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Short Term Treatment of Shrimp Aquaculture Wastewater Using Water Hyacinth (*Eichhornia crassipes*)

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Abstract: Among the environmental concerns of shrimp aquaculture is pollution from pond effluent. Water hyacinth was found to be effective in treating different types of wastewater. Therefore, in this study the potential of short term treatment of pond effluent was investigated. Wastewater from newly harvested shrimp pond was placed in fiberglass tanks outdoor where water surface was fully-cover (F), half-cover (H) and not covered (control) (C) with water hyacinth for 76 hours. Results show that percent reductions were in decreasing order of F>H>C in all the parameters studied. Ammonia nitrogen in F decreased from 1.8 mg/L to 0.2 mg/L in 46 hours whereas in H and C, their concentrations were above 0.6 mg/L. For F treatment, percentage reductions ranged from 52.5 to 100% and were in the order of NO_3-N>NO_2-N>TP>TAN>TN>TSS>RP>BOD_5>COD. In H, reduction ranged between 45.4 to 95.2% and in C they ranged from -18.5% to 74.9%. First order decay coefficient for all the parameters were the highest in F followed by H and C treatments. This study showed that even though the duration of the treatment was short, suspended solids, oxygen demand, nitrogen and phosphorus reductions were significantly higher in the water hyacinth treatments compared to treatment without water hyacinth.

Key words: Water hyacinth · Shrimp effluent · Wastewater treatment · Aquatic macrophytes · *Penaeus monodon*

INTRODUCTION

Shrimp aquaculture is an important industry as capture shrimp is not able to meet the growing global demand of shrimp products and it brings high economic returns [1]. Shrimp aquaculture is mostly concentrated in Asia and among the concerns is water pollution from intensive shrimp aquaculture [2]. Intensive shrimp farm wastewater was reported to be high in total suspended solids and high in nutrients such as nitrogen and phosphorus [3, 4] due to the low assimilation of nitrogen and phosphorus by the shrimp. Nutrient budget studies showed that shrimp could only assimilate 23-31% nitrogen and 10-13% phosphorus of the total input [5]. Thus, the remaining nitrogen and phosphorus are discharged during regular water exchange or incorporated in the pond sediment which is washed out after shrimp harvesting. An economical way to treat the wastewater is to discharge it into sedimentation ponds. In Malaysia, similar management practice is in place whereby shrimp operators are required to retain the wastewater in sedimentation ponds for 72 hours prior to release into the rivers in order to protect the surrounding environment. However, studies indicate that sedimentation ponds were effective in reducing discharges of suspended particulates but less effective in reducing nutrient concentrations [6].

Treating wastewater using aquatic macrophytes not only protects the receiving water from eutrophication and the negative impacts on aquatic organisms but also allows nutrients to be recycled. Recycling of nutrients is urgent because nutrients such as phosphorus are a non-renewable resource derived from phosphate rock and current global reserve may be depleted in 50-100 years [7]. Different aquatic plants systems for treatment of shrimp farm wastewater have been reported. Submerged aquatic plants, *Elodea densa*, were reported to reduce the peak ammonia and nitrite concentrations of recirculating *Macrobrachium rosenbergii* culture systems [8]. Experimental scale model constructed wetland with *Acrostchum aureum*, a mangrove fern, in gravel was

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reported to reduce more organic carbon, nitrogen and phosphorus more than that without plant [1]. Free water surface and subsurface flow constructed wetland cells using cattail and common reed to control water quality of recirculating aquaculture systems for shrimp culture was reported to effectively reduce total suspended solids, biochemical oxygen demand, ammonia and nitrite [9, 10]. Water hyacinth has been found to be effective and tolerant in treating piggery wastewater [11, 12] dairy farm wastewater [13, 14, 15] and urban sewage [16]. However, according to Parsons and Cuthbertson [17], water hyacinth does not tolerate salinity levels above 16 ppt. Since the effluents were normally retained in sedimentation ponds for three days only, short term treatment effect needs to be investigated. Therefore, the objective of this study was to investigate the potential of short duration treatment of brackish wastewater from shrimp pond using water hyacinth.

MATERIALS AND METHODS

The experimental study was conducted outdoor at a commercial *Penaeus monodon* shrimp farm of the Malaysian Fisheries Development Board (LKIM) at Telaga Air, Matang, located in the north east of Kuching division, Sarawak, Malaysia. The climate of the area is tropical equatorial which is warm and humid throughout the year.

The experimental design was completely randomized design with three treatments where the surface was fully covered (F), half covered (H) and not covered (C) with water hyacinth which was the control that represented the sedimentation pond. Wastewater from newly harvested *Penaeus monodon* shrimp pond was channeled into a sedimentation pond and subsequently pumped into nine fiberglass tanks of water surface diameter of 1.5 m, depth of 0.6 m and volume of 0.96 m^3. Three replicates were setup for each treatment. Equal weights of water hyacinth were placed in each replicate tank. Water samples were collected nine times at 0, 4, 8, 12, 18, 24, 36, 46 and 76 hours. Temperature and DO values were recorded using Hydrolab Data Sonde Surveyor 4a with Water Quality Multiprobe (SN39301). pH and salinity were measured using a pH meter (Cyberscan 20) and a refractometer (Atago S-10) respectively. Water in the tanks was sampled and analyzed for total suspended solids (TSS), 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total ammonia-nitrogen (TAN), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), total nitrogen (TN), reactive phosphorus (RP) and total phosphorus (TP).

TSS and BOD_5 analyses followed that of standard methods [18]. For the other parameters, water samples were filtered through a 0.45 µm pore size membrane filter before analysis using Hach procedures where concentrations were determined colorimetrically using the Hach Spectrophotometer DR2010 [19]. COD was determined using the reactor digestion method. Determination of NO_3-N and NO_2-N were based on cadmium reduction method and diazotization method respectively. TAN and TN were analyzed using Nessler method and persulfate digestion method. RP and TP analysis followed the ascorbic acid method and the acid persulfate digestion method.

First order decay equation is frequently used to quantify the decay of pollutants in wetland treatment [9, 10]. It can be expressed as

$$\frac{C}{C_o} = e^{-kt} \qquad (1)$$

where k is the decay coefficient (d^{-1}), C_o is the initial concentration and C is the concentration at time t. The values of k were obtained by the regression of ln C on t.

One-way analysis of variance (ANOVA) was used to compare the mean reduction and decay coefficients of water quality parameters. Tukey's test was performed to identify statistically significant difference between pairs of means. Data were analyzed using SPSS version 17.0.

RESULTS

During the experiment, salinity was observed to range from 24.5 to 26.5 psu in all treatments. For temperature, the ranges in the C treatment was the highest (5.7°C) followed by H (4.0°C) and F (3°C) (Fig. 1) respectively. pH values fluctuated more in C tanks than F treatment and the values in C (> 8) were consistently higher than those of F and H (Fig. 1). In the H treatment, pH was slightly higher than that of F throughout the experiment. TSS decreased exponentially in all treatments during the duration of the study in decreasing order of F>H>C (Fig. 1). The initial value of 125 mg/L decreased to 12.3 mg/L, 22.8 mg/L and 32.8 mg/L in the F, H and C treatments respectively after 76 hours.

DO in F treatment increased slightly and subsequently decreased from 3.9 to 0.04 mg/L (Fig. 1). Similar trend was observed in the H treatment but DO was slightly higher than the F treatment where it reached the highest value of 5.3 and dropped to 0.10 mg/L.

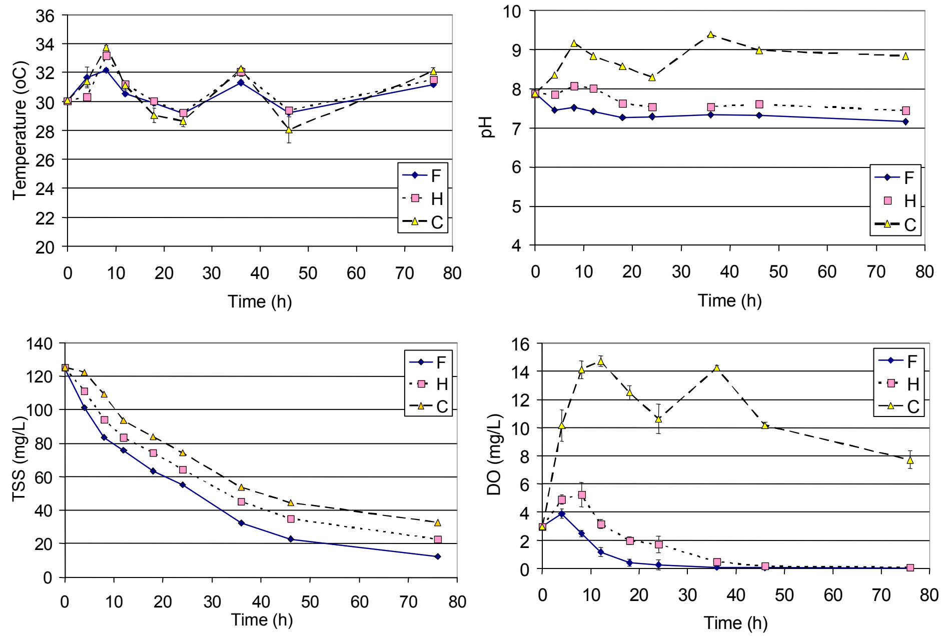

Fig. 1: Temperature, pH, TSS and DO in fully covered (F), half covered and not covered (C) with water hyacinth treatments during the course of the experiment.

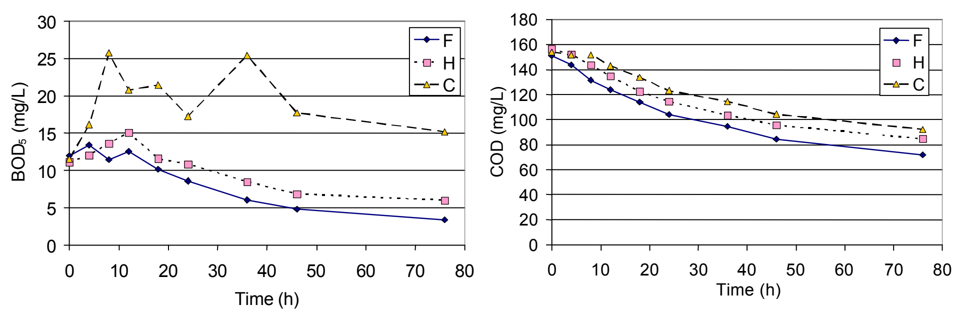

Fig. 2: BOD_5 and COD trend in fully covered (F), half covered (H) and not covered (C) with water hyacinth treatments during the course of the experiment

However, in the C treatment, DO increased to a maximum of 14.7 mg/L and I t fluctuated between 7.7 and 14.7 mg/L. In F and H treatments, initial BOD_5 of 12 and 11 mg/L decreased to 3.4 and 6.0 mg/L respectively. However, in the C treatment, BOD_5 increased from 11.5 to a maximum of 25.7 mg/L and fluctuated resulting in the final value (13.7 mg/L) higher than the initial value (Fig. 2). In the F and H treatments BOD_5 peaked at 4-hr and 12-hour after which they decayed exponentially. COD trends were similar to TSS where there was exponential decay with final concentrations increasing in the order of F>H>C. COD in F, H and C treatments decreased from initial values of 151, 156, 154 mg/L to final values of 72, 85 and 92 mg/L respectively.

Both RP and TP decreased exponentially to low values within 46 hours with final concentrations increasing in the order of F>H>C (Fig. 3). In the treatments with plants, RP initial values of 0.45 and 0.43 mg/L decreased to 0.07 and 0.12 respectively. However, in the C treatment, initial value of 0.43 mg/L decreased to 0.15 mg/L only.

For nitrogen, TAN, NO_2-N, NO_3-N and TN showed larger decrease in concentrations under the F treatment when compared to the H and C treatments (Fig. 4). TAN in F decreased from 1.8 mg/L to 0.2 mg/L in 46 hours whereas in H and C, their concentrations were still above 0.6 mg/L. The concentrations NO_2-N and NO_3-N increased initially in all treatments. For NO_2-N, subsequent decrease was most likely due to conversion to NO_3-N. Eventually,

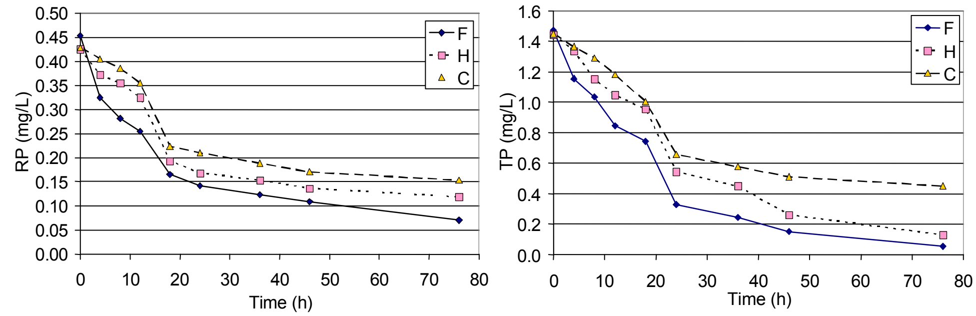

Fig. 3: RP and TP trend in fully covered (F), half covered (H) and not covered (C) with water hyacinth treatments during the course of the experiment

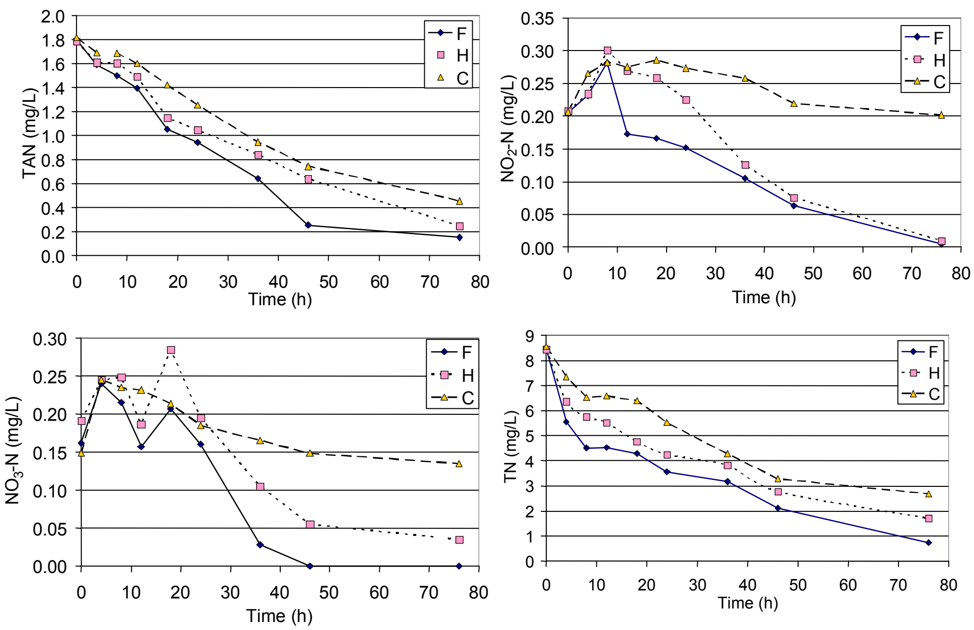

Fig. 4: TAN, NO_2-N, NO_3-N and TN trend in fully covered (F), half covered (H) and not covered (C) with water hyacinth treatments during the course of the experiment

in F and H treatments, NO_2-N decreased to zero. However, for the C treatment, NO_2-N decreased but much more slowly and remained quite high (0.20 mg/L) at the end of the experiment. NO_3-N decreased from 0.16 and 0.19 mg/L respectively to zero in F and H. It took 46 hours for NO_3-N in the F treatment to be reduced to zero and in H it decreased to 0.06 mg/L in that duration. However, in the C treatment, final concentration was still high (0.14 mg/L).

In terms of reduction, the percentage reduced were in decreasing order of F>H>C in all the parameters studied (Table 1). In all the parameters, F was significantly better than H (P=0.037) and C (P<0.0005) and H was significantly better than C (P=0.042). For F treatment, percentage reduction ranged from 52.5 to 100% with six parameters achieving more than 90% removal, BOD_5 and RP achieved 71.5 and 84.7% respectively and 52.5% for COD. Percent reduction in F treatment was in decreasing order of NO_3-N>NO_2-N>TP>TAN>TN>TSS>RP>BOD_5>COD. In the H treatment, percentage reduction ranged from 45.4 to 95.2% and similar to F, BOD_5 and COD recorded the lowest reduction of less than 50%. In the C treatment which represented the sedimentation pond, reduction ranged from-18.5% for BOD_5 to 74.9% for TAN. There was an increase in BOD_5 at the end of the experiment giving negative reduction. Both NO_2-N and NO_3-N reductions were very low, 2.3 and 6.5% respectively and reduction for other parameters ranged from 40% to 75%.

Table 1: Reduction of water quality parameters in different treatments

	Reduction (%)		
Parameter	F	H	C
TSS (mg/L)	90.1±1.1a	81.8±0.8b	73.9±2.0c
BOD_5 (mg/L)	71.5±6.6a	45.4±7.5b	-18.5±4.8c
COD (mg/L)	52.5 ±0.9a	45.8±2.3b	40.0±2.1c
RP (mg/L)	84.7±2.6a	72.1±2.9b	64.3±3.4c
TP (mg/L)	96.0±1.7a	89.0±1.4b	69.1±3.9c
TAN (mg/L)	91.7±1.6a	86.1±2.0b	74.9±1.6c
NO_2-N (mg/L)	97.6±0.3a	95.2±0.9b	2.3±0.9c
NO_3-N (mg/L)	100.0±0.0a	87.9±3.1b	6.5±5.2c
TN (mg/L)	91.4±1.7a	79.9±1.5b	68.7±1.1c

Means in the same row with the same letters are not significantly different at 5%

Table 2: First order decay coefficient, k and its goodness of fit for water quality parameters

	k (d^{-1})			R^2		
Parameter	F	H	C	F	H	C
TSS (mg/L)	0.74±0.03a	0.55±0.02b	0.46±0.02c	98.1±0.9a	97.6±1.3a	95.8±2.5a
COD (mg/L)	0.24 ±0.00a	0.20±0.01b	0.18±0.01c	94.6±1.6a	93.1±2.7a	95.7±1.8a
RP (mg/L)	0.56±0.06a	0.47±0.04ab	0.36±0.04b	87.8±5.8a	82.5±3.0a	78.8±6.6a
TP (mg/L)	1.09±0.13a	0.76±0.04b	0.42±0.06c	97.1±2.5a	96.2±0.3a	84.9±5.3b
TAN (mg/L)	0.85±0.06a	0.61±0.03b	0.46±0.02c	95.9±0.5a	98.6±0.5b	98.8±0.5b
TN (mg/L)	0.67±0.01a	0.46±0.01b	0.37±0.01c	95.1±0.7a	97.0±0.7a	94.7±1.8a

*Means in the same row with the same letters are not significantly different at 5%

Table 2 shows the values of the decay coefficient, k and its goodness of fit measured by coefficient of determination, R^2. First order decay fitted the data well with R^2 more than except for RP where R^2 ranged from 79-88% due to the drastic drop in concentration for the first 18 hours and subsequently small decrease. Decay coefficient for all the parameters were the highest for the F treatment followed by H and the lowest was the C treatment. Statistical analysis showed that all parameters except RP, the F treatment decay coefficient was significantly higher than H treatment (P=0.006) and C (P=0.006) treatment. H treatment was significantly higher than C treatment P=0.021). For RP, the H treatment was not significantly different from F treatment (P=0.146) and C treatment (P=0.078).

DISCUSSION

Mean temperature ranges for the treatments were different due to the area of exposure of the water surface to solar radiation whereby the area covered by water hyacinth was shaded from solar radiation and thus less temperature change occurred. pH, DO and BOD_5 in the C treatment fluctuated due to algae growing in the nutrient rich condition which used up carbon dioxide for photosynthesis during the day causing pH to rise to 9 or more during daytime [20]. In the process, oxygen was produced giving high DO. In the H treatment, pH was slightly higher than that of F treatment due to the influence of algae as the tank surfaces were only half covered by water hyacinth. TSS in the tanks reflects the solids discharged from the harvest ponds and sedimentation was the primary mechanism responsible for the decrease over time. However, the H and C treatments showed higher TSS than F treatment throughout the experiment due to the growth of algae which added to the TSS as the quantity of algae was proportional to the area exposed to solar radiation. Water hyacinth has been used to control algae growth [17].

DO decreased in the F treatment due to the consumption of oxygen during the oxidation of organic matter and nitrification process whereby ammonia was oxidized but minimally replaced by aeration as the surface was fully covered by plants. In the H treatment, since the surface was half covered by water hyacinth, DO was higher than F throughout the experiment due to the supply of oxygen from algae photosynthesis. The decrease of DO in the treatments with plant was also observed by Lin *et al*. [9] where it was reported that DO decreased from 5.4 to 2.0 mg/L in a combined free water surface flow and subsurface flow constructed wetland system planted with common reed in treating shrimp wastewater.

Oxygen demand reductions were higher in the treatments with water hyacinth than that without water hyacinth due to the increase in bacteria responsible for the breakdown of organic matter provided by the large surface areas of the extensive roots of the water hyacinth plants for their attachment [21]. This also explains the higher reduction of TAN, NO_2-N, NO_3-N and TN in the F and H system when compared to the C treatment. The key mechanism of P removal in pond systems was uptake by plants [22]. Both algae and water hyacinth took up P for their growth. This explains the decrease of P in all the three treatments. However, the bacteria attached to the extensive root system of water hyacinth is likely responsible for the higher reduction in treatments with plants.

The decrease in concentration of TAN in the F treatments was predominantly due to oxidation to nitrate which in the F and H systems were taken up by water hyacinth. The concentrations NO_2-N and NO_3-N increased initially in all treatments due to the addition of nitrite and nitrate from the oxidation of ammonia through nitrification process. In C treatment, due to the high DO provided by algae respiration, oxidation of ammonia to NO_2-N and NO_3-N continued and thus giving high final NO_2-N and NO_3-N and low reduction. In the F treatment, NO_3-N decreased to zero at 46 hours likely due to denitrification process. From the 18^{th} hour, since DO dropped below 1 mg/L and oxygen became the limiting nutrient and nitrification slowed down [22]. In this anoxic condition, most likely denitrification process occurred to remove nitrogen where NO_3-was reduced to NO_2-and subsequently to nitric oxide (NO), nitrous oxide (N_2O) and nitrogen gas and the last three are in gaseous form and thus were released to the atmosphere [22].

Comparing the trend of reduction of different parameters with that of the combined free water surface flow and subsurface flow constructed wetland system planted with common reed treating shrimp wastewater [9], there is similar observation of low reduction of BOD_5 (24%) but high reduction of TSS (71%), TAN (57%), NO_2-N (90%), NO_3-N, 68%. The only difference is that, it was reported that RP reduction (5.4%) was much lower than the present study. The higher removal of RP in the present study could be due to the low concentrations of RP (0.43-0.45 mg/L) and thus they were almost all taken up by the abundant water hyacinth whereas in their reported, RP was much higher, 8.5 mg/L. COD reduction in the F treatment exceeded 50% in the present study of 3.2 days was considerable as Zimmels *et al*. [16] also reported that COD decreased from 460 to 100 mg/L after 6-7 days of no circulation in water hyacinth free water surface flow system treating urban sewage in Israel.

For trend of decrease, with minimal interference from algae, the decrease was exponential which is similar to the report of Lin *et al*. [9]. In terms of values of decay coefficient, for the TAN, the value of 0.85 d^{-1} in the present study was slightly less than the combined free water surface flow and subsurface flow constructed wetland system value of 1.115 d^{-1} [9], but more than the value of 0.434 d^{-1} [23, 24] As for decay coefficient for RP of 0.56 d^{-1}, it is slightly higher than 0.479 d^{-1} reported by [9].

CONCLUSIONS

This study shows that water hyacinth fully covered treatment showed the highest reduction of oxygen demand, nitrogen, phosphorus and solids followed by half covered treatment and the least efficient was the non-vegetated treatment which represented the sedimentation pond. It is therefore recommended that water hyacinth be introduced to improve the water quality of sedimentation pond before discharge. However, DO in the water hyacinth treatment had to be increased to protect sensitive aquatic species in the river.

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