INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy

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INTRODUCTION TO GEOTHERMAL AQUACULTURE USE

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1. INTRODUCTION

1.1 Background

Aquaculture involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The main species reared in this way are carp, catfish, bass, tilapia, frogs, mullet, eels, salmon, sturgeon, shrimp, lobster, crayfish, crabs, oysters, clams, scallops, mussels and abalone.

It has been demonstrated that more fish can be produced in a shorter period of time if geothermal energy is used in aquaculture rather than water dependent upon the sun for its heat. When the water temperature falls below the optimal values, the fish lose their ability to feed because their basic body metabolism is affected (Johnson, 1981). A good supply of geothermal water, by virtue of its constant temperature, can therefore "outperform" even a naturally mild climate.

Ambient temperature is generally more important for aquatic species than land animals, which suggests that the potential of geothermal energy in aquaculture may be greater than in animal husbandry, such as pig and chicken rearing (Barbier and Fanelli, 1977). Figure 1 shows the growth trends for a few land and aquatic species. Land animals grow best in a wide temperature range, from just under 10ºC and up to about 20ºC. Aquatic species such as shrimp and catfish have a narrower range of optimum production at a higher temperature, approaching 30ºC. Trout and salmon, however, have a lower optimum temperature, no higher than 15ºC.

A total of 16 countries reported geothermal aquaculture installed for WGC2000 (Lund and Freeston, 2001). The leading countries are China, USA, Turkey, Israel, Iceland, Japan and Georgia. Unfortunately, very little information on pond sizes, the use of raceways, or kg of fish produced were presented in the country update reports. Thus, based on work in the United States, it was calculated that it requires 0.242 TJ/yr/tonne of fish (bass and tilapia) using geothermal water in ponds and 0.675 TJ/yr/tonne of fish in raceways. Using these approximate numbers, the 11,733 TJ/yr of energy reported for aquaculture, should be equivalent to producing between 17,100 to 47,800 tonnes of fish per year. The reported 600 MWt of installed capacity gives a capacity factor for the international aquaculture industry of 0.62.

2. EXAMPLES OF GEOTHERMAL PROJECTS

Fish breeding is a successful business in Japan where carp and eels are the most popular species raised. Eels are the most profitable and are reared in earthenware pipes 25-cm in diameter and 0.9-m long. Water in the pipes is held at 23ºC by mixing hot spring water with river water. The adult eels weight from 100 to 150 grams, with a total annual production of 3,800 kg. Alligators and crocodiles are also reared in geothermal water, but these reptiles are bred purely for tourism. In combination with greenhouses exhibiting tropical flora, alligator farms are becoming even more popular, making a significant contribution to the growth of the domestic tourist industry (J.G.E.A., 1974). Alligators are now raised in the USA in conjunction with a aquaculture operation in Idaho (Clutter, 2001b). In Iceland, 610,000 salmon and trout fingerlings are raised annually in geothermal water in 10 fish hatcheries, in a new and fast-growing industry (Hansen, 1981; Georgsson & Fridleifsson, 1996).

In the USA, aquaculture projects using geothermal water exist in Idaho, Oregon and California. Fish Breeders of Idaho, Inc., located near Buhl, have been rearing channel catfish in high-density concrete raceways for over 15 years. The water is supplied by artesian geothermal wells flowing at 380 L/s at 32°C. Cold water from springs and streams is used to cool the hot water to 27 - 29°C for the best production temperature. Normal stocking densities are from 80 to 160 kg of fish per cubic meter. The maximum recommended inventory for commercial production is about 1.6 to 2.4 x 10^5 kg per cubic meter per second of water. Yearly production will usually be three to four times the carrying capacity. Oxygen and ammonia are the principal factors limiting production (Ray, 1979).

Giant freshwater prawns (Macro brachium rosenbergii) were raised at Oregon Institute of Technology (OIT) from 1975 to 1988. Some research in trout culture and mosquito fish (Gambuzia affinis) has demonstrated that a tropical crustacean can be grown in cold climate as low as -7°C if the water temperature is maintained at the optimal growing temperature for this species of 27 - 30°C. Initially, two smaller outdoor ponds (1.2 m deep) were uses, before building another two of 0.2 ha each (Fig. 2). A selected brood stock was held in a small spawning building where larvae were hatched in artificial saltwater and reared to the post-larva stage, which made the facility self-supporting. Growth rates of 2 cm per month were maintained (twice that obtained in tropical climates) with a 900-cm^2 of surface area per animal maximum density. The plumbing system of the ponds consisted of perforated diffuser pipes, control valves and thermostats to maintain an optimum temperature in the pond, which provided an even distribution of geothermal energy throughout the pond (Johnson, 1978 and 1981; Smith, 1981).

A very successful catfish raising opera-tion has been launched by the Indian community at Fort Bidwell in northeastern California. Geothermal well water at 40°C is mixed with cold water to produce 27°C

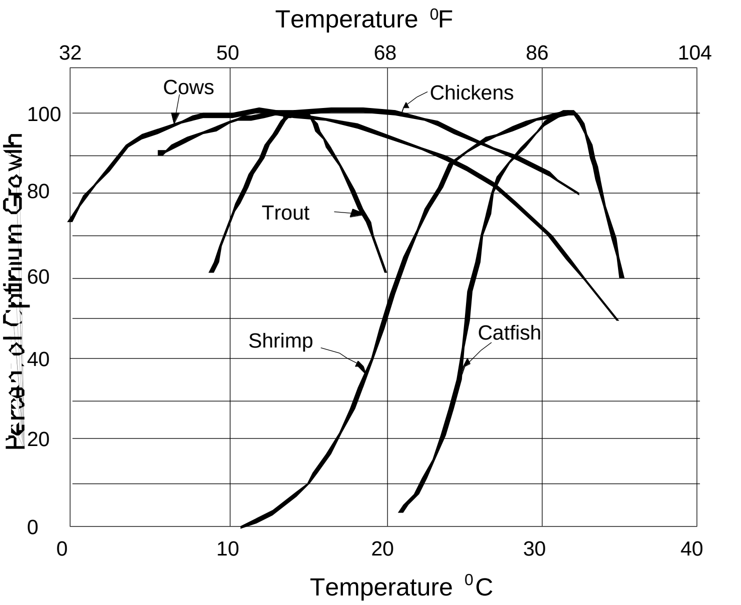

Figure 1. Optimum growing temperatures for selected animal and aquatic species (Beall and Sammels, 1991, modified).

water, which is then piped into raceways 7.6 m long x 2.4 m wide x 1.2 m deep. Two sets of parallel raceways use 57 to 63 L/s. A 0.3 m drop between raceways is used to aerate the water. The initial stock of 28 g fish at 3,000 per raceway produced a surviving 2,000 fish at 0.9 kg each in five months. Construction of the raceways and well cost $100,000. The fish are sold live at the source for $6.60 to $8.80 per kg. Production cost at Fort Bidwell is approximately $1.32/kg (Johnson, 1990).

In a tropical fish raising operation near Klamath Falls, Oregon (Lund, 1994; Clutter, 2001a), the effluent water from a greenhouse operation is used to heat 37 shallow tropical fish ponds. These ponds are 30 m long and 4 m wide and vary from 1.0 to 1.4 m in depth. They are kept at a constant 23°C temperature. At present, the owner raises 85 varieties of cichlid fish for pet stores in San Francisco and Portland. Approximately 250,000 fish 7.5 to 10 cm in length are shipped annually from the local airport. The geothermal heat is a real advantage, as the greatest demand for the fish is during the winter months, and the owner estimates the operation saves thousands of dollars annually using geothermal energy.

A summary of the leading concentrations of fish arms in the United States is given in Table 1.

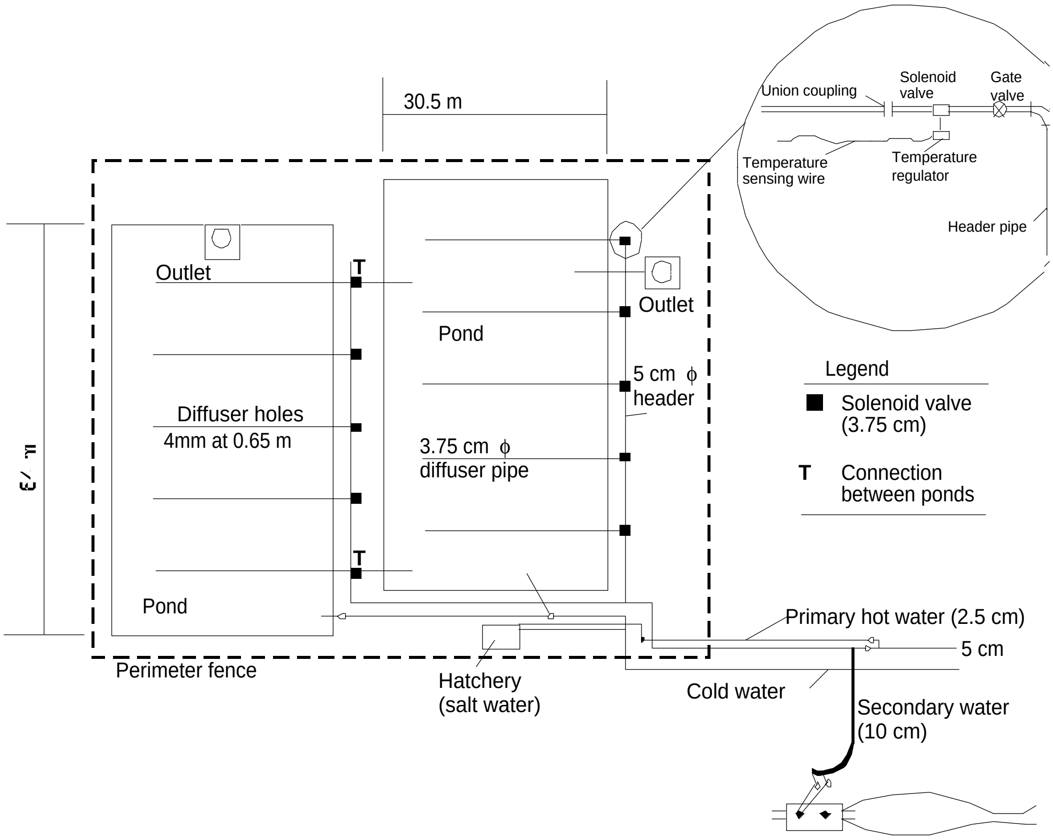

Figure 2. The geothermal aquaculture research project at Oregon Institute of Technology (Smith, 1981).

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Table 1. The Leading Concentration of Fish Farms in the United States

Location	Annual Use TJ - MWt	Load Factor	Product
Buhl, ID	310.2 - 12	80%	Catfish, Tilapia
Mecca, CA	750.0 - 10	25%	Prawns
Waushka, NV	13.8 - 2	25%	Catfish/ Tropicals
Ft. Bidwell, CA	12.1 - 1	80%	Catfish
Paso Robles, CA	11.8 - 1	50%	Catfish

In 1987, one of the largest and most successful freshwater prawn farms was established on North Island, New Zealand, to take advantage of geothermal waste heat from the Wairakei power generating field. At present, the farm has 19 ponds varying in size from 0.2 to 0.35 ha and from 1.0 to 1.2 m in depth. The ponds are kept at a temperature of 24ºC, with a variation of 1ºC from one end of the pond to the other. The farm is currently capable of producing up to 30 tonnes of prawns per year. The adult prawns are harvested at about nine months, averaging 30 to 40 per kg, and sold at US$ 17/kg wholesale, and US$ 27/kg retail. Ninety percent of the harvested prawns are sold to a restaurant on the property, which caters to about 25,000 tourists each year. In the near future, another 40 ha will be added on the other side of the Wairakei power plant, using waste cooling water from a proposed binary power generator. The farming operation could then well become the third largest freshwater prawn producer in the world, at 400 tonnes per year, which would mean an income of more than US$ 6.7 million annually (Lund and Klein, 1995).

3 GENERAL DESIGN AND CONSIDERATIONS

Based on experience at Oregon Institute of Technology, ponds for raising shrimp, gambusia and trout are best constructed with 0.1 ha of surface area. A size of 15 by 61 m is ideal for harvesting. A minimum-sized commercial operation should have 3 to 4 ha under development (water surface area), or about 30 to 40 ponds. The maxi-mum surface area that should be conside-red for a single pond is 0.2 ha. Figure 2 il-lustrates the geothermal pond design of Oregon Institute of Technology. Recent trends are to use circular holding tanks con-structed of either metal of fiberglass of six to 10 meters in diameter. An example of this type of geothermal installation for tilapia is found in Imperial Valley, CA (Rafferty, 1999). The optimum size and shape is a function of the specie.

The most important items to consider are quality of the water and disease. If geo-thermal water is to be used directly, evalu-ation of heavy metals such as fluorides, chlorides, etc., must be undertaken to deter-mine if the fish or prawns can survive. A small test program is often a wise first step. An aeration pond proceeding the stocked ponds will often solve the chemical problem.

Crops that are a good candidate for aquaculture are listed in Table 2.

Table 2. Crops That Are Good Candidates For Aquaculture

Species	Growth Period (months)	Water Temperature (°C)
Tropical fish	2 - 3	23 - 27
Catfish	4 - 6	27 - 29
Trout	4 - 6	13 - 18
Prawns	6 - 9	27 - 30

Tropical fish (goldfish) are generally the easiest to raise, and have a low investment and high yield. Smaller ponds can also be used. An average of 150,000 fish per year can be raised from 0.4 ha pond area requiring the lowest temperature water; thus, they can better use low-temperature resources of cascaded water. Freshwater prawns generally have a high mar-ket value, with marketable sizes being 35 to 44 tails to the kilogram. Channel catfish are also popular, especially as fillets. Production rates depend upon water quality and flow rates. Tilapia appears to be one of the fastest growing fish product in the U.S., and is popular with geothermal operations.

Ponds require geothermal water of 38 - 66°C and a peak flow of 19 L/s for 0.4 ha of uncovered surface area in colder climates. The long axis of the pond should be con-structed perpendicular to prevailing winds to minimize wave action and temperature loss. The ponds are normally constructed of excavated earth and lined with clay or plastic where necessary to prevent seepage loss. Temperature loss can be reduced, thus reducing the required geothermal flow, by covering the pond with a plastic bubble. Construction cost, exclusive of geothermal wells and pipelines, will run to $75,000 - $125,000 per hectare.

4. ADDITIONAL INFORMATION

An engineering design guide is available to determine the heating requirements along with designing various alternative to prevent heat loss such as sur-face covers, pond enclosures and using thermal mass for an aquaculture pond (Raf-ferty, 1998 - using U.S. units) (Rafferty, 2000 - using metric units). This design gui-de calculates heat losses from evaporation, convection, radiation and conduction.

A geothermal "Aquaculture Information Package" (Boyd and Rafferty, 1998) is also available from the Geo-Heat Center and will be described in a presentation by Boyd published in these proceedings. This package includes material on market and price information, water quailty issues in aquaculture, culture information, pond and raceway heat loss calculations, aqua-culture bibliography, and aquaculture glossary. This package is available from the Geo-Heat Center website: http://geoheat.oit.edu/pdf/aqua.pdf

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