Water Quality and Growth Performance of Hybrid Catfish (*Clarias macrocephalus* x *C. gariepinus*) Comparisons in Two Type of Water Recirculating System and a Water Exchange System

Chumpol Srithong*, Yont Musig, Nonthavit Areechon and Wara Taparhudee

ABSTRACT

Investigation on the efficiency of two water recirculation systems for hybrid catfish were conducted in culture systems using a plate separator + trickling filter and a swirl separator + trickling filter, for water treatment. Hybrid catfish with an average size of 50 g were stocked in 1000 liter-culture tanks at the rate of 400 ind/m^3. Turnover rate of water in fish culture tank was 2.0 hrs. Culture water flowed through a suspended solid treatment unit at the rate of 8.3 L/min. Culture period was 80 days. Results were compared with a water exchange system in which water in culture tanks were exchanged at 50% daily. Based on the results of this study, both water recirculation systems using either plate separator + trickling filter or swirl separator + trickling filter for water treatment were very effective for controlling total suspended solids (TSS), ammonia and nitrite in culture water. Average values of TSS, ammonia and nitrite in culture water in both water recirculation systems were significantly lower (P<0.05) than average values of these parameters in the water exchange system. Average values of TSS, ammonia and nitrite in culture water were 62.21–111.65 mg/L, 2.01-3.88 mg-N/L, and 1.10-4.50 mg-N/L in water recirculation systems with plate separator + trickling filter, 63.90–90.56 mg/L, 1.55-2.86 mg-N/L, and 1.02-3.50 mg-N/L in water recirculation systems with swirl separator + trickling filter, and 200.73-478.73 mg/L, 5.94–19.46 mg-N/L, and 3.23–20.56 mg-N/L in water exchange culturing system, respectively. Production, final weights, and survival rates of fish in both water recirculation systems were significantly higher (P<0.05) while FCR was significantly lower (P<0.05) than those of fish in the water exchange system.

Keywords: Hybrid catfish, Water recirculating system, Swirl separator, Plate separator, Trickling filter, Water exchange system

INTRODUCTION

Hybrid catfish has been one of the most popularly cultured freshwater fish species in Thailand. As an air breather, hybrid catfish can be grown at extremely high densities. The fish is mainly cultured intensively and fed with trash fish, chicken

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offal or pelleted feed, which generally cause poor water quality and heavy phytoplankton blooms throughout the grow-out period.

Pond water with rich nutrients and organic matter is periodically changed with new source water, causing pollution in receiving waters and becoming a serious environmental problem (Yi *et al*, 2003). These concerns for water supply conservation and environmental impacts of waste from aquaculture activities have focused attention on the development of technologies for water reuse (Timmons and Losordo, 1994).

Recirculating aquaculture system (RAS) is a potential technology for reducing adverse environmental impacts that need to be applied in fish farms (Boyd and Tucker, 1998). RAS is the most advanced production system placed in an insulated building, independent of the outside environment with a high degree of water recycling. In this way production of fish is possible in locations without abundant water supply or lacking a favorable climate, and are thus normally not suitable for fish culture. Impact on the outside environment by uncontrolled release of waste water can be controlled (Remmerswaal, 1993).

RAS is a configuration of several chemical, biological and mechanical processes. The system essentially has a fish culture tank, a particulate filter for solids' removal, a biofilter for ammonia removal, a pump for water circulation, and an oxygenation device.

The research on RAS has concentrated on individual components such as biofilters and particulate filter. However, the effects of filter combinations have received less attention.

In this work, we focus on the operation and capacity of the particulate removal system (swirl separator and plate separator) combined with ammonia removal system (trickling filter), in consideration of compactness, ease in installation, and lower energy requirement for operation. The overall objective was to characterize the culture system based on water quality, percent waste removal, water use, and cost of energy in different water management systems, as well as growth performance.

MATERIALS AND METHODS

The study was conducted at the Department of Aquaculture, Faculty of Fisheries, Kasetsart University, Bangkok, Thailand.

Experimental rearing systems

Three water management systems were studied, i.e. two water recirculating systems compared with a water exchange system at 50% daily. Two replications for each treatment were used.

The water recirculation systems for hybrid catfish culture were designed with plate separator + trickling filter (Fig.1) and swirl separator + trickling filter (Fig.2) for water treatment.

Water was pumped (0.075 Kw) from the sump tank to rearing tank (1,000 L) and returned by gravity to solid removal unit (swirl separator and plate separator; 150 L). Solid waste was removed at underflow of unit and the overflow water via the biofilter unit (trickling filter; 150 L). Bioballs (200

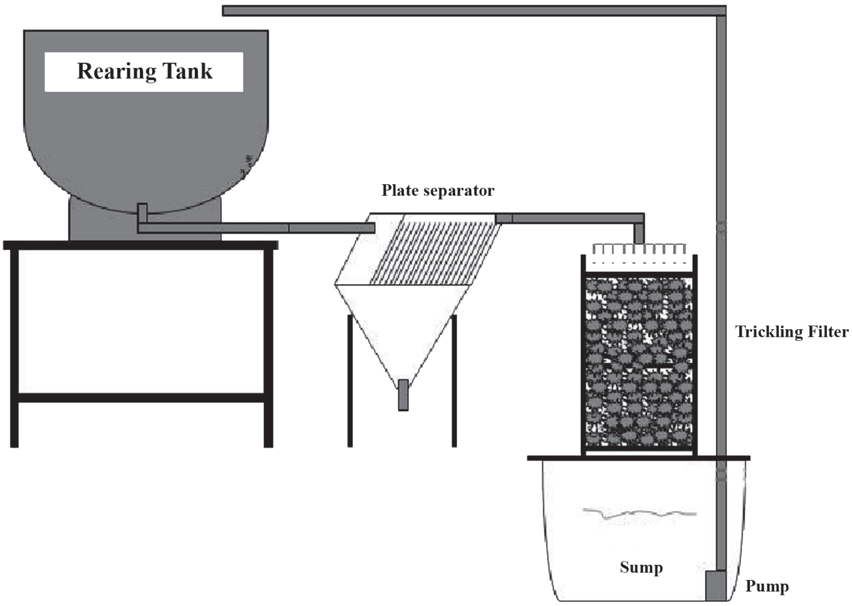

Figure 1. Water recirculating system using a plate separator + trickling filter.

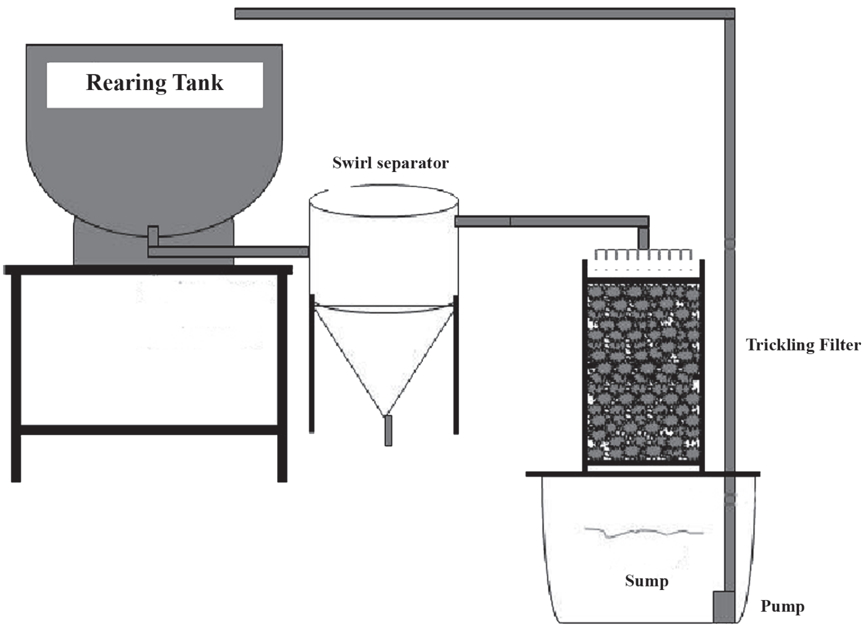

Figure 2. Water recirculating system using a swirl separator + trickling filter.

m^2/m^3 of specific surface area) were used as media in the biofilter unit in order to provide a suitable environment for nitrifying autotrophic bacteria (Fig.3). The outflow of trickling filter was collected in a sump tank (200 Liter). Turnover rate of water in fish culture tank was 2.0 hrs. Culture water flowed through a suspended solid treatment unit at the rate of 8.3 L/min. It was necessary to add dechlorinated tap water due to evaporation and water losses at under flow of solid removal unit. The amount of water for refill was recorded all throughout the study period. For the control treatment, water in the rearing tank (1,000 L) was exchanged 50% daily (Fig.4).

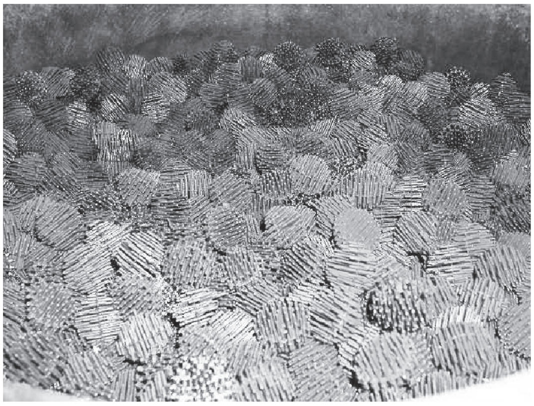

Figure 3. Bioballs as media for the biofilter in the trickling filter unit.

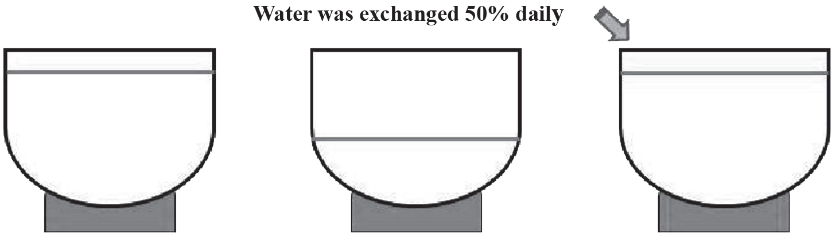

Figure 4. Water exchange system as control (without water recirculation)

Fish performance

Hybrid catfish fingerlings (50 g size) were stocked at 400 fish/m^3. They were fed with commercial floating pelleted feed (30% crude protein) twice daily at 0830 h and 1600 h. Feeding rate was based on hybrid catfish size (4% of body weight per day for 50-100 g fish, 3 % of body weight per day for greater than 100 g fish). Mortality of the experimental catfish were observed and recorded daily. Survival rate, average daily growth (ADG; g/fish/day), food conversion ratio (FCR) and yield (kg/m^3/crop) were evaluated during the 80 days experimental period.

Water quality monitoring

Water was collected weekly from each culture tank for analysis. Water parameters analyzed were total suspended solid (TSS), chemical oxygen demand (COD), total ammonia nitrogen (TAN), nitrite, nitrate, Alkalinity following the Standard Methods (APHA *et al*., 1992). Dissolved oxygen (DO) was checked daily using a DO meter (YSI model 550A). Temperature and pH were also checked daily using a pH and temperature meter (YSI model 60, YSI Incorporated, Yellow Springs, OH, USA).

Statistical analysis

Water quality parameters, growth rate, FCR, survival rate, yield, ADG, water consumption and cost of energy from the different water management systems were analyzed by one-way analysis of variance (ANOVA, $\alpha = 0.05$). The differences between mean were analyzed for significance using Duncan's multiple range test (Bhujel, 2008). Analysis was performed using SPSS (Version 17.0) the statistical software package.

RESULTS AND DISCUSSION

Effect of the culture system on water quality

Water quality readings from the three different culture systems are provided in Table 1. Plate separator and swirl separator used in RAS could control the solid waste from fish tanks. TSS concentrations were 54.25-124.20 and 54.0-106.3 mg/L, respectively (Fig.5), which indicate statistically significant difference between particulate filter ($P<0.05$). COD values were not significantly different between the two systems ($P>0.05$)

In the hybrid catfish culture by water exchange system (control), although water was exchanged 50% daily, TSS and COD concentrations were still high. Normally, excess feed and faeces would dissolve or remain as suspended solids then settle in the culture tank, while fresh faeces and excess feed could be easily removed by the two particulate filters. Water quality parameter readings, TSS and COD values in the water exchange system were significantly higher than those in the RAS ($P<0.05$) during the experimental period.

The particulate removal efficiency rates of plate separator and swirl separator were 34.67 and 38.63 %, respectively. There was no significant difference in TSS removal rate between the particulate removal systems ($P>0.05$).

Trickling filter was effective in controlling total ammonia, nitrite and nitrate (Figs. 6, 7 and 8) in the water recirculating system.

The mean concentrations of total ammonia were of 2.73, 2.24 and 11.55 mg-N/L for plate separator + trickling filter, swirl separator + trickling filter and water exchange system (control), respectively. The total ammonia concentrations in both water recirculation systems were significantly lower ($P<0.05$) than the control (water exchange system). The trickling filter had a large specific surface area and could supply dissolved oxygen for bacterial activity, resulting in large quantities of nitrifying bacteria being developed and grown for the nitrification process (Chen *et al*, 2006).

Table 1. Water quality readings in fish rearing tanks with different water management systems

Parameter	Recirculating System						Water exchange system		
	Plate separator + Trickling filter			Swirl separator + Trickling filter					
	Range	Mean	±S.E.	Range	Mean	±S.E.	Range	Mean	±S.E.
DO (mg/L)	2.4-6.2	4.14^{a}	0.98	3.1-6.0	4.24^{a}	0.66	1.2-5.5	3.35^{b}	1.25
pH	6.80-7.45	7.13^{b}	0.18	6.80-7.30	7.11^{b}	0.15	7.1-7.5	7.25^{a}	0.11
Temperature (^{o}C)	29.4-31.9	31.07^{b}	0.68	29.4-31.9	31.09^{b}	0.67	30.1-32.4	31.4^{a}	0.67
TSS (mg/L)	54.25-124.20	88.05^{b}	16.08	54.0-106.3	73.62^{c}	11.32	145.0-488.34	297.39^{a}	109.66
COD (mg/L)	74.56-196.25	140.46^{b}	38.26	74.35-182.30	129.67^{b}	32.71	89.5-392.1	186.21^{a}	89.17
Total ammonia (mg-N/L)	1.412-4.312	2.73^{b}	0.73	0.879-4.560	2.24^{b}	0.76	3.214-21.321	11.55^{a}	4.88
Nitrite (mg-N/L)	0.478-5.012	2.33^{b}	1.05	0.421-4.245	2.24^{b}	0.83	1.241-22.142	13.30^{a}	5.79
Nitrate (mg-N/L)	0.578-38.241	24.33^{b}	12.74	0.847-55.320	28.73^{a}	15.11	0.349-2.585	0.93^{c}	0.53
Total Alkalinity (mg/L as $CaCO_3$)	68-160	116.7^{b}	27.97	60-158	117.4^{b}	37.92	115-142	133.0^{a}	7.41
TSS removal rate (%)	21.86-46.06	34.67^{a}	8.06	33.10-45.86	38.63^{a}	3.55			

Mean values with different superscript letters in the same row are significantly different (*P<0.05*).

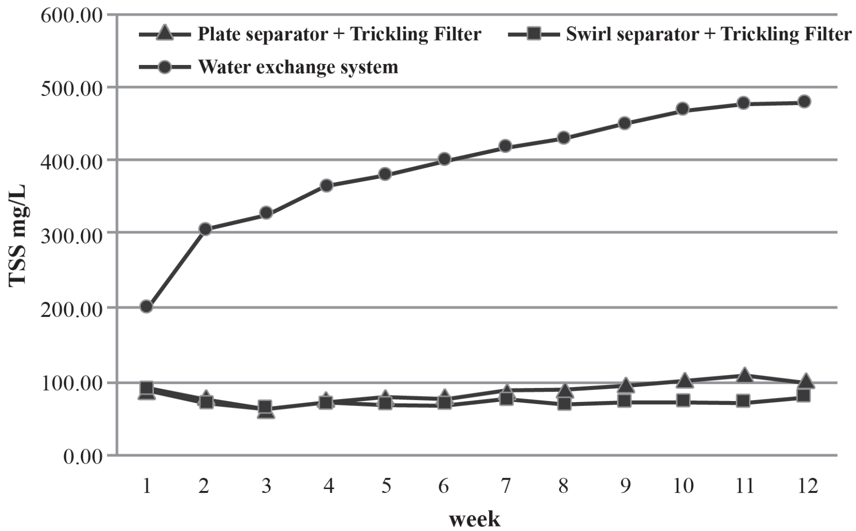

Figure 5. TSS concentration in fish rearing tanks with different water management systems

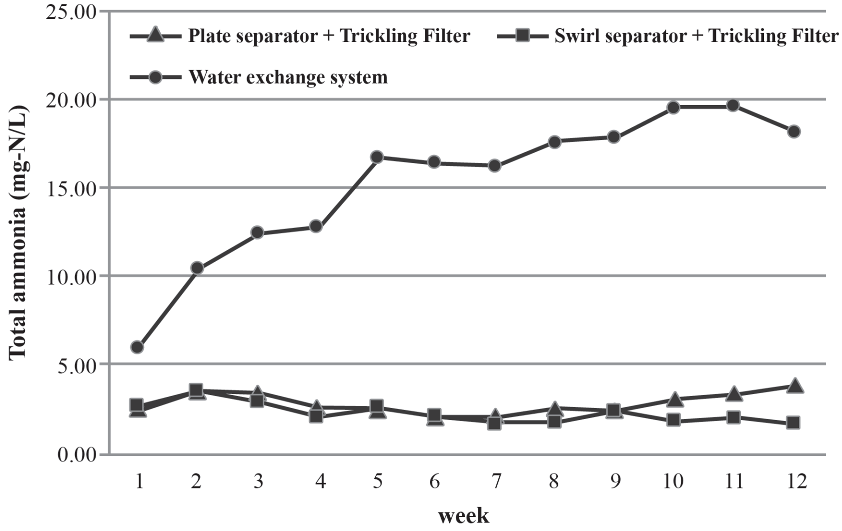

Figure 6. Total ammonia concentration in fish rearing tanks with different water management systems

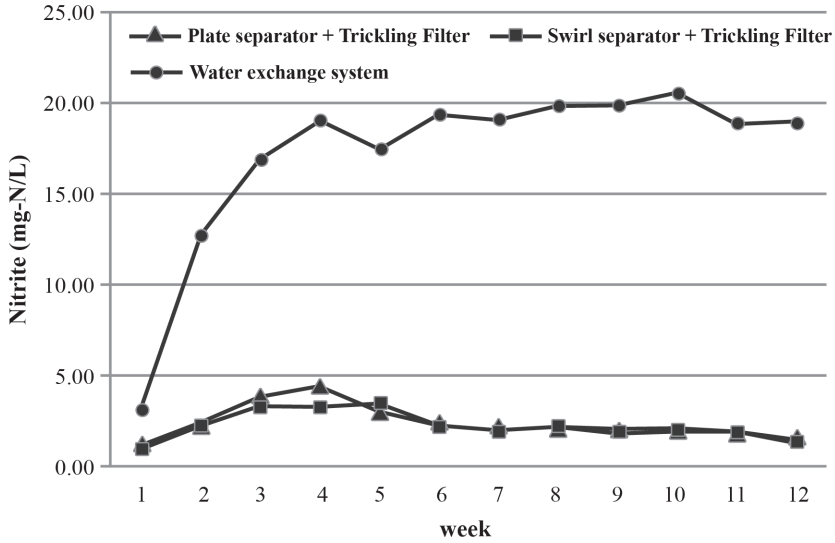

Figure 7. Nitrite concentration in fish rearing tanks with different water management systems

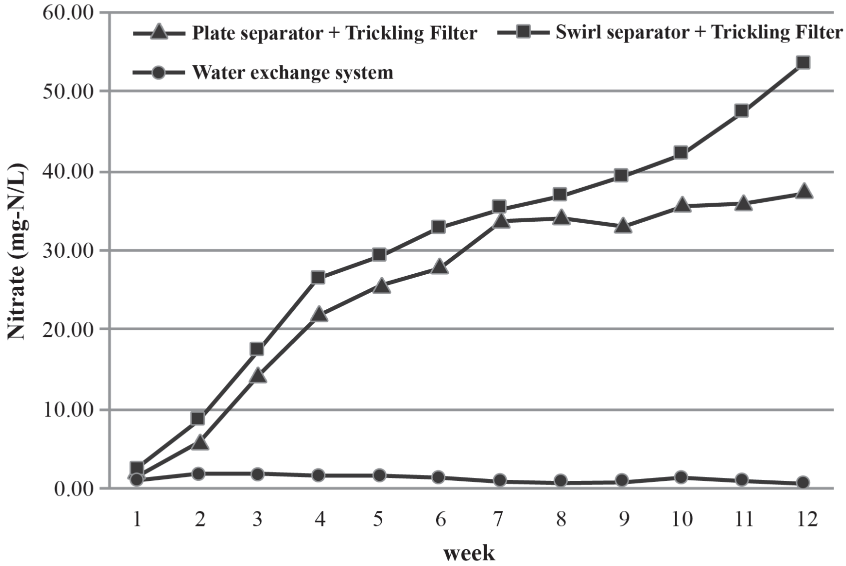

Figure 8. Nitrate concentration in fish rearing tank with different water management systems

The ammonia removal efficiency rates using trickling filter combined with a plate separator and a swirl separator were 32.41 and 36.80 %, respectively, however they are not significantly different. Performance of ammonia removal by trickling filters was found to be satisfactory, as reported by Al-Hafedh *et al*, (2003), who found, that ammonia removal using submerged-type biofilter in RAS for Nile tilapia culture was 21.19-25.49 %.

In this study, the maximum values for total ammonia in RAS with swirl separator and the water exchange system were 4.56 and 21.32 mg-N/L, respectively. It can be summarized that there is no adverse effect on growth and survival of fish because hybrid catfish can tolerate extremely high concentrations of total ammonia (greater than 80 mg-N/L). The proportion of TAN in the un-ionized form is dependent upon the pH and temperature of the water (Boyd, 1990), but the pH value in this study was recorded to be less than 7.0 (especially in RAS), so the toxicity of un-ionized ammonia was not virulent for fish.

The mean concentration of nitrate was 24.33, 28.73 and 0.93 mg-N/L for plate separator + trickling filter, swirl separator + trickling filter and water exchange culturing system, respectively. According to the nitrification activity by nitrifiers, total ammonia entering the trickling filter was oxidized to nitrite and nitrate.

Tanks were refilled with water after 50% daily exchange having low concentration of nitrate (0.05-0.124 mg-N/L), the nitrate concentration in water discharge system was significantly lower than RAS ($P<0.05$)

Some particulate waste accumulated in the biofilter unit of the RAS with plate separator in the last three weeks of this study.

This could be an additional reason for observed lower nitrification rates and higher TSS and COD concentrations than the RAS system with swirl separator. Under such conditions, oxygen limitation for nitrifiers in organic-matter-rich zones as well as competition between heterotrophic bacteria and nitrifiers, may underlie a less efficient TAN removal by this filter.

Mean DO concentrations were 4.14, 4.24 and 3.35 mg/L for plate separator + trickling filter, swirl separator + trickling filter, and water exchange system, respectively. Both water recirculation systems were significantly higher ($P<0.05$) than the control (water exchange system). The RAS combined with trickling filter, which is self-aerating, provided oxygen to the attached biofilm, allowing oxygen to be easily transferred into the water (Miller and Libey, 1984).

DO levels below 2 ppm in biological filters start to show negative effects on the activities of *Nitrobacter* and *Nitrosomonas* because the rate of oxygen diffusion into the bacterial film begins to limit the nitrification process (Malone, 1995). Intensive aeration was providing optimum DO in the system.

Under high stocking density, fish consume a large amount of oxygen and liberate large amounts of CO_2 as a result of respiration. Some organic compounds tend to accumulate in the water while some of them will be broken down by bacteria in the culture system.

pH is an important water quality parameter in recirculating systems because various processes such as nitrification and optimum health of the fish are related to the range of pH in the water. As pH decreases, ammonia is converted into a less toxic ammonium form; therefore, the increase in pH will lead towards the accumulation of ammonia in the system (Lawson, 1995). The optimum pH range for nitrifying bacteria is between 7.0 and 8.0, and below a pH of 6.8 nitrifying bacteria are inhibited and do not remove the toxic nitrogenous wastes (Michael *et al*., 1995). There are two factors responsible for the lowering down of pH: (i) nitrifying bacteria which produce acid as a result of nitrification and (ii) the respiration of fish and bacteria whereby carbon dioxide is produced and is converted into carbonic acid (Szwerinski *et.al*, 1986). However, the pH was found to fluctuate between 6.80-7.45 in the rearing tanks.

Ammonia oxidation into nitrate reveals that oxidation of 1 mg of ammonia could yield 1.98 mg of acid, 0.21 mg of bacteria cells, 4.43 mg of nitrate, 3.37 mg of water, and 5.97 mg of carbon dioxide while consuming 4.34 mg of oxygen, and 7.14 mg of alkalinity.

Alkalinity exerts an important effect on the biochemical process in re-circulating systems because nitrification is an acid-producing process that consumes alkalinity. For the ammonia oxidation into nitrate reveals that oxidation of 1 mg of ammonia yield while consuming 4.34 mg of oxygen, and 7.14 mg of alkalinity. In this study, average alkalinity was recorded to be 116.7, 117.4 and 133.0 mg/L as $CaCO_3$ for plate separator + trickling filter, swirl separator + trickling filter and water exchange culturing system, respectively. Alkalinity value in water discharged system were significantly higher than RAS ($P<0.05$) in all round culture time. For RAS, sodium bicarbonate was added to maintained alkalinity concentration at above 100 mg/L as $CaCO_3$. For this study, 3.43 ± 70.71 and 3.51 ± 17.67 kg of sodium bicarbonate was added in treatment of plate separator + trickling filter, swirl separator + trickling filter in RAS, respectively.

Effect of the culture system on hybrid catfish performance

The summary of fish growth performance is shown in Table 2. There were no significant differences in all production characteristics between the sediment removal systems that were combined with RAS ($P> 0.05$), except the FCR. But the overall fish performance in RAS combined with swirl separator for the particulate filter, seemed greater than those in the RAS using plate separator. For the hybrid catfish raised in the water discharge system, the value of fish production, average weight, survival rate, ADG and FCR were 51.8-52.1 kg, 142.0-146.0 g, 89.25-91.25 %, 1.15-1.19 g/fish/day and 1.96-1.99, respectively. Fish production performance in the water discharge system was extremely significantly lower and poorer than RAS ($P<0.05$).

Even though hybrid catfish could tolerate very poor water quality (low DO, high concentration of ammonia, nitrite, TSS), better environmental conditions provided by RAS contributes to better growth performance and FCR.

In this study, size distribution (more than 300 g, 150-300 g and less than 150 g) of catfish reared in RAS were 27.85, 44.36 and 27.80 %, respectively. Whereas those from water exchange system were 7.62, 24.93 and 67.45 %, respectively (Fig.9). These results indicate that water management in fish culture has an extreme effect on fish growth.

Table 2. Production performance of hybrid catfish reared in the different water management systems

Growth Performance Parameters	Recirculating System		Water exchange system
	Plate separator + Trickling filter	Swirl separator + Trickling filter	
At stocking:			
Mean weight (g/fish)	50.295±0.77^{a}	50.4±0.39^{a}	50.3±0.78^{a}
Total no. of fish	400±0.00	400±0.00	400±0.00
Total weight (kg)	20.11±0.30^{a}	20.19±0.15^{a}	20.14±0.31^{a}
Culture Time (Day)	80	80	80
At harvest:			
Mean weight (g/fish)	220.5±5.72^{a}	230.0±4.24^{a}	144.0±2.82^{b}
Total weight (kg)	86.65±1.62^{a}	90.85±1.20^{a}	51.95±0.21^{b}
Total no. of fish	393±2.82^{a}	395±2.82^{a}	361±5.65^{b}
Total Feed weight (kg)	79.85±0.49^{a}	80±1.41^{a}	62.75±0.35^{b}
FCR	1.20±0.03^{b}	1.13±0.00^{c}	1.97±0.01^{a}
Survival Rate (%)	98.25±0.70^{a}	98.75±0.70^{a}	90.25±1.41^{b}
Average daily growth (g/fish/day)	2.12±0.06^{a}	2.24±0.04^{a}	1.17±0.02^{b}

Mean values with different superscript letters in the same row are significantly different ($P<0.05$).

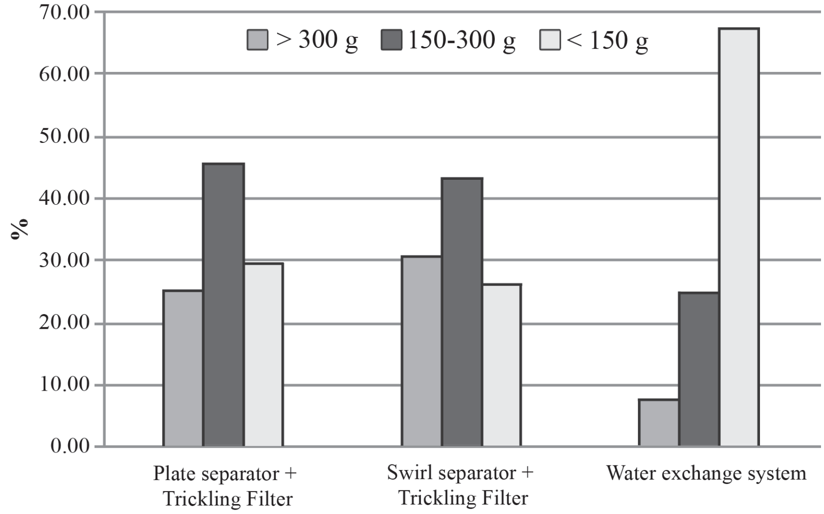

Figure 9. Size distribution of hybrid catfish at harvest reared in different water management systems

Effect of culture system on water and energy consumption

The two water recirculating systems (RAS) used between 4,750 and 5,850 L of water for hybrid catfish rearing. Whereas, the daily water exchange system used more than 40,000 L of water for fish rearing. Thus RAS could save water for culture by at least 800 % and also provide higher fish yield by 41.46 % (Table 3).

In RAS with plate separator, water volume used was higher than in swirl separator because the solid waste accumulated in the particulate filter unit in the last three weeks. There as difficulty in removing by underflow of trapped waste particulate unit; so a higher volume of water was replaced to clean the plate separator system.

Cost of energy for RAS came from using an electric pump (0.075 kW). Pump used for refilling water daily in the water exchange system was an important cost.

Table 3. Water and energy consumption for hybrid catfish reared in different water management systems

Water and Energy Usage	Recirculating System		Water exchange system
	Plate separator + Trickling filter	Swirl separator + Trickling filter	
Water volume in fish tank (L)	1,000	1,000	1,000
Water volume in RAS unit (L)	350	350	-
Water volume for makeup/refill (L)	4,500	3,400	39,000
Total water volume (L)	5,850	4,750	40,000
Energy cost (Baht) (5 Baht per unit)	1,472	1,472	1,300

CONCLUSION

Plate separator and swirl separator used in RAS had the ability to control solid waste in fish tanks. Nitrification actively worked in the trickling filter.

Although there were no significant differences in the total ammonia, nitrite, COD, DO concentrations between the particulate removal systems *(P>0.05*), the overall performance in RAS combined with swirl separator for the particulate filter, seem to maintain water quality within a suitable range for fish growth. The TSS removal efficiency of swirl separator was significantly better than plate separator, especially at the end of the study.

The efficiency of waste solid removal by water discharged was lower than RAS technology. Higher volume of water for catfish rearing in water discharged system did not extremely enhance the water quality for fish performance. The reason may be the new water refilling suddenly to fish tank had the effect on fish growth.

It can be stated that the RAS system has the efficiency to conserve water supply for fish culture; furthermore RAS is the better technique for reducing adverse environmental impacts. RAS is needed to be applied for fish farm.

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