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Utilising Constructed Wetlands From Water Hyacinth for Wastewater Treatment in Oxidation Ponds

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Abstract: Constructed wetlands are engineered to duplicate the processes occurring in natural wetlands. The main purpose of the structure is to remove contaminants or pollutants from wastewater. Constructed wetland is a new, creative, cost-effective, and green technology compared to conventional treatment systems. Water hyacinth could be cultivated for wastewater treatment and utilised to aid the purification of either industrial wastewater or sewer water. Consequently, the present study was conducted to determine the effects of constructing wetlands with water hyacinth on the wastewater quality of an oxidation pond and the cultivation of water hyacinth as constructed wetlands in an oxidation pond. Floating cages containing water hyacinth plants were monitored for two phases under different wastewater parameters. The data were compared to the Malaysian prescribed Sewage and Industrial Effluent Discharge Standards. The water hyacinth constructed wetlands produced a positive impact and met the requirements for effluent discharge standards.

Keywords: Water hyacinth, *Eichhornia crassipies*, constructed wetland, wastewater treatment

1. Introduction

Wastewater treatment plays a vital role in returning clean and safe water to its sources. Municipal wastewater discharge, such as sewerage, requires appropriate treatments before being released into the environment [1]. Various technologies, including oxidation ponds and activated sludge, have been applied in domestic wastewater treatment, but the operational costs for the methods are expensive. Consequently, there is a need for a substitute system that could overcome the drawbacks and increase the efficiency of domestic wastewater treatment.

Constructed wetlands are artificial wastewater treatment systems that duplicate the processes occurring in natural wetlands. The structure is an integrated system involving selected aquatic plants, microorganisms, and an environment that could be manipulated to improve water quality. The novel green technology has been recognised and accepted as an innovative, cost-effective, and environmentally-friendly system compared to conventional treatment systems. Constructed wetlands consist of shallow (usually under a metre deep) ponds or channels, which have been planted with aquatic plants, and rely upon natural microbial, biological, physical, and chemical processes to treat wastewater. The pollutant removal mechanisms in plant constructed wetlands comprise several physical, chemical, biological, and

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biochemical processes, including sedimentation, filtration, aerobic and anaerobic microbial degradations, plant uptake, soil absorption, and precipitation.

The application of constructed wetlands in wastewater treatment with rooted, emergent, and free-floating aquatic plants has attracted attention due to its environmentally friendly approach [2]. The pollutant removal mechanisms of the techniques involve the interactions between bacterial metabolism, plant uptake, and accumulation. As a crucial biotic factor in the treatment process, plants are the dominant feature in constructed wetlands. [3]. Among aquatic plant species, water hyacinth (*Eichhornia crassipes*) is reported as the most suitable for pollutant removal due to its rapid growth rate and extensive root system [4]. Furthermore, water hyacinth lagoons act as a horizontal trickling filter, where the submerged roots provide physical support for the growth of bacterial biofilms.

Employing water hyacinths in wastewater treatment is economical. Moreover, water hyacinth roots naturally absorb pollutants. Lead, mercury, strontium-90, and some carcinogenic organic compounds were some of the pollutants documented at concentrations of approximately 10,000 times higher in wastewater than in generic water. Consequently, water hyacinths could be cultivated for wastewater treatment and aid water purification processes of industrial wastewater and sewer water. Furthermore, the root structures of water hyacinths provide a suitable environment for aerobic bacteria to remove various impurities in water. Water hyacinths were also employed as a secondary treatment to remove biochemical oxygen demand (BOD) and suspended solids (SS) from domestic wastewater.

The application of water hyacinth is a promising, supplementary approach that requires low-cost implementation. Moreover, the method is an environmentally friendly wastewater treatment approach that could be applied mainly to domestic wastewater. Accordingly, the present study aimed to determine the effects of water hyacinth constructed wetlands on wastewater quality and the cultivation of water hyacinths as constructed wetlands in oxidation ponds.

2. Methodology

The current study employed water hyacinths in two growth phases to determine the ideal cultivation practices for developing constructed wetlands. The plants were also utilised in constructed wetlands to compare their effects under different parameters and physical and chemical characteristics of the wastewater. The constructed wetland from water hyacinth was developed in two oxidation ponds, ponds 1 and 2, that were operated by a national sewerage company in Malaysia.

The water hyacinth plants, *Eichhornia crassipies*, employed in the present study were collected from a local lake. The roots of the plants were carefully washed with tap water to remove dirt. From August to October 2021, the first phase of the investigation involved a total water hyacinth cultivation coverage of both ponds. The water quality and growth of the water hyacinth in the ponds were monitored for seven weeks, involving three stages (see Table 1).

In the second phase, floating cages of water hyacinth constructed wetland was installed at the discharge points in ponds 1 and 2 from October to December 2021. The rectangular floating cages (rafts) were 1 m × 1 m × 0.2 m (L × W × H), each containing 20 water hyacinth plants. Each raft was connected to four buoys 300 mm in diameter and 330 mm long and situated approximately 10 m above. The cages were also anchored with a 10 m steel chain attached to metal trunks in the pond bed to prevent them from being washed away by water currents. The water quality and growth of the water hyacinth were monitored for nine weeks in phase two.

Table 1 - The water hyacinth growth stages

Stage	Condition	Week
1	Water hyacinth overgrowth in ponds 1 and 2	1–2
2	Water hyacinth overgrowth in pond 2 only	3–5
3	Without water hyacinth in ponds 1 and 2	6–7

The current study performed influent and effluent wastewater sampling once a week for seven weeks based on selected parameters. Subsequently, the physical and chemical characteristics of the samples, pH, temperature, dissolved oxygen, chemical oxygen demand (COD), ammonia, and total suspended solids (TSS), were determined according to the procedures outlined in Standard Methods for Water and Wastewater Examinations [6], [7]. The wastewater samples in both ponds were also evaluated before and after introducing water hyacinth to assess the nutrient removal efficiency of the plants.

The degree of acidity or alkalinity of a solution has been reported to be influenced by the temperature at which the pH is measured. Solutions with pH values between 0 and 7 are acidic and become less acidic as the value rises, while 7 to 14 pH values indicate alkaline solutions with increasing alkalinity. The activities of hydrogen and hydroxyl ions are equal at 25.0°C pH 7.0, which is neutral and translates to 10^{-7} moles/L.

In wastewater treatment, the pH of influents has a significant impact. Consequently, pH analysis determines whether the process runs within the acceptable range. The pH value in the present study was monitored with the YSI Professional Plus Handheld. Other than pH, temperature also affects the biological processes occurring in treatment ponds. As microorganisms are unable to regulate their internal temperature, their temperature is determined by the surrounding temperature. Accordingly, the current study employed the YSI Professional Plus to record the temperature of the samples.

Bacteria and bacterial flocs, algae, protozoa, and organic debris are the most common TSS components in wastewater. In the present study, TSS was evaluated by filtering the samples through a 90 mm pre-weighed glass microfiber (GF/C) filter with a nominal pore size of 1.5 μm in a filtration apparatus attached to a vacuum pump. Subsequently, the filter was oven-dried at 105°C, chilled in a desiccator with moisture-indicating silica gel, and reweighed. The solid present on the filter is known as suspended solids. The amount of TSS in each sample was the weight discrepancy between the filter paper and dried filter paper with residual solids (Eq. (1)).

$$TSS(mg/L) = \left(\frac{A-B}{C}\right) \times 1000 \quad (1)$$

where *A* represents the mass of the nonfilterable residue on a Watman GF/C filter after evaporation at 105°C (mg), *B* denotes the mass of the filter paper prior to sample filtration (mg), and *C* is the volume of the filtrated sample (mL).

The oxygen equivalent of the organic matter content of a sample vulnerable to oxidation by a powerful chemical oxidant is measured via COD. The unreacted oxidising agent (remaining chromate) concentration could be determined by a redox back-titration or by colourimetrically assessing the amount of reduced chromium produced, in which the measured wastewater sample was then heated with a known amount of potassium dichromate-sulfuric acid solution. Subsequently, the oxygen equivalent of oxidant ingested is employed to calculate the amount consumed.

The COD analysis is utilised to assess the pollution level of wastewater and natural water, where a higher COD value indicates a more polluted test sample [7], [11], [17]. In the current study, the COD of each sample was assessed according to the USEPA Reactor Digestion Method. Two millilitres of the wastewater sample were pipetted into a digestion solution for a high range type (20 to 1500 mg/L) COD. Subsequently, the vials containing the mixture were placed in a block digester and heated at 150°C for two hours.

In the present study, the ammonia concentration in each sample was determined based on the salicylate method. The evaluation was set at a wavelength of 655 nm on a DR 3900 spectrophotometer (HACH). The technique is applicable over the 0.4 to 50 mg/L range. The amount of ammonia present in the evaluated sample is represented by a yellow colour [6], [7]. The current study also measured the nitrate content in each wastewater sample according to the high range (HR) cadmium reduction (Method 8171) at 400 nm. The method could detect nitrogen at concentrations within the 0 and 30.0 mg/L range. In the present study, one sample cell was filled with the wastewater sample and a Nitra Ver 5 Nitrate reagent powder pillow, while the second sample cell (the blank) was filled with the wastewater sample without the reagent. The Standard Methods for the Examination of Water and Wastewater were adapted for this operation.

Statistical analyses involving ANOVA in the current study were conducted with an SPSS software. The measured values obtained were expressed as the mean ± standard deviation. A confidence level of 95% was determined as notable, while a statistically significant difference was defined as $P < 0.05$. All analytical data acquired were compared to the Malaysia Sewage and Industrial Effluent Discharge Standards (see Table 2).

Table 2 - The Malaysia sewage and industrial effluent discharge standards

	Parameter	Unit	Standard	
			A	B
(a)	Temperature	°C	40	40
(b)	pH value	-	6.0–9.0	5.5–9.0
(c)	BOD at 20°C	mg/L	20	50
(d)	COD	mg/L	120	200
(e)	Suspended solids	mg/L	50	100
(f)	Oil and grease	mg/l	5.0	10.0
(g)	Ammonical nitrogen (enclosed water body)	mg/l	5.0	5.0
(h)	Ammonical nitrogen (river)	mg/l	10.0	20.0
(i)	Nitrate-nitrogen (river)	mg/l	20.0	50.0
(j)	Nitrate-nitrogen (enclosed water body)	mg/l	10.0	10.0
(k)	Phosphorus (enclosed water body)	mg/l	5.0	10.0

3. Results and Discussions

In phase 1 of the study, ponds 1 and 2 recorded mean pH values between 6.72–8.15 (see Table 3). Consequently, the water hyacinths in the oxidation ponds proliferated rapidly as the suitable pH range for water hyacinths to survive is between 4.0 and 8.0 [9]. The mean temperatures of the wastewater samples from the oxidation ponds with water hyacinth ranged between 28.87–29.54°C, while the mean values of dissolved oxygen (DO) were within 0.58–0.80 mg/L. Nevertheless, in phase 2, the DO level increased over time, which was assumably related to the high amount of oxygen released into the water column from the rapid growth of the water hyacinths [16].

Table 3 - The on-site monitoring mean values of pH, temperature, and dissolved oxygen

	pH		Temperature (°C)		DO (mg/L)	
	Pond 1	Pond 2	Pond 1	Pond 2	Pond 1	Pond 2
Phase 1	6.72 ± 0.306	7.22 ± 0.594	28.87 ± 0.492	29.10 ± 0.785	0.80 ± 0.693	0.58 ± 0.275
Phase 2	7.41 ± 0.362	8.15 ± 0.446	29.48 ± 0.712	29.54 ± 1.271	3.04 ± 1.458	3.70 ± 2.225

3.1 Laboratory Analyses of the Wastewater Samples

The mean baseline and mean values of COD, BOD, ammonia (AN), TSS, and total phosphate (TP) concentration recorded for phases 1 and 2 are presented in Table 4. In the current study, the baseline and phases 1 and 2 effluent COD levels were within the 128.85–230.42 mg/L range. In general, the COD concentration achieved standard B of the Malaysia Sewage and Industrial Effluent Discharge Standards with the application of water hyacinth. The results proved that the plant was able to reduce the COD concentration due to the activities of the microorganisms in its roots [13].

The results of phases 1 and 2 also demonstrated that the COD concentration met standard A of the Malaysia Sewage and Industrial Effluent Discharge Standards. The high number of water hyacinths indicated that the plants could be employed as polishing agents. Furthermore, the BOD mean values of the effluent samples in phase 1 were documented within 30.57–45.15 mg/L, which was lower than the baseline at 87.57 mg/L. The water hyacinths effectively reduced the BOD concentration to meet standard B of the Malaysia Sewage and Industrial Effluent Discharge Standards.

The baseline and mean effluent ammonia concentration values for phases 1 and 2 were between 12.35–11.590, 14.71–10.212, and 21.61–3.726 mg/L, respectively. The ammonia removal in phases 1 and 2 were recorded at 14.71 and 21.61 mg/L compared to the baseline (12.35 mg/L) after the water hyacinths were installed. Moreover, the ammonia concentration in phase 2 started to reduce after week 5 and met the Effluent Quality Sewage Regulation 2009 (EQSR 2009) compliance for standard B of the Malaysia Sewage and Industrial Effluent Discharge Standards. Nevertheless, due to non-functioning paddle aerators in the oxidation ponds, the ammonia concentration increased in week 9.

The baseline and phases 1 and 2 influent suspended solid concentrations ranged between 70–130, 18–102, and 48–100 mg/L, respectively. The results in Table 4 also demonstrated that after installing the water hyacinths, the average TSS in the effluent samples was reduced to the accepted level of sewage discharge as outlined in standards A and B of the Malaysia Sewage and Industrial Effluent Discharge Standards.

The available phosphate in the samples was also diminished with water hyacinth. The phosphate concentrations in phases 1 and 2 ranged between 2–10 and 2–7 mg/L, respectively, while the baseline recorded 6–12 mg/L. The water hyacinths reduced the available phosphorus in the samples as the substance is a vital nutrient for its growth. Consequently, water hyacinth could reduce phosphate concentration to the acceptable range as stated in standards A and B of the Malaysia Sewage and Industrial Effluent Discharge Standards.

Table 4 - The mean values of the influent and effluent parameters of the wastewater in the oxidation ponds

Parameter		Baseline	Phase 1	Phase 2
COD (mg/L)	Influent	230.42 ± 217.493	278.28 ± 204.408	361.28 ± 78.847
	Effluent	128.85 ± 159.309	90.14 ± 73.062	130.00 ± 26.987
BOD (mg/L)	Influent	87.57 ± 109.927	87.142 ± 63.645	137.427 ± 35.309
	Effluent	30.57 ± 44.022	30.57 ± 24.865	45.14 ± 9.094
Ammonia (mg/L)	Influent	15.44 ± 15.113	19.27 ± 13.786	31.142 ± 5.386
	Effluent	12.35 ± 11.590	14.71 ± 10.212	21.61 ± 3.726
TSS (mg/L)	Influent	92.71 ± 96.643	64.28 ± 56.620	119.42 ± 56.941
	Effluent	66.28 ± 65.708	34.57 ± 37.907	71.14 ± 18.685
Total phosphate (mg/L)	Influent	6.55 ± 6.334	8.51 ± 6.247	3.70 ± 3.709
	Effluent	6.14 ± 5.785	4.77 ± 3.706	2.14 ± 3.284

3.2 Visual Observations of the Wastewater Samples

The visual observation of the effluent wastewater from the oxidation pond was recorded based on the colour of samples taken at different parts of the oxidation ponds. The sampling was performed weekly from week one until week seven in Phase 1. Fig. 1 illustrates that fewer algae were present in pond 2 during the overgrowth of the water hyacinths. The algae were inable to grow in the pond due to the water surface of the pond being covered by the water hyacinths that resulted in causing minimum sunlight penetration into the water.

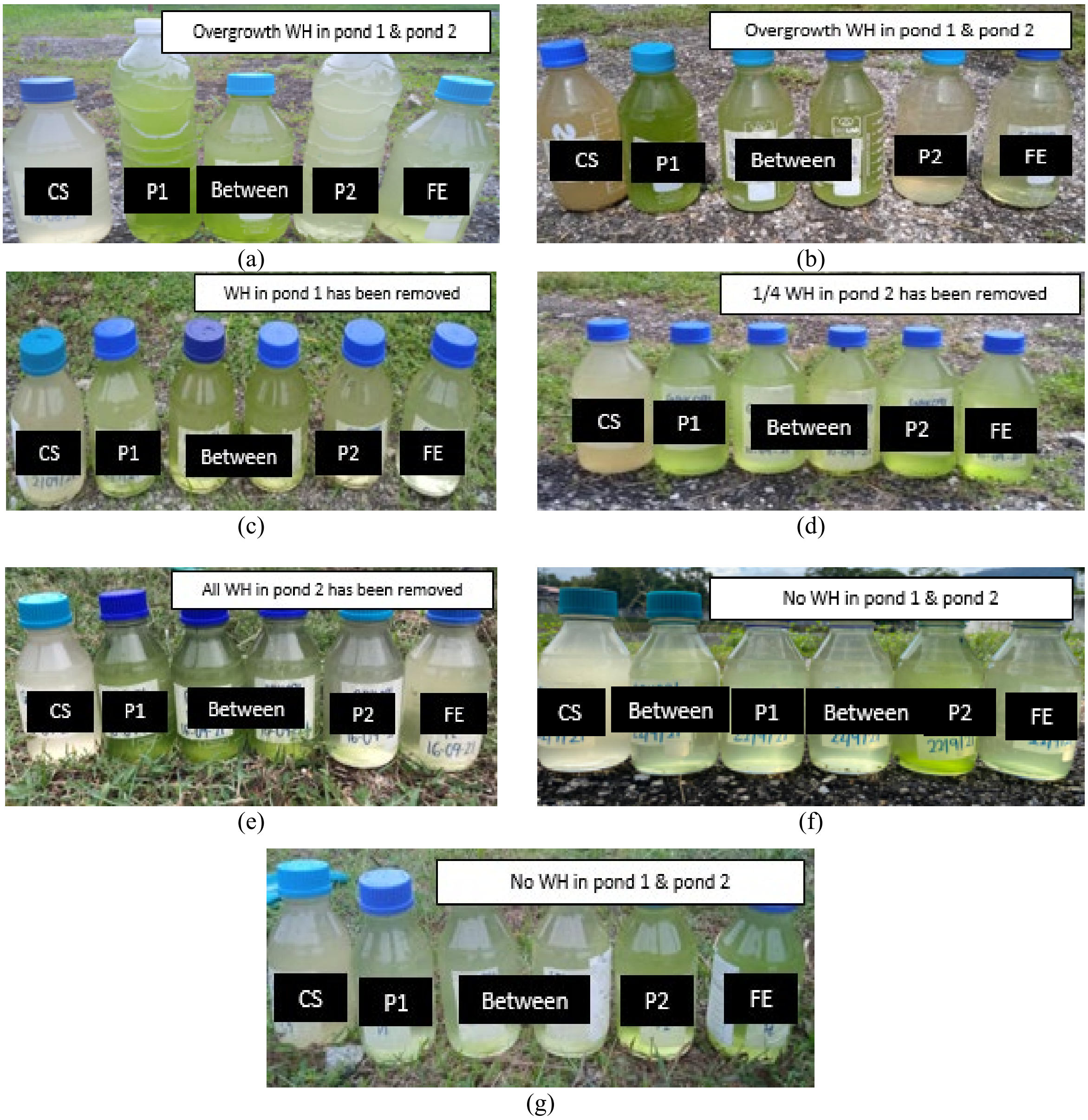

Fig. 1 - The visual observation of the wastewater samples at weeks (a) 1, (b) 2, (c) 3, (d) 4, (e) 5, (f) 6, and (g) 7 Note: CS represents crude sewage, P1 denotes pond 1, Between indicates between ponds 1 and 2, P2 represents pond 2, and FE is the effluent

3.3 The Growth of the Water Hyacinths

In the present study, the wet weight of the water hyacinths was evaluated based on the capacity of the plants in 1 m^2, which was equivalent to 26 kg wet weight [14]. For phase 1, the wet weight of the water hyacinths was only measured at stage 2 (week 5). For pond 1, the weight of the water hyacinths was estimated based on the surface area of the 10 2 m × 2 m floating cages, which totalled 40 m^2 (Fig. 2(a)). Based on the assumption, the capacity of the water hyacinths in the pond was 1040 kg (1.04 tons wet weight).

For pond 2, the total water surface was covered with water hyacinths (Fig. 2(b)), which was 1300 m^2. Accordingly, the wet weight of the water hyacinths in pond 2 was estimated at 33,800 kg (33.8 tons wet weight). Based on the estimations, the wet weight of the water hyacinths in pond 2 was higher than in pond 1. The observations were due to the presence of an aerator in pond 1 and the flow of water hyacinths from pond 1 to pond 2 increased the number of water hyacinths in pond 2.

(a) (b)

Fig. 2 - The growth of the water hyacinths in pond, (a) 1; and (b) 2

The two most important factors that affect the growth of plants are temperature and water nutrient level [12]. Phase 1 (6th October to 8th December 2021) of the present study was initiated with a different data collection. The study started with 50 plants as the polishing agents and the growth of the plants were observed to increase over the week rapidly. According to the results, the absence of interspecific competition, such as other aquatic vegetation, was one of the reasons for the swift growth of the water hyacinths.

The capacity of 1 m^3 water hyacinth is equivalent to 26 kg wet weight. After five weeks of observation on the floating cages (40 m^2), the water hyacinth population in the current study elevated to 1.04-ton wet weight for each pond. The plants exhibited the logistic growth, r2, of 0.7 to 1.00. Conclusively, the abovementioned factors were the main reasons for the rapid growth of the water hyacinths within a few weeks. Nonetheless, without proper monitoring, unexpected growth outside the cage could happen. The different locations of floating cages situated at varying phases did not affect the growth of the water hyacinths. The results demonstrated that the conditions of water treatment plants are suitable for the growth of water hyacinths.

(a) (b)

(c) (d)

Fig. 3 - The growth of the water hyacinths at, (a) week 1 in pond 1; (b) week 1 in pond 2; (c) week 9 in pond 1; and (d) week 9 in pond 2

4. Conclusion

In the present study, the application of water hyacinth as a natural polishing agent resulted in an increased dissolved oxygen level on the water surface of the oxidation ponds up to 12 (pond 1) and 10 mg/L (pond 2), which was due to the oxygen released by the roots of plants. Furthermore, the average COD removal percentages in phases 1 and 2 were 51 and 60% compared to the baseline, at 47%. Moreover, by having a high number of water hyacinth plants or employing the plants as the polishing agents in the oxidation ponds, the COD removal percentage met the prescribed standard A of the Malaysian Sewage and Industrial Effluent Discharge Standards. Consequently, the addition of water hyacinths in constructed wetlands in oxidation ponds presents the potential to assist domestic wastewater treatment. Furthermore, the application of the environmentally-friendly water hyacinth constructed in sewerage treatment plants could lower costs.

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