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Solar Water Heating for Aquaculture[1]

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Aquaculture is a significant industry in Florida with annual farm-gate sales over $50 million (1991). Production includes ornamental fish and plants for the aquarium industry, catfish, alligators, oysters, clams, Tilapia, and other miscellaneous species. Ornamental fish and plants are the largest segment of the industry with combined sales of over $42.7 million. Almost all ornamental species are tropical in origin, and, therefore, require water temperatures to remain constantly warm to maximize production. Ornamental fish and plants flourish in water temperatures between 75° and 85° Fahrenheit, which is above ambient temperatures in most ponds and buildings during the winter months. During this time, outdoor ponds are covered with plastic to conserve heat and warm well water is added during freezes. Hatcheries and shipping areas are indoor facilities which require additional heating during the winter months as well. Conventional heating systems are a significant portion of a facility's overall costs.

Increased environmental regulations, water usage restrictions, and modern technology advancements have led to an increased interest in indoor recirculating production and holding facilities. Again, supplemental heating has become a major portion of operational costs, and, as the trend continues, more energy will be required by the industry. Fortunately, solar energy is extremely well suited for this relatively low temperature heating application.

Cold weather in Florida is commonly accompanied by clear days with abundant sunshine. Inexpensive solar collectors constructed of wood and plastic operate with a relatively high efficiency when heating water below 100° Fahrenheit. Solar heating systems have been designed and utilized by other agricultural industries in Florida, such as grain drying and nurseries, but they are only marginally better than conventional heating systems because of their short term applications (i.e. during harvest months). Aquaculture is a year-around venture, and requires supplemental heating for a considerably longer period of time. The majority of costs associated with a solar heating system are in the construction, with only a minor cost associated with maintenance and operation of the small circulating pumps required. In addition, aquaculture has another advantage in that a typical facility contains a large amount of water which can serve as thermal storage. This eliminates the need for a massive external heat storage system, a major cost to most solar systems. While solar water heating systems should not be relied upon for all of a facility's

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heating needs, it will save considerable fossil fuel over a period of time.

SOLAR WATER HEATING SYSTEM DESCRIPTION

Figure 1 shows a schematic of the solar water heating system designed for the water-recirculating aquacultural production system located at the University of Florida Energy Research and Education Park. The fish holding tanks, with approximately 500 gallons capacity, are located in a greenhouse type structure covered with a double layer of black polyethylene which has been painted white on the outside to reflect the solar radiation. The water sump associated with the fish production system contains another 500 gallons of water.

In order to provide additional thermal storage and to allow the solar water heater to heat water above the temperature for optimum fish production, a 1,000 gallon concrete septic tank was installed in the ground adjacent to the greenhouse. The sides and top of the tank were insulated with 4 inches of styrofoam. It is not necessary to insulate the bottom and the lower portion of the tank in Florida, since the soil around the tank will be warmed and actually provide additional thermal storage.

During sunlight hours, the water is circulated through the solar water heater which heats the water in the hot water storage tank. When heat is required in the fish holding tank, a sump pump in the hot water storage tank is operated to pump warm water into the sump in the fish production facility. This warm water is mixed with the water in the sump which is then pumped to the fish holding tanks and returned to the sump. As water rises in the fish production sump, it reaches the level of the gravity return pipe to the hot water storage tank. Thus, the proper water level is maintained in each reservoir. It is important to have the water pumped from the solar sump and returned by gravity so that all the water will not be inadvertently pumped from the fish production tank in case of a malfunction. Both pumps in the hot water storage tank are small (1/6 horsepower) sump pumps that deliver between 15 and 20 gallons per minute. Analysis of the system's performance indicates that both pumps are oversized. For example, a 1/20 hp pump would be adequate for the pump between the hot water storage tank and the fish production sump, while the circulating pump for the solar collector could be operated with 1/10 hp.

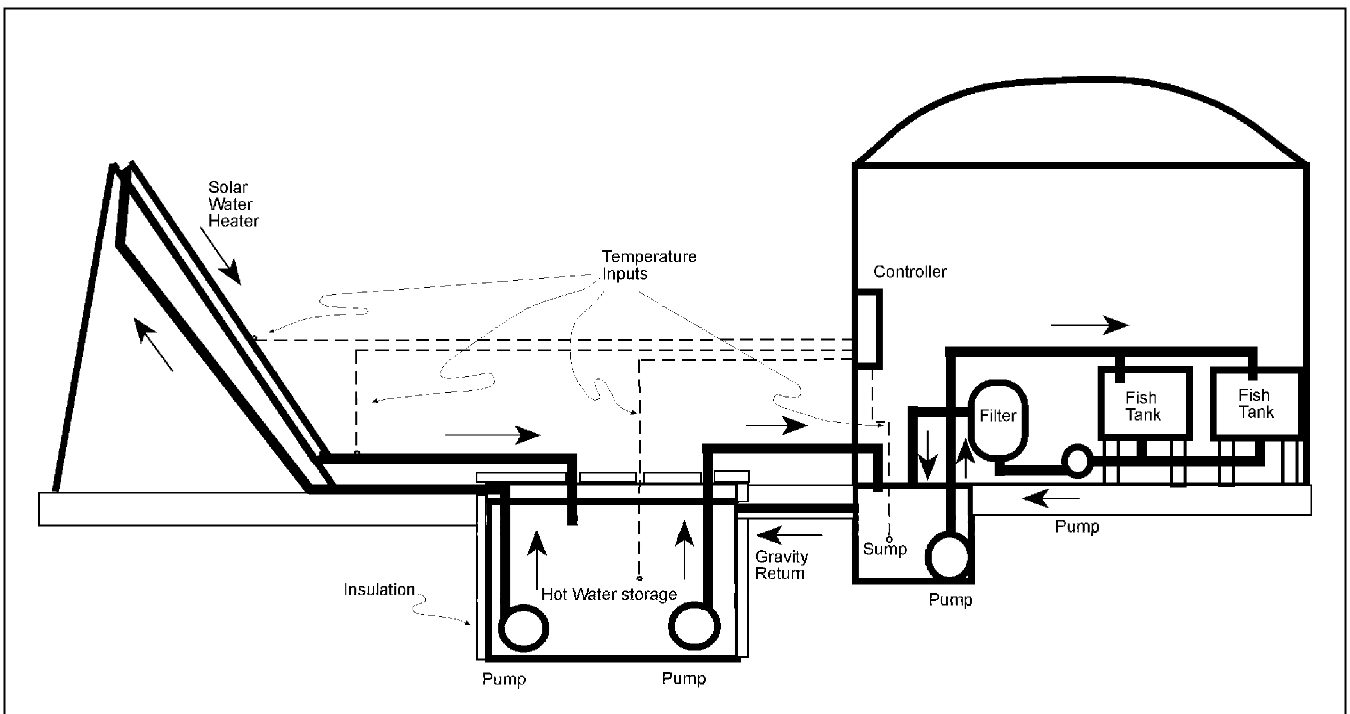

Figure 1. Solar heating system for aquacultural production.

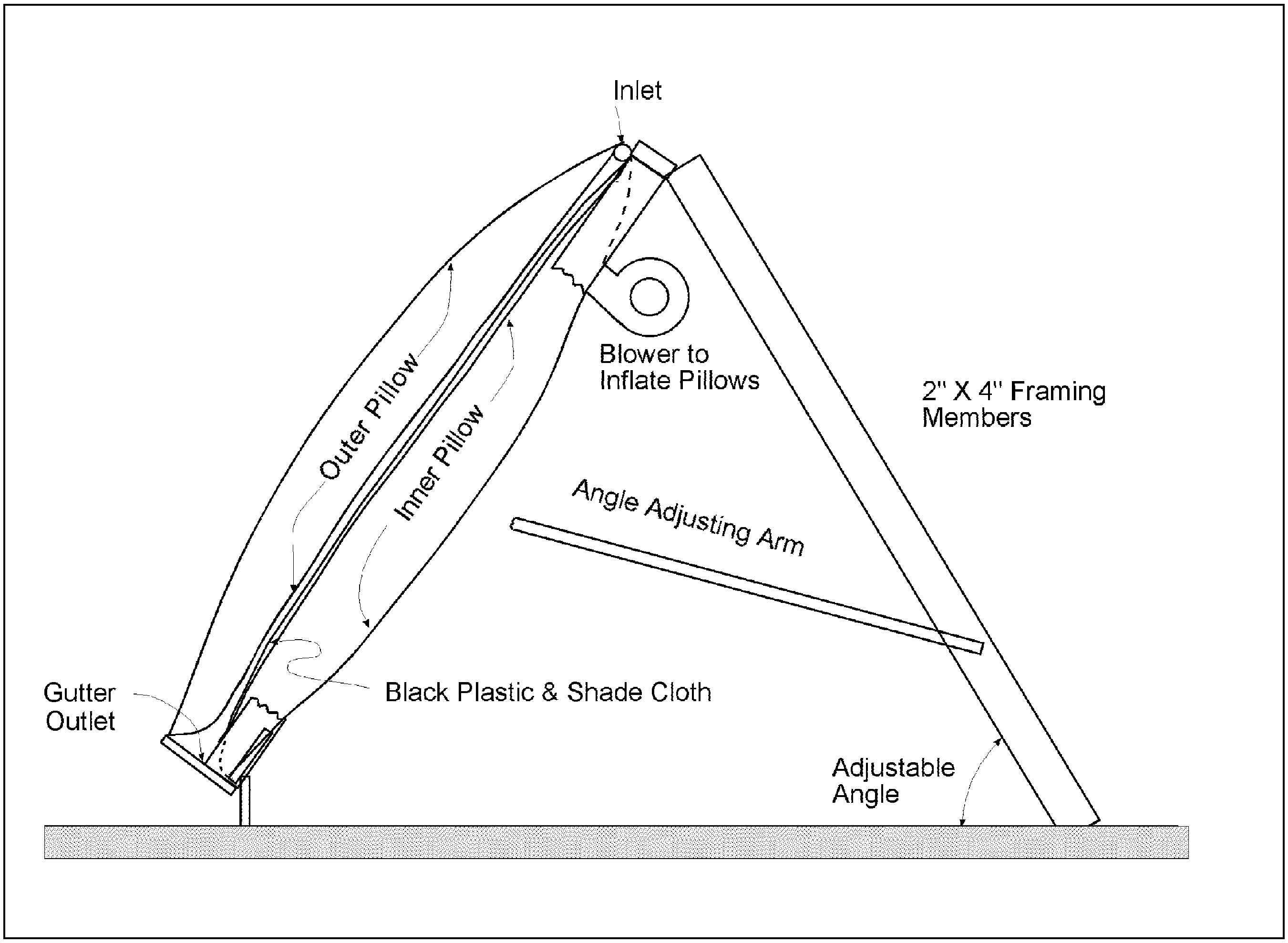

Figure 2. Cross section of solar collector.

Solar Water Heater Construction

The solar water heater is constructed primarily from wood and plastic materials (Figure 2). The solar collector is a trickle down type in which water is pumped to the top of the collector and into a inlet water manifold which is made of 1 1/4" PVC pipe with 3/32" holes on 6" centers. The water discharge from this manifold trickles down between two inflated pillows made of clear greenhouse-grade polyethylene plastic. These layers of plastic are attached to the edges of the collector frame using locking devices made for inflated plastic greenhouses. The inflated pillows provide structural integrity for the collector as well as providing some insulation on each side of the solar absorber plate.

The solar absorber plate consists of a single layer of black polyethylene plastic covered with a layer of black polypropylene shade cloth, both of which are placed between the two clear pillows. The shade cloth (type used by foliage industry for 50% shade structures) causes the water to spread out over the black plastic surface which increases the efficiency of the solar collector and also keeps the two layers of plastic from fusing together during periods when the collector is not being used.

Due to the strength characteristics of inflated structures, the framework for the collector can be very light construction made of 2×4s which are positioned around the edge of the collector and used for vertical supports spaced on 4 foot centers. The braces for supporting the collector at approximately a 40° angle from the ground are also made of 2×4s. More detail on the description and construction of this solar collector is given in a publication entitled, *Greenhouse Solar Heating*, a progress report by D. R. Mears and C. D. Baird. Also a detailed plan is provided in Florida Cooperative Extension Service Plan Number SP5149.

The heated water is collected by a plastic lined wooden gutter at the bottom of the collector which returns the heated water to the hot water storage tank by gravity flow. The two plastic pillows are inflated with a very small fan. The cost of materials for the construction of this solar water heater is between $2 and $3 per square foot which is a factor of ten less than the cost of conventional solar water heaters made from metal and glass. The solar collector does require some maintenance (about the same as that required for plastic greenhouses) and does have a shorter life than conventional solar collectors. It will be necessary to replace the plastic every 2 to 3 years; however, the plastic costs only a few cents per square foot and is very simple to replace.

Controls

The control system consists of solid state sensors and microcontrollers which sense the appropriate temperatures and operate the pumps automatically. Four thermocouples or other temperature sensors are required for this automatic control system. These temperature sensors are located in the fish holding tank, the hot water storage tank, the solar collector, and in the heated water leaving the solar collector (see Figure 1).

The controller turns on the pump, circulating water through the solar collector when the solar collector temperature is 10°F warmer than the hot water storage tank and then turns it off when the water exiting the solar collector is less than 3° warmer than the water in the hot water storage tank. This is to conserve pumping energy during periods of low solar radiation when it is not feasible to operate the solar collector.

On clear days, the solar collector operates 5 to 7 hours per day, depending upon the air temperature and the season of the year. When the fish holding tank temperature falls below the desired set point, for example 80°F, a circulating pump will start pumping water from the hot water storage tank into the fish production facility sump. This circulating pump is turned off when the fish holding tank temperature returns to its set point or when the difference between the hot water storage tank temperature and the fish holding tank temperature becomes less than 2°F. This is to conserve energy and prevent the pump from circulating water from the hot water storage tank when most of the heat has been removed. The set point temperatures and differential temperatures may be adjusted for a specific application and management strategy.

When the fish holding tank water temperature falls a predetermined amount below the set point, for example to 75°F, an auxiliary heating source will be turned on, such as a gas heater, a heat pump or electric resistance heater. A more sophisticated control strategy could be used, such as heating the water slightly above the desired set point during the day in anticipation of a cold night. The magnitude of this temperature fluctuation would need to be determined for a specific application so that the fish would not be adversely affected by thermal stress.

ENERGY ANALYSIS AND POTENTIAL ENERGY SAVINGS

The 300 square foot solar collector used in this demonstration will produce approximately 200,000 Btus on a clear day. The recommended 1/10 hp circulating pump operating 6 hours per day requires 0.6 kwh of electrical energy or 6,500 Btus of fossil fuel equivalents (FFE). This is assuming that 3.2 units of fossil fuel are required to produce and deliver 1.0 unit of electrical energy. This results in a coefficient of performance (COP) of more than 30. The COP is calculated by dividing the energy output (200,000 Btus) by the energy input (6,500 Btus).

The heat loss from the hot water storage tank is less than 10 percent (20,000 Btus) per day, giving a net heat available of 180,000 Btus per day. The recommended 1/20 hp circulating pump for pumping hot water to the fish production sump requires about 0.3 kwh of electrical energy (3,300 Btus FFE) for 5 hours of operation. This gives an overall COP based on FFE of more than 18. This compares to a COP based on FFE of 0.3 for electrical resistance heating, 0.7 to 0.8 for oil and gas heating and 1.5 for a high efficiency heat pump. Thus, it is seen that the energy efficiency of the solar heating system far exceeds that of other types of heating systems. Note: the commonly reported COP is misleading since it does not account for the conversion of fossil fuel to electrical energy or the combustion efficiencies.

As an indication of the operation of the solar heating system, the total heat produced by the solar water heating system used for this demonstration was a little more than 3 million Btus for the month of January, 1994. This heat provided less than 50% of the total heat required to maintain the fish holding tank water at 80°F. However, January, 1994 was an unusually cold month and it would not be feasible to provide 100% of the heat required for extreme conditions. Solar heating systems should never be designed to provide all of the heating requirement since the full capacity of the system would not be utilized for most of the year. It is generally recommended that the solar heating system be sized to provide about 50% of the annual heating requirement. This will allow the solar heating system to operate at or near full capacity for a large portion of the year. Solar heating systems should always be designed with a backup heat source.

SUMMARY

Environmental regulations, water usage restrictions, and advances in aquacultural technology have led to an increased interest in indoor recirculating systems. These systems require supplemental heating and temperature control systems for the maintenance and production of fish to be successful. Currently, these systems rely on conventional electric and gas heating systems which are a major portion of the costs of operation. Solar water heating systems are extremely well suited to supplement these systems, and will save significant amounts of money and fossil fuel. The design presented here is simple and easily built using existing materials which most facilities are already familiar with. While it is not recommended that a facility rely completely upon a solar heating system, it is possible to provide at least 50% of the heating needs from the sun.

Solar water heating systems constructed of wood and plastic film cost $2 to $3 per square foot, and produce approximately 500 Btus per square foot, per day, or 180,000 Btus per year. Savings in money spent on fossil fuel heating systems show a return on investment within as little as 1 year. Construction is the major cost associated with solar heating systems, with operation and maintenance being relatively inexpensive. As more and more production moves to indoor recirculating facilities, solar water heating systems present an affordable and cost effective alternative to traditional heating systems.