Study on the Effectiveness of a Pond-Based Recirculating System for Shrimp Culture

Production System Design and Best Management Alternatives/Experiment/09BMA04UM

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ABSTRACT

An experiment was conducted in four earthen ponds (about 0.35 ha each) at Haoshideng Shrimp Farm, Hainan Province, China from March 2010 to July 2011 to test efficiency of a pond based recirculating shrimp culture system equipped with a water treatment facility consisting of a screen drum filter and a foam fractionating unit. Shrimp post-larvae were stocked at 100 shrimp m^{-2} and cultured in replicates in a recirculating system and an open system with 15% weekly water exchange. The experiment was repeated for twice in two years in the same ponds with similar weather conditions. Shrimp survival rate ranged from 59 - 64% and shrimp yield ranged from 8081 – 9931 kg ha^{-1}, with the recirculating system having significantly higher shrimp survival rate and yield than the open system. When pond water passed through the treatment facility, TSS, COD, TAN, TKN and TP in water were significantly reduced and DO increased. Biweekly water sampling and analyses however did not show any significant differences in water quality for ponds of each system, indicating the water treatment facility had a waste nutrient removing capacity equivalent to 15% water exchange weekly. The recirculating system was more environmentally friendly without effluent discharge during production, and produced higher yields than the exchange system.

INTRODUCTION

Worldwide shrimp production increased rapidly from 71,432 metric tons in 1980 to 3,399,105 metric tons in 2008 with a total value of USD 14.3 billion (FAO, 2010). Despite continuously increasing market demand, further development and expansion of shrimp is constrained by environmental concerns associated with discharge of effluents and dispersal of solid wastes to the environment. This has renewed interest in recirculating systems due to their perceived advantages, including reduced use of water, greater control of the culture environment, reduced or eliminated use of antibiotics and hazardous chemicals, and close to zero discharge of effluents. Attempts have been made to develop recirculating shrimp culture systems using indoor tanks or raceways (Wyk et al., 1999) and outdoor ponds (Lin, 1995; Neori et al., 1996; Shpigel and Neori, 1996; Neori and Shpigel, 1999; Jones et al., 2001). Commercial-scale aquaculture has become possible using these systems and practices. However, a tank- or raceway-based indoor recirculating system is technically sophisticated, economically expensive, and may be impractical for the majority of small-scale shrimp farmers in Asia. On the other hand, integrated pond-based recirculating systems require a large percentage of the farm area to culture treatment organisms such as seaweeds, bivalves, and filter-feeding fish, which limits their application. Combining shrimp pond culture with efficient waste treatment components similar to those used in indoor tank systems but with limited complexity of operation and maintenance may be a feasible alternative.

Hainan province, the only tropical area in China, is one of the major shrimp production areas. The environmental impact of shrimp culture has become a serious concern. Thus, this experiment was conducted to test a pond-based recirculating system at Haoshideng Shrimp Farm in Hainan province to eliminate effluent discharge and use solid wastes as fertilizer for coconut trees.

The specific objectives were:

1. To evaluate effectiveness of combining a screen drum filter and a foam fractionating unit to remove solid wastes and improve water quality of shrimp culture ponds;
2. To compare water quality parameters in recirculating and open shrimp culture ponds;
3. To compare overall production performance between recirculating and open shrimp culture ponds.

MATERIALS AND METHODS

The experiment was conducted in four earthen ponds of 0.33 ha at Haoshideng Shrimp Farm, at the northern tip of Hainan province, China from March 2010 to July 2011. Drainage pipes were located in the center of ponds and pond bottoms and dikes were lined with plastic. Pond water depth was maintained at about 1.3 m and four paddle wheels were installed in each pond to provide aeration. White shrimp post-larvae were stocked at 100 pieces m^{-2} and fed with commercial pellets. The feeding rate was determined using feeding trays.

The four shrimp ponds were randomly divided into treatment and control groups, with two ponds in each group. Water in ponds of the treatment group flowed through a screen drum filter and a foam fractionating unit before recirculating back to the ponds (Figure 1). Water in ponds of the control group was exchanged weekly at 15%. Unfortunately both ponds and water were limited, constraining the number of replicates. To overcome this shortfall, the experiment was repeated for twice in two years with the same ponds and facilities and similar weather conditions.

Water quality parameters in ponds were measured once every two weeks. Temperature, DO, and pH at dawn were measured in situ using a DO meter (YSI Model DO-100) and a pH meter (YSI Model pH-200). Secchi disk visibility, water depth, and salinity were measured in situ at 0900 h using a Secchi disk and a hand-held refractometer. Pond water was sampled once at 0900 h for analyses of specific reactive phosphorus (SRP), total phosphorus (TP), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), total ammonia nitrogen (TAN), total Kjedahl nitrogen (TKN), chemical oxygen demand (COD), chlorophyll α, total suspended solid (TSS), and total alkalinity following standard methods (APHA et al., 1995).

For ponds of the treatment group, water was also sampled once every two weeks before and after circulation through the screen drum filter and foam fractionating unit for water quality analysis. The same parameters and methods were used as above.

Data from two replicate experiments were pooled together. Production and pond water quality parameters were analyzed statistically by analysis of variance (Steele and Torrie, 1980), while paired t-test was used to compare water quality parameters before and after water treatment in the recirculating system. SPSS (version 16.0) statistic software package (SPSS Inc., Chicago, USA) was used for statistical analyses. Differences were considered significant at an alpha level of 0.05. Means were given with ± standard error (S.E.). Percentage data were transferred to arcsine before analysis but presented in the original form.

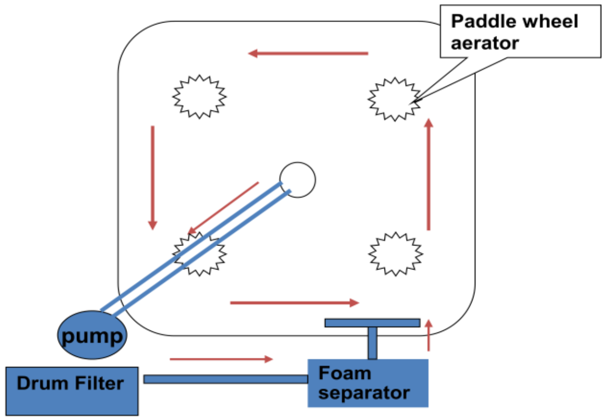

Figure 1. The work flow chart of the recirculating system for shrimp culture

RESULTS

The technical details of the recirculating system (Table 1) included a screen drum filter and a foam fractionating unit designed for a pond area about 0.35 ha. The screen drum filter separated suspended solids with particle size larger than 700 μm, through physical filtration while the foam fractionating unit further partially separated smaller suspended particles and some large organic molecules by injecting air bubbles and foam formation. Testing of water drained from the central drainage pipe before treatment, recirculating back to ponds after treatment, and waste water collected from the treatment units showed a significant decrease of total suspended solids, COD, total ammonia nitrogen, TKN, TP after water treatment ($P<0.05$), while nitrite and nitrate nitrogen trends were not significant (Table 2). DO was significantly increased after water flowing through the treatment unit.

Table 1. Mechanical specifications of a screen drum filter and a foam fractionating unit used in this experiment

Parameters	Specifications
Screen drum filter	
Motor power (Kw)	0.5
Drum length (m)	1.2
Drum diameter (m)	0.7
Screen mesh size (μm)	700
Drum rotation speed (revolution minute^{-1})	10
Water flow-through rate (m^3 h^{-1})	25
Operation time (h day^{-1})	24
Foam fractionating unit	
Power (Kw)	1.0
Unit volume (m^3)	1.5
Water flow-through rate (m^3 h^{-1})	25
Flow system	1

Table 2. Water quality change before and after water passed through the screen drum filter and the foam fractionating unit in recirculating ponds of the experiment.

Parameters	Before	After	Mixed waste water
DO (mg L^{-1})[1]	4.80 ±0.51	5.23 ±0.42	-----
pH	7.94±0.21	8.08±0.13	7.41±0.24
TSS (mg L^{-1})[1]	0.0412±0.0243	0.0346±0.0204	1.3289± 0.4159
COD (mg L^{-1})[1]	7.9536±2.7042	6.9161±2.4644	75.2052±19.5465
Nitrite (mg L^{-1})	0.2036±0.2649	0.2023±0.2642	0.5002±0.5616
Nitrate (mg L^{-1})	0.3054±0.4154	0.3046±0.4155	0.7155±0.7652
TAN (mg L^{-1})[1]	0.2598±0.2159	0.2356±0.1984	2.0654±1.6868
TKN (mg L^{-1})[1]	4.4895±2.3567	3.9385±2.0335	41.4196±18.1711
TP (mg L^{-1})[1]	0.6226±0.1190	0.5432±0.1650	4.1941±1.5894

Parameters followed by a superscript had significant differences between before and after values ($p<0.05$).

Shrimp grew better in treatment ponds than control ponds. Shrimp in treatment ponds had significantly higher survival rate, daily weight gain, and yield per unit area than shrimp in control ponds ($P<0.05$). FCR was not significantly different between treatment and control ponds (Table 3).

Table 3. Growth and production performance of white shrimp in ponds in each treatment.

Parameter	Open system	Recirculating system
Stocking		
Pond size (ha)	0.34±0.01	0.37±0
Biomass (kg $pond^{-1}$)	10.2±0.17	10.95±0.09
Number of post-larvae (No. $pond^{-1}$)	340,000±5,774	365,000±2,887
Density (shrimp m^{-2})	100±0	100±0
Harvest		
Growing period (days)	99±1.73	98±1.73
Shrimp (No. $pond^{-1}$)	199,609±6,972	233,761±4,974
Biomass (kg pond-[1])	2747.25±44.97	3624.25±44.05
Mean weight (g $shrimp^{-1}$)	13.81±0.46	15.54±0.5
Total weight gain (kg $pond^{-1}$)	2737.05±44.82	3613.3±44.05
Performance		
Daily weight gain (g shrimp-[1] day^{-1})	0.14±0[b]	0.16±0[a]
Yield (kg ha^{-1})	8081.02±59.32[b]	9931.1±137.68[a]
Survival (%)	0.59±0.02[b]	0.64±0.01[a]
FCR	1.29±0.04	1.21±0.03

Values in a row with different superscripts were significantly different between pond types ($p < 0.05$).

There were also no significant differences in water quality parameters between treatment and control ponds (Table 4).

Table 4. Values of water quality parameters measured during the experiment.

Parameter	Open system	Recirculating system
Mean Values		
Secchi disk visibility (cm)	48.03±0.89	48.91±3.06
Water depth (cm)	132.69±0.28	133.47±1.03
Temperature (^{o}C)	29.01±0.09	28.85±0.04
DO (mg L^{-1})	6.72±0.23	6.73±0.04
Salinity (PPT)	30.11±0.08	30.06±0.3
pH	8.1±0.04	8.03±0.02
SRP (mg L^{-1})	0.08±0.01	0.09±0.01
TP (mg L^{-1})	0.72±0.1	0.69±0.07
Nitrite (mg L^{-1})	0.15±0.05	0.16±0.02
Nitrate (mg L^{-1})	0.28±0.01	0.31±0.05
TAN (mg L^{-1})	0.17±0.01	0.22±0.02
TKN (mg L^{-1})	4.15±0.26	4.38±0.43
COD (mg L^{-1})	8.18±0.17	7.95±0.4
Chl-a (mg L^{-1})	265.05±27.08	233.57±33.39
TSS (g L^{-1})	0.05±0.01	0.04±0.01
Alkalinity (mmol dm^{-3})	3.04±0.08	3.1±0.06
End values		
Secchi disk visibility (cm)	32.5±2.5	29.5±2.1
Water depth (cm)	136.25±1.25	135.5±1.66
Temperature (^{o}C)	32±0.06	31.96±0.05
DO (mg L^{-1})	7.29±0.59	7.95±0.55
Salinity (PPT)	30.9±0.25	31.03±0.09
pH	7.55±0.22	7.63±0.11
SRP (mg L^{-1})	0.09±0.04	0.05±0.03
TP (mg L^{-1})	0.73±0.06	0.83±0.09
Nitrite (mg L^{-1})	0.28±0.14	0.24±0.05
Nitrate (mg L^{-1})	0.26±0.12	0.11±0.05
TAN (mg L^{-1})	0.25±0.07	0.29±0.05
TKN (mg L^{-1})	4.5±0.48	5.16±0.47
COD (mg L^{-1})	11.1±0.21	11.51±0.03
Chl-a (mg L^{-1})	298.52±57.81	546.9±128.94
TSS (g L^{-1})	0.04±0.01	0.06±0.02
Alkalinity (mmol dm^{-3})	2.9±0.15	3±0.08

DISCUSSION

Water exchange was traditionally used to maintain pond water quality and reduce waste accumulation in intensive shrimp culture (Fast, 1991). It however carries the risk of introducing diseases with inflow water, and could cause drastic changes in pond water quality (Hopkins et al., 1995). In this experiment, 15% of the pond's volume was exchanged weekly in control ponds. This water exchange maintained water quality at similar levels to the treatment ponds, but probably was a stress factor which resulted in lower shrimp survival and production in control ponds.

This experiment did not reveal any significant differences in nutrient contents in pond water between the open system and the recirculating system. This indicated that the water treatment facility had a nutrient removing capacity equivalent to a 15% water exchange weekly.

Environmental pollution has been associated with intensive shrimp pond culture since early 1910s (Pruder, 1992; Phillips et al., 1993; Boyd and Clay, 1998; Fast and Menasveta, 2000). This is primarily caused by the nature of the systems in which only small portion of the nutrient input is harvested through shrimp, while the majority is discharged into natural waters (Briggs and Funge-Smith, 1994; Lin, 1995; Teichert-Coddington et al., 2000; Jackson et al., 2003). Sophisticated waste treatment systems are often costly and impractical, especially for small scale shrimp farms which are still the dominant types in major shrimp producing countries such as China. This experiment demonstrated that installation of simple waste water treatment facilities such as screen drum filters and foam fractionators is effective to remove wastes produced in shrimp ponds without effluent discharge to surround environment during culture. In addition, shrimp survival and production was actually improved in the recirculating system. The recirculating system was therefore more environmentally friendly and more productive than the traditional open system with period water exchange.

ANTICIPATED BENEFITS

Whiteleg shrimp (*Litopeneaus vannamei*) is the most important shrimp species cultured throughout the region. Testing and demonstration of the proposed pond-based recirculating system will lead to further development, fine tuning and extension of recirculating systems which are suitable to the majority of small scale shrimp farms in Asia. This will reduce environmental impacts of intensive shrimp culture and improve its sustainability. Since shrimp imports are dominated by the U.S., better knowledge of sustainable shrimp culture will benefit NGOs like World Wildlife Fund, as well as private citizens and markets concerned with reducing the environmental footprint of shrimp culture.

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