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An In-pond Raceway System Incorporating Removal of Fish Wastes

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ABSTRACT

*An aquaculture system called 'in-pond raceway (IPR)' was studied for channel catfish (*Ictalurus punctatus*) production. The raceway was a rectangular-shaped box ($4{\cdot}9 \times 1{\cdot}2$ m $\times$ $1{\cdot}2$ m high), built from treated lumber and suspended between walkways of a floating pier. A set of air-lift pumps located at the head-end of the raceway circulated pond water into the raceway. The raceway had an approximately 4% bottom slope along the 4·9 m length to assist the movement of fish wastes (feces and uneaten feed). In 1992 four raceways were stocked with an average of 2078 fingerlings per raceway. Mortalities during the 124-day culture period averaged 341 fish (16·4%) per raceway. The growth rate averaged 1·29 g day^{-1} with an average food conversion ratio (FCR) of 1·95. The average total weight of the harvested fish was 297·3 kg per raceway (52·2 kg m^{-3}). A total of 20·1 m^3 of effluent containing fish wastes was removed and sampled. The samples were analyzed for concentrations of total solids, BOD and nutrients (nitrogen and phosphorus). The system was intended to remove settleable wastes with primary and secondary waste collectors. Soluble wastes were allowed to enter the pond.*

INTRODUCTION

Increased demand for fish and a decreased ocean-fish catch have resulted in high fish prices and increased investment in aquaculture as a means to boost fish supplies worldwide (Shell, 1983; Sandifer, 1988). In most common aquaculture systems, fish are reared in ponds, cages or raceways. Due to the production characteristics of these systems, environmental concerns have been raised in the United States and many other countries. Effluent containing fish wastes (uneaten feed and feces) from these systems can cause water-quality degradation in the production system and in water downstream. Cultured catfish produce wastes that yield 4·9 g of BOD per kg of live-weight of fish per day (Murphy & Lipper, 1970). This rate is greater than the BOD produced from wastes of an equivalent weight of most livestock animals. The effluent from fish ponds is low in dissolved oxygen and high in nutrients (Boyd *et al.*, 1979). This condition can cause eutrophication problems in the receiving water bodies.

Cages suspended in open water bodies have been used for many years to rear fishes (Beleau, 1985; Beveridge, 1987). Advantages of these systems over land-based aquaculture systems are: little or no land ownership, flexible sizing of enclosure volume, lower capital costs, and a large ratio of source water to cage volumes (Beveridge, 1987). Fish production from a cage culture varies by management intensities. Cage culture of carps in China yielded up to 7·5 kg m^{-3} from low-intensity systems and up to 13·5 kg m^{-3} from semi-intensively managed cages (FAO, 1983). Cage studies at Auburn University, Auburn, Alabama, stocked with 400 catfish m^{-3} yielded 180 kg m^{-3} (Schmittou, 1969). However, the impacts of the intensively stocked cages on water quality have not only raised conflicts with other users of the water bodies, but also caused problems in the cage operations themselves. The latter problems are mainly due to fish wastes from feces and/or excessive feeding practices collecting in the system or entering the pond. Also, when fish are confined, they are exposed to suboptimal environmental conditions such as dissolved oxygen levels, high water temperatures, and elevated light intensities. High incidences of mechanical lesions and lower levels of immunological response often result under these conditions (Beveridge, 1987; Collins, 1988).

Cage production is often limited in stocking rate because of problems associated with localized water-quality deterioration and rapid spread of disease. Masser *et al.* (1991) reported that disease outbreaks occurred in 64% of the cage-culture facilities in the Piedmont region of Alabama during 1990. Mortalities were reported in 91% of these cases. The relative frequency of diseases appears to be greater in fish raised in cages than in those raised in ponds (Collins, 1988). These problems may be alleviated by continued water circulation and aeration, removal of wastes, and an efficient method of disease control. The objective of this study was to develop an aquaculture system which circulates and aerates pond water while removing fish wastes before they can enter the pond. An aquaculture system called 'In-pond raceway' (IPR) was designed and tested with channel catfish (*Ictalurus punctatus*) reared in the system.

Air-lift pumps were used in the IPR system to continuously circulate water from the pond. The air-lift pumps aerated the pumped water during periods of low dissolved oxygen in the pond and maintained saturation levels during periods of supersaturation of pond water. The system collected and removed settleable fish wastes before the effluent entered the pond.

MATERIALS AND METHODS

This study evolved from one IPR unit in 1991 to a total of four units in 1992. A schematic layout of the four IPR units and two additional units for future expansion is shown in Fig. 1. Each IPR was composed of three major components: water circulation and aeration by a set of air-lift pumps, a fish culture section and waste collectors. A primary waste collector was located at the tail end of a raceway. A secondary waste collector was installed to settle and store the waste transferred from the primary waste collectors until removed by a submersible pump. The field view of the study site is shown in Fig. 2.

The raceway was a rectangular-shaped box, built from treated plywood and suspended between walkways of a floating pier. It had dimensions of 4·9 m × 1·2 m × 1·2 m deep at the deepest section (Fig. 3). It was submerged in the pond except for the top 0·1 m, which extended above the water surface. The water depth was 0·9 m at the head-end of the raceway and 1·1 m at the tail-end to maintain a 4% bottom slope in the 4·9 m long fish culture section. The slope assisted the movement of settled fish wastes (feces and uneaten feed) as water moved toward the tail-end of the raceway. A 0·12-m high opening across the bottom at the tail-end of the raceway (Fig. 3) allowed the water and fish wastes to exit into the primary waste collector. Fish were kept from escaping through this opening by a mesh screen (25 mm × 12 mm opening) which extended across the raceway 0·15 m from the tail-end. The total volume in the fish culture section was approximately 5·7 m^{-3} per raceway (4·75 m × 1·2 m × 1·0 m average depth below the water line). The top of the raceway was covered with two screen doors hinged on one side to allow easy access for operation while protecting the fish from possible predators.

A set of air-lift pumps (Fig. 4) was installed at the head-end of each raceway to circulate and aerate the water pumped into the pond. A screen (25 × 12 mm mesh) was placed over the outlet of the air-lift pumps so fish would not escape through the pumps. Air was supplied to the air-lift pumps through air intakes by regenerative air blowers. Air

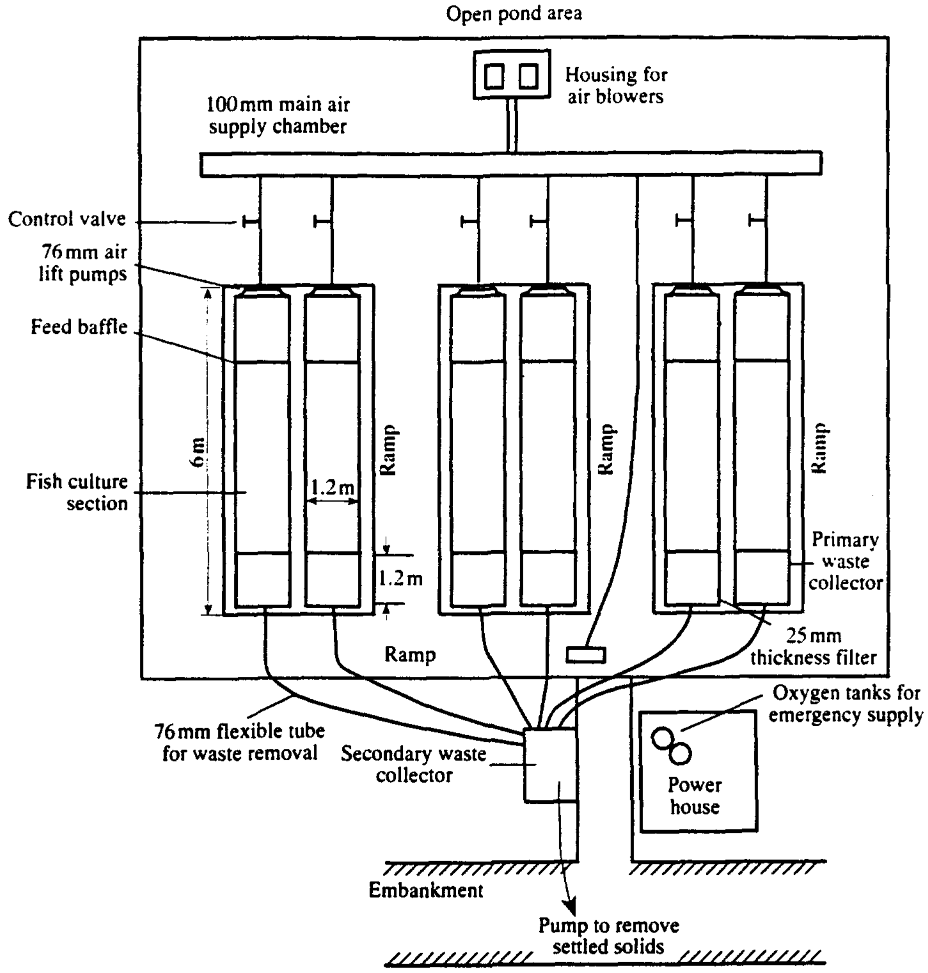

Fig. 1. Schematics of six in-pond raceways showing air-lift pumps, fish culture section, and primary and secondary waste collectors. The two units on the right will be installed for the 1993 culture season.

intakes to the pumps were 1·0 m below the pond surface and connected to the air blower by a combination of flexible tubing and PVC pipe as shown in Figs 4 and 5. One 0·75 kW air blower supplied air to the air-lift pumps for two raceways. Volume of water pumped by the air-lift pumps was controlled by adjusting the amount of air flow using an air-bypass valve installed for each raceway. The water intake of the air-lift pumps was positioned near the surface of the pond (0·3–0·4 m below the surface) so that relatively warm and highly oxygenated water could be utilized. Although water circulation was the primary purpose of the air-

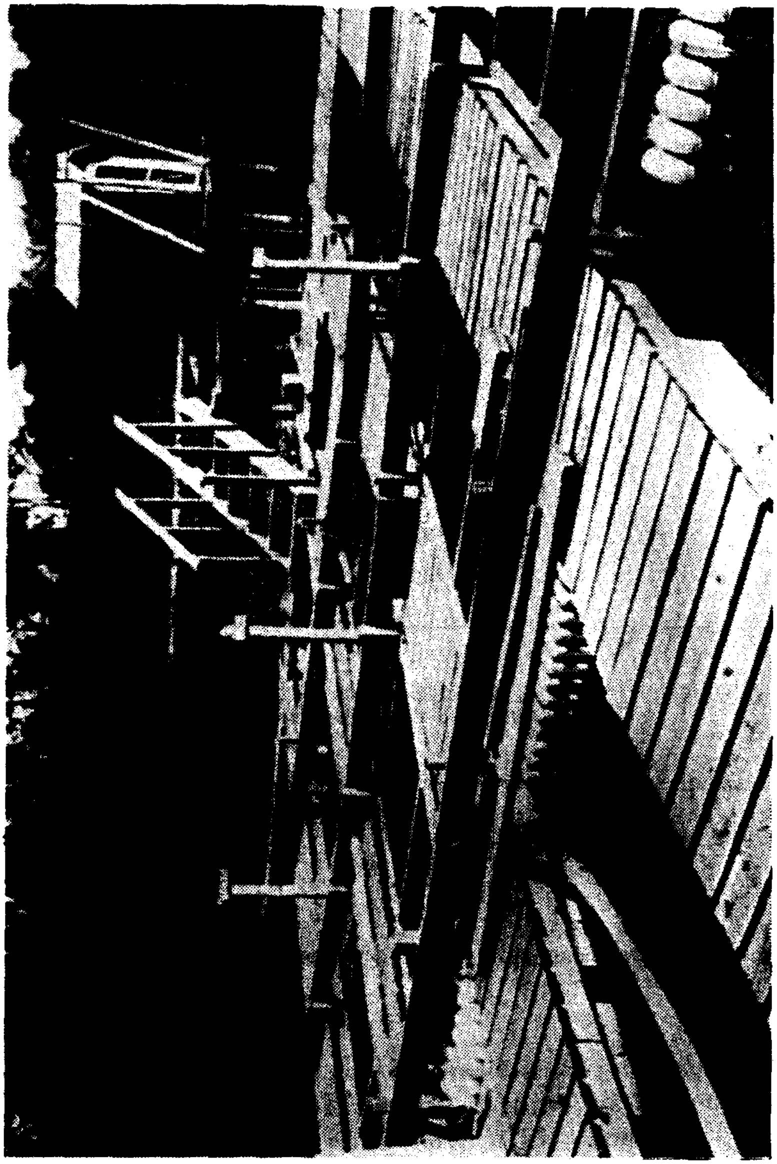

Fig. 2. Field view of the in-pond raceway study site at the Fisheries Research Unit of Auburn University, Auburn, Alabama.

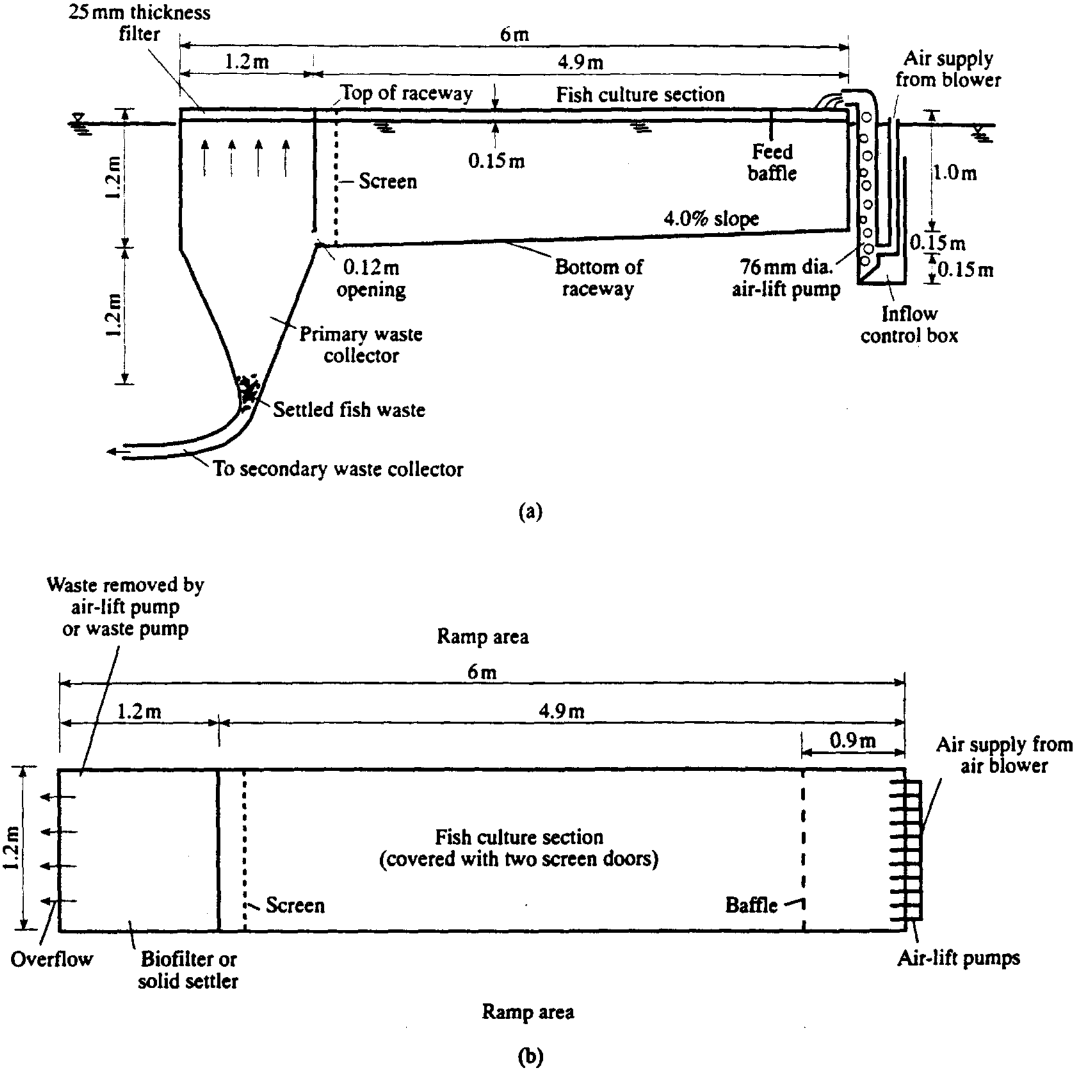

Fig. 3. Schematics of an in-pond raceway: (a) cross-sectional view; (b) top view.

lift pumps, aeration was considered an important benefit, especially when oxygen concentration in the pond dropped below saturation at night. Figure 5 shows a set of air-lift pumps in operation. Aeration of the air-lift pumps is indicated by the bubbling discharge in the figure.

An oxygen supply system was installed in case of unexpected electric power outages. The oxygen supply system consisted of two oxygen cylinders connected to a normally-closed electric solenoid valve that would open if electrical power was interrupted. High-pressure tubing led

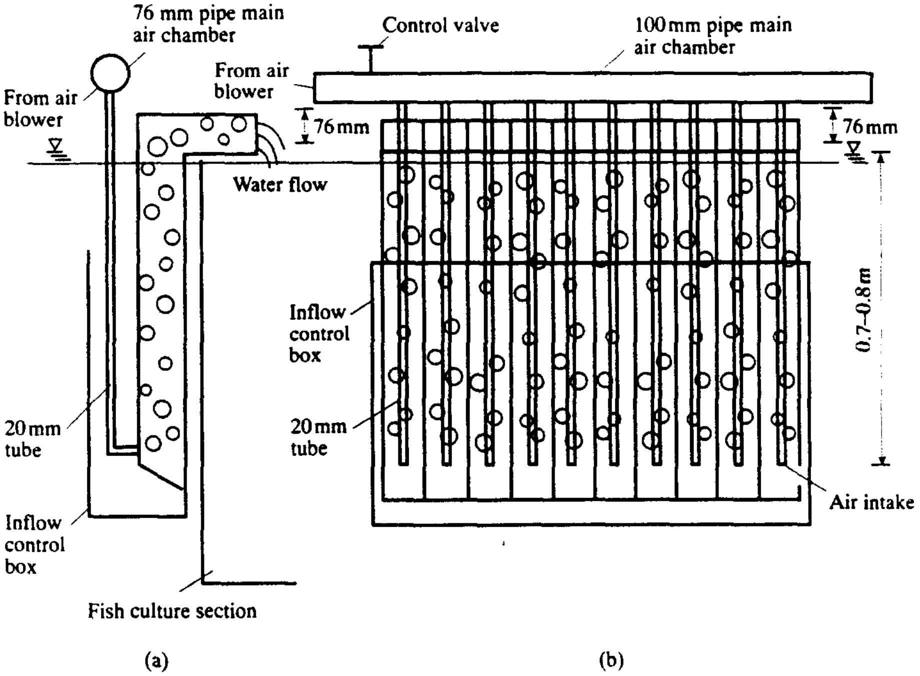

Fig. 4. Details of a set of air-lift pumps for water circulation and aeration: (a) side view; (b) front view.

to the raceways and oxygen was delivered into the fish culture section of the raceways through mili-pore tubing. This system also was utilized to maintain adequate oxygen supplies during bath treatments for disease and other raceway management procedures.

Fish wastes moved down the raceway with the water flow. The top of the collector extended 0·1 m above the water surface, with a total height of 2·4 m from the bottom of the cone (Fig. 3). Water exited through a 1·2 m × 0·15 m mesh-screened weir opening on the top across the tail-end of the collector. The water in the system continued to flow due to the descending order of the hydraulic heads maintained in the system from the raceway to the waste collector and finally the pond. Settleable fish wastes were accumulated in a cone-shaped primary waste collector (Fig. 3) which was atttached to the tail-end of each raceway. However, some portion of the waste was carried into the pond by the overflow.

A 0·3 kW submersible sludge pump was used to periodically remove the wastes directly from the bottom of each primary waste collector in 1991. In 1992, a box-shaped secondary waste collector (Fig. 6) was installed in order to solve problems developed by waste build-up in the primary waste collector, which caused a moderate increase in ammonia

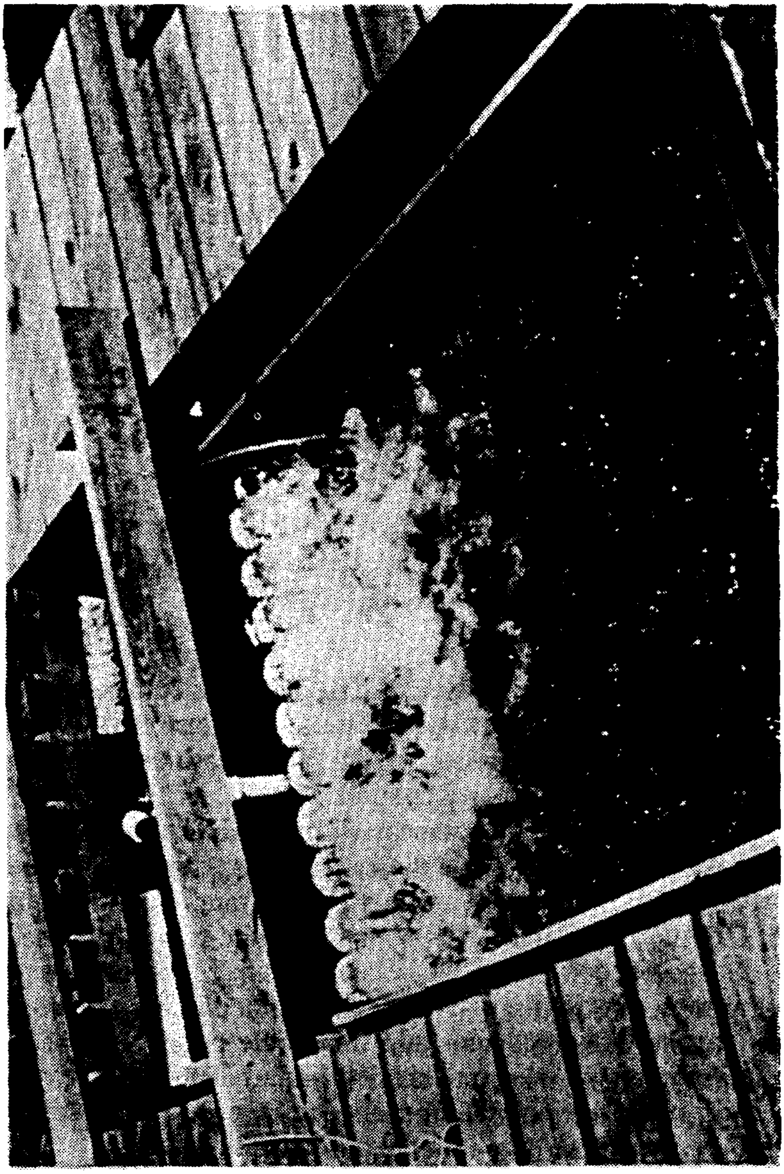

Fig. 5. A set of air-lift pumps in operation.

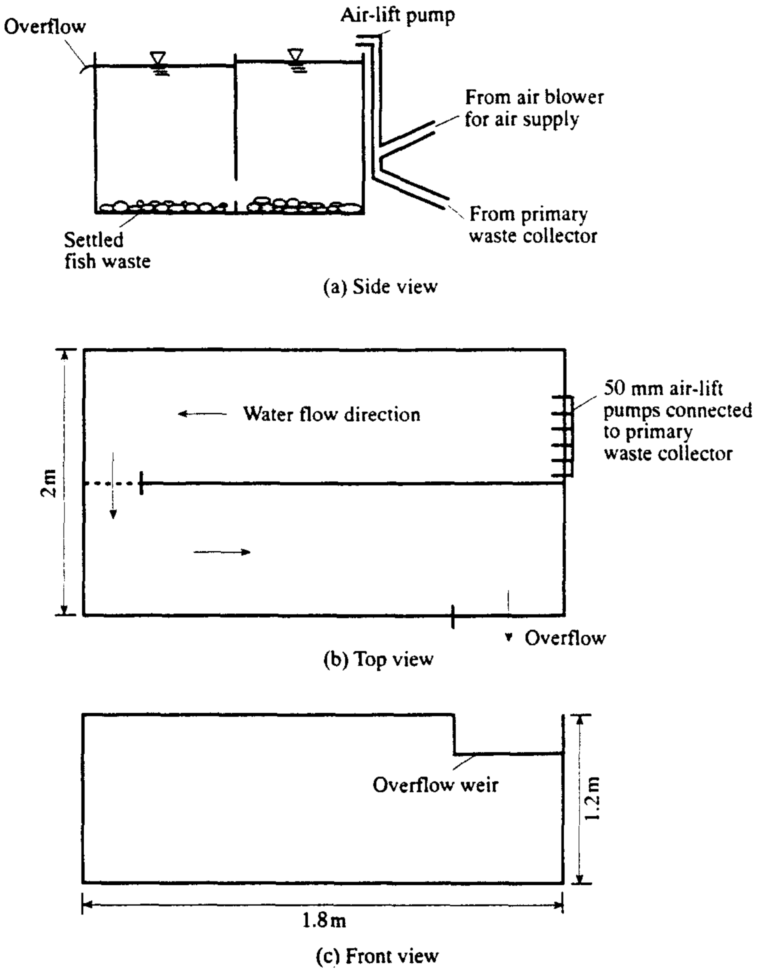

Fig. 6. The secondary waste collector used to settle and store fish wastes pumped from the primary waste collector by air-lift pumps: (a) side view; (b) top view; (c) front view.

concentrations in the fish culture section. A single 50-mm diameter air-lift pump was connected to each primary waste collector by a 76-mm diameter flexible tube. This air-lift pump was used to continuously pump the wastes into the secondary waste collector. The secondary waste collector functioned as a solids settler and for storage of the settled wastes until removal. The pumping rate of this air-lift pump was limited (< 0·5% of the total flow in the raceway) by the small pipe and a low rate of air flow. The same air blower used for the raceways supplied the air. The secondary waste collector was divided in the middle with an opening at the bottom of the divider, and inlet and outlet openings were located strategically so as to increase flowing time. The increased flowing time provided settleable solids with an extended settling time before the effluent entered the pond. The same sludge pump used in 1991 was used to remove the wastes from the secondary waste collector biweekly during the culture period. There was an overflow weir on the top of the secondary waste collector through which excess effluent entered the pond. The amounts of water and fish wastes removed were measured and wastes were analyzed for total solids, BOD and nutrients (nitrogen and phosphorus).

RESULTS AND DISCUSSION

Table 1 shows initial stocking rate, harvested fish counts and weight, and feeding rates for the four raceways used in 1992. An average of 2078 fingerling channel catfish (364 fish m^{-3}) per raceway was stocked in the raceways on 3 June 1992. The average weight per fish was 22·9 g. This is comparable to stocking rates of commercial catfish production systems in land-based raceways, 282–565 fish m^{-3}, and those in cages, 282–353 fish m^{-3} (Tucker & Robinson, 1991). Fish were fed all they would consume of a commercial 32% floating catfish ration twice daily (8:00 am and 5:00 pm) throughout the 124-day culture period. The average feeding rate was 492·3 kg per raceway. The average feed conversion ration (FCR) was 1·95 (amount of feed fed divided by weight gain) for the number of fish harvested.

An average of 1737 fish per raceway (304 fish m^{-3}) was harvested on 25 September. The average total weight of harvested fish was 297·3 kg

TABLE 1

Initial and Final Stocking Rates, and Feeding and Feed Conversion Ratio (FCR) for the Four Raceways during the 1992 Culture Season (13 June to 25 September)

Items	*Raceway no.*				
	1	*2*	*3*	*4*	*Mean*
Number of fish stocked	2072	2084	2075	2079	2078
Total stocking weight (kg)	47·5	47·2	48·1	47·5	47·5
Number of fish harvested	1846	1684	1648	1770	1737
Total harvesting weight (kg)	361·7	254·3	277·8	295·4	297·3
Total harvesting weight (kg m^{-3})[a]	63·4	44·6	48·7	51·8	52·2
Total feed fed (kg)	566·6	446·7	450·8	504·2	492·3
Feed conversion rate (FCR)	1·8	2·1	1·9	2·0	1·95

[a] Based on the total volume for fish growth of 5·7 m^3 per raceway.

per raceway (52·2 kg m^{-3}) and the average weight per fish harvested was 171·2 g. The average growth rate was 1·29 g day^{-1}. There was an average of 341 fish mortalities (16·4%) during the culture period. The lower than expected growth rate and the moderate mortality resulted from disease problems in the pond during the study period. Mortality of channel catfish in floating cages studied in the same pond showed 19·25% during the same period.

Fish wastes were removed daily from the secondary waste collector by a 0·3 kW submersible sludge pump and sampled a total of eight times (approximately every 2 weeks) during the culture period. The pump was operated until clear water was observed in the discharge. A total of 20·1 m^3 water containing fish wastes was removed from the secondary waste collector. The samples were analyzed for concentrations of total solids, BOD, and nutrients (nitrogen and phosphorus). Table 2 shows the mean concentrations and the total amounts of the waste constituents removed. The high concentrations of BOD (81·29 mg liter^{-1}) and total ammonia nitrogen (2·9 mg liter^{-1}) suggest elevated bacterial activities in the secondary waste collector before the removal. Total nitrogen and total phosphorus removed from the system were 1·8% and 1·6%, respectivly, of the total amounts added to the raceways as feed. The results suggest a relatively poor performance of the waste removal system.

TABLE 2

Concentrations and Amounts of Constituents in the Effluent Containing Fish Wastes Removed during the 1992 Culture Season (13 June to 25 September)

Constituents	*Mean concentrations (mg liter^{-1})*	*Standard error of mean (mg liter^{-1})*	*Amount removed*[a] *(g)*	*Typical range of catfish production in ponds*[b] *(mg liter^{-1})*
Total solids				20–30
settleable solids	12·54	2·13	250·8	
dissolved solids	0·21	0·06	4·2	
BOD	81·29	5·06		10–15
TKN[c]	14·01	2·76	208·2	2–3
TAN[d]	2·90	2·02	58	<2
NO_2-N	0·006	0·002	0·12	<0·5
NO_3-N	0·05	0·01	1·0	0·1–0·2
PO_4-P	0·03	0·03	0·6	0·05–0·1
Total P	2·36	0·32	47·2	<0·3

[a] Total amount of removed constituents based on a total of 20·1 m^{-3} effluent.

[b] Source: Boyd (1990).

[c] Total Kjeldahl nitrogen.

[d] Total ammonia nitrogen.

Problems associated with the waste system included: (1) inefficient settling of the fish wastes in the primary waste collectors, which caused large amounts of settleable wastes to enter the pond; (2) clogging of the tubes between the primary and secondary waste collectors; and (3) inability of the system to remove soluble constituents from the primary waste collectors. The first two problems were mainly due to the slow flow of effluent passing through the tubes. As to the third problem, a biofilter would be required to remove soluble constituents before the effluent leaves the primary waste collector. The system was, however, designed to collect and remove only settleable wastes.

SUMMARY

An aquaculture system called 'in-pond raceway' (IPR) was studied at the Auburn University Fisheries Experiment Station. Four rectangular-shaped raceways (4·9 m × 1·2 m × 1·2 m high) were built from treated lumber and suspended between walkways of a floating pier. A set of air-lift pumps circulated the pond water into the raceway. The raceways were designed to maintain the movement of fish wastes (feces and uneaten feed) in the raceway toward the tail-end, and fish wastes were collected and removed before entering the pond. The system was intended to remove settleable fish wastes with primary and secondary waste collectors. Soluble fish wastes were allowed to enter the pond. Fish wastes removed were analyzed for concentrations of total solids, BOD, and nutrients (nitrogen and phosphorus). Because of the inefficient settling capability of fish wastes in the system, only a small fraction of the nutrients added to the raceway as feed was removed.

This new IR aquaculture system sustained a high stocking rate with water circulation supplemental aeration, and showed potential for removing fish wastes before they enter the pond. The study will continue to identify and solve problems and improve components of the system. The following areas will be emphasized in this effort: construction cost, energy consumption, performance of air-lift pumps, alternative waste removal systems and disposal of the removed wastes.

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