS, BOD, NH_4 and PO_3. At 4th day of HRT, the effluent quality could achieve the wastewater discharge standard (Department of Industrial Works of Thailand) then HRT of 4th day was chosen for condition optimization in this experiment.

Pollutant Treatment Performance

Fig. 3 demonstrated the comparisons of COD and Dissolved Oxygen (DO) at various plant densities. The influent COD was in range of 174 – 228 mg/l. COD removal efficiencies at 4^{th} day of HRT at various plant densities were 41%, 60% and 74% for 15, 20 and 25 plant/m^2 respectively. Moreover, the DO concentration in all varied plant densities was in aerobic condition with effluent DO higher than 2 mg/l.

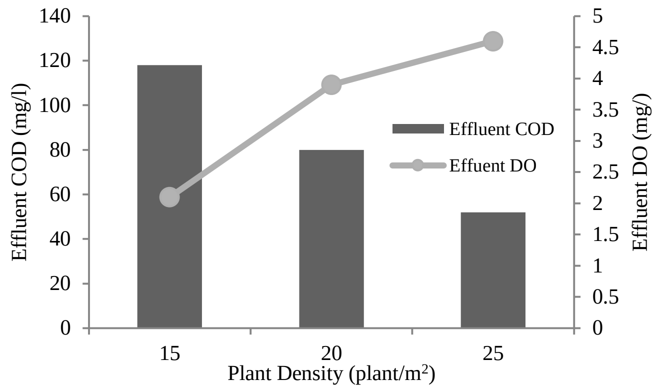

Fig. 3. Effluent COD and OD in various plant densities

Fig. 4 displayed comparisons of the effluent TSS and ammonium. Similar to effect on COD treating performance, the higher plant density provided more TSS and ammonium removing efficiency. The influent TSS was in range of 66 – 83 mg/l and influent ammonium was in range of 47 – 68 mg/l. TSS removal efficiencies at 4th day of HRT were 75%, 88% and 93% for plant densities of 15, 20 and 25 plant/m2, respectively. Ammonium removal efficiencies at 4th day of HRT were 65%, 86% and 99% for plant densities of 15, 20 and 25 plant/m2, respectively.

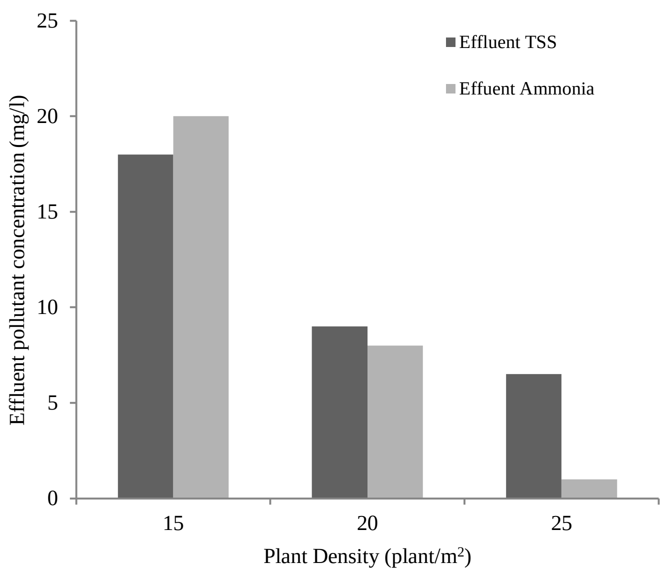

Fig. 4. Effluent TSS and Ammonia in various plant densities

Heat Transfer Reduction

Besides wastewater treatment potency, the constructed wetland also provided beautiful landscape and reduced the heat transfer to model house [24]. Fig. 5 showed the heat reduction of the model house with vegetated constructed wetland at various plant densities. Variation of plant density in wetland resulted in heat reduction (ΔT) to the model house which was accounted by eq. 1

$$Heat\ reduction\ (\Delta T) = Outside\ temp.(°C) - Inside\ temp.(°C) \ldots\ldots \text{ eq.1}$$

Likewise other parameters, increasing plant density also gave a positive result for heat reduction. Constructed wetlands with 0, 15, 20 and 25 plant/m^2 of plant density provided 1.8, 2.7, 3.1 and 5.3 °C of heat reduction, respectively.

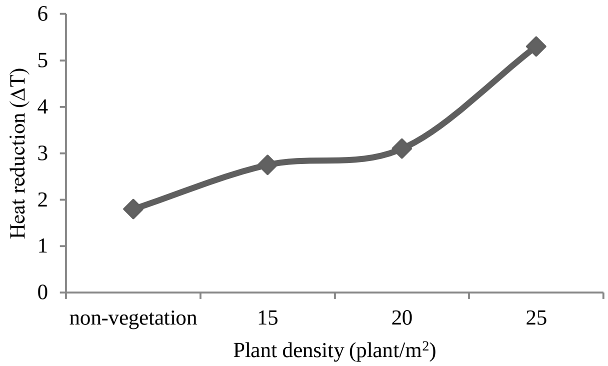

Fig. 5. Comparison of heat reduction for model house by various plant densities on constructed wetlands

DISCUSSION AND CONCLUSIONS

COD Treating Performance and DO Escalation

Higher plant density tends to give better performance for COD removing and DO increasing significantly ($p<0.05$). COD or other organic substances were adsorbed or assimilated by a root zone microorganism and/or biofilm of constructed wetland media surface [2]. Oxygen is required for plant aerobic respiration but the wetland plants are partially submerged. The plants needed to develop the aerenchyma, the plant tissue which allows oxygen to move from aerial part to aquatic part of plant. This oxygen promotes microbial activity and nitrification process [11]. All experimental conditions gave higher DO than 1 mg/l which is considered as aerobic condition and also prevents the malodor.

TSS and Ammonia Treating Performance

Reduction of TSS was because most TSS had been trapped in the root zone of constructed wetland and settled at the bottom of the wetland system. While the microorganism which grew in the submerged region of plant took the main role of the contributor for nitrogen removal in wastewater treatment by forming the biofilm layer [12]. Most TSS was filtrated and sedimented at the inlet zone of wetland even in low HRT [8]. The suspended solids were removed entirely by physical processes, involving sedimentation, filtration and adsorption [13]. These processes are influenced by temperature, pH, and alkalinity of the water, inorganic carbon source, microbial population and concentrations of dissolved oxygen [14]. Most ammonium was oxidized within the system using oxygen through nitrification process [2]. Increase of plant density provided higher TSS and ammonium removing efficiency, it is claimed that the actual wetland efficiency is not only primarily achieved from the activity of the principal wetland components, but reached through cooperation of all components.

The comparison of effluent quality and standard quality for non-potable and irrigation purpose is as illustrated in Table 1.

TABLE 1
QUALITY COMPARISON OF EFFLUENT AND STANDARD

Parameters	Constructed wetland effluent	Standard quality for irrigation purpose		Standard quality for non-potable purpose***
COD (mg/l)	52.0	>200*	-	>50.0
TSS (mg/l)	6.5	>150*	>100**	>60.0
Ammonia (mg/l)	1.0	-	-	-
DO (mg/l)	4.6	>1 to prevent malodour		

(Adopt from [15]; *China, **Taiwan)
(***On-site non-potable water use, [16])

According to the compared results, Effluent parameters quality was passing through the standard quality. Therefore, constructed wetland effluent was capable to be utilized for non-potable or irrigation purpose.

Indirect Benefits

Constructed wetland also provided the heat transfer reduction as indirect effect because of plant photosynthesis, evapotranspiration, oxygen and water vapors were emitted to surrounding atmosphere. The emitted water vapors could reduce the temperature around the vegetation by adsorption of heat for phase transformation from liquid to vapor. Planting many kinds of tree near the house could reduce heat transfer to house due to tree's shade, absorption of heat and reduction of scattered heat [17], [19], [23].

Generally, reduction of ambient temperature by 1 °C can reduce electricity cost from air-conditioning by 10% (EGAT, 2016). For the model house with 9 m^2 floor area required 9,000 BTU (2.637 kW) size in minimum for sufficient cooling efficiency which costs the electricity for 411 Thai-Baht/month approximately [18], [22], [25].

$$Electricity\ cost\ (per\ month) = \frac{cooling\ capacity \times hour\ of\ usage\ (80\%) \times cost/unit \times day}{Coefficient\ of\ Performance}$$

$$= \frac{2.637\ kW \times 8\ hr\ (80\%) \times 3\ THB\ per\ unit\ \times 30\ day}{3.46}$$

$$= 411\ THB/month$$

If constructed wetland with 25 plant/m^2 plant density were installed near house, the electricity cost could reduce by 53%. The final electricity cost would save up to about 215 THB/month

CONCLUSION

Increasing plant density directly improved the treatment performance. Higher plant density resulted in higher COD, Ammonia and TSS removing efficiency. Constructed wetland in this experiment is capable for domestic wastewater treatment in house because this system could provide the acceptable effluent quality which allowed to use the effluent for non-potable purpose and also provided heat reduction which leads to lower house temperature and reduce usage of air-conditioning by 50% approximately.

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