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Performance of a constructed wetland treating intensive shrimp aquaculture wastewater under high hydraulic loading rate

Ying-Feng Lin[a,*], Shuh-Ren Jing[a], Der-Yuan Lee[b], Yih-Feng Chang[b], Yi-Ming Chen[a], Kai-Chung Shih[a]

[a]*Department of Environmental Engineering and Science, Chia-Nan University of Pharmacy and Science, Tainan 717, Taiwan, ROC*
[b]*Department of Environmental Resources Management, Chia-Nan University of Pharmacy and Science, Tainan 717, Taiwan, ROC*

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A constructed wetland was found to be technically and economically feasible for managing water quality of an intensive recirculating aquaculture system.

Abstract

A water treatment unit, mainly consisting of free water surface (FWS) and subsurface flow (SF) constructed wetland cells, was integrated into a commercial-scale recirculating aquaculture system for intensive shrimp culture. This study investigated performance of the treatment wetlands for controlling water quality. The results showed that the FWS–SF cells effectively removed total suspended solids (55–66%), 5-day biochemical oxygen demand (37–54%), total ammonia (64–66%) and nitrite (83–94%) from the recirculating water under high hydraulic loading rates (1.57–1.95 m/day). This led to a water quality that was suitable for shrimp culture and effluent that always satisfied the discharge standards. The area ratios of wetlands to culture tank being demonstrated (0.43) and calculated (0.096) in this study were both significantly lower than the reported values. Accordingly, a constructed wetland was technically and economically feasible for managing water quality of an intensive aquaculture system.

Keywords: Constructed wetland; Recirculating aquaculture system; Removal rate constant; Pacific white shrimp; Aquaculture wastewater

1. Introduction

Recirculating aquaculture systems that integrate wastewater treatment processes into aquaculture production to maintain proper water quality are receiving interest worldwide (Lawson, 1995; Davis and Arnold, 1998). A recirculating aquaculture system allows for intensive culture with limited pollutant discharge, thereby reducing water and land usage, and minimizing adverse environmental impacts.

Removal of solids, organic matter, ammonia, and nitrite are critical for a recirculating aquaculture system (Lawson, 1995). Solids are usually removed using physical processes, including sand and mechanical filters. Biological processes such as submerged biofilters, trickling filters, rotating biological contactors, and fluidized bed reactors are employed in the oxidation of organic matter, nitrification, or denitrification. The disadvantages of these treatment methods are that they produce sludge, require much higher energy, and depend on frequent maintenance. Development of an effective, low-cost treatment is therefore imperative if aquaculture is to expand continually at the present rate (Zachritz and Jacquez, 1993).

Constructed wetland technology has grown in popularity for wastewater treatment since the early 1970s

* Corresponding author. Tel.: +886 6 2660390; fax: +886 6 2669090.
E-mail address: yflin@ms12.hinet.net (Y.-F. Lin).

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(IWA, 2000). During the past three decades, constructed wetlands have been used to treat acid mine drainage, industrial wastewater, agricultural and urban storm runoff, and effluent from livestock operations. Various biotic and abiotic processes regulate pollutant removal in wetlands (Kadlec and Knight, 1996; USEPA, 2000). Microbial mineralization and transformation (e.g., nitrification–denitrification) and uptake by vegetation are the main biotic processes, whereas abiotic processes include chemical precipitation, sedimentation, and substrate adsorption. Constructed wetlands are characterized by the advantages of moderate capital costs, low energy consumption and maintenance requirements, landscape esthetics and increased wildlife habitat (IWA, 2000).

Aquaculture wastewater is a good candidate for treatment using constructed wetlands due to its low strength in pollutants. However, there is a concern about the feasibility of wetlands to become a cost effective method because wetlands typically require a low hydraulic loading rate (HLR) and a long hydraulic retention time (HRT) to achieve efficient pollutant removal. That means wetland method may need a large land area when a great amount of aquaculture wastewater needs to be treated.

Previous studies (Schwartz and Boyd, 1995; Sansanayuth et al., 1996; Lin et al., 2002a,b) have demonstrated that constructed wetlands can efficiently remove the major pollutants from catfish, shrimp and milkfish pond effluents, including suspended solids, organic matter, nitrogen, phosphorus, and phytoplankton under an HLR and HRT ranged between 0.018–0.135 m/day and 1–12.8 day, respectively. These hydraulic conditions would result in a wetland size being 0.7–2.7 times of pond area for treating the polluted fishpond effluents (Schwartz and Boyd, 1995; Lin et al., 2002a). These suggestions may not be applicable when aquaculture production is a top priority for land use in a fish farm.

In a recirculating aquaculture system, treatment units are usually operated under a high hydraulic loading to rapidly remove toxic pollutants and maintain an appropriate water quality in the culture tank. Using high HLR to operate the constructed wetland may potentially reduce the required area ratio of wetlands to culture tank. However, information on using constructed wetlands for treating recirculating aquaculture water under a high HLR is still less extensively studied (Zachritz and Jacquez, 1993; Tilley et al., 2002; Lin et al., 2003).

In this study, constructed wetlands were integrated with an indoor recirculating aquaculture tank with a limited water exchange, to regulate the water quality for intensive culture of Pacific white shrimp (*Litopenaeus vannamei*). The main objectives of the study were to: (1) investigate the performance of the constructed wetlands in treating the recirculating water under high HLRs; (2) examine the effect of wetland treatment on water quality in the culture tank; (3) determine area requirement of wetlands for achieving successful treatment performance.

2. Materials and methods

2.1. Recirculating aquaculture system

The recirculating aquaculture system was built in a fish farm at Tainan County, Taiwan during March 2001. This system mainly consisted of an indoor culture tank and an outdoor water treatment unit (Fig. 1), which was made of brick and concrete in main body. Pipelines made of polyvinyl chloride were installed to connect the culture tank and treatment unit to recirculate the water.

The culture tank was 8 m × 8 m × 1.5 m (inner length, width and height) in size, maintaining a water depth of around 1.2 m. Tube diffusers, connected to an air compressor, were installed in the culture tank to supply oxygen for shrimp culture. Tank water flowed continuously to the water treatment unit by gravity, and the flow rate was controlled by a gate valve.

The water treatment unit was measured by 2.1 m × 15.2 m (inner width and length), and was divided longitudinally by a brick-concrete wall (10 cm thick) to form a U shaped ditch with an equal inner width of 1 m. This ditch was separated into four cells: a settling cell, a free water surface wetland (FWS cell), a subsurface flow wetland (SF cell), and a sump.

The settling cell (inner length of 1.5 m) received the recirculating water from the culture tank. A perforated acrylic baffle was installed across the cell width at 25 cm from the inlet end for flow distribution. The bottom of the cell is sloped at about 14% toward the inlet end, with

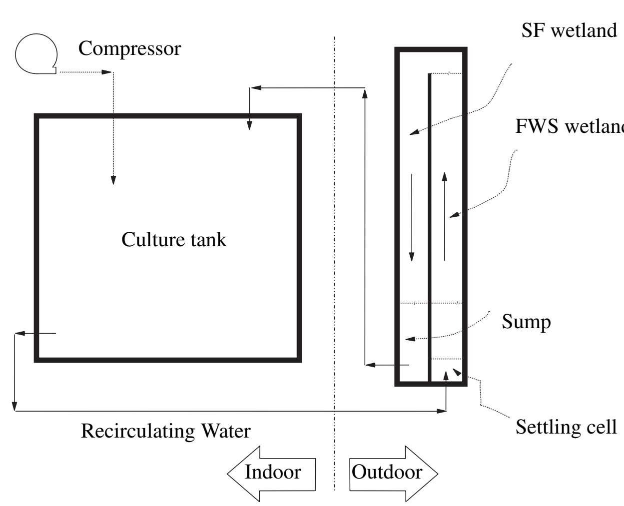

Fig. 1. Schematic diagram of the recirculating aquaculture system.