FILTRATION TECHNIQUES FOR SMALL-SCALE AQUACULTURE IN A CLOSED SYSTEM

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Abstract: Recirculating 2271-liter culture systems were designed and evaluated as potential fish production units. System components include a culture tank, sedimentation basin, and a biological filter. Three different biological filter types were compared: a commercially available plastic filter media, a rotating biodisc filter, and a submerged gravel filter. Each duplicated system was stocked with 5 cm fingerling channel catfish, *Ictalurus punctatus*, which were fed daily. The experiment continued until maximum loading capacities were attained. In the 155 day growing period, the greatest standing crop attained was 41.2 kg using the rotating biodisc filter. Excepting one replication which exhibited 100 percent mortality due to an aerator failure, survival rate was 95 percent or greater, with feed conversions ranging from 1.27 to 1.62.

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Biofiltration is being used to a limited extent in connection with salmonid production (Burrows and Combs 1968, Meade 1974), and is applicable to warm water fish culture for maintaining water quality and the treatment of discharge water (Ruane et al. 1976). However, there has been little progress towards the general utilization of these methods due to the economic disadvantages of pumping large volumes of water (Parker and Broussard 1977).

Experimentation with recirculating, filtered systems has been very successful in culturing large quantities of fish with a limited water supply, but using a high flow rate, and a high filter to tank ratio (Broussard and Simco 1976, Lomax 1976, Liao and Mayo 1974, Parker and Simco 1973). The pumping costs and complex technology involved with this high density production still appear prohibitive to its general application. However, with applications requiring less intensive culture, such as family food production or within the bait fish industry, biofiltration may provide an alternative to flow-through techniques. Various filter designs (up draft, submerged, trickling, gravity flow) and filter media (plastic scraps, oyster shell, coal slag, teflon rings, styrofoam) have been used experimentally each demonstrating advantages and disadvantages (Broussard and Simco 1973, Spotte 1979).

Mock et al. (1975) demonstrated the need for the removal of suspended solids before nitrification in a biological filter. This inhibits clogging of the filters and reduces biological oxygen demand. To accomplish this, we included a settling basin consisting of commercially available plastic tube settlers in all trials.

This experiment compares 3 different filter media for application in small-scale recirculating systems. To reduce energy consumption submerged filters were tested, with water flow provided by a floating, mechanical aerator. Since the efficiency of a filter is determined by the available surface area for the growth of nitrifying bacteria, and the availability of oxygen for use in oxidizing nitrogenous metabolites, filter media was chosen to maximize these conditions. Plastic tube settlers as used in the settling basins were also used as the filter media in one trial. A rotating biodisc filter similar to that used by Lewis and Buynak (1976) was used in the second, and a submerged gravel filter was used in the third.

METHODS

Three recirculating systems with 2 replications were constructed identically except for the design of the biological filter. Each culture system consisted of 3 components—a fish culture tank, a settling basin, and a biological filter (Fig. 1)

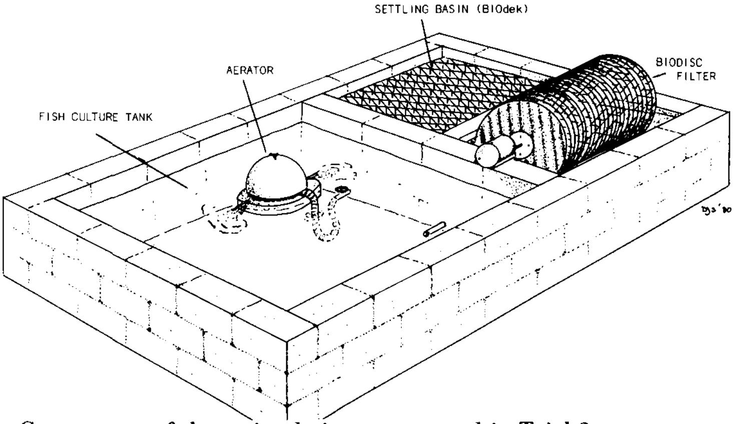

Fig. 1. Components of the recirculating system used in Trial 2.

Culture Tanks and Settling Basins

All units were constructed of cinder blocks and were painted on the inside with a cement-base, waterproof masonry paint. Fish tanks were 1.8 m x 2.1 m, with a depth of 0.4 m. The water volume was 1,512 liters. Settling basins had inside dimensions of 1.2 m x 0.9 m and provided a working volume of 648 liters at a depth of 0.6 m. Each settling basin contained 0.34 m^3 of B10 dek, modular PVC tube settlers obtained from the Munters, Corp., Fort Myers, Florida. Tube settlers have been promoted both for reducing the required size of the settling tanks and improving performance. Tube settlers enhance the ability to capture settleable solids at high flow rates because the depth of settling has been reduced to a few centimeters in the tube (EPA 1974, 1975).

Biological Filters

In the first system (Trial 1), the plastic tube settlers used in the settling basin were also used as the medium in the biological filter. In addition to their application in suspended solids removal, the tube settlers can also be used as a biological filter due to their high void space (95% or greater) and large surface area for the growth of nitrifying bacteria (140 m^2/m^3 material). The filter compartment itself was a 0.9 x 0.9 x 0.6 m cinder block structure which held 0.262 m^3 of the tube settlers, providing 36.4 m^2 of surface area. They were placed 10 cm above the floor facilitating an uninhibited flow from the filter.

In trial 2, biological filtration was provided by a rotating biodisc filter. It consisted of 52 corrugated fiberglass plates, 61 cm in diameter mounted on a stainless steel shaft. The filter was supported by pillow blocks attached at each end of the 0.9 x 0.9 m biofilter tank and positioned so that the water covered slightly less than the radius of the disc. Power was supplied to the drive shaft by a 1/20 HP gearmotor which rotated the discs at a speed of 6RPM's. Thus, the discs were alternately submerged and exposed to the air providing 30.4 m^2 of surface area for growth of the aerobic nitrifying bacteria.

The third system (Trial 3) utilized a bed of limestone gravel as the filter medium. A perforated fiberglass plate positioned 10 cm above the floor of the filter tank supported the 0.24 m^3 gravel bed consisting of 2 graded layers. A 20 cm deep layer of 1.3 cm stone was placed on the filter plate, followed by a 10 cm deep layer of 0.6 cm gravel.

Aeration and Circulation

All systems were aerated by 1/20 HP floating mechanical aerators. The units also pumped water through the systems at the rate of 28 liters per minute. The flow pattern through the components was identical in all systems. The aerator located in the culture tank, pumped the water through a flexible hose into the bottom of the settling basin. Water was pumped upward through the tube clarifiers to a level providing a head of 25 cm. The water flowed from the settling basin into the filter through a 2.5 cm pipe. This pipe was placed below the surface of the water in the settling basin to prohibit the discharge of floating sludge into the filter. The water flowed down through the filter media and then through an outlet, located below the filter plate, back into the culture tank.

Flushing of the Settling Basin

In order to control turbidity and BOD due to fecal material and uneaten food, the settling basins were flushed periodically. This was accomplished by discontinuing the flow of water from the aerator and removing the settling tubes. Water and sludge in the settling basin were drained and replaced with 570 liters of aged tap water. This procedure was used whenever sludge was observed collecting above the settling tubes.

Conditioning of Filters

On 27 March 1978, 100 channel catfish *(Ictalurus punctatus)* averaging 13.1 grams were stocked in each tank. On 4 April each tank received 100 additional channel catfish averaging 15.0 grams. The levels of ammonia, nitrite, and nitrate were monitored daily to determine the variation between trials of the activation time of the filters.

After 59 days, all tanks were restocked with catfish. Restocking was necessary due to a loss of fish from nitrite toxicity which occurred in all systems during filter conditioning. Acclimation was complete and no further losses were incurred.

Stocking and Management of Fish

The stocking procedure included weighing and measuring individually a 10 percent random sample of fish, with the balance of fish weighed in bulk. Stocking weights and densities for each system are shown in Table 1. For the first week all losses, attributed to transport and handling, were replaced.

The fish were fed a commercial pelleted sinking ration (35% crude protein) 7 days per week at the rate of 1-5 percent of the calculated standing crop. This rate varied according to feeding vigor of the fish and the quality of the water. The amount fed was adjusted weekly based on an assumed feed conversion ratio of 1.5. After 44 days, a 10 percent random sample of fish from each trial was weighed and feed weights were adjusted accordingly.

Water Quality Analysis

The relative capability of each system to perform as a mechanical filter was determined weekly by measuring the turbidity of the water, using a Hach 2100A turbidimeter.

Ammonia and nitrite levels were measured daily and nitrate levels weekly. Determinations were made using standard methods of nesslerization for ammonia and diazotization for nitrite and nitrate levels (APHA 1975), with quantitative determinations made colorimetrically using the Bausch and Lomb Spec 20 spectrophotometer.

Daily dissolved oxygen and temperature readings were taken using a YSI Model 51 dissolved oxygen meter. The pH readings were determined with an Orion Model 407A pH meter and total hardness was taken monthly using standard methods.

Flow rates were measured periodically for uniformity and temperature was maintained between 24°C and 27°C using electric space heaters.

Harvesting

Table 1. Sizes, numbers and densities of channel catfish stocked with production data over a 154 day period (May 24 to October 25, 1978).

Trial No.	Filter Type	Tank No.	No. Stocked	Initial avg. and tot. wts. (g)	Percent survival	Food Conversion Rate	Final av. and tot. wts. (g) (kg)	Gain in Biomass (kg)	Percent/[2] Recirculation
1	Plastic Filter Media	1	100	17.2-1714.7	98	1.27	198.6-19.5	17.8	97
		4	100	18.2-1814.7	99	1.39	230.2-22.8	21.0	96
II	Bio-Disc	2	200	16.9-3377.8	97.5	1.28	214.4-41.8	38.4	96
		3	200	16.9-3387.2	95	1.44	213.1-40.5	37.1	97
III	Submerged Gravel	5	200	16.0-3190.4	--[1]	1.36	121.3-24.3	21.1	98
		6	200	16.1-3218.6	96.5	1.62	159.2-30.7	27.5	96

[1]Tank #5 had 100 percent mortality due to loss of aeration on 9/12/78.

[2]Based on Percentage of water exchanged per day.

When flushing the settling tanks and reduced feeding did not result in reducing total NH^3-N levels below 1.0 mg/l (pH 6.0), it was assumed that feed conversions were being adversely affected (Colt et al. 1978). The fish were then harvested, counted, and weighed to determine survival rates, food conversion ratios, and the total productivity of the systems.

The capabilities of each filter were ascertained by the effectiveness of the filter to control the parameters of ammonia, nitrite, and turbidity as well as the level of fish production sustained.

RESULTS

Conditioning of Filters

In Trials 1 and 2, using plastic filter media and biodiscs, acclimation of the filters took 32 days, while the gravel filters (Trial 3) took 20 days. Stress on the fish during the acclimating procedure resulted in mortality primarily due to prolonged toxic levels of nitrite and secondarily from infections of Costia.

The significantly slower response of the filters to varying feeding rates in Trial 1 (tube settling material) prompted us to stock these systems with one half the density of the other trials.

Fish Production

Net gains averaging from 19.4 kg to 37.8 kg were obtained, with the highest yields obtained from Trial 2, utilizing rotating biodisc filters (Table 1). This trial produced an average standing crop of 18 kg/m^3, with daily gains averaging 245 g/day.

All fish fed well throughout the experiment, with food conversion ratios ranging from 1.27-1.62 in individual tanks. One of the gravel filtration systems exhibited 100 percent mortality due to an aeration failure, reducing net gains in that trial. Percentage survival in all other tanks ranged from 95-99 percent, with all losses occurring after the handling of the fish during sampling procedures.

Water Quality

Filter systems exhibited varying degrees of effectiveness in removing ammonia and nitrite nitrogen (Table 2). Filter material used in Trial 1 failed to provide substantial nitrification. Throughout the experiment, even at one-half of the fish density, water quality of this system remained marginal with NO^2-N levels averaging 0.33 mg/l and with slow recovery to acceptable levels after flushing of the settling tanks.

The revolving biodisc filter, once acclimated, yielded the most stable water quality with very quick recovery from high ammonia levels. The greatest yield was produced using this filter design, with an average net gain of 37.8 kg.

As the fish biomass increased in each tank with subsequently higher feeding levels, flushing of settling basins became increasingly frequent. Dissolved oxygen levels decreased with increased turbidity. This in turn reduced feeding vigor and the relative efficiency of the system.

Percentage recirculation ranged from 96-98 percent, based on the amount of make-up water exchanged per day (Table 1). With a 2-4 percent water exchange, nitrate levels never exceeded 30 ppm.

The pH of the water fell continuously throughout the experiment in all systems, due to biological nitrification in the filters, but remained within acceptable limits.

DISCUSSION

Much information was acquired during the acclimating procedures for the three filter designs. With increasing ammonia levels in all three systems, the growth of nitrifying

Table 2. Ranges and Means (in parenthesis) of various water quality parameters.

Trial #	Tank #	NH^3-N(mg/l)	NO^2-N(mg/l)	NO^3-N(mg/l)	pH	D.O (mg/l)	Hardness (grains)	Temperature (°C)	Turbidity (NTU)
I	1	0.0-0.96 (0.34)	0.084-0.620 (.273)	8.2-24.1 (14.27)	7.20-8.90	6.25-7.70 (6.92)	15-20 (17)	24.0-28.8 (26.6)	3.0-7.25 (4.42)
	4	0.0-1.40 (0.49)	0.069-1.87 (.386)	8.6-24.1 (15.07)	6.65-8.95	5.34-7.45 (6.27)	15-19 (18)	24.0-29.0 (26.9)	2.4-9.3 (5.06)
II	2	0.05-2.22 (0.61)	0.028-0.80 (0.186)	9.0-26.6 (16.47)	6.10-8.90	4.5-7.45 (6.14)	16-21 (20)	24.0-29.0 (27.5)	1.0- 8.2 (3.76)
	3	0.05-2.55 (0.67)	0.034-0.58 (0.188)	9.2-24.4 (15.89)	6.00-8.85	5.0-7.35 (5.97)	15-23 (19)	24.0-29.0 (27.0)	2.2-11.0 (5.26)
III	5	0.13-3.85 (0.68)	0.023-2.20 (0.292)	9.0-24.1 (15.82)	7.00-8.80	4.69-7.05 (5.46)	16-20 (18)	24.0-28.8 (27.4)	1.3-9.7 (5.57)
	6	0.10-3.37 (0.67)	0.025-2.13 (0.223)	6.5-24.9 (14.85)	7.00-8.75	2.5-6.65 (4.83)	12-18 (16)	24.1-29.0 (27.0)	2.2-12.0 (5.86)

bacteria resulted in various profiles of ammonia and nitrite reduction. The gravel, although washed thoroughly, can be assumed to have some levels of nitrifying bacteria present while the plastic tube settlers and revolving biodisc filters are practically free of these bacteria. This was evident in the conditioning time required and in developing toxic levels of ammonia and nitrite. Loss of fish can be avoided by seeding the filters and providing a source of ammonia chemically.

Clogging of gravel filtration units has required extensive backwashing capabilities in the past. Utilization of an effective settling tank provided sufficient pretreatment of all filter systems and made back washing of the gravel filters unnecessary.

Levels of ammonia, nitrite, and nitrate decreased in response to the flushing of the settling basins. Effectiveness of the filters was directly correlated to the levels of dissolved oxygen which in turn was affected by suspended fish wastes. It became evident during the last several weeks of the experiment that if the material accumulated in the settling basin could be removed with greater ease and with less water exchange, water quality could be improved by more frequent flushing and a greater holding capacity could be realized.

SUMMARY AND CONCLUSIONS

A net gain in biomass to 41.2 kg with 96.5 percent recirculation in the biodisc filter *system in a five month period demonstrates the potential of this culture method for raising* adequate quantities of fish for family use. To determine the economic feasibility of this system, it is necessary to consider amortized construction costs for the system and direct fish production costs of fingerlings, food, and electricity. Analysis has determined that the combination of aeration and pumping capabilities with a 1/20 HP device reduces energy requirements to a point making this level of production economical. Therefore, the feasibility of this system will be determined by the degree of simplification that can be accomplished without jeopardizing the technological basis on which it depends.

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