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Studying on the Treatment of High Salinity Concentration Wastewater from Shrimp Farm by Floating Constructed Wetlands (FCWs) Models: Effect of Plant Cover Area

Nga Dinh Thi*, Anh H. Q. Le, Tuan D. Phan

Hochiminh City University of Natural Resources and Environment, 236B, Le Van Sy St., Ward 1, Dist. Tan Binh, Hochiminh City, Vietnam
dtnga@hcmunre.edu.vn

This study was processed to investigate FCWs systems' performance cultivated by native plants for treating high salinity level of shrimp farm wastewater. Three circular FCWs models (pond 1; pond 2; pond 3), which had 10 m^2 in surface area and 1 m in depth, were operated in 45 d period. The pond' surface was covered of 0 % (pond 1), 20 % (pond 2), and 40 % (pond 3) by native plant species as *Scirpus littoralis Schrab,Cyperus alternifolius, Paspalum vaginatum* with the same area ratio for each plant in the ponds. The influent and effluent flow rate was 1.67 m^3 d^{-1}, the hydraulic retention time was maintained at 6 d during the experimental period; the obtained result revealed that the FCWs model, which covered by 20 % of plants on the surface, displayed the maximum removal was 77.8 % for BOD_5; 84.0 % for COD, 96.2 % for NH_4^+ - N; and 89.4 % for TN. It was also observed that the more cover area on the surface of the pond, the less development of the algal community in the pond body. It is concluded that the FCWs model covered by native plants is feasible for the treatment of shrimp's farm wastewater. The coverage of 20 % is suggested for the establishment of floating constructed wetlands.

1. Introduction

Constructed wetlands (CWs) are natural-like models in which natural subjects such as vegetation, soils, and microorganisms are constructed in a system for the purpose of wastewater treatment (Phan and Dinh, 2017) . The treatment activity in CWs is the encompassment of biological, physical, and chemical routes that happens inside models that could help to the removal of organic and inorganic compounds such as BOD, COD, TSS, nitrogen, phosphorus (Zhang et al., 2014) and heavy metals (Kumar et al., 2011). Wetlands also provide important ecosystem services, such as carbon sequestration, flood mitigation, biodiversity facilitation and preservation, nutrient cycling and recreation (Overbeek et al., 2020). Because of its advantages, the constructed wetlands-based models have been developed and applied in many countries. The models are variable and different in term of construction styles and operational factors. Some commonly constructed wetlands are free water surface horizontal subsurface flow (Vymazal and Kröpfelová, 2009), vertical flow and the hybrid models (Parde et al., 2021). One of a constructed wetland-based on model widely used is floating constructed wetlands (FCWs). In a FCW model, plants are cultivated on the surface of a pond. The plant roots develop openly into the water body of the pond. Combining the network among plant roots, algae, and microbial community provides a great condition for the symbiosis in pollutant removal contented in the wastewater (Masinire et al., 2020). It was confirmed the mechanisms for wastewater remediation in FCWs systems, including filtration by the root carpet; adsorption and absorption by the uptake of the organism in the water body; and the sedimentation by the gravity of the suspended solid (Benvenuti et al., 2018). In the floating constructed wetlands model, plants play significant roles such as taking up nutrients; stabilizing the pool bed; avoiding the turbulence; increasing the suspended solids (Shahid et al., 2018) and providing the living conditions for other algae, bacteria, and protozoa (Ibekwe et al., 2007). There have been many authors introduced the plants for cultivating in CWs models and salt tolerance such as *Scirpus littoralis Schrab* (Trang, 2018); *Cyperus alternifolius* (Yan et al., 2016), *Paspalum vaginatum* (Hu et al., 2020); and *Phragmites australis* (Phan and Dinh, 2017); *Typha orientalis*

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(Trang, 2018). Profits of applying floating wetlands modes in the shrimp farm involve taking advantage of available areas for wastewater remediation, reserving water for crop cultivation, environmental protection, creating a green landscape for the farm, flood prevention (Ibekwe et al., 2007). Besides the plants, the vital function of algae such as nutrient uptake and oxygen providing for the microorganism in their symbiosis relationship (García-Martíneza et al., 2019). Lau and colleagues confirmed that in a pond, the higher of algal concentration higher removal of nitrogen and phosphorus. The extraordinary algal density leads to the accumulation of toxic compounds released from their metabolism and cause eutrophication (Lau et al., 1995).
Until now, there have been several authors who described the effect of plant density on the performance of constructed wetlands models. Panrare et al. (2016) elucidated that the increased plant density could enhance COD removal, Ammonia and TSS in a CWs models for treating domestic wastewater. The 50 % plant cover was shown to be the most effective ratio of plant to surface water for maximum efficiency of free water constructed wetland (Ibekwe et al., 2007). In addition, it was revealed that the high level of salts in wastewater could inhibit the growth of the plants and microbial community in CWs models (Liang et al., 2017). Establishing a suitable treatment system by taking advantage of local conditions is a premised approach for the treatment of shrimp farm wastewater.
This study aimed to investigate FCWs systems' performance cultivated by native plants in the treatment of high salinity levels of shrimp farm wastewater. The comparison of pollutants removal efficiency was explored in the change of plant cover area in the models.

2. Materials and methodology

2.1 Waste sources and reactor conjugation

The model used wastewater from tiger shrimp farm at industrial scale in Hoa Binh district, Bac Lieu province, Vietnam. On this farm, the intensive shrimp farming was cultivated with the density of 80 species.m^{-2} (or shrimp.m^{-2}). The wastewater was taken in the day 40 to 70 of the cultivated period. Besides the polluted matters, the shrimp's farm wastewater also contented native algae in which the dominant species including *Bacillariophyta, Chlorophyta Chlorophyta, Euglenophyta (*Figure 1). The water quality in shrimp farm effluents is shown in Table 1 bellow:

Figure 1: The plants and root systems of the pilot models

Table 1: Shrimps farm wastewater quality

Parameters	Units	Concentration
BOD_5	mg O_2 L^{-1}	81 - 98
COD	mg O_2 L^{-1}	120 - 148
NH_4^+-N	mg L^{-1}	5.2 - 6.9
TKN	Mg L^{-1}	8.5 - 10.5
Salinity	‰	20 - 25
Algae community	Cells L^{-1}	50 x 10^5

Three floating constructed wetlands models at pilot scale were conducted parallel. The models had a circular shape with 10 m^2 in surface area and 1 m in working height (extra 0.2 m protected height). The reactors were constructed by a steel frame and coated by HDPE, the bottom had a light funnel design, and a tube was installed at the centre of the bottom for sludge withdraws. The pipes for injecting and withdrawing wastewater were installed from the top of the reactor.

2.2 Phytological planting and acclimation

Three plant species were chosen to cultivate in the floating constructed wetland: *Scirpus littoralis Schrab; Cyperus alternifolius, Paspalum vaginatum.* These plants are available in the research area and they are salinity tolerant. Before experimenting, the plants were acclimated to high salinity water. After constructing the ponds, freshwater from canal was pumped into the models to reach the design level, and then the plants were arranged with the coverage surface of 0 %, 20 %, and 40 %, for pond 1, pond 2, and pond 3, in which the area ratio of each plant species was equal for every pond. When the trees in models started to root and grew new shoots, the shrimp farm wastewater was injected into the models to replace 25 %; 50 %; 75 % and 100 % of the pond's wastewater; the duration of each period was 20 d. The salinity level of the shrimp farm wastewater was 22-25 ‰.

2.3 Experimental procedure

After acclimating stage, the shrimp farm wastewater was pumped to the models. The reactor was operated by semi-continues mode. The influent and effluent flow rate was 1.67 m^3 d^{-1}, the hydraulic retention time was maintained at 6 d during the experimental period. Samples of inflow and outflow were taken every 3 d. The experiment's duration was 45 d, and the effluent and influent samples were analyzed to access the performance among models.

2.4 Data analysis

The influent and effluent samples were monitored every 3 d to determine the performance of FCWs. Water quality parameters including COD, BOD_5, TN, NH_4^+ - N were measured in a quality laboratory by succeeding the guideline from the American Public Health Association (APHA, 2019). Before COD analysis, the samples were pretreated with chloride ion by modification method to avoid the interference (Ma and Gao, 2010). The algae community was also sampled and quantitative analysis during time course by hemocytometer (Marienfeld, Germany).

3. Results and discussion

3.1 Chemical oxygen demand (COD) removal

Figure 2a illustrates the COD value of different plant densities over 45 d. The influent COD was stable but the effluent was gradual decreased during the time course. During the first 9 d of the experiment, the COD concentrations of the three ponds all decreased, the COD removal efficiency in pond 2 and pond 3 were similar and much higher than that in pond 1. After that, the COD removal rate in the pond 1 and pond 3 was slightly increased to day 30 of the operation and getting stable until the end of the experiment. Remarkably, the COD removal rate of pond 2 significantly increased throughout the time course. The maximum COD removal efficiency of pond 1; pond 2; and pond 3 was 42.6 %; 84 %; and 56.9 %. At the end of the operational period, the effluent COD concentration reached 72 mg L^{-1} (pond 1), 20 mg L^{-1} (pond 2) and 55 mg L^{-1} (pond 3). Overall, the performance of pond 2 was the best and pond 1 was the worst among 3 ponds. The operational conditions of 3 ponds were similar except for the plant's density on the ponds' surface. It could be attributed to the role of covered plants in the models' treatment activity. Perhaps, the coverage of 20 % surface area promoted the relationship among algae, plants and microorganisms in the water body of the pond 2 resulting in the good performance in COD removal. Previous studies also elucidated that the removal of COD was enhanced by the presence of microbial communities and the entrapment of suspended particles in roots of the plants. The biofilm formation attached to the roots may also provide support in the removal efficiencies of COD by decomposing of organic matters into simple nutrients (Nawaz et al., 2020).

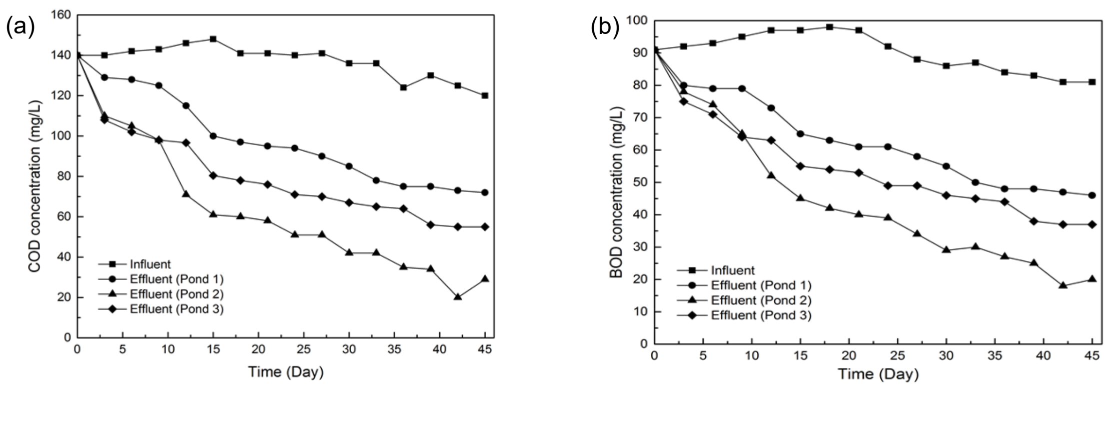

Figure 2: The variation organic matters in three ponds during time course: (a) COD; (b) BOD_5

3.2 The biochemical oxygen demand (BOD5) removal

Figure 2b shows the BOD_5 profile of the influent and effluent during the time course. In the same trend with COD decomposition, BOD_5 values also decreased along with the operational time. The pond 2 with 20 % coverage of plants attended the most significant decline of BOD output concentration, reached 20 mg L^{-1} and the maximum treatment efficiency was about 75 %. Although growing up to 40 % of plant, BOD_5 removal in pond 3 has a clear downtrend comparing with that in pond 2, it is approximate 37 mg L^{-1} and the treatment efficiency is 54 %. Pond 1 was weakest in BOD_5 removing; the maximum BOD_5 removal efficiency was only 43.2 %. Park and colleagues reported that the planted pond was significantly improved the aerobic decomposition of organic matter than those in controls model without plants (Park et al., 2019). Similar studies have been reported by earlier investigations, which emphasized the key role of plant' roots in COD and BOD_5 reduction from highly polluted wastewater (Nawaz et al., 2020).

3.3 Total nitrogen (TN) removal

Nitrogen is an element for cell construction; it is essential for the growth of all living organisms in the shrimp farm. The excess of nitrogen in the pond, especially NH_3 leads to poison the shrimps. The removing nitrogen matters containing in shrimp farm before reusing is very important in this shrimp cultivation industry. In this study, it could be assumed that the input nitrogen for ponds came from the shrimp's farm wastewater if the nitrogen containing in rainfall was ignored. In the aquatic systems, nitrogen attends the nitrogen cycle throughout the processes of nitrification, ammonification, denitrification and nitrogen fixation (Howard-Williams, 1985). Figure 3a describes the TN profile during the time course. The TN concentration in the influent has fluctuated in the range of 8.5 – 10.8 mg L^{-1}. During the operational time, the TN was gradually decreased in all ponds. Pond 1 was weakness at TN removal, the maximum removal rate of 58.2 % and the treatment activity was stable from day 27 to day 45 of the experiment, the model could bring TN to 3.9 mg L^{-1} on the last day. Interestingly, from the start to day 24 of the experiment, pond 3 performed better than pond 2 in term of TN removing, from day 24 to 43 the reverse trend of TN removing happened in those ponds. The improvement of TN removal in pond 2 during the late phase could be attributed to the achievement of the balance stage for plants and algae's growth in this pond. In addition, it was enhanced the entrapment activity by biofilm on roots in occulted vegetable treatments of pond 2 and pond 3 (Shahid et al., 2018).

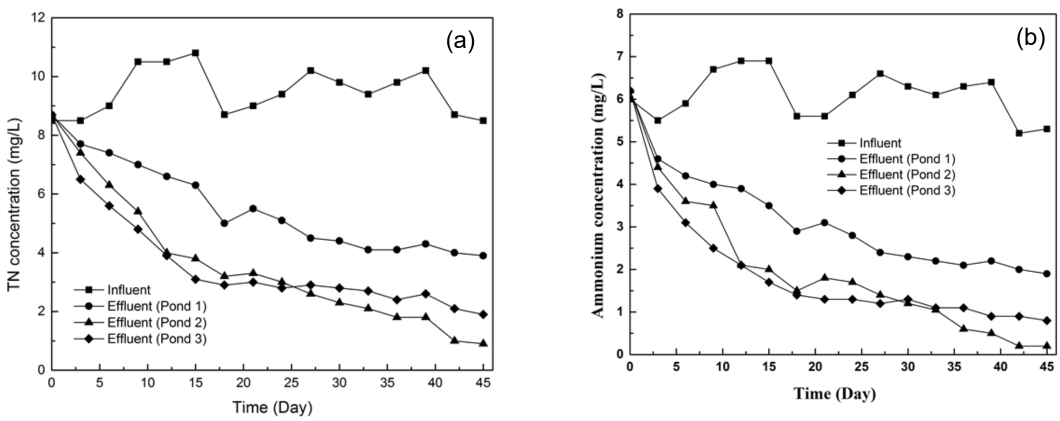

Figure 3: The change of nitrogen compounds during time course: (a) Total nitrogen; (b) Ammonium nitrogen

3.4 Ammonium nitrogen (NH_4^+) removal

Figure 3b showed that the NH_4^+ concentration decreased sharply after the start in all ponds. The removal of NH_4^+ in ponds 2 and 3 were similar for the first 30 days of operational period. From the day of 33 to 45, pond 2 performed better and could drop NH_4^+ to 0.2 mg L^{-1} at the end of the experiment. The NH_4^+ removal rate of pond 1 was significantly increased until day 15 and slowly in the later phase until the last day of the investigation and obtained NH_4^+ concentration to 1.9 mg L^{-1} at the end point. In overall, the maximum NH_4^+ removal efficiency was 66.7 %; 96.2 % and 84.9 % for pond 1, pond 2 and pond 3. The performance of pond 2 and 3 in removing NH_4^+ were better than that of pond 1. We can elucidate that the plants and algae could improve the nitrogen consumption in the lagoon. The pathway of NH_4^+ conversion in the wetland systems and ponds was indicated as followed: Firstly, the uptake by plants and algae; secondly, the consumption for nitrification and denitrification processes in the nitrogen cycle; thirdly, the N evaporation process (Phan and Dinh, 2017). The denitrification performance in which nitrate is produced from ammonium could be associated with enhanced microbial nitrification and the root biofilm facilitate the breakdown of pollutants and nitrogen removal (Shahid et al., 2019). It is reported that the plant displayed a significant effect in the COD, BOD_5, TKN and NH_4^+ removal, compared with the non-vegetated treatment, and the better removal efficiency was observed with 20 % plant coverage density.

3.5 Algal community

It was reported that the consumption of nutrient during the growth of algal community relies on many factors such as algae species, light intensity, turbidity, temperature, and other competitive factors. The complex relations among chemical, biological, and physical elements in the pond can control the development of algae cell numbers and metabolic activities (Lau et al., 1995). The profile of algal population in the FCWs during time course is illustrated in the Figure 4. It is clear to see that algae grew well in pond 1 from the start of the experiment and reached 50.2×10^3 cells L^{-1} at the day twenty-fourth of the experimental period. After that, the slow growth was achieved the stable condition in next phase and gradually decrease in the last days. At the end of the operational period, the concentration of algae in this pond was $46.9x10^3$ cell L^{-1}. In pond 2 and pond 3, algae's growth was good in the first phase of the experiment and became worse in the later phase. Maybe the cover of plants on the pond's surface (20 % surface area of pond 2 and 40 % surface area of pond 3) could prevent the light transfer to the ponds' body and completed nutrient with algae. The better development of plants on the surface, the worse growth of algae in water. The result of FCWs models performance demonstrated that pond 2 was the best performance in organic compounds and nitrogen removal among the three ponds. Perhaps, the coverage of 20 % plants on the surface could provide an appropriate environment for the symbiosis of plants, algae, microorganisms, and other organisms present in the FCWs models in this case study.

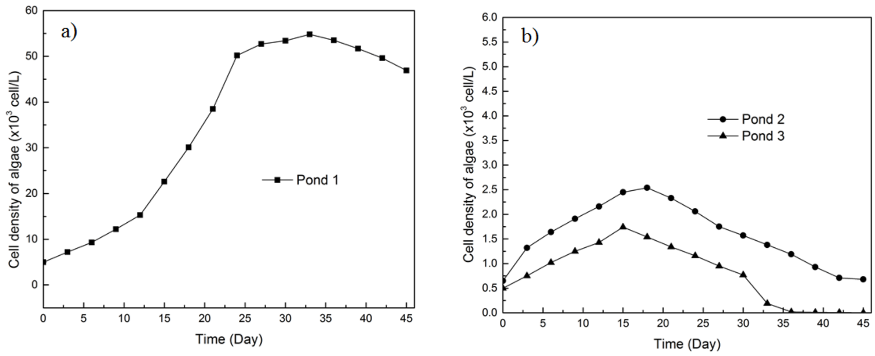

Figure 4: The development of algal community during time course: (a) pond 1; (b) pond 2 and pond 3

4. Conclusion

This study successfully acclimated native plants in the Mekong Delta area of Vietnam, including *Scirpus littoralis Schrab; Cyperus alternifolius, Paspalum vaginatum* in the floating constructed wetland models for the treatment of shrimp farm wastewater. The effect of plants cover area on the FCWs models was investigated. The result revealed that the removal of organic matters and nutrients was strongly depended on the plant surfaces covered. The 20 % cover area of plants could provide the highest removal efficiency of COD, BOD_5, TN, NH_4^+ - N among these three options of surface coverage. It is demonstrated that the FCWs is suitable for the treatment of shrimp farm wastewater at the site with many advantages such as high removal efficiency; mechanical facilities requirement; easy for construction, operation and maintenance; available plants; and low cost of materials for building the models. It is necessary to have further research about the application of full-scale FCWs to treat aquatic industry effluent in variable operational factors. The detail calculation the benefit and cost in terms of economic, environmental, and sustainable development needed to be done.

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