DIRECT HEAT UTILIZATION OF GEOTHERMAL RESOURCES

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INTRODUCTION

Direct or non-electric utilization of geothermal energy refers to the immediate use of the heat energy rather than to its conversion to some other form such as electrical energy. The primary forms of direct use include swimming, bathing and balneology (therapeutic use), space heating and cooling including district heating, agriculture (mainly greenhouse heating and some animal husbandry), aquaculture (mainly fish pond and raceway heating), industrial processes, and heat pumps (for both heating and cooling). In general, the geothermal fluid temperatures required for direct heat use are lower than those for economic electric power generation.

Most direct use applications use geothermal fluids in the low-to-moderate temperature range between 50 and 150ºC, and in general, the reservoir can be exploited by conventional water well drilling equipment. Low-temperature systems are also more widespread than high-temperature systems (above 150ºC), so they are more likely to be located near potential users. In the U.S., for example, of the 1,350 known or identified geothermal systems, 5% are above 150ºC, and 85% are below 90ºC (Muffler, 1979). In fact, almost every country in the world has some low-temperature systems; while, only a few have accessible high-temperature systems.

Traditionally, direct use of geothermal energy has been on a small scale by individuals. More recent developments involve large-scale projects, such as district heating (Iceland and France), greenhouse complexes (Hungary and Russia), or major industrial use (New Zealand and the U.S.). Heat exchangers are also becoming more efficient and better adapted to geothermal projects, allowing use of lower temperature water and highly saline fluids. Heat pumps utilizing very low-temperature fluids have extended geothermal developments into traditionally non-geothermal countries such as France, Switzerland and Sweden, as well as areas of the midwestern and eastern U.S. Most equipment used in this project is of standard, off-the-shelf design and need only slight modifications to handle geothermal fluids (Gudmundsson and Lund, 1985).

Worldwide, the installed capacity of direct geothermal utilization is 9,047 MW_t and the energy use is about 120,000 TJ/yr (33,514 GWh/yr) distributed among 38 countries. This amounts to saving an equivalent 3.65 million tonnes of fuel oil per year (TOE). The distribution of the energy use among the various types of use is shown in Figure 1 for the entire world and, for comparison, the U.S. The installed capacity in the U.S. is 1,875 MW_t and the annual energy use is 13,890 TJ

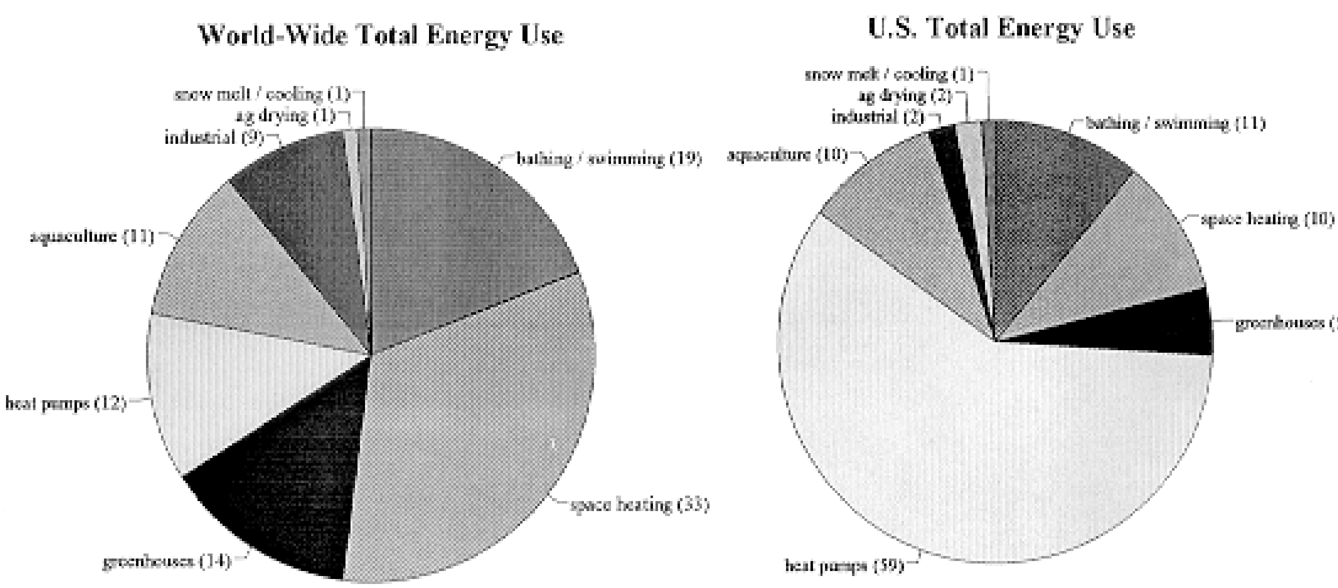

Figure 1. Distribution of geothermal energy use in the world and the U.S.

(3,860 GWh), saving 0.47 million TOE (Lienau, et al., 1995). Internationally, the largest uses are for space heating (33%) (3/4 of which is due to district heating), and for swimming, bathing and balneology (19%); whereas, in the U.S.. the largest use is for geothermal heat pumps (59%). In comparison, Iceland's largest geothermal energy use is 74% for space heating (4,530 GWh/yr)--primarily with district heating system (Ragnarsson, 1995). The worldwide use data is based on Freeston (1996), but have been modified according to Freeston (1990), country update reports from the World Geothermal Congress (1995), and the author's personal experience.

The Lindal diagram (Gudmundsson, et al., 1985), named for Baldur Lindal, the Icelandic engineer who first proposed it, indicates the temperature range suitable for various direct use activities (Figure 2). Typically, the agricultural and aquacultural uses require the lowest temperatures, with values from 25 to 90°C. The amounts and types of chemicals such as arsenic and dissolved gases such as boron, are a major problem with plants and animals; thus, heat exchangers are often necessary. Space heating requires temperatures in the range of 50 to 100°C, with 40°C useful in some marginal cases and ground-source heat pumps extending the range down to 4°C. Cooling and industrial processing normally require temperatures over 100°C. The leading user of geothermal energy, in terms of market penetration is Iceland, where more than 85% of the population enjoys geothermal heat in their homes from 27 municipal district heating services, and 44% of the country's total energy use is supplied by direct heat and electrical energy derived from geothermal resources (Ragnarsson, 1995).

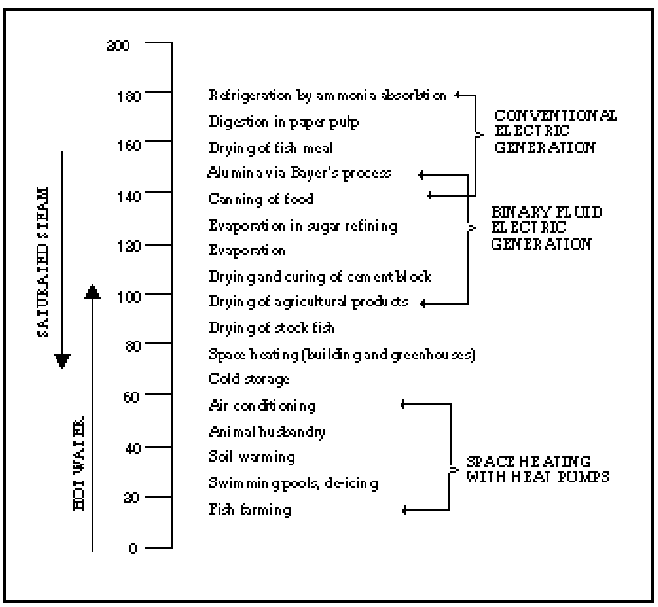

Figure 2. Lindal diagram.

Swimming, Bathing and Balneology

Romans, Chinese, Ottomans, Japanese and central Europeans have bathed in geothermal waters for centuries. Today, more than 2,200 hot springs resorts in Japan draw 100 million guests every year, and the "return-to-nature" movement in the U.S. has revitalized many hot springs resorts.

The geothermal water at Xiaotangshan Sanitarium, north-west of Bejing, China, has been used for medical purposes for over 500 years. Today, the 50°C water is used to treat high-blood pressure, rheumatism, skin disease, diseases of the nervous system, ulcers, and generally for recuperation after surgery. In Rotorua, New Zealand at the center of the Taupo Volcanic Zone of North Island, the Queen Elizabeth Hospital was built during World War II for U.S. servicemen and later became the national hospital for the treatment of rheumatic disease. The hospital has 2000 beds, and outpatient service, and a cerebral palsy unit. Both acidic and basic heated mud baths treat rheumatic diseases.

In Beppu, on the southern island of Kyushu, Japan, the hot water and steam meet many needs: heating, bathing, cooking, industrial operations, agriculture research, physical therapy, recreational bathing, and even a small zoo (Taguchi, et al., 1996). The waters are promoted for "digestive system troubles, nervous troubles, and skin troubles." Many sick and crippled people come to Beppu for rehabilitation and physical therapy. There are also eight Jigokus ("burning hells") in town showing various geothermal phenomena, used as tourist attractions.

In the former Czechoslovakia, the use of thermal waters has been traced back before the occupation of the Romans and has had a recorded use of almost 1,000 years. Today, there are 60 spa resorts located mainly in Slovakia, visited by 460,000 patients usually for an average of three weeks each. These spas have old and well-established therapeutic traditions. Depending on the chemical composition of the mineral waters and spring gas, availability of peat and sulfurous mud, and climatic conditions, each sanitarium is designated for the treatment of specific diseases. The therapeutic successes of these spas are based on centuries of healing tradition (balneology), systematically supplemented by the latest discoveries of modern medical science.

Bathing and therapeutic sites in the U.S. include: Saratoga Springs, New York; Warm Springs, Georgia; Hot Springs, Virginia; White Sulfur Springs, West Virginia; Hot Springs, Arkansas; Thermopolis, Wyoming and Calistoga, California. The original use of these sites were by Indians, where they bathed and recuperated from battle. There are over 190 major geothermal spas in the U.S. with an annual energy use of 1,600 TJ (Lienau, 1995).

Space Conditioning

Space conditioning includes both heating and cooling. Space heating with geothermal energy has widespread application, especially on an individual basis. Buildings heated from individual wells are popular in Klamath Falls, Oregon; Reno, Nevada, and Taupo and Rotorua, New Zealand. Absorption space cooling with geothermal energy has not been popular because of the high-temperature requirements and low efficiency. Geothermal heat pumps (groundwater and ground-coupled) have become popular in the U.S. and Switzerland, used for both heating and cooling.

An example of space heating and cooling with low-to-moderate temperature geothermal energy is the Oregon Institute of Technology in Klamath Falls, Oregon. Here, 11 buildings, approximately 62,000 square meters of floor space, are heated with water from three wells at 89°C. Up to 62 L/s of fluid can be provided to the campus, with the average heat utilization rate over 0.53 MW_t and the peak at 5.6 MW_t. In addition, a 541 kW (154 tons) chiller requiring up to 38 L/s of geothermal fluid produces 23 L/s of chilled fluid at 7°C to meet the campus cooling base load.

District Heating

District heating originates from a central location, and supplies hot water or steam through a network of pipes to individual dwellings or blocks of buildings. The heat is used for space heating and cooling, domestic water heating, and industrial process heat. A geothermal well field is the primary source of heat; however, depending on the temperature, the district may be a hybrid system, which would include fossil fuel and/or heat pump peaking.

Geothermal district heating systems are in operation in at least 12 countries, including Iceland, France, Poland, Hungary, Turkey, Japan and the U.S. The Warm Springs Avenue project in Boise, Idaho, dating back to 1892 and originally heated more than 400 homes, is the earliest formal project in the U.S. The Reykjavik, Iceland, district heating system is probably the most famous. This system supplies heat for a population of around 145,000 people. The installed capacity of 640 MW_t is designed to meet the heating load to about -10°C; however, during colder periods, the increased load is met by large storage tanks and an oil-fired booster station.

In France, production wells in sedimentary basins provide direct heat to more than 500,000 people from 40 projects. These wells provide from 40 to 100 L/s of 60 to 100°C water from depths of 1,500 to 2,000 m. In the Paris basin, a doublet system (one production and one injection well) provides 70°C water, with the peak load met by heat pumps and conventional fossil fuel burners.

Agribusiness Applications

Agribusiness applications (agriculture and aquaculture) are particularly attractive 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 also has excellent possibilities. A number of agribusiness applications can be considered: greenhouse heating, aquaculture, animal husbandry, soil warming and irrigation, mushroom culture, and biogas generation.

Numerous commercially marketable crops have been raised in geothermally-heated greenhouses in Hungary, Russia, New Zealand, Japan, Iceland, China and the U.S. These include vegetables, such as cucumbers and tomatoes, flowers (both potted and bedded), house plants, tree seedlings, and cacti. Using geothermal energy for heating reduces operating costs (which can account for 35% of the product cost) and allows operation in colder climates where commercial greenhouses would not normally be economical.

The use of geothermal energy for raising catfish, shrimp, tilapia, eels, and tropical fish has produced crops faster than by conventional solar heating. Using geothermal heat allows better control of pond temperature, thus optimizing growth. Fish breeding has been successful in Japan, China and the U.S. A very successful prawn raising operation, producing 400 tonnes of Giant Malaysian freshwater prawns per year at U.S. $17 to 27/kg, has been developed near the Wairakei geothermal field in New Zealand (Lund and Klein, 1995). The most important factors to consider are the quality of the water and disease. If geothermal water is used directly, concentrations of dissolved heavy metals (fluorides, chlorides, arsenic, and boron) must be considered.

Livestock raising facilities can encourage the growth of domestic animals by a controlled heating and cooling environment. An indoor facility can lower mortality rate of newborn, enhance growth rates, control disease, increase litter size, make waste management and collection easier, and in most cases, improve the quality of the product. Geothermal fluids can also be used for cleaning, sanitizing and drying of animal shelters and waste, as well as assisting in the production of biogas from the waste.

Industrial Applications

Although the Lindal diagram shows many potential industrial and process applications of geothermal energy, the world's uses are relatively few. The oldest industrial use is at Larderello, Italy, where boric acid and other borate compounds have been extracted from geothermal brines since 1790. Today, the two largest industrial uses are the diatomaceous earth drying plant in northern Iceland, and a pulp, paper and wood processing plant at Kawerau, New Zealand. Notable U.S. examples are two onion dehydration plants in northern Nevada (Lund, 1995), and a sewage digestion facility in San Bernardino, California. Alcohol fuel production has been attempted in the U.S.; however, the economics were marginal and thus, this industry has not been successful.

Drying and dehydration are important moderate-temperature uses of geothermal energy. Various vegetable and fruit products are feasible with continuous belt conveyors or batch (truck) dryers with air temperatures from 40 to 100°C. Geothermally drying alfalfa, onions, pears, apples and seaweed are examples of this type of direct use. A new development in the use of geothermal fluids is for enhanced heat leaching of precious metals in Nevada by applying heat to the cyanide process (Trexler, et al., 1990). Using geothermal energy increases the efficiency of the process and extends the production into the winter months.

ECONOMIC CONSIDERATIONS

Geothermal projects require a relatively large initial capital investment, with small annual operating costs thereafter. Thus, a district heating project, including production wells, pipelines, heat exchangers, and injection wells, may cost several million dollars. By contrast, the initial investment in a fossil fuel system includes only the cost of a central boiler and distribution lines. The annual operation and maintenance costs for the two systems are similar, except that the fossil fuel system may continue to pay for fuel at an ever-increasing rate; while, the cost of geothermal fluid is stable. The two systems, one with a high-initial capital cost and the other with high-annual costs, must be compared.

Geothermal resources fill many needs: power generation, space heating, greenhouse heating, industrial processing, and bathing to name a few. Considered individually, however, some of the uses may not promise an attractive return on investment because of the high-initial capital cost. Thus, we may have to consider using a geothermal fluid several times to maximize benefits. This multi-stage utilization, where lower and lower water temperatures are used in successive steps, is called cascading or waste heat utilization. A simple form of cascading employs waste heat from a power plant for direct use projects.

Geothermal cascading has been proposed and successfully attempted on a limited scale throughout the world. In Rotorua, New Zealand, for example, after geothermal water and steam heat a home, the owner will often use the waste heat for a backyard swimming pool and steam cooker. At the Otake geothermal power plant in Japan, about 165 tonnes per hour of hot water flows to downstream communities for space heating, greenhouses, baths and cooling. In Sapporo, Hokkaido, Japan, the waste water from the pavement snow melting system is retained at 65°C and reused for bathing.

Recent international data (Freeston, 1996) gives US $270/kW of installed capacity for all projects reported, with a range from US $40 to US $1880/kW. In the U.S., the annual operation and maintenance cost is estimated at 5% of the installed cost.

FUTURE DEVELOPMENT

There appears to be a large potential for the development of low-to-moderate enthalpy geothermal direct use across the world which is not currently being exploited due to financial constraints and the low price of competing energy sources. Given the right environment, and as gas and oil supplies dwindle, the use of geothermal energy will provide a competitive, viable and economic alternative source of renewable energy. Future development will most likely occur under the following conditions:

1. Collocated resource and uses (within 10 km apart),
2. Sites with high heat and cooling load density (>36 MWt/sq km),
3. Food and grain dehydration (especially in tropical countries where spoilage is common),
4. Greenhouses in colder climates,
5. Aquaculture to optimize growth--even in warm climates, and
6. Ground-coupled and groundwater heat pump installations both for heating and cooling).

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