SHORT COMMUNICATION

Aquatic plants for domestic wastewater treatment: Lotus (*Nelumbo nucifera*) and Hydrilla (*Hydrilla verticillata*) systems

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Abstract

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Aquatic plants for domestic wastewater treatment: Lotus (*Nelumbo nucifera*) and Hydrilla (*Hydrilla verticillata*) systems

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A pilot scale aquatic pond, with dimensions of 1.8 m in length, 0.6 m in width and 1.2 m in depth, was constructed at the Hat Yai Municipality Central Wastewater Treatment Plant, Thailand. The experiment was carried out to investigate the enhanced removal efficiency of unconventional plants for aquatic treatment system as post treatment. Wastewater from the selected pond of the Hat Yai Municipality Central Wastewater Treatment Plant was introduced to the systems using peristaltic pumps to maintain a fixed flow rate at HRT of 5.4 and 10.5 days, respectively. Lotus (*Nelumbo nucifera*) and hydrilla (*Hydrilla verticillata*) were planted along with one control unit. Influent and effluent were analyzed for pH, SS, BOD_5, TKN, NH_3-N, NO_2^--N, NO_3^--N, TP and Coliform bacteria twice a week. The results showed that ponds with aquatic plants were superior to those without plants. The system with lotus showed the best removal efficiency for wastewater treatment. For the system with hydrilla, it was found that pH and SS of the effluent were high. It might not be suitable to use hydrilla for effluent polishing. This study could emphasize that lotus and hydrilla could provide an alternative aquatic plant system for wastewater treatment.

Key words : aquatic plant, lotus, hydrilla, wastewater treatment

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การบำบัดน้ำเสียชุมชนโดยใช้ระบบบ่อร่วมกับพืชน้ำ: บัวหลวงและสาหร่ายหางกระรอก

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ในการศึกษานี้ได้ดำเนินการก่อสร้างบ่อทดลองขนาดความยาว 1.8 เมตร ความกว้าง 0.6 เมตร และความสูง 1.2 เมตร จำนวน 3 บ่อ ณ ระบบปรับปรุงคุณภาพน้ำ เทศบาลนครหาดใหญ่ อำเภอหาดใหญ่ จังหวัดสงขลา เพื่อทดลองและศึกษาประสิทธิภาพการบำบัดน้ำเสียของพืชน้ำชนิดอื่น ๆ ซึ่งยังไม่เป็นที่แพร่หลายในการบำบัดน้ำเสียแบบระบบบ่อร่วมกับพืชน้ำ สำหรับการวิจัยในครั้งนี้ได้นำพืชน้ำ 2 ชนิดมาใช้ ได้แก่ บัวหลวง และสาหร่ายหางกระรอก ซึ่งดำเนินการทดลองไปพร้อมกันกับบ่อควบคุม ที่ระยะเวลากักพักน้ำ 5.4 และ 10.5 วัน ตามลำดับ โดยใช้น้ำเสียจากบึงประดิษฐ์ที่ 2 ในการเดินระบบที่ความลึกน้ำ 0.9 เมตร ดัชนีคุณภาพน้ำที่วิเคราะห์ ได้แก่ pH, SS, BOD_5, TKN, NH_3-N, NO_2^--N, NO_3^--N, TP และ Coliform bacteria ผลการทดลองแสดงให้เห็นว่าระบบบ่อบำบัดน้ำเสียที่มีพืชน้ำให้ประสิทธิภาพโดยรวมดีกว่าเมื่อเปรียบเทียบกับระบบบ่อที่ไม่มีพืช โดยเฉพาะอย่างยิ่งระบบบ่อบำบัดน้ำเสียที่มีบัวหลวงให้ประสิทธิภาพดีที่สุด สำหรับระบบบ่อบำบัดน้ำเสียที่มีสาหร่ายหางกระรอกพบว่าค่า pH และของแข็งแขวนลอยในน้ำที่ผ่านการบำบัดมีค่าสูงกว่ามาตรฐาน อย่างไรก็ตามพืชน้ำทั้งสองชนิดอาจเป็นอีกทางเลือกหนึ่งสำหรับการนำมาใช้ในการบัดน้ำเสียแบบระบบบ่อร่วมกับพืชน้ำ

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Aquatic plant system has been accounted as one of the processes for wastewater recovery and recycling. The main purposes of using this system have focused on waste stabilization and nutrient removal. The principal removal mechanisms are physical sedimentation and bacterial metabolic activity as in the conventional activated sludge and trickling filter (USEPA, 1991). Plant assimilation of nutrients and its subsequent harvesting are another mechanism for pollutant removal. Low cost and easy maintenance make the aquatic plant system attractive to use. Thus, constructed ponds with aquatic plants are increasingly applied as a viable treatment for municipal wastewater. However, there are some constraints with using aquatic plants such as the requirement for large area of land, the reliability for pathogen destruction, and the types and end-uses of aquatic plants.

Water hyacinth (*Eichhornia crassipes*) treatment systems are generally known in tropical areas. The system with water hyacinth can operate at higher loading rates. Their end-use products can be utilized for mulch and organic fertilizer. Dry water hyacinth petioles can be woven into baskets and purse (Polprasert, 1996). Beside that, they are many potential aquatic plants that can be used for wastewater treatment but they have not been investigated or there is a lack of data collections. This study aims to investigate the efficiency of unconventional plants for aquatic treatment system such as lotus (*Nelumbo nucifera*) and hydrilla (*Hydrilla verticillata*) as the substitution plants in tropical zones.

Lotus is a floating attached plant, which is an important and popular cash crop in many Asian countries. Lotus has multiple uses, for example, stems and rhizomes as fresh vegetables; seeds as dessert and medicine; flowers as religious ornaments, and several parts as raw materials to produce cosmetics (Yi, Lin and Diana, 2002).

Hydrilla is a submerged perennial plant which is used as mulch, animal feed and aquarium decoration (Polprasert, 1996). It tolerates a wide range of water conditions and can grow at a lower light intensity. Some research reported that hydrilla and the other submerged plants play a major role in taking up and binding N and P in rivers (Vincent, 2001).

Material and Method

Three concrete ponds, each with a dimension of 0.6 m width, 1.8 m length and 1.2 m depth, were constructed at the Hatyai Municipality Central Wastewater Treatment Plant, Southern Thailand, under the realistic conditions as shown in Figure 1. Lotus and hydrilla were planted along with one control unit without plant (Figure 2). Wastewater from the second constructed wetland of the Hat Yai Municipality Central Wastewater Treatment Plant was introduced to the experiment using peristaltic pumps to operate and maintain a fixed flow rate. The experiment was divided into two schemes which are summarized as shown in Table 1.

RUN No.1 was operated at a hydraulic retention time (HRT) of 5.4 days in order to simulate the maximum receiving flow of the treatment plant from the Hatyai Municipality. This run was conducted from July 6, 2003 till September 11, 2003. RUN No.2 examined the performance of lotus and hydrilla systems when operated at an organic loading rate the same as the design criteria for non-aerated water hyacinth system (USEPA, 1991). This run was conducted at HRT of 10.5 days starting on September 19, 2003 till November 21, 2003. The influent and effluent of each unit was analyzed for pH, 5-day biochemical oxygen demand (BOD_5), suspended solids (SS), total kjeldahl nitrogen

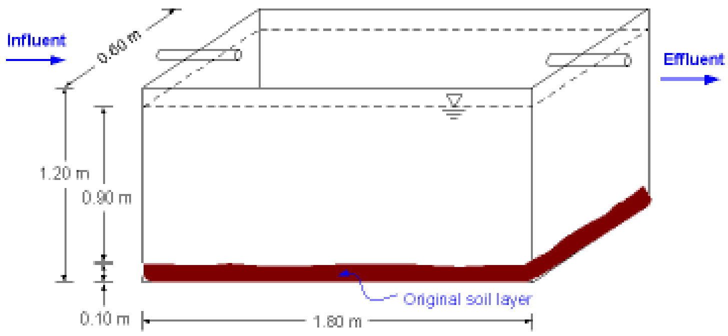

Figure 1. Pilot scale experimental unit set up.

Figure 2. Experimental units with lotus and hydrilla, and control unit at the Hat Yai Municipality Central Wastewater Treatment Plant.

Table 1. Experimental runs and operating conditions.

RUN No.	HRT (d)	HLR (m^3/ha-d)	BOD_5 Loading ($kgBOD_5$/ha-d)	TKN Loading (kgTKN/ha-d)
1	5.4	1,680	20-50	2.0-4.5
2	10.5	850	10-30	0.6-1.5

(TKN), ammonia nitrogen (NH_3-N), nitrite nitrogen (NO_2^--N), nitrate nitrogen (NO_3^--N), total phosphorus (TP) and total coliform bacteria (TC) twice a week in accordance with the procedure outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA and WEF, 1998).

Results and Discussions

The study focussed on the overall performances of lotus and hydrilla systems for post treatment of domestic wastewater. Performance of pilot scale experiments at RUN No.1 and RUN No.2 is shown in Table 2. Removal of water quality parameters such as pH, BOD_5, SS, nitrogen, phosphorus and total coliform bacteria showed the differences between various plants and control unit as follows:

a) pH

The average pH of both runs of the hydrilla and control units was significantly higher than that of the lotus unit. pH in hydrilla and control units was found to be higher than 10.0 and about 8.0 in lotus unit. The increasing pH in control and hydrilla units should be the effect of decreasing carbon dioxide from the photosynthesis of algae and hydrilla, respectively in the water column (Crites and Tchobanoglous, 1998). When the free carbon dioxide is below its equilibrium with air, an increase in pH will occur. The alkalinity forms change as the following equations (Sawyer, Mccarty and Parkin, 1994):

$$2HCO_3^- \leftrightarrow CO_3^{2-} + H_2O + CO_2$$
$$CO_3^{2-} + H_2O \leftrightarrow 2OH^- + CO_2$$

Thus, the removal of carbon dioxide tends to cause a shift in the form of alkalinity present from bicarbonate to carbonate, and from carbonate to hydroxide.

The Effluent Standards enacted by the Pollution Control Department, Ministry of Natural Resource and Environment, Thailand (1996) specified the pH of effluent to range between 5.5 and 9.0. It can be seen from Table 2 that only effluent from the lotus unit could meet this standard.

b) Suspended Solids

From Table 2, the average SS removal efficiency was highest in the lotus unit (67-70%) and slightly less in hydrilla (53-56%) and control (22-33%) units, respectively. Since most of the effluent SS concentrations in aquatic ponds are normally from algae, this situation suggested that the leaves of floating-leaf plants in lotus unit above the water surface can prevent wind action and suppress sunlight. These conditions are unfavorable for growth of suspended algae in the water column and also enhance sedimentation (Jiang and Xinyaun, 1998). In hydrilla and control units, there was sufficient light to stimulate the growth of algae, which resulted in higher concentrations of effluent SS. Adsorption and filtration of SS by submerged plant in hydrilla unit could increase SS removal efficiency to be higher than in the control unit without plant. The longer hydraulic retention time of 10.5 days could effect a higher SS removal efficiency than 5.4 days because SS concentrations are easily settled in conditions of slow water flow in the aquatic system.

The Effluent Standards of Thailand specified SS in effluent at 30 mg/l. Both experimental runs of lotus unit could meet this regulation while

Table 2. Performance of aquatic plant system treating domestic wastewater.

a) RUN No.1 (HRT = 5.4 days)

Parameter	Influent	Effluent					
		Lotus	%RE	Hydrilla	%RE	Control	%RE
pH	7.3±0.2	7.7±0.2	-	10.5±0.4	-	10.0±0.4	-
SS (mg/l)	65±18	21±8	67	31±15	53	44±18	33
BOD_5 (mg/l)	18.0±3.7	6.7±1.6	63	9.9±3.2	45	14.3±3.5	21
TKN (mg/l)	2.01±0.39	0.97±0.43	52	0.74±0.41	63	1.03±0.50	49
NH_3-N (mg/l)	1.03±0.24	0.21±0.15	80	0.14±0.11	87	0.11±0.08	89
NO_3^--N (mg/l)	0.041±0.012	0.040±0.011	-	0.044±0.012	-	0.038±0.015	-
NO_2^--N (mg/l)	0.004±0.002	0.003±0.002	-	0.002±0.001	-	0.002±0.001	-
TP (mg/l)	0.65±0.14	0.29±0.06	55	0.41±0.06	37	0.46±0.06	29
TC (MPN/100 ml)	1.17×10^4 ± 4.64×10^3	8.60×10^3 ± 6.15×10^3	26.6	4.47×10^1 ± 3.50×10^1	99.6	2.80×10^2 ± 1.80×10^2	98.5

b) RUN No.2 (HRT = 10.5 days)

Parameter	Influent	Effluent					
		Lotus	%RE	Hydrilla	%RE	Control	%RE
pH	8.4±1.1	8.0±0.4	-	10.8±0.3	-	10.0±0.3	-
SS (mg/l)	65±21	20±10	70	28±15	56	50±14	22
BOD_5 (mg/l)	19.4±8.8	4.1±3.4	79	9.5±4.7	51	15.8±3.7	18
TKN (mg/l)	1.41±0.32	0.52±0.23	63	0.70±0.23	50	0.55±0.29	61
NH_3-N (mg/l)	0.88±0.18	0.29±0.18	68	0.20±0.22	77	0.12±0.11	86
NO_3^--N (mg/l)	0.047±0.012	0.048±0.017	-	0.041±0.018	-	0.045±0.023	-
NO_2^--N (mg/l)	0.005±0.002	0.005±0.003	-	0.002±0.001	-	0.003±0.002	-
TP (mg/l)	0.61±0.23	0.21±0.10	66	0.21±0.10	65	0.21±0.08	66
TC (MPN/100 ml)	2.56×10^3 ± 1.92×10^3	1.62×10^3 ± 8.79×10^2	36.8	8.00×10^0 ± 7.00×10^0	99.7	5.30×10^1 ± 6.30×10^1	97.9

Note: $\overline{X}$ ± SD, %RE = Removal Efficiency (%)

hydrilla unit was under suspicion. The data of SS removal in this experiment are shown in Figure 3.

c) 5-day Biochemical Oxygen Demand

The requirement of the Hat Yai Municipality Central Wastewater Treatment Plant specified BOD_5 in effluent at 10 mg/l to be compatible with a nearby canal (Klong Kud) that is less than the Thailand Effluent Standards (20 mg/l). As shown in Table 2 and Figure 4, both lotus and hydrilla units could meet this regulation. The stems and leaves of aquatic plants provide a good habitat for bacteria to attach and grow to assimilate the colloidal/soluble BOD_5 remaining in wastewater (Sooknah, 2000). The average removal efficiency of BOD_5 in the hydrilla unit (45-51%) was lower than in the lotus unit (63-79%). This occurrence might be the effect of higher suspended solids (algae) in the hydrilla unit. Excessive amount of algae, which is accepted as organic matter, could contribute to the higher BOD_5 in effluent (Kim and Kim, 2000). BOD_5 removal efficiency was also a function of hydraulic retention time. The longer hydraulic retention time increased the interaction

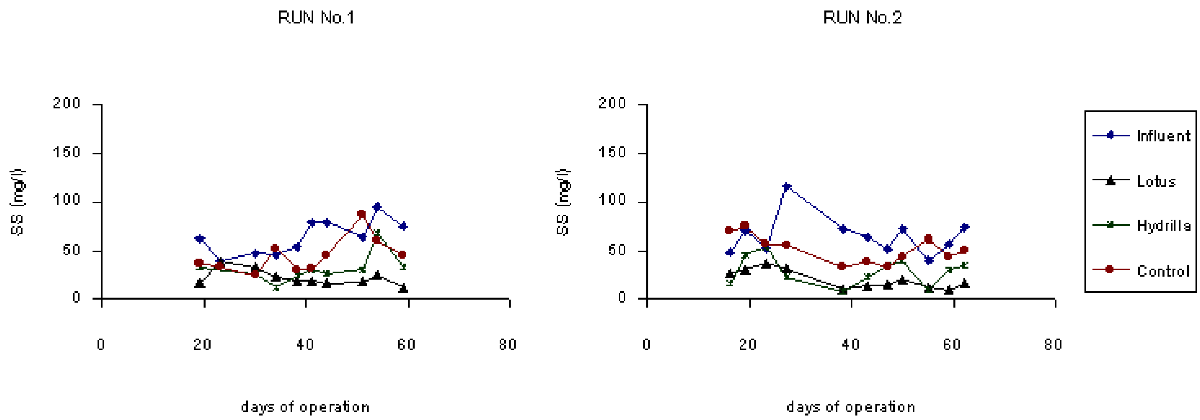

Figure 3. Results of SS removal from experimental units.

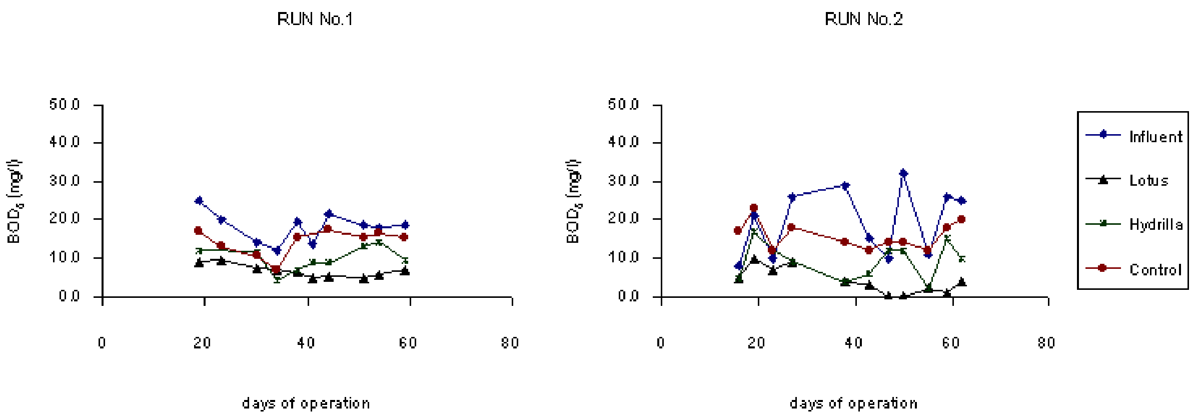

Figure 4. Results of BOD_5 removal from experimental units.

within the aquatic plant system, which resulted in higher organic matter removal.

d) Nutrients

Nutrients, especially nitrogen and phosphorus, have been recognized as the pollutants that contribute to algal bloom or eutrophication in lakes and slowly flowing water. The Effluent Standards of Thailand specified nitrogen as TKN should be less than 35 mg/l in effluent. Even though nitrogen was found to be at low concentration, a problem with high amount of algae in the effluent of the Hat Yai Municipality Central Wastewater Treatment Plant has occurred. As seen in Table 2 and Figure 5, nitrogen removal efficiency among lotus, hydrilla and control units was not different and ranged from 49 to 63 percent. Aquatic plants, themselves, can assimilate nitrogen for their growth and provide a good habitat for bacteria to enhance nitrification and denitrification which should result in higher nitrogen removal efficiency than in the control unit. In contrast, the decay of plant biomass could reduce this removal efficiency. For phosphorus removal, the lotus unit showed higher efficiency than hydrilla and control units, respectively in RUN No.1 but there was no difference in RUN No.2. Phosphorus removal mechanisms are plant uptake, and chemical adsorption and precipitation in the soil (Crites and Tchobanoglous, 1998). In general, chemical

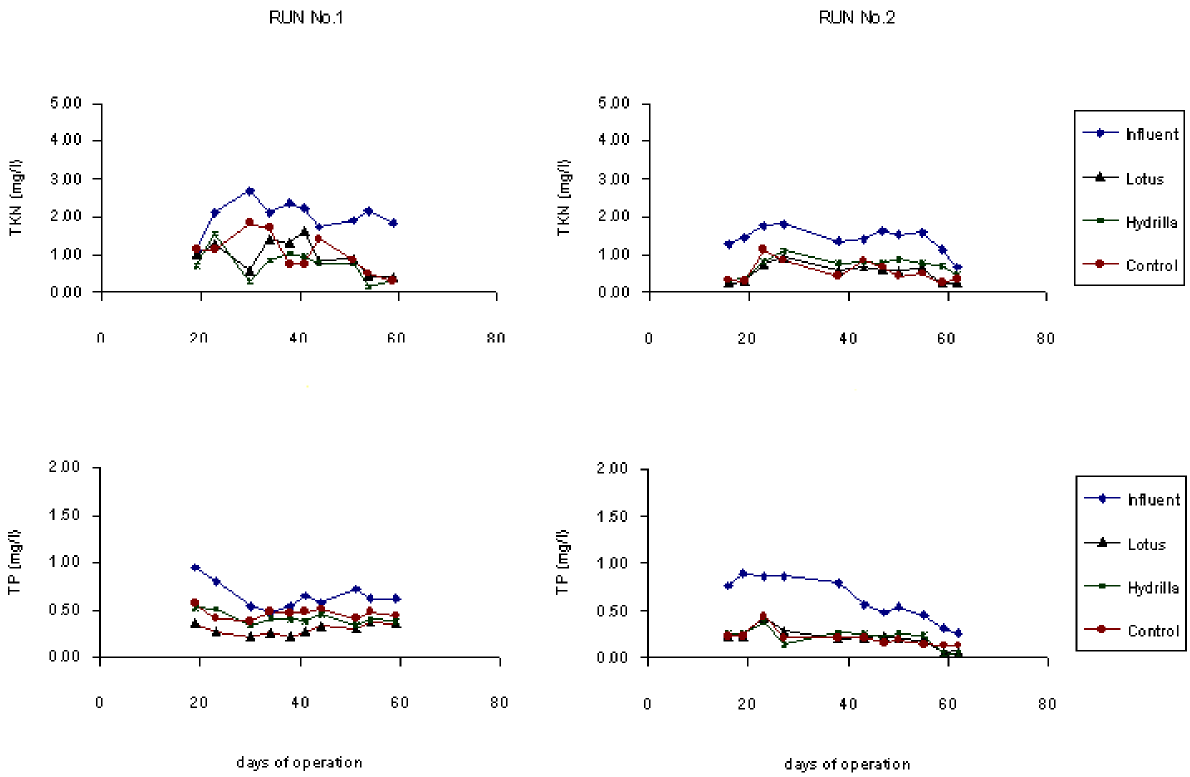

Figure 5. Results of nutrients removal from experimental units.

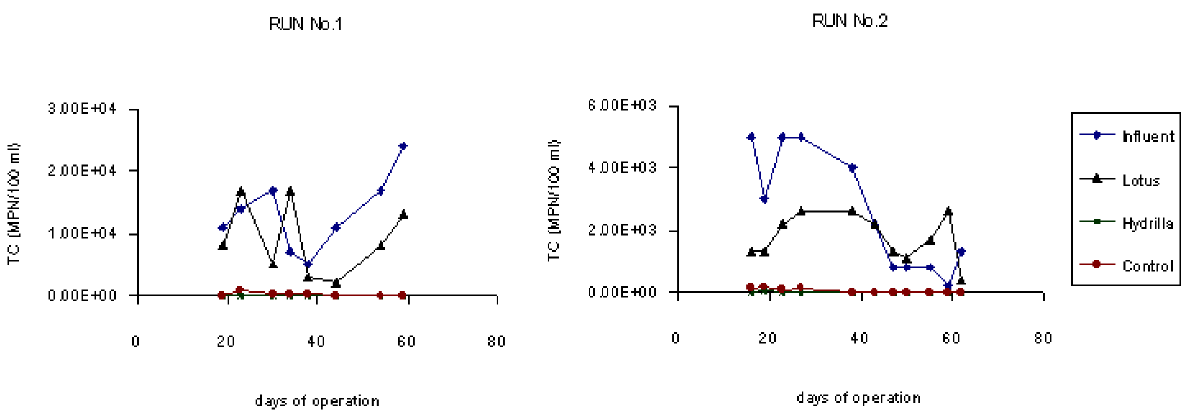

Figure 6. Results of TC removal from experimental units.

adsorption and precipitation are more significant mechanisms of removal (Polprasert, 1996). It could be explained that in RUN No.1 with lower hydraulic retention time, plant uptake of phosphorus for their growth, especially in the lotus unit, could be dominant for phosphorus removal. The longer hydraulic retention time in RUN No. 2 increased the interaction within the system and resulted in enhanced sedimentation of phosphorus.

e) Total Coliform Bacteria

Total coliform bacteria removal efficiency of hydrilla and control units were found to be nearly 100 percent while in the lotus unit it fluctuated and was lower than 40 percent (Table 2 and Figure 6). The high removal of total coliform bacteria in hydrilla and control unit could be from their receiving direct sunlight and their high pH. Prolonged exposure to ultraviolet (UV) radiation and toxic chemicals from algae are a result of being away from a suitable host for microorganisms (Polprasert, 1996). The coverage and shading effect of floating-leaf plants over the water surface could reduce the reliability of pathogenic destruction in the lotus unit.

Conclusions

Based on the results presented, the system with lotus showed the best removal efficiency for pollutant removal in domestic wastewater as post treatment while the hydrilla unit was troubled with high pH in the effluent and under suspicion with SS removal. Hydrilla might not be suitable for effluent polishing. However, constructed ponds with aquatic plants could result in higher efficiency and greater advantage than a system without plant. Lotus and hydrilla, especially lotus, could provide an alternative plant in aquatic plant systems.

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