AGRICULTURE AND AQUACULTURE APPLICATIONS OF GEOTHERMAL ENERGY

John W. Lund
Geo-Heat Center
Oregon Institute of Technology

Introduction

Agriculture and aquaculture applications are particularly attractive for geothermal applications because they require heating at the lower end of the temperature range where there is an abundance of geothermal resources. Use of waste heat or the cascading of geothermal energy from power plants or other high-temperature uses also have excellent possibilities. A number of agribusiness applications can be considered such as greenhouses, aquaculture, animal husbandry, soil warming and irrigation, mushroom raising, and biogas generation.

Greenhouses

There are numerous uses of geothermal energy for greenhouse heating throughout the world. In the USSR it is reported that over 6,200 acres (2,500 ha) of agricultural land are heated by geothermal of which 25 acres (10 ha) are covered by greenhouses. In Hungary over 300 acres (120 ha) of greenhouses are heated geothermally. Many of these greenhouses are built on rollers, so they can be pulled from their location by tractors, the ground cultivated with large equipment, and then the greenhouse returned to its location. In addition, to minimize cost, much of the building structure pipe supporting system also acts as the supply and radiation systems for the geothermal fluid. Greenhouses cover about 20 acres (8.0 ha) in Japan where a variety of vegetables and flowers are grown. Individual greenhouses, operated by farmers and covering 3,200-16,000 ft^2 (300-1300 m^6) use 158°-212°F (70°-100°C) géothermal water. Many large greenhouses, totaling about one acre (0.4 ha), are operated as tropical gardens for sightseeing purposes. New Zealand has numerous greenhouses using geothermal hot water and steam. At the Land Survey Nursery in Taupo, greenhouses are heated by geothermal steam and soil is sterilized (pasteurized) at 140°F (60°C) to kill insects, fungus, worms, and some bacteria. In Iceland over 35 acres (14 ha) are heated, including a greenhouse, restaurant, and horticulture college at Hveragerdi. Everything from bananas, coffee beans, cacti, and tropical flowers to the standard tomatoes and cucumbers are grown in these greenhouses. Studies of the economic feasibility of greenhouses in Iceland have been based on a theoretical 82-acres (33.5 hectares) facility, which would grow asparagus on 25 acres (10 ha), anthurium on 25 acres (10 ha), roses on 25 acres (10 ha), lettuce on 2 acres (1 ha), and cucumbers on 1 acre (0.5 ha). Projected profit on the initial investment would amount to 11 percent before taxes, and the greenhouses would provide jobs for 250 persons (Hansen, 1981).

Numerous geothermally heated greenhouses exist in the U.S.; several examples are described as follows. In Salt Lake City, Utah, a 250,000-ft^2 (23,000-m^2) greenhouse is using 200 gpm (12.6 l/s) of 120°F (49°C) water for heating. Utah Roses, Inc., is producing cut roses for a national floral market. The 4,000-ft (1,200-m) geothermal well is replacing a natural gas/oil heating system. Fifteen miles (24 km) south of Klamath Falls, Oregon, on the Liskey ranch, approximately 50,000 ft^2 (4,600 m^2) of greenhouses were heated with 195°F (90°C) water from a 270-foot (82-m) deep well. One of the greenhouses consists of four 42-ft by 150-foot (13-m by 46-m) buildings connected to form one large complex. Initially tree seedlings were raised for federal and private agencies. More recently, succulents and cacti were raised. All plants are grown in trays on raised tables, with the heat supplied by pipes under each table (Laskin, 1978). At Honey Lake, California, near Susanville, over thirty 30-ft by 124-ft (9-m by 38-m) Quonset-design greenhouses are used to raise cucumbers and tomatoes. The vegetables are raised by hydroponics, with the heat being supplied by forced air heaters. Production rates are about 1,500 pounds (680 kg) of cucumbers per unit per week and 850 pounds (358 kg) of tomatoes per unit per week. The cover of each greenhouse consists of two layers of six-mil sheeting (plastic). A small electric air blower continually inflates the area between the two layers and maintains an air space of about 6 inches (15 cm), resulting in heat savings of approximately 40 percent over conventional coverings. The savings using geothermal heat as compared to conventional fuel averages $4,500 per acre per year (11,100/ha/yr) (Boren and Johnson, 1978). A similar analysis has been made for a greenhouse provided in La Grande, Oregon. The double 6-mil polyethylene covering required 45 percent less heating than single layer (Higbee and Ryan, 1981).

A number of commercial crops can be raised in greenhouses, making geothermal resources in cold climates particularly attractive. These include vegetables, flowers (potted and cut), house plants, and tree seedlings. The optimum growth temperature of cucumbers, tomatoes, and lettuce are shown in Figure 1 (Barbier and Fanelli, 1977). Cucumbers grow best in the temperature range 77°-86°F (25°-30°C), tomatoes near 68°F (20°C), and lettuce at 59°F (15°C) and below. The growing time for cucumbers is usually 90 to 100 days, while the growing cycle for tomatoes is longer, in the range 9 to 12 months. The use of geothermal energy for heating can reduce operating costs (which can account for 35 percent of the product cost) and allows operation in colder climates where commercial greenhouses would not normally be economical. In addition, greenhouses can be suited to large quantities of relataively low-grade heat. Furthermore, better humidity control can be derived to prevent condensation (mildew), botritis, and other problems related to disease control (Schmitt, 1981).

Greenhouse heating can be accomplished by (1) circulation of air over finned-coil heat exchangers carrying hot water, often with the use of perforated plastic tubes running the length of the greenhouse in order to maintain uniform heat distribution, (2) hot-water circulating pipes or ducts located in (or on) the floor, (3) finned units located along the walls and under benches, or (4) a combination of these methods. A fifth approach is using hot water for surface heating. Surface-heated greenhouses were developed several decades ago in the USSR. The application of a flowing layer of warm water to the outside surface of the greenhouse can provide 80 percent to 90 percent of the energy needed. The flowing layers of warm water prevent snow and ice from accumulating.

The most efficient and economical greenhouse development consists of large structures covering one-half to a full acre (0.2 to 0.4 ha). A typical size would be 120 by 360 ft (36 by 110 m), constructed of fiberglass with furrow-connected gables. Heating would be from a combination of fan coils connected in series with a network of horizontal pipes installed on outside walls and under benches. A storage tank would be required to meet peak demand and for recirculation of the geothermal water to obtain the maximum temperature drop. Approximately 100 gpm (6.3 l/s) of 140°-180°F (60°-82°C) water will be required for peak heating. The average is much less. Fortunately most crops require lower nighttime than daytime temperatures.

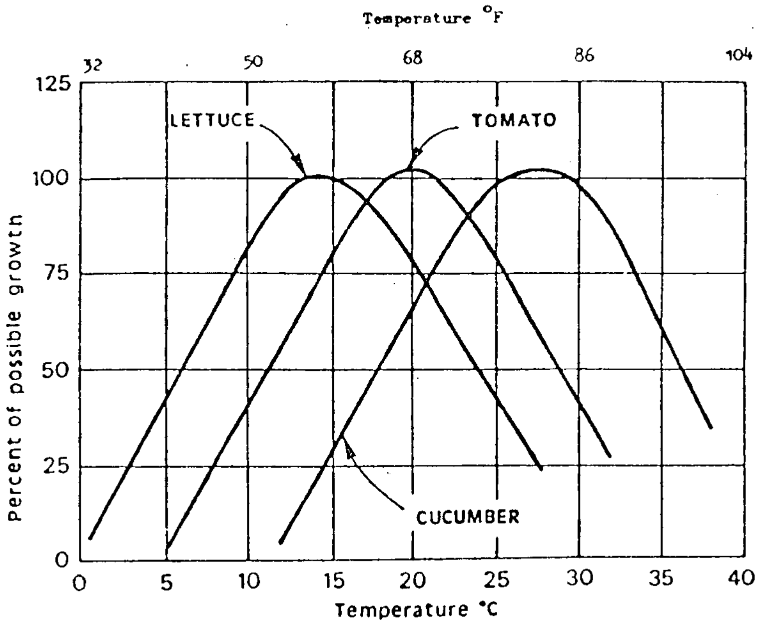

Figure 1.—Optimum growing temperature for selected agriculture products.

Greenhouse construction and outfitting will run from $5 to $10 per square foot ($54 to $108 per m^2). A recent paper by Kevin Rafferty of the Geo-Heat Center (1984) presents a detailed guide for the design of greenhouses.

Aquaculture

Aquaculture involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The principal species that are typically raised are aquatic animals such as carp, catfish, bass, tilapia, frogs, mullet, eels, salmon, sturgeon, shrimp, lobster, crayfish, crabs, oysters, clams, scallops, mussels, and abalone.

The use of geothermal energy for aquaculture rather than water dependent upon the sun for its heat has demonstrated that more fish can be produced in a shorter period of time. When the water temperature is below the optimal range, the fish loses its ability to feed because the basic body metabolism is affected (Johnson, 1981). Thus a good geothermal supply, due to its constant temperature, can "out-perform" a natural mild climate.

Fish breeding is a successful business in Japan where carp and eels are bred and raised. The eels are the most profitable and are raised in 10-inch (25-cm) diameter by 3-ft (6-m) long earthenware pipes. Water in the pipes is held at 73°F (23°C) by mixing hot spring water with river water. The adult eels weigh from 3.5 to 5 (100 to 150 grams), with a total annual production of 8,400 lbs (3,800 kg). Alligators and crocodiles are also raised in geothermal water. These reptiles are being bred purely for sightseeing purposes. In combination with greenhouses offering tropical flora, alligator farms are offering increasingly large inducements to the local growth of the tourist industry (Japan, 1974). Icelandic fish hatcheries raise 610,000 salmon and trout fingerlings annually in geothermal water. A total of 10 fish hatcheries existed around the country—a new and fast-growing industry (Hansen, 1981).

In the U.S., aquaculture projects using geothermal water exist in Idaho, Oregon, and California. Fish Breeders of Idaho, Inc., located near Buhl, has been raising channel catfish in high-density concrete raceways for over ten years. The water is supplied by artesian geothermal wells flowing at 6,000 gpm (380 l/s) at 90°F (32°C). Cold water from springs and streams is used to cool the hot water to 80°-85°F (27°-29°C) for the best production temperature. Normal stocking densities are from 50 to 10 pounds of fish per cubic foot of space (80 to 160 kg/m^3). The maximum recommended inventory for commercial production is about 10,000 to 15,000 pounds per second foot of water (1.6 to 2.4 x 10^5 kg/m^3/s). Yearly production will usually be three to four times the carrying capacity. Oxygen and ammonia are the principle factors limiting production (Ray, 1979).

Giant freshwater prawns (*Macrobrachium rosenberqii*) have been raised at Oregon Institute of Technology since 1975. Some work has also been done in trout culture and mosquito fish (*Gambuzia affinis*). This work has provided data demonstrating that a tropical crustacean can be grown in a cold climate (as low as -20°F or -7°C) where the water temperature is maintained at the optimal growing temperature for this species of 81°-86°F (27°-30°C). Initially two smaller outdoor ponds 4 feet (1.2 m) deep were used, and more recently two half-acre (0.2 ha) ponds were built. A selected brood stock is held in a small spawning building where larvae are hatched in artificial saltwater and reared to the post-larva stage which make the facility self-supporting. Growth rates of ⅞ " (2 cm) per month have been maintained (twice that obtained in tropical climates) with a 1 ft^2 (900 cm^2) of surface area per animal maximum density. The plumbing system of the ponds consists of perforated diffuser pipes, control valves and thermostats to maintain an opitmum temperature of the pond. This provides an even distribution of geothermal energy throughout the pond (Johnson, 1978 and 1981; Smith, 1981).

A very successful catfish raising operation has been started by the Indian community at Fort Bidwell in northeastern California. Geothermal well water at 105°F (40°C) is mixed with cold water to produce 80°F (27°C) water which is then piped into 25-ft long by 8-ft wide by 4-ft deep (7.6-m x 2.4-m x 1.2-m) raceways. Two sets of parallel raceways use 900-1,000 gpm (57 to 63 l/s). A one-foot drop between raceways is used to aerate the water. One ounce (28 g) fish at 3,000 per raceway are initially stocked, producing a surviving 2,000 fish at 2 pounds (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 $1.40 per pound ($3.09/kg) and delivered live to San Francisco where they wholesale for $2.00 per pound ($4.41/kg) and retail for $3.00 to $4.00 per pound ($6.60 to $8.80 per kg). Production cost at Fort Bidwell is approximately $0.60 per pound ($1.32/kg) (personal communication with William Johnson).

Other fish-raising projects are underway in Corsicana, Texas, and Ely, Nevada.

Aquaculture ponds are best constructed with ¼ acre (0.1 ha) of surface area. A size of 50 ft by 200 ft (15 by 6/m) is ideal for harvesting. A minimum-sized commercial operation should have 7 to 10 acres (3 to 4 ha) under development (water surface area), or about 30 to 40 ponds. The maximum surface area that should be considerd for a single pond is one-half an acre (0.2 ha).

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

Crops that are a good candidate for aquaculture are given in table 1.

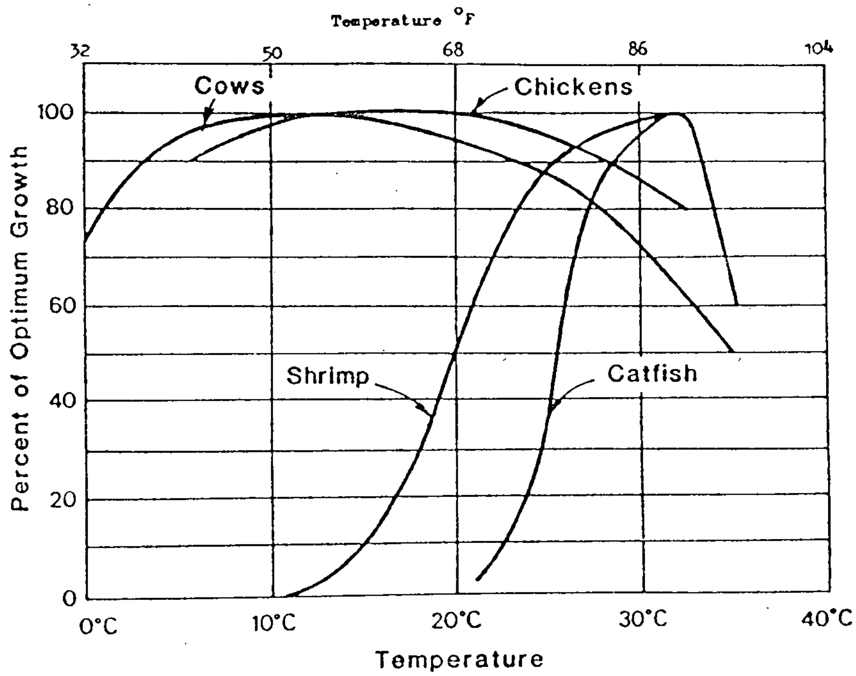

Figure 2.—Optimum growing temperatures for selected animals and aquatic species.

TABLE 1
Aquaculture Crops

Specie	Growth Period	Water Temperature	
Tropical Fish	2-3 months	74°-90°F	(23°-27°C)
Catfish	4-6 months	65°-75°F	(18°-24°C)
Trout	4-6 months	55°-65°F	(13°-18°C)
Prawns	6-9 months	81°-86°F	(27°-30°C)

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 a one acre (0.4 ha) pond, require the lowest temperature water, thus they can better use low-temperature resources of cascaded water. Freshwater prawns generally have a high market value, with marketable sizes being 16 to 20 tails to the pound (0.4 kg). Channel catfish are also popular, especially as fillets. Production rates depend upon water quality and flow rates.

Ponds require geothermal water of 100° to 150°F (38° to 66°C) and a peak flow of 300 gpm (19 l/s) for one acre (0.4 ha) of uncovered surface area in colder climates. The long axis of the pond should be constructed perpendicular to prevailing winds to minimize wave action and temperature loss. The ponds are normally constructed of excavated earth and lined with 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 $30,000-$50,000 per acre ($75,000-$125,000 per hectar).

Ambient temperature is generally more important for aquatic species than land animals. This suggests that the potential use of geothermal energy for aquaculture may be greater than for animal husbandry, such as pig and chicken rearing. Figure 2 shows the growth trends for a few land and aquatic species (Barbier and Fanelli, 1977). Land animals grow best in a wide temperature range, from just under 50°F (10°C) and up to about 68°F (20°C). Aquatic species such as shrimp and catfish have a narrower range of opitmum production at a higher temperature, approaching 86°F (30°C). Trout and salmon, however, have a lower optimum temperature no higher than 59°F (15°C).

REFERENCES

American Society of Civil Engineers (ASCE), July 1985, "Shrimp Farm is Made Feasible," *Civil Engineering Magazine*, NY.

Barbier, E., and M. Fanelli, 1977, "Non-Electrical Uses of Geothermal Energy," *prog. Energy Combust. Sci.*, V. 3, No. 2.

Boren, K. L., and K. R. Johnson, 1978, "The Honey Lake Project," *Geo-Heat Center Bulletin*, Vol. 4, No. 1, Klamath Falls, Oregon (Nov.).

Goodwin, Harold L., and Joe A. Hanson, 1974, "The Aquaculture of Freshwater Prawns," The Oceanic Institute, Waimanalo, Hawaii.

Gudmundsson, J. S., and J. W. Lund, 1985, "Direct Uses of Earth Heat," *International Journal of Energy Research*, Geothermal Issue, England.

Hansen, Anders, 1981, "Growing Under Glass," *Iceland Review*, Vol. 19, No. 4, Rekjavik, Iceland.

Higbee, Charles V., and Gene P. Ryan, 1981, "Greenhouse Heating with Low-Temperature Geothermal Water," *Transactions*, Vol. 5, Geothermal Resources Council, Davis, California (Oct.).

Hirai, W. A., and Associates, Inc., 1982, "Feasibility of an Ice-Making and Cold-Storage Facility Using Geothermal Waste Heat in Puna District, Island of Hawaii," *Final Report*, Geo-Heat Center, Klamath Falls, Oregon.

Japan Geothermal Energy Association, 1974, "Geothermal Energy Utilization in Japan," Tokyo.

Johnson, William C., 1978, "Culture of Freshwater Prawns Using Geothermal Waste Water," Geo-Heat Center, Klamath Falls, Oregon.

Johnson, William C., 1981, "The Use of Geothermal Energy for Aquaculture," *Proceedings*, The First Sino/U.S. Geothermal Resources Conference (Tianjin, PRC), Geo-Heat Center, Klamath Falls, Oregon.

Laskin, Saul, 1978, "Klamath Greenhouses," *Geo-Heat Center Quarterly Bulletin*, Vol. 3, No. 4, Klamath Falls, Oregon (July).

Rafferty, Kevin, 1985, "Some Considerations for the Heating of Greenhouses with Geothermal Energy," *Geo-Heat Center Report*, Klamath Falls, Oregon.

Ray, Leo, 1979, "Channel Catfish Production in Geothermal Water," *Special Report No. 5*, Geothermal Resources Council, Davis, California.