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Energy Use of Recycling Water Aquaculture Systems for Ornamental Fish Production[1]

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Most of Florida's ornamental fish production takes place in outdoor ponds, where production success is often subject to such natural occurrences as winter weather, the presence of aquatic weeds, and predation by birds and other animals. Most facilities also use tanks for holding, breeding, and producing certain fish species. Energy consumption is greatest for water pumping and heating and can become a major business expense, especially during the winter and spring.

Increased water consumption is also becoming a critical problem in Florida, as more and more people compete for the same resource. Pond production requires not only available water but also land suitable for fish pond development. Land values and regulations controlling development continue to eliminate many potential pond production sites, a situation that threatens to limit expansion of the ornamental fish production industry in Florida.

One alternative is a recirculating aquaculture system, which removes some of the inefficiencies inherent in production or holding systems. Water reuse reduces pumping costs and retains energy normally used to heat water. In addition, it enables production to occur in a controlled environment where losses to predators and seasonal drought do not influence production plans. Finally, it permits a reduction in water consumption and the production of large numbers of fish in a small area.

This publication describes the components of a recirculating water system that can be used for holding and/or production of ornamental fish. It also explains how such a system can be designed to be more energy efficient than conventional systems. Recirculating systems may not be applicable to all situations, since they require a high level of management capability and a large initial capital investment. Certain species and varieties of ornamental fish may not reproduce or develop in an indoor system, and water quality and disease management have historically caused problems in recirculating systems. The alternative offered in this publication can save energy and reduce water consumption in many situations, especially in holding facilities. This is not to suggest that pond production of ornamental fish is not a viable option. Information regarding the energy required for conventional ornamental fish production, especially in open ponds, is extremely limited. Also, since production techniques vary within the industry, it is difficult to generalize about energy requirements. Nevertheless, the data and examples provided in this publication will serve to demonstrate how modern technologies can be employed to reduce the costs of ornamental fish production.

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COMPONENTS OF AQUACULTURE SYSTEMS

The basic components of a typical outdoor pond system are a water supply, a water distribution system, an aeration system, fish ponds, and a water discharge or retention system. Many ponds are equipped with covers to provide protection from cold and predators. Most buildings used for holding or fish production are heated. Some facilities directly heat the water in these buildings, employing conventional gas or electric resistance heaters.

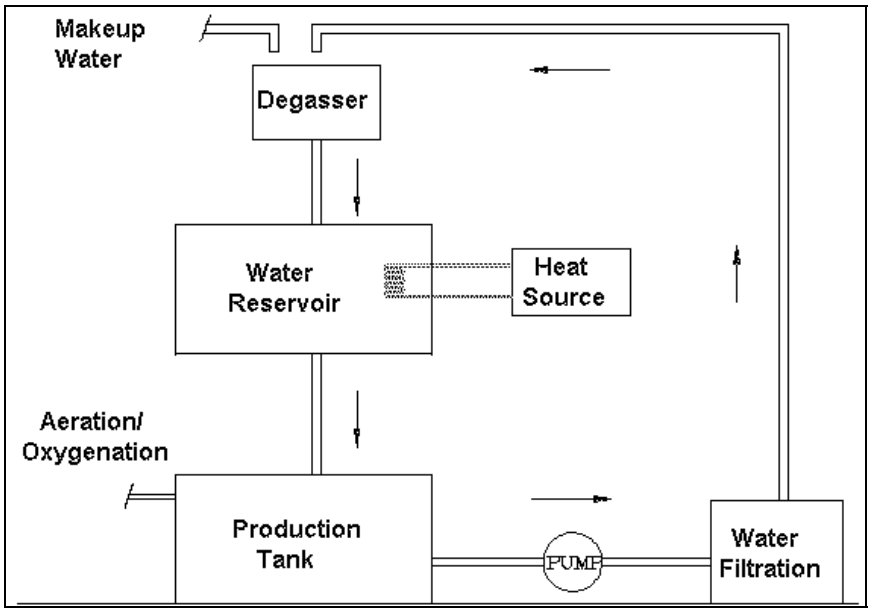

Figure 1. Typical water recycling aquaculture production system.

Although recycling systems may vary in several respects, a typical system consists of a water supply, a water distribution system, tanks for holding fish, a filtration system, an aeration/degasser system, a heating/cooling system, and a building to house the system (see Figure 1).

ENERGY SAVED IN PUMPING

Most of the energy used in ornamental fish production is applied to pumping and temperature control. This publication highlights these two important aspects of ornamental fish production systems.

While flow rates in a recirculating water system may actually be higher than in flow-through systems, the lower pumping head saves energy. In flow-through systems, water is pumped from wells as deep as 500 feet. Many wells on fish farms have diameters of 4-6 inches, and pumps often have 5- to 10-horsepower capacities. Recirculating systems, on the other hand, may pump as little as 10 feet of head and can be operated on as little as 1/2 horsepower. In a recycling system, the only head losses are elevation head losses between the tanks on the floor and elevated tanks and friction head losses in the pipes, fittings, and filter.

Electric energy is sold by the kilowatt hour (1 horsepower = 0.746 kilowatts). In Florida in 1992, a typical price for a kilowatt hour of electricity was $0.08. Operating a 5- to 10-horsepower pump at 75% efficiency costs approximately $10-$19 per day, while operating a 1/2-horsepower pump costs about $1 per day. Clearly, the lower initial and operating costs of the smaller pump are among the major advantages of recycling systems.

Before pumps are selected for a recycling water system, the required flow rate must be determined. This is based on the flow rate needed to maintain water quality for a given weight of fish and the expected head requirements of the system. The main limiting factors in recycling systems are nitrogenous wastes (e.g., ammonia, nitrites, and nitrates) and oxygen. There must be sufficient flow through the tanks to replace water before it becomes high in nitrogenous wastes or low in dissolved oxygen. Nitrogenous wastes, produced in proportion to the amount of feed consumed by the fish in the system, almost always constitute the primary limiting factor. Most of the energy that provides flow in a recycling system is used to overcome differences in elevation between the sump and the fish tanks and to overcome friction in the plumbing. The energy that provides flow in outdoor flow-through systems is consumed chiefly in pumping water from a source such as a deep well and in overcoming friction in the pipes and fittings of the water distribution system. Energy is also used initially to fill both indoor water recycling systems and outdoor ponds. When viewed as a proportion of the total energy used per unit of production, the amount of energy used for filling water recycling systems is small; however, the energy used to fill outdoor ponds contributes significantly to production costs in some systems.

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Table 1. Flow rates for typical water recycling systems.

Weight of fish in kilograms	Weight of fish in pounds	Flow rate in liters per hour	Flow rate gallons per minute
2,000	4,400	38,400	169
1,000	2,200	19,200	85
500	1,100	9,600	42
250	550	4,800	21

The values in Table 1 are based on the following assumptions:

- The fish consume an amount of feed equivalent to 1% of their total body weight every day.
- The feed has a protein content of 35%.
- The biological filter has a removal efficiency of 35%.
- All the ammonia produced by the metabolizing of feed is excreted in 6 hours.
- The fish are fed four times per day.

For the water recycling systems described in Table 1, a flow rate of 0.038 gpm per pound of fish is required to control ammonia. In an average water recycling system housed in a 20- by 30-foot structure, with 550 pounds of fish and a flow rate of 21 gpm, approximately 50 feet of 1-1/2-inch PVC pipe with a friction head loss of 1.6 feet would be required. Assuming there were twelve 90° elbows and four gate valves in the system, an additional 1.6 feet of water head loss would occur in the elbows and gate valves. A typical elevation head for a system of this size is 5 feet. Therefore, the total head in plumbing would be 8.2 feet of water. Assuming an additional 5.8 feet of head loss in filters, the total head would be 14.0 feet of water. If a pump with an operating efficiency of 50% were used, a 0.15-horsepower (i.e., 0.11-kilowatt) motor would be required to produce a flow of 21 gpm against 14 feet of water head. A motor operated continuously at an efficiency of 75% would require 3.5 kilowatt hours of energy per day.

A flow-through system housed in a similar structure and using tanks of the same size would require a continuous flow of 21 gpm from a deep well. A standard ornamental fish production system includes a 150-foot well located 50 feet from the building. This type of system requires a pump that can supply the same quantity of water as the recycling system but at a much higher head. The head losses for the system include 150 feet of elevation head loss from the water level to the ground surface and a friction loss of 1.6 feet of water in the 50 feet of pipe between the well and the production structure, in addition to friction losses in the plumbing within the structure. A typical flow-through system with 550 pounds of fish and a flow of 21 gpm, housed in a 20- by 30-foot structure, would require approximately 25 feet of 1-1/2-inch PVC pipe, with a friction loss in the pipe of 0.8 feet of water. Assuming there were six 90° elbows and two gate valves in the system, an additional 1.6 feet of water head loss would occur in the elbows and gate valves. A typical elevation head for tanks in a system of this size is 5 feet. The total dynamic head for the flow-through system would be 158.2 feet of water. A pump operating at an efficiency of 50% would require 1.7 horsepower (i.e., 1.25 kilowatts) to produce a flow of 21 gpm against 158.2 feet of water head. If the pump were powered by an electric motor operated continuously at 75% efficiency, it would use 40.1 kilowatt hours of energy per day.

In a typical 550-pound system, 36.6 fewer kilowatt hours of energy per day are consumed by using recycling instead of flow-through systems. The ornamental fish industry in Florida is composed of 1,240 acres of outdoor ponds with an annual production of approximately 2,280,000 pounds of fish. If half the industry used indoor water recycling production systems similar to the one described, the energy savings would be 76,000 kilowatt hours per day, or 27,700,000 kilowatt hours per year. At $0.08 per kilowatt hour, this would result in savings of $6,000 per day, or $2,200,000 per year for the industry.

It is difficult to make comparisons between indoor recycling systems and outdoor pond systems because of system variations. In general, however, recycling systems have the potential to reduce pumping costs, particularly during spring droughts when water levels must be maintained, and during cold periods when water is pumped to maintain water temperatures. Energy usage for outdoor ponds varies considerably and is heavily influenced by the depth of water in a system's well. When well water is available at a depth of 70 feet or less, or when groundwater is high and evaporation low, the difference between the amount of energy consumed in recycling systems and that used in pond systems is minimal. However, recycling

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systems have potential advantages over pond systems when well water is available only at a depth greater than 70 feet or when space is limited. Assuming an average weight of 1 gram per fish and a volume of 10,000 fish per pond, a 550-pound recycling system would have the same capacity as 24 outdoor ponds. In addition, a typical 24-pond system occupies 2-3 acres of land that could be used more productively for other purposes.

SELECTION OF PUMPS AND PLUMBING COMPONENTS

Size and output must be considered when selecting pumps. A pump must be large enough to deliver the desired quantity of water, usually measured in liters per hour or in gallons per minute. The pump must also be able to deliver this quantity of water at the operating pressure or total head required by the system.

Total head includes the pressure required at the pipe outlet (i.e., pressure head); the pressure needed to raise water to the desired elevation (elevation head); the pressure necessary to overcome friction (friction head); and the pressure required to raise water from a sump or other water source to the pump (suction head). Head can be measured either in feet of water or in pounds per square inch (psi) (psi x 2.31 = feet of water).

A pump's efficiency varies with the rate of output and the total dynamic head. The manufacturer should provide a table or graph describing the relationship between these factors and pump efficiency. The consumer must make sure that the pump selected offers the desired output at the highest pump efficiency. Careful pump selection enables the user to operate a smaller pump (i.e., one with a lower horsepower) than is required by most wells.

PVC pipe and fittings are recommended for recycling water systems. The advantages of PVC pipe are that it is relatively inexpensive and is subject to less pressure drop due to friction than other types of pipe. Fittings are a major source of friction loss in piping systems. A 90° standard elbow experiences the same amount of pressure drop as 32 diameters of straight pipe. Therefore, when the layout of a pipe system is being planned, the number of elbows and other fittings should be minimized. Since valves are another source of friction loss, gate valves should always be used instead of globe valves. An open gate valve has a friction loss equivalent to 7 diameters of straight pipe, whereas an open globe valve has a friction loss equivalent to 300 diameters of straight pipe.

HEATING SYSTEMS

Heating systems in conventional fish production buildings are often inefficient because they typically heat air rather than water. When water is heated, either gas or electric water heaters are employed, limiting efficiency. In addition, many of these buildings use flow-through systems, which allow heated water to be discharged and wasted. In outdoor pond systems, plastic covers must be used or water pumped to protect the fish during severe winter weather. Using conventional methods often slows or stops production during periods of peak market value.

Water heating is costly and requires a great deal of energy. In flow-through systems, most of this energy is lost when the water is discharged. Recycling water systems save a significant amount of energy and can provide year-round production capabilities. A recycling system directly heats water; then, instead of discarding this expensive heated water, the recycling system removes the nitrogenous wastes, aerates and degasses the water, and returns the water to the tanks.

Most indoor systems rely on electric resistance heaters to heat water. Although these heaters are clean, convenient to use, and accessible, they are expensive to operate. For operations requiring heat for more than a few days per year, a heating system that burns fuel to heat water is much less costly to operate than one employing electric resistance heaters. For example, assuming a cost of $1 per gallon, propane burned to generate heat provides about 80,000 Btu of energy per dollar. In comparison, if electricity costs $0.08 per kilowatt-hour, the amount of electricity used to power resistance heating elements provides only 43,000 Btu per dollar.

Heat pumps offer another alternative for water heating. They allow temperature to be controlled at lower costs than either conventional electric or gas-powered heaters and have the additional advantage of being able to cool water during the summer. For specific information on selecting and installing a heat pump in a recycling system, University of Florida IFAS Circular 1096, *Heat Pump for Heating and Cooling Water for Aquacultural Production*, should be consulted.

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HOUSING

A water recycling system must be housed in a building to be effective. A wide array of structures can be used for ornamental fish production. Greenhouse structures such as those used by the horticulture industry for plant production are commonly employed. Greenhouse structures are inexpensive, with material costs of approximately $1 per square foot; however, they have short lifespans, are very hot in the summer, and are difficult to insulate properly, causing high energy usage for heating systems in the winter and cooling systems in the summer. Economical wood or metal frame structures, with material costs as low as $4-$6 per square foot, offer an alternative to greenhouse structures. Although construction costs for wood or metal frame buildings are greater than for greenhouse structures, making their initial cost higher, these structures have much longer lifespans than greenhouse structures. The best greenhouse plastics last for only three years in Florida, while a well-constructed wood or metal frame building has an expected lifespan of more than 20 years. Wood or metal frame buildings are also better able to withstand the high winds that occur periodically in Florida.

A wood or metal frame structure can easily be insulated, reducing its energy usage to a level well below that of a greenhouse structure. The overall thermal resistance to heat flow, referred to as the "total R," indicates the effectiveness of a building's insulation. The higher the total R value, the lower the heat loss or gain. A double poly greenhouse has a total R value of 1.4 hr-ft^2 °F/Btu. A frame structure with a total R value of 10-20 hr-ft^2 °F/Btu can easily be constructed. Structures with higher total R values reduce heat loss in the winter and heat gain in the summer, lowering energy consumption.

CONCLUSIONS

Indoor recycling systems offer several advantages over conventional ornamental fish production and holding facilities, including increased energy efficiency. The use of such modern system components as heat pumps and energy-efficient building materials allows producers to minimize energy expenditures. Because recycling systems have lower water head requirements than outdoor pond systems, equal or greater flow rates can be achieved with less energy. Proper design, including accurate calculation of head requirements, minimization of the number of fittings and valves used in plumbing systems, and careful pump selection diminish energy needs. Additional benefits of using recycling systems may include reductions in water consumption per unit of fish produced, decreases in land usage, elimination of losses due to predation, and attainment of year-round production capabilities.

Recycling systems will not immediately replace pond-based production facilities in Florida. Problems characteristic of certain species, fish diseases, water quality management issues, and economic factors will continue to favor the use of outdoor ponds for some time to come. Nevertheless, recycling systems offer real solutions to many problems encountered in commercial ornamental fish production. Foremost among these solutions is a substantial decrease in energy usage.