Geothermal heating of greenhouses and aquaculture facilties

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Abstract

There are at least 37 greenhouse and 58 aquaculture sites using geothermal energy in the United States. The installed capacity is 119 and 140 MWt respectively. The annual energy use is 1,132 and 3,000 TJ (315 and 833 GWh/yr) respectively. Aquaculture has the largest use of geothermal energy in the U.S. at 35%, and greenhouses amounts to slightly over 13% of the total energy use, if geothermal heat pumps are not considered. These industries have grown 60 and 120% in energy use in the past five years, which amounts to 10 and 17% annual compounded growth. The Geo-Heat Center in Klamath Falls has a technical assistance program to provide advice and preliminary engineering and economic analysis of projects for potential greenhouse and aquaculture developers. The Office of Geothermal and Wind Technologies, U.S. Department of Energy, funds the program.

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1 Introduction

1.1 Greenhouses

A number of commercial crops can be raised in greenhouses, making geothermal resources in cold climates particularly attractive, where growth can be optimized in a controlled environment. These include vegetables, flowers (potted and cut), houseplants, and tree seedlings. As an example, the optimum growth temperature of cucumbers, tomatoes, and lettuce is shown in Figure 1 (Barbier and Fanelli, 1977). Cucumbers grow best in the temperature range 25 to 30°C, tomatoes near 20°C, and lettuce at 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 cost (which can amount to as much as 35 percent of the product cost) and allows operation in colder climates where commercial greenhouses using fossil fuels or electricity would not normally be economical. In addition, greenhouses are suited to large quantities of relatively low-grade heat (40 to 50°C and above). Furthermore, better humidity control can be derived to prevent condensation and problems with diseases such as mildew and gray mold (Botrytis) (Schmitt, 1981).

Greenhouses are one of the largest low-enthalpy energy consumers in agriculture (Popovski, 1998). Some of the advantages of using geothermal energy are:

- Good correlation between the sites of greenhouse production area and low-enthalpy geothermal resources,
- Low-enthalpy geothermal resources are common in many countries and area of the United States,
- Geothermal energy requires relatively simple heating installations, but advanced

computerized installations can later be added for total conditioning of the inside climate in the greenhouse,

- The economic competitiveness of geothermal energy for greenhouse heating, especially in colder climates,
- Strategic importance of energy sources that are locally available for food production, and
- Using a geothermal resource in combination with an existing fossil fuel system for peak heating (Rafferty, 1997).

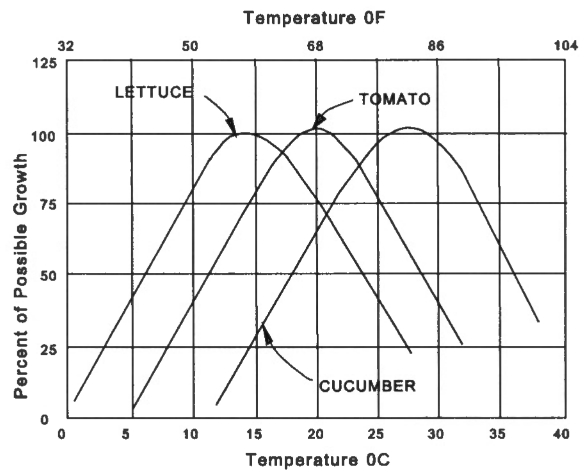

Figure 1: Optimum temperature for growing selected agricultural products.

The use of low-temperature geothermal resources for space heating is fairly simple, often using standard, "off-the-shelf" equipment. If the geothermal fluid is corrosive or causes scaling, a plate heat exchanger can isolate the fluid from the greenhouse heating equipment. Most standard greenhouse heating systems are consisting of: unit heaters with and without a plastic distribution tube, finned pipes, bare tubes, fan coil units, or a combination of these, are adaptable to geothermal. Fossil fuel peaking can be incorporated with the geothermal heat (Rafferty, 1997).

Greenhouses heated geothermally have been in place since the late 1970s in the United States, and today there are approximately 40 applications in 10 western states covering about 44 ha. There are also many installations in about 20 countries, with Hungary, China and Tunisia being the world leaders (Popovski, 1998). These geothermally heated installations cover almost 1,000 ha. These installations are estimated to require between 13 and 27 TJ/yr/ha for heating with about 20 TJ/yr/ha being the average worldwide (Lund and Freeston, 2001).

The heating system design for greenhouses must consider losses from (1) transmission loss through the walls and roof, and (2) infiltration and ventilation losses due to the heating of cold outside air. The design procedure, including heat loss calculations and selection of the heating equipment, is beyond the scope of this paper, but can be found in Rafferty and Boyd (1997) or Rafferty (1998a).

1.2 Aquaculture

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, alligators, mussels and abalone.

It has been demonstrated that more fish can be produced in a shorter period of time if geothermal energy is used for aquaculture pond and raceway heating 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, but virtue of its constant temperature, can therefore "outperform" even a naturally mild climate.

Optimum 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 2 shows the growth trends for a few land and aquatic species (Beall and Sammels, 1991). Land animals grow best in a wide temperature range, from just under 10°C and up to about 20°C. Aquatic species such as shrimp and catfish have a narrower range of optimum production at a higher temperature approaching 30°C. Trout and salmon; however, have a lower optimum temperature, no higher than 15°C.

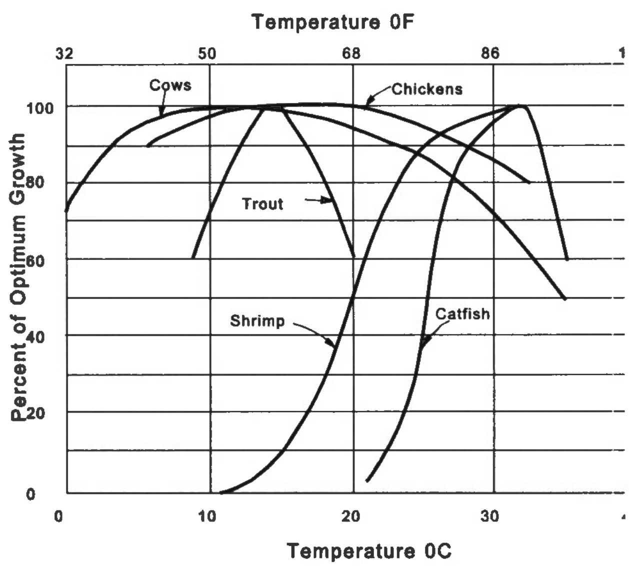

Figure 2: Optimum temperatures for growing selected animal and aquatic species.

Aquaculture pond and raceway heating is one of the most common uses of geothermal resources. Because of the significant heating requirements of these facilities and their ability to use low-temperature fluids (30°C and above), they are a natural application. This use of geothermal resources allows aquaculture operations to be sited in colder climates or closer to markets where conventional heating may not be economical. Geothermally heated aquaculture ponds are most common in the Imperial Valley of California (Rafferty, 1999), and geothermal water used in raceways are most common along the Snake River plain. There have been geothermal applications in place since the 1970s, and today there are at least 30 applications in 12 western states, and in over 15 countries, with the U.S. and China being the world leaders. In the United States almost 5,000 tonnes of Tilapia, catfish and bass are raised annually using geothermal water, with installations as far south as Louisiana, Mississippi, Alabama and Georgia. We calculate that it takes 0.242 TJ/yr/tonnes of fish using geothermal water in ponds and 0.675 TJ/yr/tonnes of fish in raceways (Lund and Freeston, 2001).

In the design of geothermally heated ponds and raceways, in order to determine the heat loss, it is necessary to first select the temperature at which the water must be maintained. Then, for a non-covered body of water, exposed to the elements, it exchanges heat with the atmosphere by way of four mechanisms: (1) evaporation, (2) convection, (3) radiation, and (4) conduction. These calculations are not covered in this paper, but can be found in Boyd and Rafferty (1998) or Rafferty (1998b).

2 United States Status

2.1 Greenhouses

The Geo-Heat Center has data on 37 greenhouse sites in the United States amounting to 43.8 ha and with an installed heating capacity of 119 MWt and annual energy use of 1132 TJ. The list of these installations is shown in Table 1.

Table 1. Geothermal greenhouse locations and energy data for the U.S.

State	# of Sites	Temp.	Capacity	Annual Energy		Area
		°C	MWt	GWh/yr	TJ/yr	ha
CA	4	48-82	6.10	7.0	25.3	1.66
CO	1	71	0.47	2.1	7.6	0.20
ID	13	44-90	19.64	43.4	157.1	5.59
MT	4	43-66	5.01	18.0	64.5	1.61
NM	4	64-118	49.32	155.7	560.1	19.54
OR	4	42-104	3.41	8.6	31.4	1.22
SD	1	68	1.14	3.0	10.8	0.04
UT	5	88-95	33.79	75.8	272.7	13.45
WY	1	37	0.23	0.6	2.2	0.08
Total	37		119.11	314.2	1131.7	43.75

The best example of geothermally heated greenhouse development is in the state of New Mexico. Geothermal greenhousing accounts for more than half the greenhouse area in the state. In fact, New Mexico leads the U.S. in geothermal greenhouse development, and has the two largest in the U.S.: Burgetts Greenhouses and Masson Greenhouses located in the southwestern portion of the state. The success is due to several factors including good climate with abundant sunshine and low humidity, inexpensive and, collocation of geothermal resources with a supply of fresh water, a good agricultural labor force, and the availability of favorable shallow geothermal resources (well depths less than 300 m and resource temperature ranging from 62 to 116°C). The other contributing factor is the stimulation provided by the New Mexico State University Geothermal Research Greenhouse and Aquaculture Center managed by the Southwest Technology Development Institute. This facility, leased to potential commercial developers, allows the client to determine if the greenhouse business is suitable for their investment. As a result, during the last 15 years, five clients have leased the facility, three as new business startups and two from out-of-state businesses interested in moving to New Mexico. All have since developed commercial operations elsewhere in the state (Witcher, 2002).

2.2 Aquaculture

The Geo-Heat Center has data on 45 aquaculture sites in the United States producing almost five million kg of fish annually. We also have some limited information on eight sites in the southeastern U.S. The total installed heating capacity is 129 MWt and the annual energy use is 2,795 TJ. The list of these installations is shown in Table 2.

Table 2. Geothermal aquaculture facility locations and energy data for the U.S.

State	# of Sites	Temp. Range	Capacity	Annual Energy	
		°C	MWt	GWh/yr	TJ/yr
AZ	4	27-41	19.04	66.8	240.0
CA	16	16-61	49.59	350.5	1260.2
CO	4	18-48	10.52	68.4	245.9
ID	9	32-38	26.64	186.7	671.8
MT	1	21	0.29	2.1	7.4
NM	1	85	1.17	8.2	29.5
NV	5	33-132	5.27	37.0	133.2
OR	2	82	2.34	16.4	59.0
SD	1	69	1.76	12.3	44.3
UT	1	52	11.72	24.0	86.4
WY	1	26	0.56	4.9	17.5
Total	45		128.90	777.3	2795.2

The largest increase in geothermal direct-use in the U.S. in the past five years has been in aquaculture pond and raceway heating. Ten new pond-heating projects were recently identified in the Imperial Valley of California along with the expansion of two existing projects (Rafferty, 1999). Approximately 3.66 million kg of Tilapia, catfish and hybrid striped bass are raised here annually. Most are shipped live to markets in Los Angeles and San Francisco. A second area identified as having a significant increase in aquaculture projects is along the Snake River Plain of southern Idaho. Seven new projects have been identified in this area, adding one million kg of Tilapia and catfish in annual production. These installations use cascaded water in raceways for raising their fish; whereas, in the Imperial Valley, ponds and tanks are most common. Fish from the Idaho sites are also shipped live to cities in Canada and northwestern U.S. An unusual development associated with one project in Idaho, is the introduction of alligators in the geothermal water to feed on the entrails from cleaning fish for market. The alligators solve the problem of waste disposal and also are marketed for their hides and meat (Clutter, 2002).

An additional eight sites have been reported in the southeastern U.S. using geothermal water in the 20 to 30°C range. In addition there are approximately four sites in Arizona raising Tilapia or shrimp and one in Montana raising white shrimp. This bring the total number of sites to 58 with an estimated capacity of 140 MWt and annual energy use of 3,000 TJ (833 GWh/yr).

3 Greenhouse and aquaculture information packages

In response to numerous requests for information from prospective developers of greenhouse or aquaculture projects using geothermal energy, the Geo-Heat Center prepared two comprehensive documents to assist these developers (Rafferty and Boyd, 1997; Boyd and Rafferty, 1998). The content of these two documents is outlined below:

The "Geothermal Greenhouse Information Package" is intended to provide a foundation of background information for developers of geothermal greenhouses. The material is divided into seven sections covering such issues as crop culture and prices, operating costs for greenhouses, heating system design, vendors and a list of other sources for information.

The "Aquaculture Information Package" is intended to provide background information to developers of geothermal aquaculture projects. The material is divided into eight sections and includes information on market and price information for typical species, aquaculture water quality issues, typical species culture information, pond heat loss calculations, an aquaculture glossary, regional and university aquaculture offices and state aquaculture permit requirements.

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