Design and Performance of an Indigenous Water Recirculating Aquaculture System for Intensive Production of Nile Tilapia, *Oreochromis niloticus* (L.), in Saudi Arabia

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ABSTRACT

The increasing demand for fish, and the scarcity of fresh water in Saudi Arabia both press the need to adapt new technologies for intensive water recirculating aquaculture to maximize water recycling and increase fish production. Using locally available materials, a commercial-scale recirculating aquaculture system was developed in triplicate to produce Nile tilapia. The system was operated to produce more than 50 kg fish/m^3/cycle, and the filters were evaluated for their efficiency in removing organic wastes from the effluent. Each replicate consisted of a culture tank, two mechanical filters with sand/gravel medium, two submerged biofilters with plastic media, a sump and two pumps. Mixed sex tilapia with an average size of 76.4 g were stocked at a density of 188 fish/m^3 and fed a 34% protein diet at 3% body weight per day (initially). Water temperature was maintained at 28 ± 1ºC, water flow rate was adjusted to 300 liters/min and the culture tank and biofilter were aerated. Water

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samples were collected from the inlet and outlet of each component and were analyzed for important parameters.

Values (± SE) of total ammonia nitrogen (TAN) (0.98 ± 0.1 ppm) and nitrite-nitrogen (NO_2-N) (0.48 ± 0.02 ppm) in the fish culture tanks were within the acceptable limits, while the other water quality parameters were also maintained under normal range by the filtration system. Removal rates (± SE) of 186.7 ± 31.59 g TAN/m^3/day and 66.53 ± 16.9 g NO_2-N/m^3/day, respectively, as well as TAN and NO_2-N removal efficiencies (31.45 ± 2.32% and 21.05 ± 3.8%, respectively) were measured across the PVC biofilter medium. The area specific TAN and NO_2-N removal rates (± SE) or nitrification rates (0.34 ± 0.06 g/m^2/day and 0.15 ± 0.05 g/m^2/day) for the biofilter were comparable with the performance of other commercial intensive recirculation systems. Mean final weight (±SE), final biomass, growth rate, SGR, FCR, and percent survival for the mixed-sex tilapia were 277.21 (1.76) g/fish, 50.21 kg/m^3, 1.34 g/fish/day, 0.86%, 1.89, and 96.53%, respectively, whereas the average water use was 0.4 m^3/kg of fish production. Locally available materials were found to be appropriate for solid and organic waste removal. More than 85% of the system water volume could be recycled daily, while fish production per unit space was also multiplied 3-6 fold compared to the traditional culture practice.

INTRODUCTION

The development of freshwater aquaculture in Saudi Arabia has been slow because of water scarcity coupled with harsh, arid climatic conditions. Flow-through systems consisting of ponds or tanks made of concrete or fiberglass use excess groundwater and space to achieve only limited production (El-Gamal 2001). Increasing demand for fresh fish and the scarcity of fresh water press the need to adapt new technologies of intensive water-recirculating aquaculture to facilitate more fish production by maximum recycling of water.

Recirculating aquaculture systems represent a relatively new and expanding technology with a wide variation in system design and quality available. Compared with ponds and flow-through aquaculture, a recirculating system generally occupies very little area, requires less water than conventional aquaculture and provides a predictable and constant environment for the culture species (Dunning *et al.* 1998). Designed to conserve both land and water resources, recirculating systems can be located in areas not conducive to open pond culture, where water is of poor quality, ambient temperatures are outside the optimum range for the species to be cultured, or if the species is exotic. Because of these advantages, interest in water recirculating systems for fish production continues to grow, despite the lack of concensus available for their design and operation.

Recirculating aquaculture systems recycle and reuse water with mechanical and biological treatment between each use; thus, they require wastewater treatment and filtration techniques for continuous waste removal. These techniques have traditionally been relatively expensive and require skilled personnel to operate (Losordo *et al.* 1992). Imported aquaculture wastewater treatment systems can be installed, but due to particular local farming and operating conditions, lack of expertise, and the high price tag, these treatment systems may not be suitable. The design of the wastewater treatment and water reuse system needs to be efficient, cost-effective, and simple to operate. The design needs to consider the use of local materials under specific fish culture and environmental conditions. The development of an efficient wastewater treatment system that takes into consideration culture conditions necessitates testing of various mechanical and biological filters.

Establishment and testing of recirculating aquaculture technologies using local resources under specific climatic and culture conditions is, therefore, one of the most significant approaches for maximizing water reuse and intensifying fish production in Saudi Arabia.

Although few farms are mechanized, water aeration or oxygenation is a common practice in Saudi Arabia. Fish feeds are made locally, formulated according to the dietary requirements of farmed fish. Food conversion ratios (FCR) are normally 2-2.5 for tilapia species. Annual productivity rates for most tilapia farms range from 5 to 25 kg/m^3 (El-Gamal 2001). These yields are not satisfactory despite the incentives provided by the government of Saudi Arabia, such as interest-free loans to farmers, appropriate technical support, inexpensive energy, subsidized costs for fish feed, etc. (Al-Thobaity and James 1994, Al-Sahli and Dass

1995). Objectives of this research, therefore, were to use locally-available filter media in the development of a closed aquaculture system to achieve a better FCR (<2), an annual tilapia productivity of 100 kg/m^3 when producing 2 crops/year, and to cut average water requirements per kg fish production from several m^3, common in flow-through systems, to less than 0.5 m^3.

MATERIALS AND METHODS

System Components

The water recirculating system was a large-scale fish culture unit that was built in triplicate. Each set contained one fish tank, two mechanical filters, two biological filters, and a sump tank. All fish culture tanks, filters, and sump tanks were made of fiberglass (SKAFCO, Riyadh, Saudi

Figure 1. Schematic diagram of the water recirculating aquaculture system. 1. Fish Rearing Tank; 2. Mechanical Filters; 3. Biofilters; 4. Sump Tank; 5. Pump

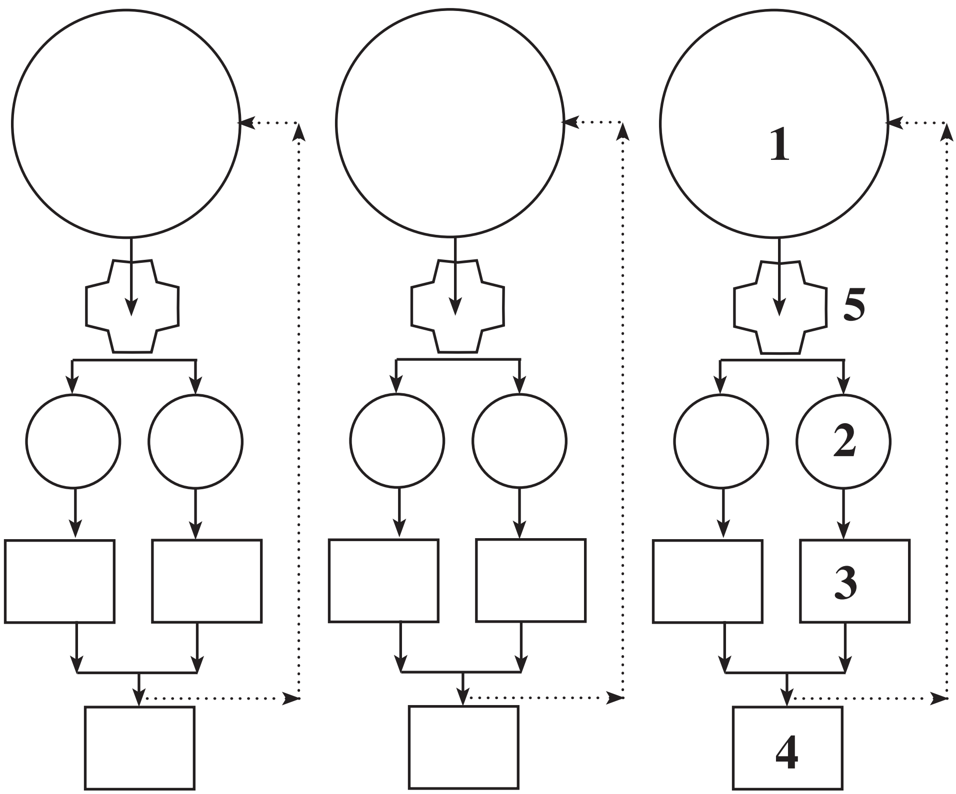


Table 1. Specifications for the water recirculating aquaculture system.

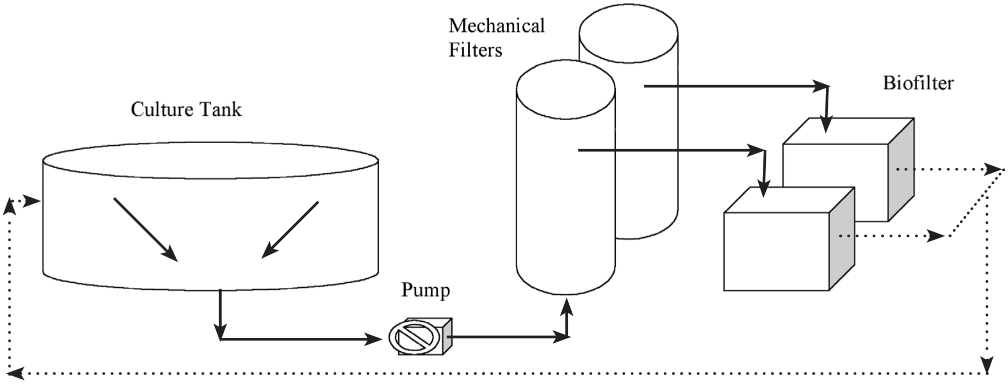
Specifications of Tanks	Number & Shape	Dimensions Meters (m)	Total Volume m^3	Water Volume m^3
Fish Rearing Tanks	3, Circular	4.0 Dia, 1.00 H	12.6/Tank	8.0/Tank
Solid Filters	6, Cylindrical	1.0 Dia, 1.50 H	1.18/Tank	--
Biofilters	6, Rectangular	1.25 L, 1W, 1 D	1.25/Tank	1.0/Tank
Sump	3, Rectangular	1 L, 1 W, 0.7 D	1.00/Tank	--

Arabia). The fish culture tanks (12.5 m^3) were circular, 4 m in diameter. The mechanical filters were also circular, 1 m diameter, 1.5 m height. The biological filters were rectangular, 1 m x 1 m x 1.25 m (Table 1, Figure 1).

Operation

Effluents from fish culture tanks were pumped into the two up-flow cylindrical filters containing a 15-cm layer of coarse gravel and a 35-cm layer of sand (number 20) as filter media for solid particle removal. Water was introduced from the bottom of the cylindrical filters through a 7.62-cm diameter inlet. Backwash from the filters was carried out using a perforated 25-mm diameter circular brass pipe which was connected to a compressor. Compressed air routed through the pipe agitated the sand medium once daily while water back flowed through the filter under the drain. Backwash was collected at the bottom of the cylinder and discharged through an opening to a drain. The outflow of each of the two cylinders was connected to one submerged biofilter where the water filled in by gravity. Two biofilters in a replicate contained locally available plastic media (PVC pipes, 2.5 cm diameter cut into 5-cm pieces). Each of the two biofilters in a replicate had a surface area of 200 m^2 for bacterial growth. Thus, total biofilter surface area for a replicate was 400 m^2, which was based on the calculations that 400-450 kg of fish fed at 2% body weight would produce 240-270 g TAN/day and the ammonia removal rate was expected to lie between 0.50-0.70 g TAN/m^2/Day (Lawson 1995). Two water pumps (0.75 kw each) located outside the

Figure 2. Connections and flow pattern in a replicate of the water recirculating aquaculture system.



fish tank were used alternatively to pump water from each fish tank to the solids-removing filters while the water was recirculated back by gravity from the biofilters to the fish culture tank (Figure 2). A sump tank (2.25 m^3) was used to collect filter backwash, drains, and overflows. Wastewater from the sump could either be pumped back into the system through the mechanical filters or discharged outside the system.

Experimental Conditions

Rearing tanks were stocked at a density of 188 fish/m^3 with mixed sex Nile tilapia (*Oreochromis niloticus*) weighing (on average) 76.41 g/fish. Floating pellets (4 mm) containing 34% protein were used to feed the fish at a rate of 3% body weight per day. Feeding rate was decreased to 2% after the first two months. Daily ration was equally divided for a morning (0800 h) and evening (1600 h) feeding. The water temperature was maintained at 28 ± 1ºC by installing heaters with thermostats. Water flow rate was maintained at 300 liter/min throughout the experiment and 10% of the total water in each rearing tank was exchanged daily in the morning for the first two months. For next two months, water exchange was increased to 12% of the total water in the rearing tank, and in the last month it was raised to 15%. Details of the mechanical and biofiltration components are given in Table 2.

Each fish rearing tank and biofilter was aerated by 22 (15.2 cm x 3.8 cm x 3.8 cm) and 8 (7.6 cm x 2.5 cm x 2.5) air diffusers, respectively. Two foam fractionators were used in each rearing tank to remove fine solids, reduce dissolved organics like proteins, and to control carbon dioxide. Performance of the filters was evaluated by measuring filter reductions (in and out samples) of TAN (total ammonia nitrogen), NO_2-N (nitrite-nitrogen) and accumulation rates of NO_3-N (nitrate-nitrogen). The operational goals included maintaining the DO (dissolved oxygen) above 5.0 ppm and TAN and NO_2-N below 1.0 ppm. At the end of the experimental period all the fish were sexed and weighed to get the final biomass and total weight gain.

Table 2. Physical parameters of the water recirculating aquaculture system.

Unit	Parameter	Description
Culture tanks	Flow rate	300 L/min
	Water volume	8 m^3/tank
	Number of culture tanks	3 (1/replicate)
	Water level control	Central stand pipe
	Residence time	26.67 minutes
Mechanical filter	Type	Upflow; submerged
	Total number of mechanical filters	6 (2/replicate)
	Filter medium characteristics	Dual Sand/Gravel (2 mm particle size)
	Filter bed depth	Two layers 15 + 35 cm
	Filter bed volume	0.39 m^3
	Mechanical filter water volume	0. 97 m^3
	Specific hydraulic loading rate	553.85 m^3/m^3/day
	Residence time	2.6 minutes
Biofilters	Types	Downflow; submerged
	Total number of biofilter tanks	6 (2/replicate)
	Filter volume/biofilter tank	0.364 m^3
	Specific hydraulic loading rate	594 m^3/m^3/day
	Residence time	2.42 minutes
	Filter medium characteristics	
	1. Type	PVC pipes
	2. Specific surface area	550 m^2/m^3 respectively
	3. Total surface area/biofilter	200 m^2
	4. Total surface area/replicate	400 m^2

Water Quality Determination

Water samples were collected weekly from the inlet and outlet of each culture tank, mechanical and biofilter unit of the system. Samples were analyzed for TAN (total ammonia nitrogen), NO_2-N (nitrite-nitrogen) and NO_3-N (nitrate-nitrogen) using a Hach DR 4000 spectrophotometer (Hach, Loveland, CO, USA). Water temperature, pH, DO (dissolved oxygen), total alkalinity and free CO^2, (carbon dioxide) were recorded twice a week following standard methods (APHA 1998).

Calculations

Daily weight gain (DWG) expressed as g/fish/day, percent specific growth rate (SGR) and feed conversion ratio (FCR) were calculated by using the following formulae:

DWG = (final weight - initial weight) / No. of fish / time (days)

SGR (%) = (*ln* final weight – *ln* initial weight) / days x 100

FCR = total dry feed weight / (final fish biomass - initial fish biomass)

The efficiency of the biofilters in nitrogenous waste removal was determined using the estimated waste loading and removal rates as follows:

Waste loading rate (g/m^3/day) = C_i x Q

Waste removal rate (g/m^3/day) = (C_i - C_e) x Q

Removal efficiency (E) = Waste removal rate / waste loading rate x 100

where: C_i = influent waste concentration (g/m^3)

C_e = effluent waste concentration (g/m^3)

Q = water flow rate (m^3/m^3/day)

Table 3. Water quality data recorded in the fish culture tanks of the water recirculating aquaculture system.

Parameters	Range	Mean	± SE
Water Temperature (°C)	27.5 – 28.5	27.81	0.02
Dissolved Oxygen (mg/L)	3.51 - 4.71	4.33	0.21
pH	8.25 - 8.91	8.37	0.14
Total Ammonia-N (mg/L)	0.75 - 1.1	0.98	0.1
Nitrite-N (mg/L)	0.41 - 0.54	0.48	0.02
Nitrate-N (mg/L)	6.32 - 9.73	8.02	0.54
Free CO_2 (mg/L)	6.43 - 6.98	6.75	0.09
Total Suspended Solids (mg/L)	9.14 – 16.7	13.24	0.61
Total Dissolved Solids (mg/L)	1233 - 1268	1255.2	6.03

Table 4. Waste loading rates, waste removal rates, waste removal efficiencies and specific waste removal rates of the biofilter utilizing plastic-pipe medium.

Waste	Plastic pipes (± SE)
Ammonia	
Loading Rate (g/m^3/Day)	580.93 (61.23)
Removal Rate (g/m^3/Day)	186.7 (31.59)
Specific Removal rate (g/m^2/Day)	0.34 (0.06)
Removal Efficiency (%)	31.45 (2.32)
Nitrite	
Loading Rate (g/m^3/Day)	286.31 (13.6)
Removal Rate (g/m^3/Day)	66.53 (16.9)
Specific Removal rate (g/m^2/Day)	0.15 (0.05)
Removal Efficiency (%)	21.05 (3.8)

RESULTS AND DISCUSSION

Values of critical metabolic wastes like total ammonia nitrogen (TAN) (0.98 ± 0.1 mg/L) and nitrite-nitrogen (NO_2-N) (0.48 ± 0.02 mg/L) were well within the acceptable limits, while other quality parameters in the culture water were also maintained under normal ranges by the filtration system (Table 3). Removal rates (± SE) were calculated to be 186.7 (± 31.59) g TAN/m^3/day and 66.53 (± 16.9) g NO_2-N/m^3/day, whereas TAN and NO_2-N removal efficiencies (± SE) were 31.45% (± 2.32) and 21.05% (± 3.8) respectively for the biofilter. Specific TAN and NO_2-N removal rates (± SE) were 0.34 (± 0.06) g/m^2/day and 0.15 (± 0.05) g/m^2/day, respectively for the PVC hose biofilter medium (Table 4).

Mean weight (± SE) for the mixed sex tilapia population (49.88% males and 50.12% females) produced in the recirculating system was calculated to be 277.21 (1.76) g/fish. A final biomass of 50.21 kg/m^3 was harvested after the experiment finished at a growth rate of 1.34 g/fish/day. The FCR averaged to 1.89 and the SGR was 0.86% while the survival was recorded to be 96.53% (Table 5).

Table 5. Growth data of Nile tilapia in the water recirculating aquaculture system.

Parameters	**Tank 1**	**Tank 2**	**Tank 3**	**Average**
Period	01 Aug-30 Dec	01 Aug-30 Dec	01 Aug-30 Dec	01 Aug-30 Dec
Days	150	150	150	150
Initial weight (g ± SE)	79.13 (1.61)	72.77 (2.07)	77.33 (2.15)	76.41(1.94)
Total Initial Biomass (Kg)	118.7	109.16	116.3	114.72
Initial Biomass (kg/m^3)	14.84	13.65	14.54	14.34
Final Weight (g ± SE)	282.47 (1.79)	281.94 (1.63)	267.22 (1.85)	277.21(1.76)
Total Final Biomass (Kg)	416.92	414.17	373.84	401.64
Final Biomass (kg/m^3)	52.12	51.77	46.73	50.21
Growth rate (g/Fish/Day)	1.36	1.39	1.27	1.34
Net Yield (g/m^3/Day)	248.53	254.13	214.6	239.09
FCR	1.85	1.86	1.96	1.89
SGR (%/Day)	0.85	0.9	0.83	0.86
Final density (number/m^3)	184	183	175	181
Survival (%)	98.4	97.93	93.27	96.53

Solids in Water Recirculating System

Performance of solid upflow sand and gravel filters in the system during the experiment was found to be satisfactory as reflected from the values of total suspended solids (TSS) in the outflow water going to the biofilters. The average TSS value was found to be 13.24 mg/L in the rearing tanks of the system; that is below the allowable limit of TSS in recirculating systems (Lawson 1995) while total dissolved solids (TDS) averaged to 1255.2 mg/L. Reported solids production values (uneaten feed and excreta) in fish culture systems range from 11 to 38% of the applied feed (McLaughlin 1981, Chen *et al*. 1993). The large variation can be attributed to difference in feed, species management, and variability in the rates of decay of organic matter within the culture units.

Nitrogen in Water Recirculating System

Total Ammonia Nitrogen (TAN) is the most critical water quality parameter in intensive recirculating systems. According to Lawson (1995) and Van Rijn and Rivera (1990), TAN should be kept at less than 1 mg/L in intensive recirculating systems. TAN consists of two fractions, un-ionized ammonia (NH_3) and ionized ammonia (NH_4^+). The former is extremely toxic to fish. The proportion of TAN in the un-ionized form is dependent upon the pH and temperature of the water. The higher the pH and temperature of the water, the higher the percentage of toxic un-ionized ammonia. During the operation of the recirculating system, an average TAN value of 0.92 mg/L was recorded in the rearing tanks. Based on the mole fraction values of un-ionized ammonia for different temperature and pH (Huguenin and Colt 1989), the concentration of NH_3-N was calculated to range between 0.009 and 0.06 mg/L in the rearing tanks, and averaged 0.034 mg/L. Levels of un-ionized ammonia, which may adversely affect growth in tilapia, ranged from 0.24 mg/l to 0.5 mg/l (Balarin and Haller 1982, Daud *et al*. 1988). At a level of 0.25 mg/l un-ionized ammonia, the health and growth of the fish may be impacted.

Nitrite-nitrogen (NO_2-N) and nitrate-nitrogen (NO_3-N) are the products of ammonia oxidation. Nitrate-nitrogen is not generally of great concern to aquaculturists as it has been shown that aquatic species can tolerate extremely high (greater than 100 mg/L) concentrations of NO_3-N

(Ebeling *et al*. 1993). Nitrite-nitrogen is also not as toxic as ammonia-nitrogen, however, it is harmful to aquatic species and must be removed from the system. According to Ebeling *et al*. (1993), concentrations of nitrite-nitrogen should not exceed 0.5 mg/L in culture water whereas the level of concern was reported to be 0.45 mg/l of nitrite-nitrogen by Balarin and Haller (1982). Average concentration of NO_2-N in commercial scale operation of the recirculating system during this study was recorded to be 0.58 mg/L in the rearing tanks.

Nitrification and Biofiltration Efficiency

Removal rates (± SE) of the biofilter medium consisting of pieces of PVC pipe were 186.7 (31.59) g TAN/m^3/day and 66.53 (16.9) g NO_2-N/m^3/day, respectively, whereas TAN and NO_2-N removal efficiencies were 31.45% and 21.05%, respectively (Table 4). Miller and Libey (1985) have reported the best TAN removal efficiencies of rotating biological contactor (RBC) to be 74-82% compared with a trickling filter (23-52%) and a fluidized sand bed filter (8-32%).

Overall nitrification rates (specific removal rates) for the biofilter medium averaged 0.34 g TAN/m^2/day and 0.15 g NO_2-N/m^2/day. Lekang and Kleppe (2000) have reported a nitrification rate between 0.1 and 0.2 g TAN/m^2/day for trickling biofilters with plastic media while Van Rijn and Rivera (1990) reported a removal rate of 0.43 g TAN/m^2/day for trickling filters. In their study of biofilters, Westerman *et al*. (1993) found nitrification rates of 0.25 g TAN/m^2/day for the rotating biological filters and 0.1-0.15 g TAN/m^2/day for upflow sand and bead filters. Various biofilter media configurations are commercially available with maximum ammonia (TAN) removal rates between 0.28 and 0.55 g TAN/m^2/day (Kruner and Rosenthal 1983, Nijhof and Bovendeur 1990, Van Rijn and Rivera 1990, Kikuchi *et al*. 1994). According to Van Rijn (1996), maximum ammonia removal rates are sometimes misleading as they are often measured at unrealistically high ammonia levels. Ammonia oxidation follows a hyperbolic trend with increasing ammonia concentration (Michaelis–Manten Kinetics) and maximum ammonia removal rates are found at very high ambient ammonia concentrations (Brune and Gunther 1981).

Dissolved Gases

A minimum DO concentration of 5 mg/L is required for proper functioning of the recirculating system (Greiner and Timmons 1998). When DO levels drop below 2 mg/L, the 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). During this experiment, the aeration was maintaining optimum DO in the system, keeping the average DO content at 4.3 mg/L, within a range of 3.5 to 4.7 mg/L.

Accumulation of free CO_2 lowers the pH in recirculating aquaculture systems, especially when alkalinity is low. In recirculating systems, this gas becomes problematic and can adversely affect fish health under high stocking densities, where fish consume large amount of oxygen and liberate large amounts of CO_2 as a result of respiration. A free CO_2 concentration greater than 50 mg/L is reported to be toxic for most fish species (Heinen *et al*. 1996). During the operation of the recirculating system in this study, free CO_2 averaged 6.75 mg/L with a range from 6.4 to 7.0 mg/L.

pH

pH is an important water quality parameter in recirculating systems because various processes such as nitrification and fish health are related to the range of pH in the water. As pH decreases, ammonia is converted into a less toxic ammonium form, therefore, an increase in pH will lead to the accumulation of ammonia in the system (Lawson 1995). The optimum pH range for nitrifying bacteria is between 7.0 and 8.0. If pH drops below 6.8, nitrifying bacteria are inhibited and do not remove the toxic nitrogenous wastes (Michael *et al*. 1995), though nitrifying bacteria can adapt to pH values outside this range if given enough time (Wheaton *et al*. 1994). Basically, two factors are responsible for lowering pH: the nitrifying bacteria that produce acid as a result of nitrification; and respiration of fish and bacteria, producing carbon dioxide which is converted into carbonic acid. During this study, pH was found to occur in its optimum range, averaging 8.4 in the system.

Fish Production

Overall, growth of mixed sex tilapia in all three replicates of the recirculating system was satisfactory (Table 5). Among the three replicates, there was no significant difference ($p > 0.05$) in the feed conversion ratio, daily weight gain, net yield and total weight gain of the fish. The mean daily growth rate of 1.34 g/fish/day in our study was similar to the 1.2 g per day reported by Ridha and Cruz (2001) for Nile tilapia in the recirculating system in Kuwait. The mean FCR of 1.89 recorded in this study is comparable with the 1.86-2.04 reported by Rakocy *et al*. (1992) and the 1.98 and 2.04 reported by Ridha and Cruz (2001) for Nile tilapia. Average net yield (239.09 g/m^3/day) showed little variation between the system replicates.

Water Conservation

Compared to semi-intensive culture practices in Saudi Arabia where 20-25% of total water is exchanged daily to produce 8-15 kg fish/m^3 of water, only 10-15% of total water was exchanged daily in the intensive recirculating aquaculture system to produce 50 kg fish/m^3/crop. Calculating from these figures, there is a requirement of approximately 3 to 4.5 m^3 of water to produce one kg fish in semi-intensive aquaculture. In contrast, the production of one kg fish required approximately 0.4 m^3 of water in the water-recirculating intensive aquaculture.

Socio-economics of Aquaculture in Saudi Arabia

Inland aquaculture is mostly practiced indoors in Saudi Arabia, and farm raised tilapia weighing > 200 g are well received (Siddiqui and Al-Najada 1992). Under good conditions and a nutritious feeding regime, Nile tilapia usually attain 250-500 g in 6-8 months in tank systems. Owing to the shortage of fresh water, integrated and closed culture systems that allow water to be reused need to be developed more extensively. Recirculating systems have two disadvantages: they are expensive to establish, and require expertise to operate. These problems are minor, however, compared to the many advantages Saudi Arabia has created to promote aquaculture development. The government supports the industry with research and development, as well as extension programs that provide brood stock, hatchery-reared seeds, essential technical and commercial information, and training (Al-Thobaity and James 1994, Al-Sahli and Dass 1995). Land in Saudi Arabia is inexpensive, and because aquaculture can be practiced on non-arable land, competition with the nation's important agriculture industry is reduced. Furthermore, credit is readily available (interest-free loans are provided by the government to farmers for purchase of machinery and other facilities), energy is inexpensive (aquaculture is somewhat energy intensive), and fish feed is subsidized by the government (Ming-Hsien 2004). The nation's climate, as noted, can be harsh, but aquaculture systems technology makes it possible to raise fish even in these conditions.

CONCLUSION

To save maximum water and increase fish production per unit volume of water in a large scale water recirculating system, locally available sand/gravel and small pieces of plastic electrical hose were found to be an appropriate media for solid (mechanical filtration) as well as organic waste (biological filtration) removal, respectively, from the fish culture effluents. Accordingly, only 10-15% of total system water was exchanged daily to sustain 50.21 kg fish/m^3, compared to extensive and semi-intensive traditional culture practices in Saudi Arabia where 20-25% water is exchanged daily to produce only 8-15 kg fish/m^3 of water. The implementation of water recirculation aquaculture technology in Saudi Arabia can effectively check water waste. More than 85% of water may be recycled using local materials in the design of water filtration components. Fish production per unit space can also be multiplied by more than 3-6 fold in the water recirculating fish culture systems. The remarkable reduction in water use associated with recirculation technology, and the availability of local materials for establishing the filter components would encourage local farmers to embrace the new techniques and enable a rapid transfer of the technology to the private sector.

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