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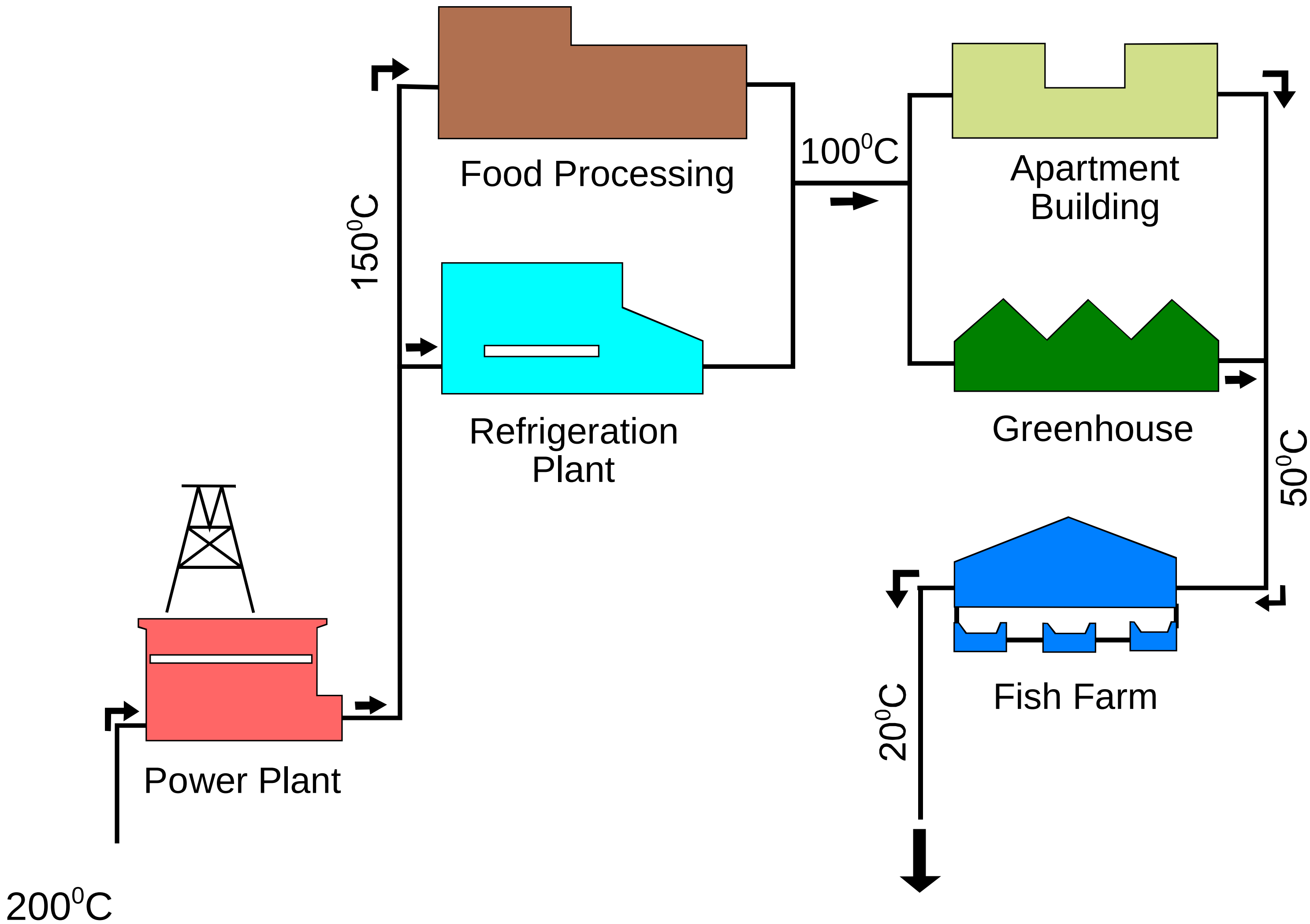

Industrial Uses of Geothermal Energy

Vol. 24, No. 3 September 2003

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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

CONTENTS

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EXAMPLES OF INDUSTRIAL USES OF GEOTHERMAL ENERGY IN THE UNITED STATES

John W. Lund
Geo-Heat Center

INTRODUCTION

Industrial applications and agricultural drying uses of geothermal energy are few in number in the United States. Several large operations dominate the scene, followed by a few minor projects. Some of these applications were initially reported in a paper presented in Iceland in 1992 at the meeting on "Industrial Uses of Geothermal Energy" by Gene Culver of the Geo-Heat Center (Culver, 1992). Since that time several operations have been suspended (heat leaching in Nevada) and a large one started (zinc extraction in California). This paper presents selected current industrial uses and also discusses those which are of interest from the past. The present total installed capacity is about 70 MWt and the annual energy use about 1,500 TJ (415 GWh), the majority of which is due to the zinc extraction operation.

ZINC EXTRACTION

The main industrial operation using geothermal energy in the United States is the CalEnergy Operating Corporation $200 million Mineral Recovery Project on the shores of the Salton Sea in southern California's Imperial Valley (Clutter, 2000). CalEnergy currently operates ten geothermal power plants with a capacity of 347 net MWe at the Salton Sea. Unit 5, the most recent unit, a 49-MWe facility that uses high-temperature waste brine from four of the existing plants, was constructed to fuel the minerals recovery project and produce electricity. The mineral recovery project will produce 30,000 tonnes of 99.99-percent pure zinc annually for Cominco Ltd. The facility, constructed in 1999 and placed in operation in late 2002 (Fig. 1), will be the lowest cost producer of zinc in the world, and the first and only operation specifically designed to harvest mineral from high-temperature geothermal brine in the United States. Prior to the construction of the zinc extraction facility, the spent brine from eight geothermal power plants was being injected at 182ºC, thus in an effort to capture more energy from the resource, a 49-MWe Unit 5 (triple flash) was constructed and brought on-line in conjunction with the zinc recovery facility. Unit 5 uses the spent brine from four other plants to produce electricity for the minerals recover operation, tapping about 20 MWe of the power plant's production (which is about 30 MWt of heat energy input assuming a 67% conversion factor). This also reduces the brine temperature to 116ºC, which is the desired temperature for the zinc extraction process. It is estimated that 1,200 TJ of energy is used annually in this process, which includes the electrical energy thermal equivalent input along with some process steam provided to the plant.

The mineral recovery facility uses existing technology of ion exchange, but also employs solvent extraction and "electrowinning" to extract zinc from the spent brine. The brine at over 9,000 tonnes per hour, comes from all the power plants, and after the metal is extracted, the remaining brine is injected back into the geothermal reservoir.

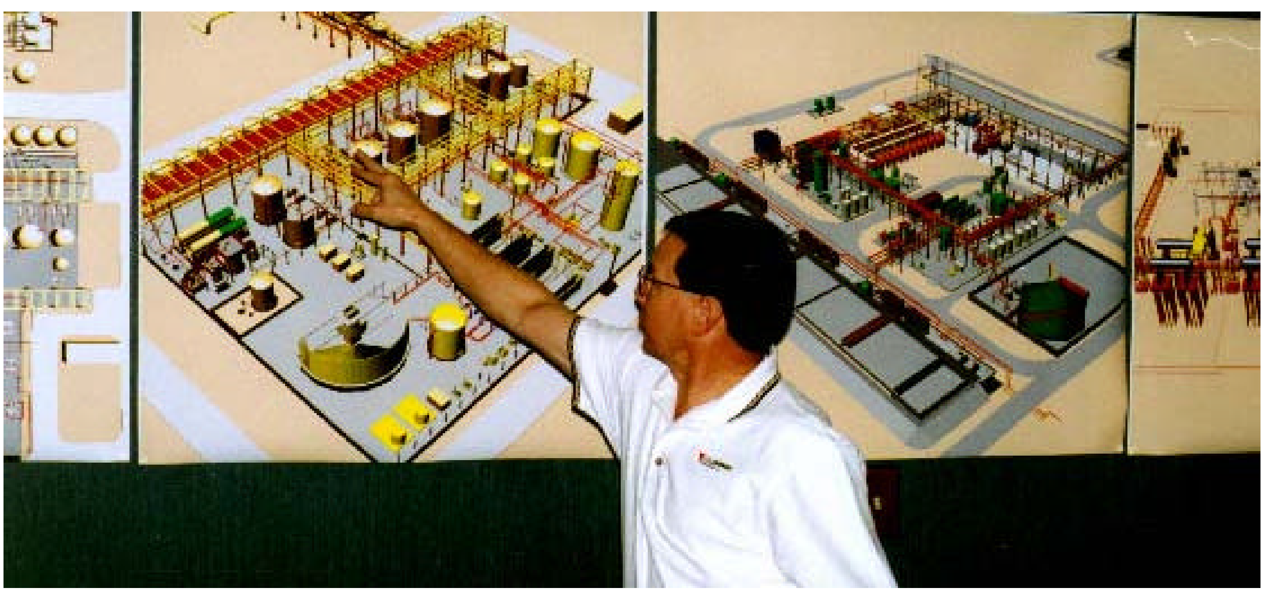

Figure 1. ***CalEnergy engineer pointing out the minerals recovery facility, with the ion exchange and solvent extraction plant on the right and the electrowinning facility on the left (Clutter, 2000).***

The process, as described by CalEnergy personnel is summarized as follows (Clutter, 2000). The brine first passes through an ion exchange resin similar to that used in water softening equipment - but modified with organic molecules that are very specific to zinc in the right conditions. After being pumped to a second facility, a solvent extraction process then transforms the resultant zinc chloride into zinc sulfate, which is passed across electrowinning cells that separate sulfate molecules from zinc atoms. The result is nearly pure zinc deposited on large cathodes. The metal builds up to more than six mm in thickness on the cathode in 24 hours when it is removed. The metal is then melted into approximately one tonne ingots for sale to Cominco.

The brine contains 550 to 600 mg/L of zinc, and thus the project is estimated to recover 30,000 tonnes of zinc per year. In addition to zinc, CalEnergy is also investigating extracting high grade silica and manganese in the future. The plant is presently only operating at 40 percent of capacity.

HEAP LEACHING

Heap leaching for gold recovery is a simple process that eliminates many of the complicated steps required in conventional milling (Trexler, et al., 1990). The process consists of placing the crushed ore on an impervious pad and then sprinkling or dripping a dilute sodium cyanide solution over the heap. The solution trickles through the material, dissolving the gold in the rock. The pregnant (gold) solution drains from the heap and is collected in a large plastic-lined pond. The pregnant solution is then pumped through tanks containing activated charcoal, absorbing the gold. The gold bearing charcoal is chemically treated to release the gold, and the gold bearing strip solution is treated at the process plant to produce a doré, or bar of impure gold. The doré is then sold or shipped to a smelter for refining. The barren cyanide solution is then pumped to a holding basin, where lime and cyanide are added to repeat the leaching process. A similar process is followed for extracting silver from the crushed ore.

Cyanide leaching can recover over 95 percent of the gold ore. Using geothermal energy increases the gold recovery, as the heat allows year-round operation, and the gold and silver recovery can be enhanced by five to 17 percent by accelerating the chemical reaction. This year-round operation is important in Nevada, as winter weather allows under normal circumstances only mid-March through late October operation using a minimum outside production temperature of 4°C. The additional benefits are increased revenue to the mine operator, year-round employment for the labor force, and increased royalty payments for mineral leases to both federal and state governments.

Two mines in Nevada have used geothermal fluids in their heap leaching operations to extract gold and silver from crushed ore: Round Mountain Gold and the Florida Canyon Mine, located in the north-central part of the state.

Round Mountain mines an estimated 95,000 tonnes of ore per day containing approximately one gram/tonne of gold, and in 2001 extracted over 21,000 kg of gold. The mine used geothermal fluids from two shallow wells at 82°C and 69 L/s. Heat from the geothermal fluid is transferred to the cyanide leach solution through a plate heat exchanger (Fig. 2). The average monthly heat production during the months of operation was approximately 42 TJ and the annual use was estimated at 208 TJ with an installed capacity of 14.1 MWt (Lund, et al., 1985). At the Florida Canyon Mine, almost 13,000 tonnes of ore were produced daily (1990). The average gold content is about 0.7 g/tonne, and they produce almost ten kg of gold per day. The geothermal fluid is produced at 99°C and 23 L/s, and piped through a shell-and-tube heat exchanger where heat is transferred to the cyanide solution. It is estimated that 42 TJ of energy was used annually from the geothermal fluid with an installed capacity of 1.4 MWt (Lund, et al., 1985).

Experimental work using geothermal energy was carried out by the University of Nevada from 1988 to 1991 with positive results (Trexler, et al., 1991). Unfortunately, these two mines are presently shut down due to low prices for gold and silver, high operating costs, and the federal royalty charge for the use of the geothermal energy produced from wells on Bureau of Land Management land. The royalty cost is ten percent of the equivalent avoided competing fuel cost.

MILK PASTEURIZATION

Medo-Bel Creamery, in Klamath Falls, Oregon used geothermal heat in its milk pasteurization process for about 50 years (Lund, 1997). A 233-m deep well provided 6.3 L/s of

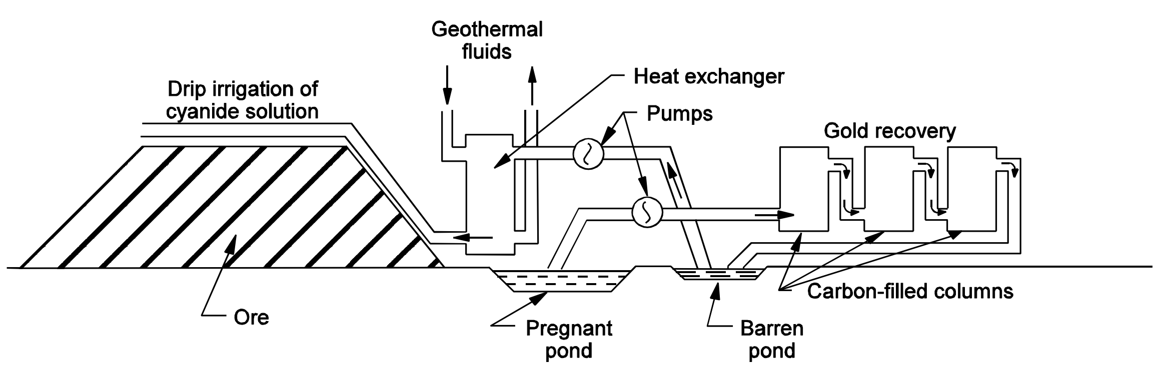

Figure 2. Idealized thermally enhanced heap leaching system (Trexler, et al., 1991).

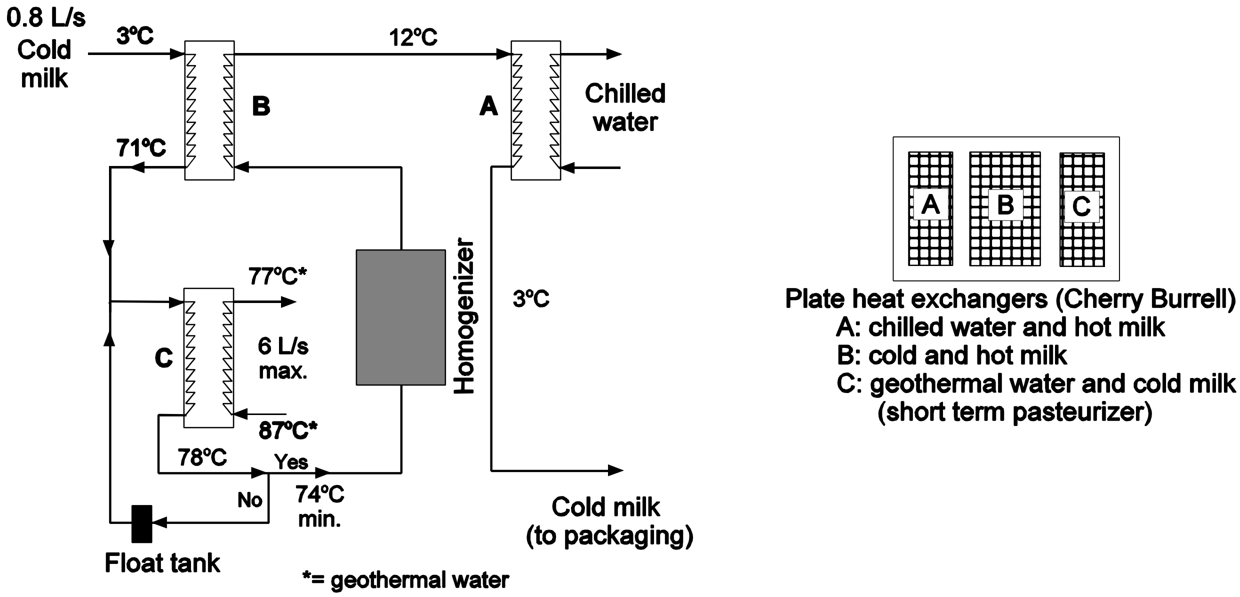

Figure 3. Medo-Bel milk pasteurization flow diagram (Lund, 1997).

87ºC geothermal fluid to a three-section plate heat exchanger. The incoming cold milk at 3ºC was preheated by milking coming from the homogenizer in one section of the heat exchanger. The milk was then passed to the second section of the heat exchanger where the geothermal fluid heated the milk to a minimum temperature of 78ºC for 15 seconds in the short-time pasteurizer. If the milk temperature dropped below 74ºC, the short-time pasteurizer automatically recirculated the milk until the required exposure was obtained. Once the milk was properly pasteurized, it was passed through the homogenizer and then pumped back through the other side of the first section of the heat exchanger where it was cooled to 12ºC by the incoming cold milk. It was finally chilled back to 3ºC by cold water in the third section of the plate heat exchanger, where the milk went into cartons (Fig. 3). Milk was processed at a rate of 0.84 L/s, and a total of 225,000 kg were processed each month. Some steam was necessary in the process to operate equipment; thus, geothermal water was heated by natural gas to obtained the required temperature. Geothermal hot water was also used for other types of cleaning, and for batch pasteurizing of ice cream. The heat was used to pasteurize the ice cream mix at 63ºC for 30 minutes.

The annual operational cost of the system was negligible, just for a 5 kW pump costing $120 per month. Pipe corrosion from the 800 mg/L sulfate-sodium water was the only maintenance problem. However, the savings amounted to approximately $1,000 per month as compared to conventional energy costs. Geothermal hot water was also used to heat the 2,800 m^3 buildings, which amounted to a substantial savings during the winter months. The estimated peak energy use was 1.0 GJ/hr (0.3 MWt) and the annual use was about 1.0 TJ.

SLUDGE DIGESTION

The city of San Bernardino, California installed a primary anaerobic sewerage digester in 1983 (San Bernardino Municipal Water District, undated). The process uses 58EC geothermal fluid which replaced methane that was burned to fuel the digester (Fig. 4). At the time of the implementation of the geothermal conversion, the city wastewater treatment plant was processing an average of 80,000 m^3 per day of domestic and industrial wastewater. The process includes primary and secondary treatment of all waste water, and tertiary treatment of 11,000 m^3 per day which is reclaimed for process, washdown and irrigation purposes. The sludges and other solids collected throughout the treatment process are pumped from their various collection points to the thickeners, where they are concentrated through settling. This thickened sludge is then pumped to the digesters. Digestion is a biological process that uses living anaerobic (absence of free oxygen) micro-organisms to feed on the organics. The process is aided by heating and mixing to break down the organic material into a digested sludge and methane gas. The methane gas is collected and used for fuel in various in-plant engines which drive pumps and compressors, while the well digested sludge is dried (Racine, et al., 1981).

The geothermal design required an 18.5 m^2 spiral plate heat exchanger designed to transfer 1.6 GJ/hr of heat to the digester sludge in a 7,600 m^3 volume tank. The total dissolved solids in the geothermal water is 290 mg/L which is of better quality than the treated water from the boiler system. The geothermal water, at maximum flow of 25 L/s, enters the heat exchanger at 58ºC and exits at 53ºC. The annual cost saving (1983) for the single digester was estimated at almost $30,000. The system has since been expanded to four digesters, with geothermal providing 6.4 GJ/hr (1.8 MWt) of heat and an estimated annual load of 53 TJ. The resulting

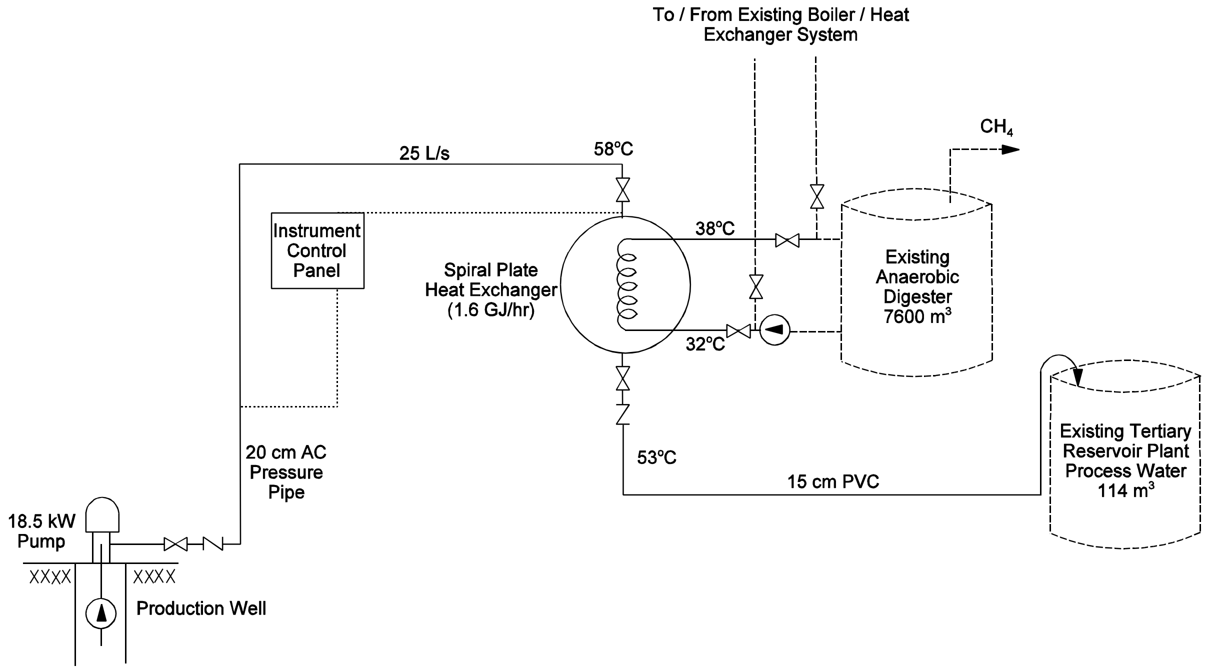

Figure 4. Diagram of geothermal heating of the anaerobic digester (Racine, et al., 1981).

payback of investment is less than 10 years (San Bernardino Municipal Water District, undated). The city also has a geothermal district heating system that serves 14 major buildings for an installed capacity of 13 MWt.

AGRICULTURAL DRYING

Two large geothermal onion and garlic dehydrators are located in Nevada, in the northwestern part of the state: Integrated Ingredients near Empire and at Brady's Hot Springs. These two large units can process almost 12 tonnes of wet onions per hour and use 35 MJ of geothermal energy per kg of dry product to dry it from about 80 percent to 5 percent moisture content (Lund and Lienau, 1994a). The daily use of energy for both facilities is about 1.37 TJ and the annual use, based on a 150 day working season, is about 208 TJ/year.

Onion and garlic dehydration at these Nevada locations involves the use of a continuous operation, belt conveyor using fairly low-temperature hot air from 40 to 105EC (Lund and Lienau, 1994a). A typical processing plant will handle 4,500 kg of raw product per hour (single line), reducing the moisture from around 80 percent to 5 percent in about six hours. The continuous belt drier, is a single-line unit 65 m long and 3.8 m wide, requiring 2,450 m^3 of air per minute and up to 42 GJ per hour (Fig. 5). Due to the moisture removal, the air can in some cases only be used once, and thus is exhausted. Special silica gel – Bryair, desiccation units are usually required in the final stage. The drier normally consists of four sections, A through D, with each one requiring lower temperature air (96 to 74ºC), but with increasing depth of product (from 5 cm to 2 m) (Fig. 6)

The Integrated Ingredients plant uses a high temperature resource (146ºC), which is also used by four ORMAT 1.5 MWe binary units (Lund and Lienau, 1994b). Up to 75 L/s are supplied to the plant at 130ºC and finally discharged as low as 71ºC. Thus, a maximum of 80 GJ/hr is used by the plant (approximately 11 MJ/kg of wet product). The facility also has a cold storage warehouse which can store as much as 22,000 tonnes of product, which can provide year-round operation. Recent improvements at the plant allows the drier to handle 7,250 kg/hr and produce 1,500 kg/hr of dry product, and a second line is being considered. The Brady's Hot Spring plant has a similar operation using 132ºC fluid. This was the first U.S. vegetable dehydration plant to utilize geothermal energy (Lund, 1994). This unit has only three stages (A through C). During the six-month operating season, almost 23 million wet kg of onions are processed. The 58-m long dehydrator uses from 88 to 49ºC air in the various stages. The plant has also processes celery and carrots to extend the operating season.

SUMMARY AND CONCLUSIONS

There are other smaller industrial uses of geothermal energy in the United States such as: 1) laundries in California, Nevada, Montana and Oregon; where in San Bernardino, California approximately 34,000 m^3/month of geothermal water is used with an annual savings of $354,000 (Fisher and Bailey, 1994); 2) mushroom growing in Oregon where 22.5 tonnes of white button mushrooms are produced annually (Culver, 1992); 3) mineral water processing in California using geyser water (Calistoga Water); and 4) an industrial park at the Puna geothermal facility, Hawaii with a variety of

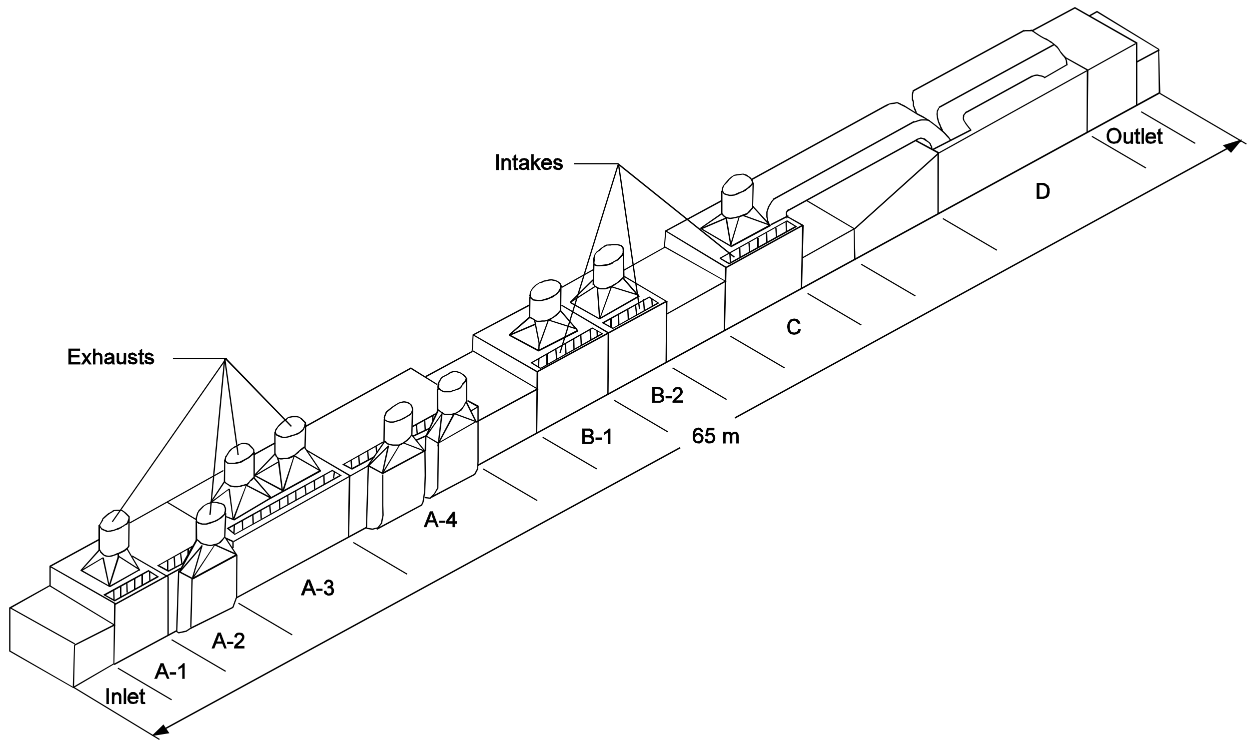

Figure 5. Typical single-line continuous belt drier.

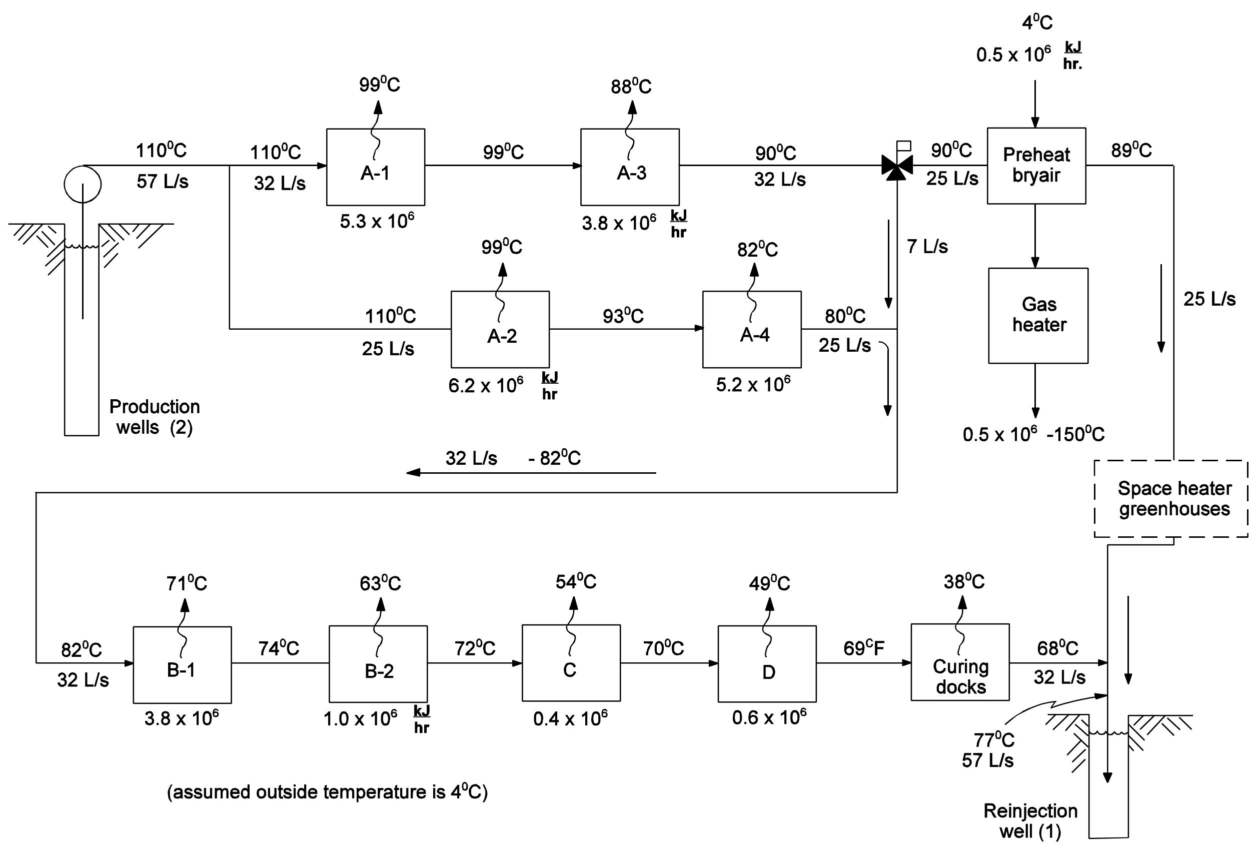

Figure 6. Temperature and energy requirements for each compartment of a single-line onion dehydrator.

experimental uses of geothermal energy (Boyd, et al., 2002). Another potential use that has not been documented is enhanced petroleum recovery in northeastern Wyoming by injecting geothermal water into the reservoir. Unfortunately, the Geo-Heat Center has not been able to obtain any reliable information on this large operation, since it is privately run. The most successful operations in the United States are the onion dehydration plants in Nevada. The current installed capacity of all these industrial uses is approximately 70 MWt and the annual use 1,500 TJ (415 GWh), but, has been as high as 100 MWt and 2,000 TJ (555 GWh) in the past. Additional information on industrial applications can be found in Lienau and Lund (1998).

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INDUSTRIAL PROCESSES AND THE POTENTIAL FOR GEOTHERMAL APPLICATIONS

Kevin Rafferty
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INTRODUCTION

Industrial applications constitute the smallest sector of direct use and the only one which has experienced a decline in recent years (-7% annual growth 1995-2000). Despite this performance, the industrial sector, at least in theory, offers a very attractive target for geothermal use. Industrial processes operate at high load factor relative to other geothermal applications, offer a concentrated load at a single location and in some cases are characterized by energy as a significant portion of production cost. Together these qualities suggest attractive conditions for geothermal application.

Historically this has not translated into extensive use however. In fact, over the past 20 years, only a handful of projects have been initiated and several of these have ceased operation. The single remaining large application, food dehydration, has been very successful with two large facilities currently operating in northern NV. Another large industrial user was formerly gold mining. These operations also located in northern NV, used the geothermal to heat a solution sprinkled on low-grade ore to remove remaining gold. From a practical standpoint, the mining applications were very successful but due to a combination of downturn in the gold market and high federal royalty costs for the geothermal, all of these operations have ceased.

The issues that have prevented wide-scale use of geothermal in the industrial sector relate to the high temperature requirements for most processes, the use of steam rather than hot water and the fact that geothermal resources tend to be dominated by low-temperature hot water production. Though it is unlikely that large potential exists in the industrial sector there may be some niche opportunities which to date have not been capitalized upon.

THE DELIVERED COST OF HEAT

A pivotal factor in the economics of a specific direct-use project is the extent to which the resource is used on an annual basis--often expressed as load factor. High load factor correlates with lower cost of delivered heat and industrial applications often exhibit higher load factors than most other geothermal applications.

In direct-use systems, heat is only supplied to the process, the building, the greenhouse, etc., when it is needed and in most cases, this is driven by climate. In warmer portions of the year, little or no heat is required. As a result, the load factor, the ratio of the actual heat used divided by the heat delivered if the system ran at full capacity 8760 hrs/yr, can vary from about 15% to 75% depending on the application. Load factor is normally expressed as the decimal

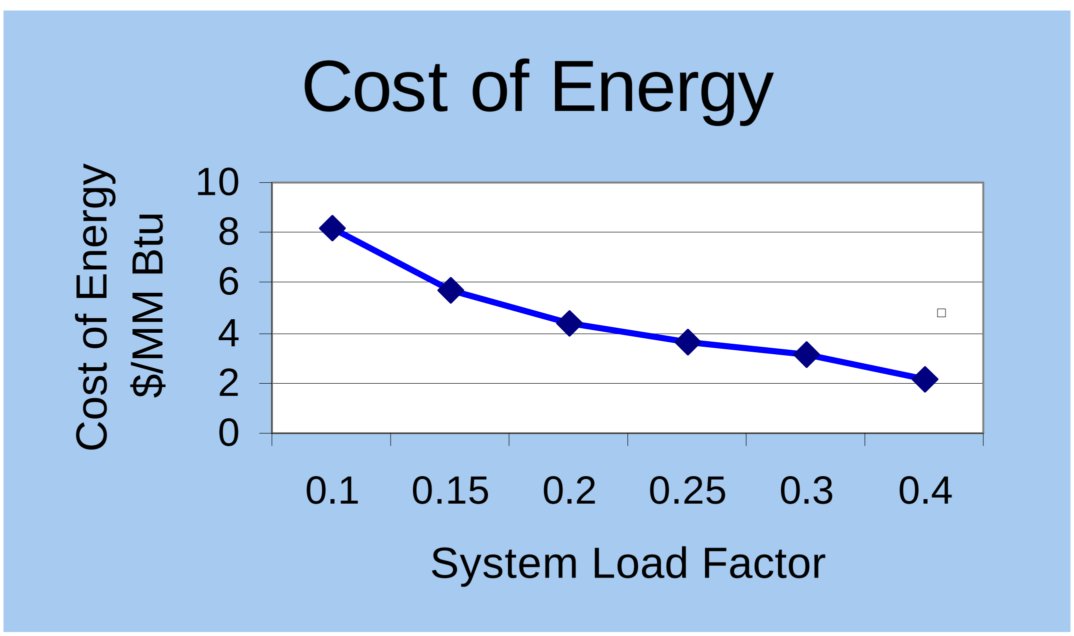

Figure 1. The influence of load factor on energy cost.

equivalent such as 0.15 for 15%. Geothermal power plants operate in the range of 0.90 to 1.0. In direct-use, a space heating only application might have a load factor of 0.15 to 0.20, greenhouses 0.18 to 0.24, aquaculture (outdoor open ponds) 0.50 to 0.80 and industrial applications 0.30 to 0.75 (depending on the number of shifts and the nature of the process). Since the cost of the well and pump is related to the peak heating requirement rather than the annual, the greater the quantity of heat over which the capital cost is spread and the lower the unit cost of delivered heat. The cost of delivered heat is a function of the load factor which in turn is a function of the application. The typically high load factor of industrial applications makes them an attractive target for geothermal energy use.

Figure 1 provides an example of the influence of load factor. The plot of cost of delivered heat vs load factor is based upon a system designed for a peak load of 20,000,000 Btu/hr using three 1500-ft production wells and a single injection well. The cost of heat includes capital, maintenance and operating components. Referring to Figure 1, the same geothermal system would produce the following cost of delivered heat for various applications.

Space heating application (load factor 0.15)	\$5.50 per 10^6 BTU
District heating system (load factor 0.20)	\$4.30 per 10^6 BTU
Greenhouse (load factor 0.22)	\$4.05 per 10^6 BTU
Industrial application (load factor 0.40).	\$2.10 per 10^6 BTU

For comparison, natural gas at \$0.60 per therm and 75% efficiency amounts to approximately \$8.00 per million Btu. Clearly, industrial applications stand out among other applications types in terms of potential savings.

The economics of direct-use is a strong function of the type of application to which the heat is applied. There is no pressing need to reduce the costs of resource development to reduce the cost of direct-use delivered heat. Those costs are already low. The strategy necessary is identifying applications with naturally high load factors (such as industrial applications) or configuring the design to artificially increase the load factor.

Base load (geothermal)/peak load (conventional fuel) design of some systems, though not widely practiced in the U.S., can have a powerful impact on the load factor of the geothermal component. The extent to which it improves overall economics, however, is variable with the type of application. The specifics of the strategy was explored in some detail for greenhouses in (Rafferty, 1996).

TEMPERATURE REQUIREMENTS OF INDUSTRIAL PROCESSES

Part of the reason for the general lack of industrial applications is the nature of the way industry uses heat. An evaluation of industrial energy use (Brown, et al., 1985) found that of 108 industrial processes surveyed (representing 80% of U.S. industrial energy usage) 97% of all processes required heat input in the form of steam at 250°F or higher. An examination of direct-use wells in eight states (Figure 2) reveals that 99% of all wells are 250°F or less. In the context of geothermal, temperatures above 250°F are in the range of resources that would be used for electric power generation rather than direct-use.

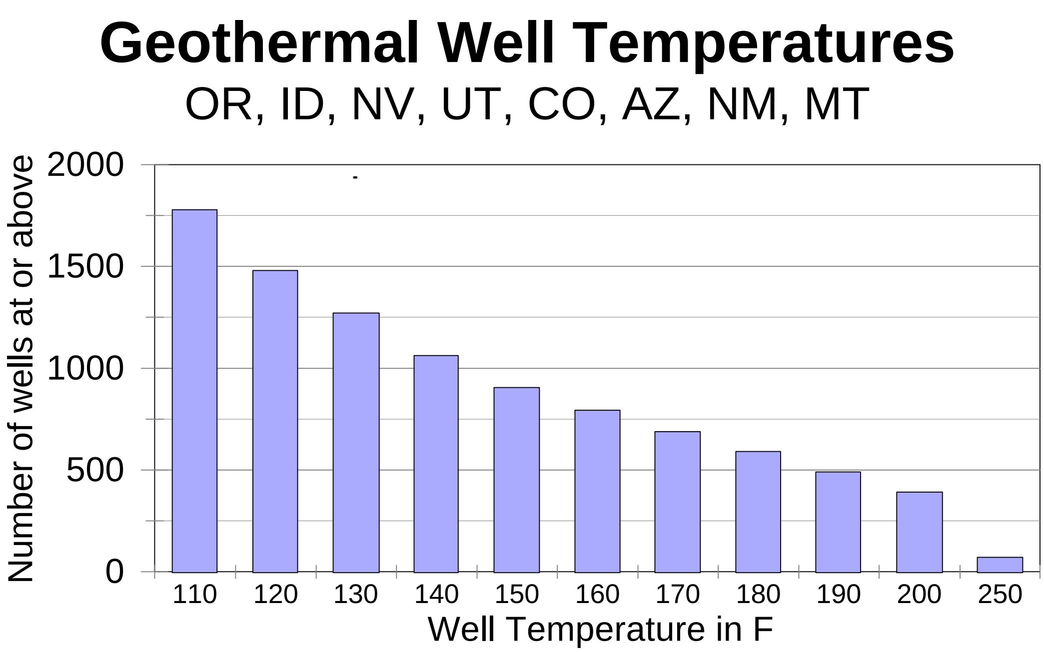

Figure 2. Geothermal well temperatures in eight western states.

In most industrial processes, opportunities for lower temperature heat input are satisfied through heat recovery within the process itself and unless the steam is consumed in the process, no boiler make-up water heating is required.

The opportunities in the industrial sector, though attractive from an energy use perspective, are fundamentally mismatched to direct use geothermal in terms of temperature (assuming higher temperature resources are used for electric power generation).

Using information from the Brown, et al., work, an evaluation of the 108 industrial processes was done to identify those processes most applicable to geothermal use. The individual processes were ranked first by the percentage of the heating requirements that were at or below 250ºF and secondarily by the energy use per unit of production. This approach was based on the assumption that industries most likely to use geothermal would be those that could displace all or most of existing energy requirements and do so at

TABLE 1

Process	SIC	Heat Requirement Btu/Unit	% Steam/HW	Temp ºF	% of Heat Input <250ºF	Notes
Rayon	28231	46892	92/2	250/200	100	per lb.rayon produced
Acetate	28232	34305	96/4	250/140	100	per lb. acetate produced
manmade fabric fnsh	22621	13,000	100	250	100	per lb. product
polypropylene	28242	9766	100	260	100	per lb. product
dipped latex	30691	7563	100	230	100	per lb. latex product
molded latex	30692	7563	100	240	100	per lb. latex product
acetelyene	28133	5970	100	250	100	per lb. acetelyene
acrylics	28243	5064	0/100	180	100	per lb. ac fibre 30wet/70dry
paper finishing	26211	4900	100	250	100	per lb. paper produced
bldg paper and board	26611	4360	100	250	100	per lb. building paper
bldg paper/brd intgrtd	26612	4215	100	250	100	per lb. building paper
alk/chlorine-mercury	28121	4000	100	250	100	per lb. chlorine product
alk/chlorine-soda ash	28124	3690	100	250	100	per lb. NaCO3 product
SBR rubber	28221	3097	100	250	100	per lb. product
wet corn milling	20461	2853	100	250/200	100	per lb. corn input
canned fruit	20331	2521	76/24	250/140	100	per can (24/case)
butyl rubber	28222	2500	46/54	250/180	100	per lb. rubber
saw mills	24211	2475	100	250	100	per lb. lumber produced
polybutadiene	28223	2264	100	250	100	per lb. polybutadiene
polyisoprene	28224	2252	100	250	100	per lb. product
meat packing	20111	2184	88/12	250/140	100	per lb.
phosphoric acid	28693	1915	100	250	100	per lb.
canned drinks	20333	1763	70/30	250/140	100	per can (24/case)
potash	28194	1100	100	250	100	per lb. potash product
malt beverages	20821	901	52/48	250/185	100	per lb. beverage produced
photographic film	38611	878	62/38	250/180	100	per lb. film product
pharmaceut preps	28341	582	100	250	100	per $ of sales
fluid milk	20261	555	100	250	100	per lb.
cakes/pies	20512	530	89/11	250/180	100	per lb. product
alk/chlorine-soda ash	28123	470	100	250	100	per lb. NaCO3 product
bread/cake	20511	465	94/6	250/185	100	per lb. product
cement	32731	6.5	0/100	140	100	per lb. cement product
canned vegetables	20332	2708	88/12	250/140	90	per can (24/case)
cane sugar	20621	2317	72/28	300/145	87	per lb. sugar, various temps
inorganic pigments	28162	18645	100	350/250	72	per lb. TiO2
beet sugar	20631	1011	94/6	280/140	67	per lb. input
cumine phenol	28652	9483	100	500/250	56	per lb. phenol
nylon 6	28245	9987	100	550/250	46	per lb. nylon product
EP rubber	28225	3595	100	420/250	30	per lb. product
PVC suspension	28211	1269	100	370/250	30	per lb. PVC
sodium	28195	2092	100	275/250	27	per lb. sodium
car bodies	37111	1264	77/23	250/180	23	per lb. finished product
styrene	28651	14360	100	400/230	20	per lb. styrene prod

temperatures closest to those commonly available from geothermal. Table 1 presents the results. The first column identifies the industry and the second column the Standard Industrial Code (SIC) associated with it. Column three provides the unit heat requirement of the process. This is most often expressed in Btu per pound of product. Industries with the highest unit energy use would be most likely to consider geothermal use. Column four indicates the percentage of steam versus hot water used in the process. Industrial processes are heavily dominated by steam as the heating medium, but there are a few that have significant hot water use (acrylics, butyl rubber, malt beverages and concrete). Column five provides key process temperature requirements. Most industries have heat inputs at multiple temperatures in different stages of the process and in the column the highest and lowest values are indicated. Column six is a key value--the percentage of the process heat requirement that is at or below 250°F. In most cases, the requirement is at 250°F (15 psi steam).

Column 6 indicates the unit upon which the heat requirement is based. In most cases this is per pound of product.

Most the industries with favorable heat use characteristics are in the plastics, rubber, chemical and paper sectors. Interestingly of the 108 processes evaluated, dehydration was not included (though several other food processes were). Based on the energy use per pound of product for geothermal dehydration facilities (Lund, 1994), onion and garlic dehydration would rank just below Acetate in Table 1 in terms of heat energy consumed per unit of production. The success of geothermal dehydration applications suggests that the unit energy approach to industry ranking may have some merit.

The amount of energy consumed in the industrial sector is substantial. For just the two top processes (Rayon and Acetate), according to Chemical and Engineering magazine, the total U.S. production in 2001 was 235,000,000 lbs. At an average of 40,000 Btu per pound of product, the energy consumed amounts to 9.4×10^{12} Btu--roughly equivalent to the annual energy supplied by all existing direct use projects in the U.S. combined.

AN UNTAPPED OPPORTUNITY?

One of the opportunities we have not taken adequate advantage of in the U.S. is combining direct-use with electric power production. This strategy has very attractive features relative to stand-alone development of geothermal resources for direct-use--particularly in the industrial sector. Effluent from geothermal electric power production, especially that from flash plants (flash tanks) is:

- At relatively high temperature,
- Devoid of risk relative to drilling for similar temperature resources,
- Characterized by far lower cost than developing a resource from scratch, and
- Available in substantial quantity

Hurdles would remain in the areas of land access, agreement with the resource/plant owner, location acceptability for the industrial concern, fluid chemistry, etc., but it is strategy that warrants greater attention and promotion than has been accorded it in the past. With the use of vapor recompression technology, it would be possible to boost low pressure steam from flash effluent to higher pressure for industrial uses. In some cases, generation of low pressure steam from hot (190+ °F) fluid streams may also be possible. This could significantly enhance the utility of power plant effluent heat.

Binary plant effluent owing to its typically lower temperature would be a secondary source appropriate for use but more likely for the lower temperature applications (greenhouse/aquaculture) than for industrial purposes.

VAPOR RECOMPRESSION

Vapor recompression is a technology used in various industries in which low pressure steam exiting from one part of a process (often a cooking or evaporation process)is directed to a compressor where the pressure of the steam is raised so that it can be used in a higher temperature/pressure part of the process. There are limitations in terms of the amount of pressure that can be added at the compressor (most applications are at compression ratios of less than 2:1). This translates into a minimum geothermal fluid temperature requirement of approximately 190°F.

The attractiveness of recompression is that only that energy required to boost the steam to the higher pressure is added at the compressor. This amounts to only a fraction of the energy required to generate equivalent pressure steam at the same pressure with a boiler. Figure 3 presents an example of the recompression strategy for a geothermal application. A flow of 1000 gpm of 230°F water is delivered to a flash tank maintained at 0 psig (atmospheric pressure). Approximately, 8800 lb/hr of steam is liberated in the tank (slightly less than 2% of the inflow) and the remainder is discharged as 212°F water. The compressor raises the pressure of the steam to15 psig and a small flow of water is sprayed into the discharge to control superheat. A total of approximately 9000 lb/hr of steam is delivered at 252°F for use in an industrial process.

The economics of the steam generation are the compelling feature of a process such as this. To produce the flow of steam in the example a 30 hp motor would be required to drive the compressor. At $0.07 per kWh, the energy cost of the steam would amount to approximately $1.68 per million Btu. To generate the equivalent flow of steam using a boiler (75% efficiency, $0.60 per them gas and 200°F condensate return) would amount to $8.57 per million Btu. The compressor supplied steam costs (energy only) just 20% of boiler supplied steam.

The values in the example are not suggested to be the optimum configuration for a recompression design but only to illustrate the potential of the technology. It is potentially one method of capturing moderate pressure/temperature, steam based, industrial applications with low-temperature geothermal water resources.

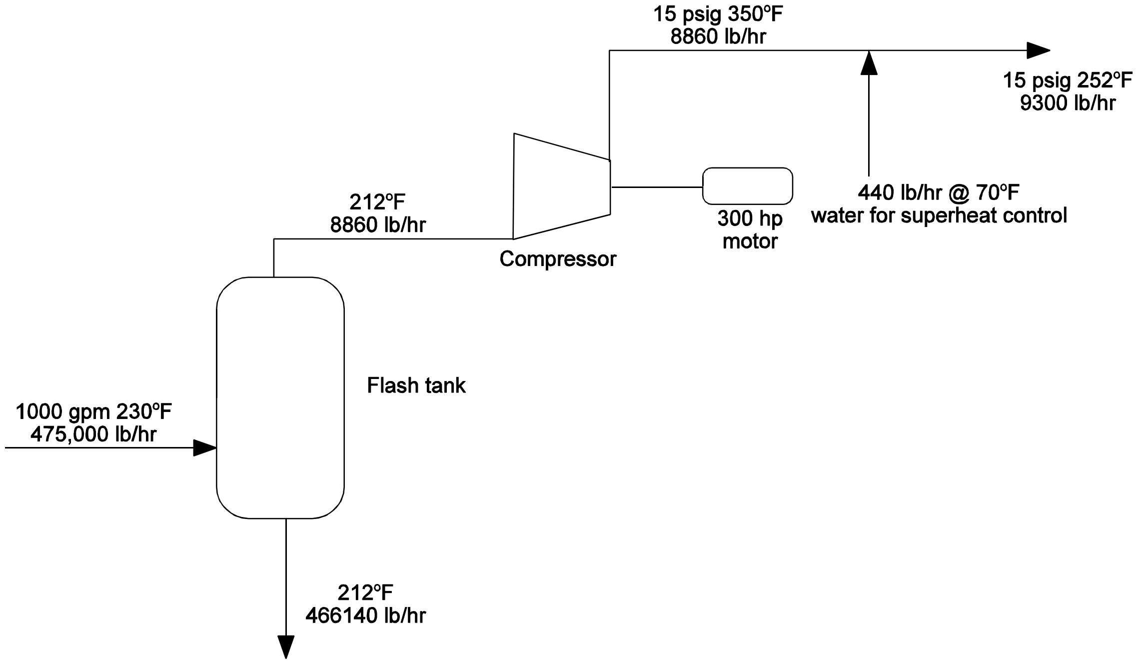

Figure 3. Vapor recompression using geothermal.

CONCLUSION

Although industrial processes consume substantial amounts of heat, the temperatures at which the heat is required are far above the typical range encountered in low-temperature geothermal resources. As a result, it is unlikely that most industries will be able to take advantage of geothermal resources. By carefully targeting those processes characterized by the lower temperature heat input requirements, possibly taking advantage of power plant effluent and technologies such as vapor recompression, there may be niche applications which can yield attractive savings.

Although the industrial processes in Table 1 have been sorted by energy use and temperature level, many other issues can impact the ability to use geothermal resources and the ranking should be considered very preliminary. Geographic limitations would be a critical factor. For paper, celluose fibre and chemical based industries, proximity to feed stocks may be a significant consideration. To gain a more realistic picture of the potential, a more detailed evaluation of the most favorable processes addressing such issues as geography, production volume, transportation costs and other issues would be necessary. In parallel an evaluation of the role, if any for vapor recompression would be useful. An examination of hardware requirements, availability, costs, performance of existing systems in industry and suitability for geothermal fluids (materials) would help to bring clarity to the prospects for this technology.

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NEW SNOW MELT PROJECTS IN KLAMATH FALLS, OR

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INTRODUCTION

A $1.3-million dollar project consisting of two bridge replacements was a joint effort by the Oregon Department of Transportation (ODOT) and the city of Klamath Falls. The two bridges replaced are on Eberlien Avenue and Wall Street, which spans over the A canal that furnishes irrigation water to the farmers south of town. The replacement of the Wall Street Bridge and approach road incorporated a snow melt system designed by Meredith Mercer of ODOT using geothermal for the street, bridge deck and sidewalks. Due to the location of the A canal, the Wall Street approach road has about a 13.25% grade to the bridge and can be very hazardous during the winter season. The cost of the snow melting system for the Wall Street Bridge was $170,000 for the hydronic tubing placement, and $36,000 for the mechanical equipment and plumbing. This is the second bridge project in Klamath Falls, which will utilize geothermal for snow melting (Lund, 1999). The geothermal heat will be provided by the city of Klamath Falls District Heating System. The project was completed in June 2003.

Oregon Institute of Technology also placing a new snow melting system on an existing stairway by the College Union building and a snow melt system in a new handicap ramp on the north side of the College Union building.

WALL STREET BRIDGE AND STREET PROJECT

The Wall Street Bridge and Street Project has approximately 10,330 ft^2 (960 m^2) of snow melting surface (Figure 1). The bridge deck and sidewalks snow melt area are 88.6 ft (27 m) by 42 ft (12.8 m) for a total of 3720 ft^2 (345.6 m^2) of surface area. The approach road and sidewalk snow melt area are 157.5 ft (48 m) by 42 ft (12.8 m) for a total of 6613 ft^2 (614.4 m^2) with an estimated heat output of 60 Btu/ft^2/hr (189 W/m^2).

A separate heat exchanger installed in the city's heat exchanger building will be used for the Wall Street Project, which will tap into the geothermal return water of the district heating system before it is injected into the ground. The heat exchanger specifications are 316 stainless steel plates with standard nitrile gaskets providing approximately 600,000 Btu/hr (174 kW) and designed for 150 psi (1,030 kPa) operating pressure (Figure 2). The heat exchanger will transfer heat to a 35% propylene glycol solution, which will be circulated in a closed loop to the approach road and bridge. The geothermal water side of the heat exchanger will enter at about 150ºF (66 ºC) and leave at 110ºF (43 ºC). The glycol solution side of the heat exchanger will enter at about 100ºF (38 ºC) and leave at about 130ºF (54 ºC). The geothermal loop side of the heat exchanger has a 1/3-hp (250 W) vertical

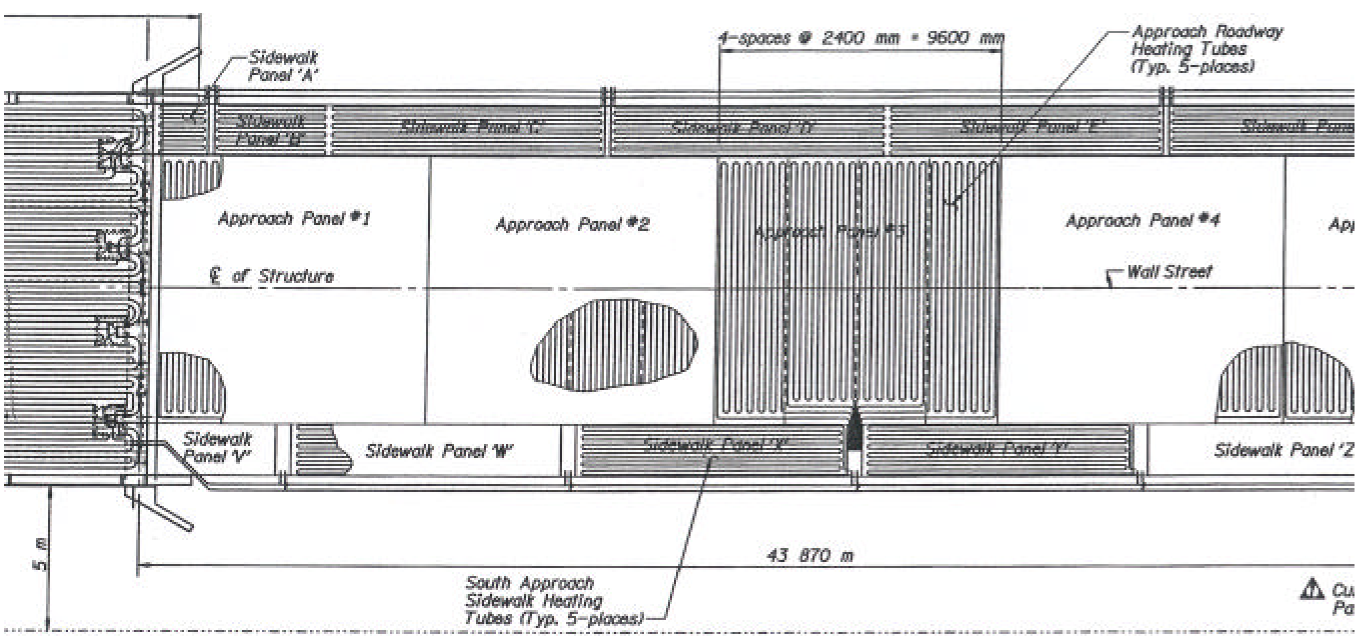

Figure 1. Portion of the Wall Street Project (ODOT, 2003)

in-line centrifugal pump installed with a flow rate of 40 gpm (2.5 L/s). The bridge loop side of the heat exchanger has a 1/2-hp (375 W) vertical in-line centrifugal pump installed in that side to circulate the solution with a flow of 45 gpm (2.8 L/s). This loop has more capacity installed than will be needed at this time. The system was designed for possible snow melt systems to be added in the future. An expansion tank is also connected to the heat exchanger, which has a minimum volume of 55 gal (210 L) and a minimum 22 gal (85 L) acceptance capacity. The system will run continuously during the winter season.

Figure 2. Snow melt heat exchanger in the city's Heat Exchanger building.

The approach road and bridge is about 1/2 of a mile (800 meters) from the heat exchanger building. The pipeline from the heat exchanger building to the approach road consists of a 4-in.(100 mm) high density polyethylene (HDPE) pipe when it leaves the building, then transitions into a 3-in. (75 mm) HDPE pipe at the approach road to the bridge.

The bridge project was completed in parts. The first part was removal of the existing bridge deck, then building of the new bridge deck. The bridge loop system was then tied into the bridge reinforcing steel. After the concrete was placed on the bridge deck and curing completed, they worked on the bridge sidewalks and loop system. Concrete was then placed on that part of the bridge and allowed to cure. They then worked on the bridge railing. While the bridge railing was being worked on, they removed the existing approach road material down to the sub-base. The road was then prepared and reinforcing of the road was placed. The loops for the approach road were tied into the reinforcing. The concrete was then placed and allowed to cure. The formworks for the sidewalks were completed, and the concrete placed and allowed to cure.

The mains control valve box (Figure 3), located on the southeast corner of the approach road, is where the main line is split into two lines. One line goes over to the north sidewalk with a 1-in (25-mm) supply and return line for the north sidewalks, and the other goes up the south side with a 3-in (75-mm) supply and return line for the manifolds located on the south side and the bridge deck manifolds.

Figure 3. Details of the main control valve box.

The glycol solution will be pumped through the tubing in the bridge deck and approach road. The tubing placed was Wirsbo 5/8-in (16 mm) ID hePEX (a cross-linked polyethylene), which was used on the other bridge deck (Lund, 1999). The loop system consists of about three miles (4,700 m) of tubing. The approach road has five approach panels consisting of four loops for a total of 20 loops. The bridge deck has 11 loops. The sidewalks of the bridge has two loops each. The approach road sidewalks has 11 separate loops, six on the north side and five of the south side.

The loop system for the bridge was placed longitudinally on the bridge deck with the loops ending on the approach roadside of the bridge (Figure 4). The loop systems for the bridge and approach road sidewalks was placed longitudinally (Figure 5). The approach road loop system was placed latitudinally with the loops ending on the south side of the road (Figure 6). All the loops are attached to reinforcing steel by wire at approximately eight inches (200 mm) on center. The ends of the loop systems for the bridge goes through the bridge deck. A protective sheath was placed around the tubing where the loops pass through the bridge deck.

There are a total of 12 manifold boxes used on this project. The bridge and bridge sidewalks has four manifold boxes placed underneath the east side of the bridge deck between the plate girders (Figures 7 and 8). The two manifold boxes nearest to the edge of the bridge has two 2-port supply and two 2-port return manifolds and the two manifold boxes in the center of the bridge has either 4-port supply and a 3-port return or the other way around (Figure 9). The middle loop down the centerline of the bridge has a supply loop on one manifold and a return loop on the other manifold.

Figure 4. ***Bridge decking loops attached to the reinforcing steel.***

Figure 5. ***Bridge sidewalk loops.***

Figure 6. ***The approach road loops placed latitudinally.***

The north sidewalks consists of six loops have three manifold boxes each with a 2-port supply and 2-port return manifold. The south sidewalks (five loops) and the

Figure 7. ***Manifold under the bridge deck before they are placed in boxes.***

Figure 8. ***Manifold boxes under the bridge.***

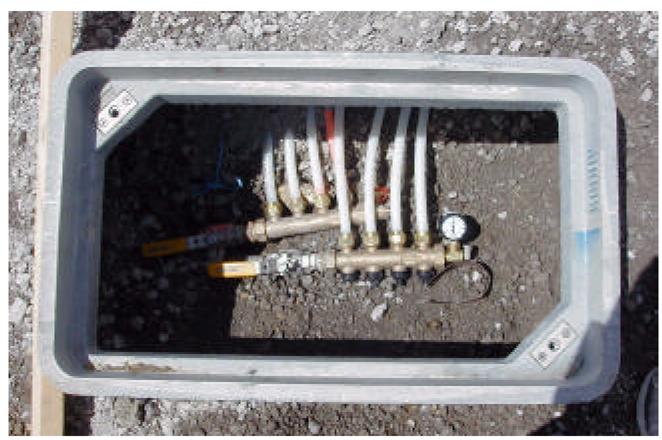

Figure 9. ***Detail of a manifold box for the south sidewalk.***

approach road utilize five manifold boxes each with a 2-port and a 4-port supply, and a 2-port and a 4-port return manifold. The 2-port are for the sidewalk loops and the 4-port being for the road loop.

All the loop systems were pressure tested using air to check for leaks in the loops. The loops were continuously pressurized with 51 psi (350 kPa) air for at least 24 hours before concrete placement. The pressure was maintained during placement of the concrete and three days following placement.

The entire geothermal portion of the snow melting project was awarded at $170,000, which figures out at $16.45 per square foot. However, costs for state projects tend to be two to three times higher than private projects due to the requirements to pay prevailing wages and rigorous inspection standards. In addition, all plans are in metric, which may have posed a problem of conversion for local contractors.

To isolate the actual cost of purchasing and installing the pipes, the following items should be deducted. The supply line from the heat exchange building to the construction site, about 1/2 mile apart, is estimated to cost $50,000 to $80,000; the manifold boxes ran $600 a piece and testing of the system cost $10,000. Thus, the actual cost of the piping was around $7 to $10 per square foot. Non-state projects would probably run $3.50 to $4.00 per square foot.

OREGON INSTITUTE OF TECHNOLOGY PROJECT

The Oregon Institute of Technology (OIT) placed a snow melt system in an existing stairway by the College Union building. The project consisted of placing a slurring concrete mix over the existing stairway, then the tubing was tied to the formwork longitudinally with the stairway. They used a two-loop system for a total of 565 ft (172 m) of tubing placed, and the surface area that will be snow melted is 540 ft^2 (50 m^2) (Figure 10) (Keiffer, 2003).

The other snow melt system was incorporated into a new handicap ramp placed on the north side of the College Union building. This system also used two loops for a total of 489 ft (149 m) of tubing and the surface area to be snow melted is 469 ft^2 (43.5 m^2) (Keiffer, 2003).

Figure 10. Detail of the snow melt system for the stairs.

This brings the total amount of snow melting on the OIT campus to approx. 3,300 ft^2 (310 m^2). Both systems are connected to the campus heating system via the campus tunnel system (Boyd, 1999).

ACKNOWLEDGMENTS

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USE OF GEOTHERMAL ENERGY AND SEAWATER FOR HEATING AND COOLING OF THE NEW TERMINAL BUILDING IN THE AIRPORT OF THESSALONIKI

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INTRODUCTION

Following promising results of the recent geothermal exploration in the region next of the airport "Makedonia" of Thessaloniki, the Civil Aviation Authority of Greece, which is responsible for managing the airport, will drill a deep (up to 800 m) geothermal borehole within the premises of the airport, in order to investigate and exploit local geothermal potential for heating and cooling the new terminal building. The energy needs of the building have been estimated as 8 MW_t and 16,800 MWh for heating (Mendrinos, et al., 2003). The cooling needs of the building may be even higher.

GEOLOGICAL AND GEOTHERMAL BACKGROUND

The airport "Makedonia" is located a few kilometres south of the city of Thessaloniki on the coastline of Thessaloniki's bay (Figure 1), within the basin of Anthemountas, which is a recent tectonic depression filled with younger sediments forming an extension to the wider basin of Thessaloniki-Thermaikos. The extent of the Thessaloniki-Thermaikos basin is shown in Figure 2. According to Fytikas and Papachristou (2003) the stratigraphy of the region comprises: a) volcanic (dounites and peridotites) and/or metamorphic rocks with intense fracturing (Gabbros

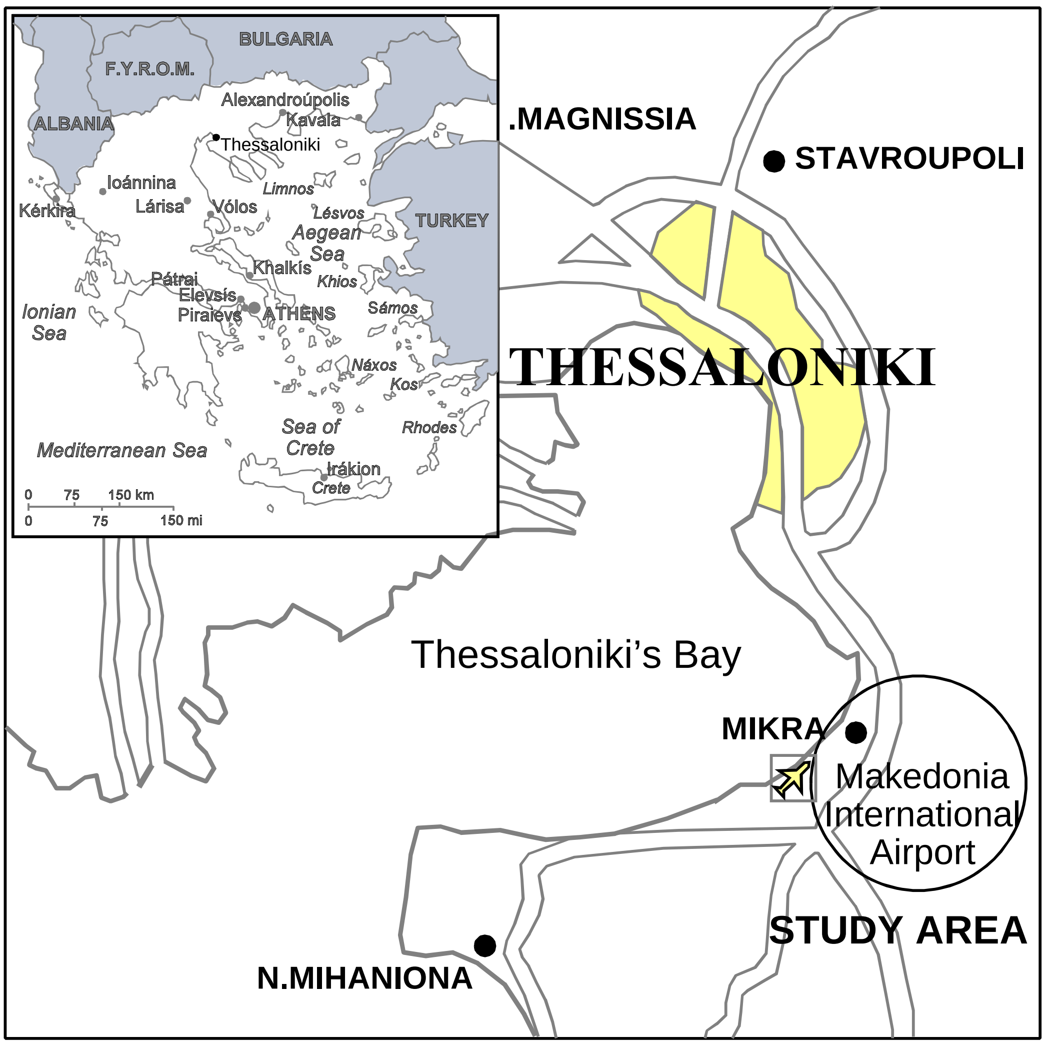

Figure 1. Map of the study area.

and gneiss) of the basement encountered at around 1000 meters depth, b) the base conglomerate, c) Pliocene marine sandstones and green clays with limestones intercalations; river and lake sediments with lenses and layers of sand, silt, sandstones, marls, marly limestones and red-layers, d) Quarternary deposits of red silt, sand, conglomerates and breccias, and e) younger sedimentary deposits of terrestrial origin.

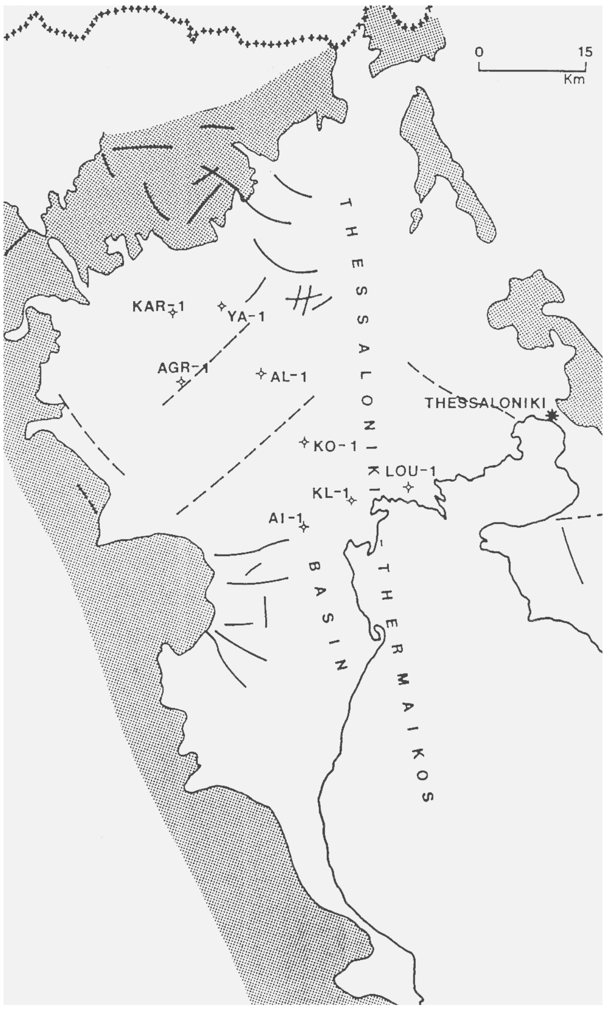

Figure 2. ***Extent of the Thessaloniki-Thermaikos Basin (Karytsas, 1990).***

The geological cross section, corresponding to the upper stratigraphy of the basin, of the slim exploratory well drilled in the vicinity of the airport is presented in Figure 3.

Recent geothermal research in the region undertaken by the Institute of Geological and Mineral Research of Greece indicated the presence of 42ºC artesian water at 550m depth below the ground surface. According to geological and geophysical data, the warm permeable horizons extend between depths of 550 - 1000 m (Fytikas and Papachristou, 2003). As a result, we conclude that a deeper borehole having an 8-in. production casing may well yield a sustainable flow of 75 m^3/h water with temperature of at least 42ºC.

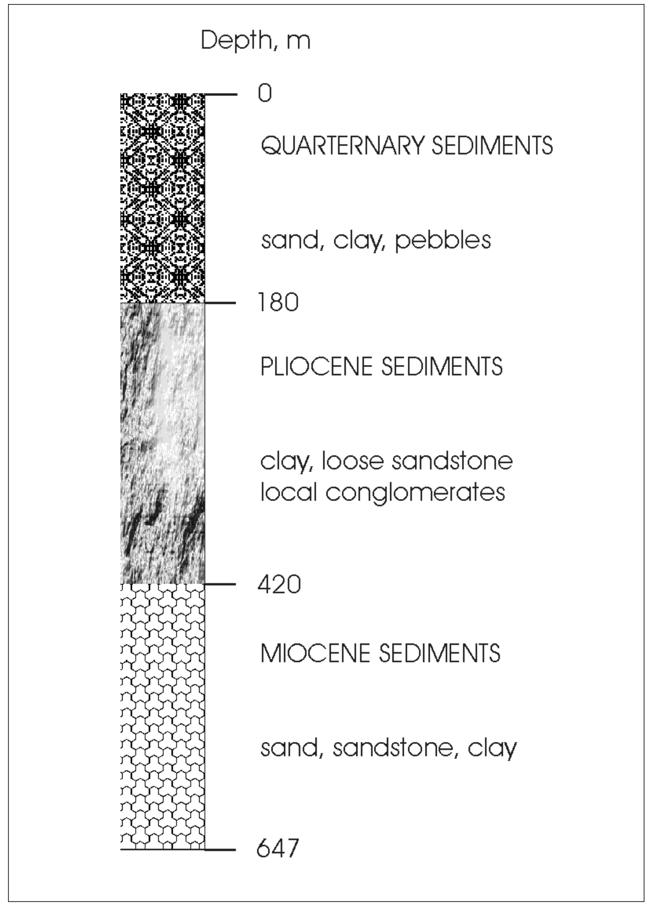

Figure 3. ***Stratigraphy of the area as indicated by deep exploratory drilling in the vicinity of the airport (reconstructed from Fytikas and Papachristou, 2003).***

THE PROPOSED HEATING AND COOLING SYSTEM

Due to the need for providing both heating and cooling to the new terminal building, we propose a hybrid system utilising both seawater and geothermal fluids. Its layout is presented in Figure 4.

In order to maximize temperature drop and geothermal energy output from a given flow rate, we propose the geothermal fluid to feed a water source heat pump. Similar heating and/or cooling systems using groundwater or seawater coupled with water source heat pumps have been constructed or planned for several locations in Greece. These include the heating and cooling of municipal and other public buildings in the Municipality of Langadas (Mendrinos, et al., 2002b), the heating and cooling of the Mining-Electrical Engineering Building of the NTUA campus (Karytsas, et al., 2002). Other buildings include the Educational Centre in Legraina, Attica, the new CRES office building in Pikermi, the office building of Thenamares Ship Management in Kavouri, Athens and the new Concert Hall of Thessaloniki (Mendrinos, et al., 2002a).

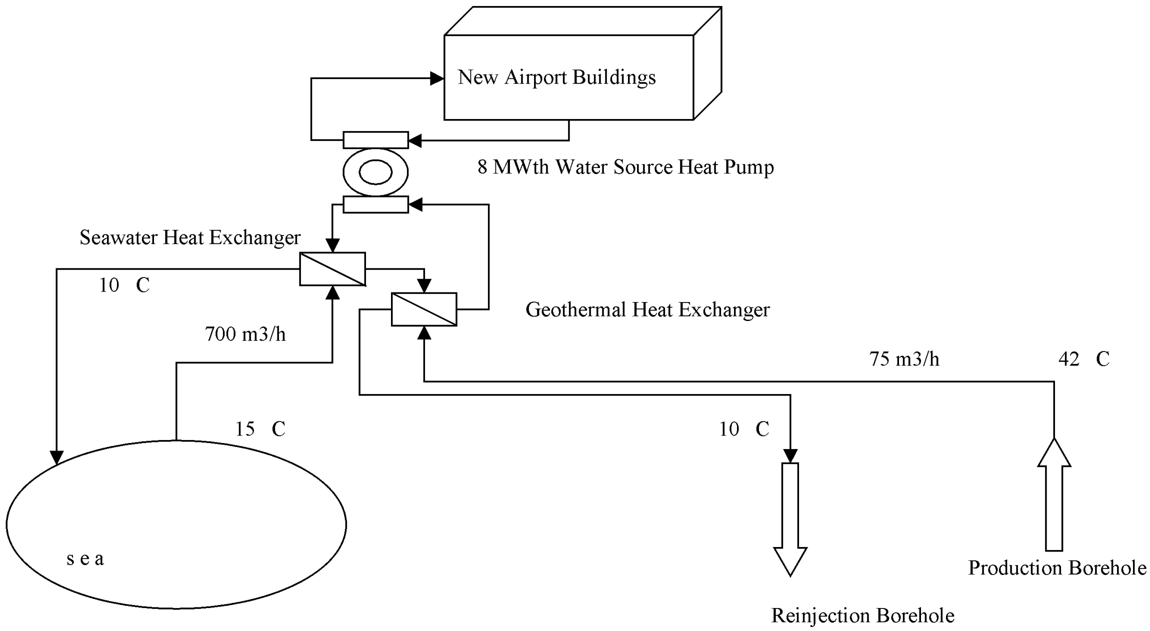

Figure 4. ***Geothermal and seawater system coupled with water-source heat pumps for heating and cooling of the new terminal building of the airport of Thessaloniki "Makedonia." This system can supply the buildings with 8 MWt of heating and 7 MWt of cooling.***

Assuming production temperature slightly over 42ºC for the geothermal water, its direct use from one production borehole would correspond to a maximum 5ºC temperature drop or 435 kW only a very small amount compared with the 8000 kW_t needed for the heating of the building.

Our proposal for the buildings heating and cooling system combines one or more water-source heat pumps of total rated power 8 MW_t, using as heat sources during the winter period both 42ºC geothermal water and seawater of 15ºC. We propose to use one production and one reinjection borehole in order to minimize capital costs associated with the boreholes drilling and completion, and maximize the load factor of the geothermal system. The maximum temperature drop of the geothermal circuit will amount to 32ºC, which corresponds to reinjection temperature of 10ºC at peak load. The energy transfer to the heat pumps by the geothermal water and the seawater will take place with the aid of two separate plate heat exchangers. The heat pumps will be fed by the geothermal water in first, in order to maximize water input temperature at the evaporator of the heat pumps and as a result, their energy performance.

During the summer period, the water-source heat pumps will provide cooling and will use 25ºC seawater as a heat sink.

The geothermal fluid supply system components will include one production and one reinjection well, each one 800 m deep with about an 8 inch inner casing, insulated buried transmission piping of 10-in. diameter, plate heat exchanger, submersible production pump of 70 hp producing 75 m^3/h flow from 100m water level within the production well, frequency modulator (inverter) and temperature sensors for flow regulation.

The seawater supply system may include 60 - 120 shallow wells each 10 - 20 m deep, or alternatively two trenches 400 m^3 each excavated within the sand at 1 m distance from the waterside, equipped with pumps of total power of 100 hp for 700 m^3/h total flow, buried transmission lines, plate heat exchanger, as well as inverter(s) and temperature sensors for flow regulation. During the cooling mode, the geothermal system will remain out of operation, with seawater only serving as the heat sink for the heat pumps. In that case, the seawater can absorb all 8 MW of heat rejected by the heat pumps, which corresponds roughly to 7 MW of cooling within the buildings. The temperature difference of the seawater will be approximately 5ºC in heating mode during winter and 10ºC in cooling mode during summer.

In the peak heating mode, the water circuit feeding the evaporators of the heat pumps, will gain 3.4ºC from the seawater heat exchanger and 2.2ºC from the geothermal heat exchanger and will enter the evaporators at 10ºC. The corresponding flow rate will be approximately 1100 m^3/h requiring water pumps of power equal to 150 hp. In all other cases of the heating mode, the automation controls will ensure that the geothermal system operates at full power and that only the additional energy required will be provided by the seawater. In that case, the temperature of the evaporators circuit can be relaxed to higher values close to the upper limits allowed by the heat pump manufacturer (e.g., 18ºC), in order to increase the energy efficiency of the heat pump. The water circuit connected to the heat pumps condensers will require flow rate of 1,250 m^3/h and pumps of 170 hp.

A power substation able to supply 2.6 MWe of useful electricity should be installed, in order to supply the electricity needed for the heat pumps, the pumps, the fan-coils and the fans of the heating and cooling system.

ENERGY BALANCE

One geothermal production borehole yielding 75m^3/h and 42ºC corresponds to 3.25 MW$_{th}$ heat pumps output in heating mode and can cover 12,960 MWh of heating, or 77% of heating needs. The remaining 3,840 MWh, or 23% of heating needs will be provided to the heat pumps by the seawater, which will cover the peak loads. The energy output of the heat pumps in the heating mode corresponding to geothermal water and seawater is presented in Figure 5.

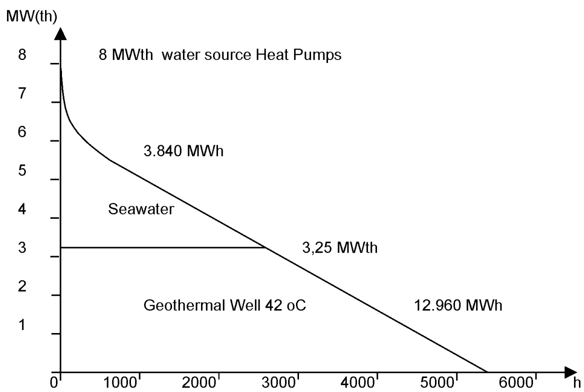

Figure 5. ***Energy output of the water-source heat pumps for heating throughout the year according to the heat source (geothermal water or seawater) feeding the heat pumps.***

The main energy sources for the heating of the new terminal building are: a) geothermal energy included in the 42ºC groundwater, b) thermal energy released by seawater while dropping its temperature from 15 to 10ºC, and c) electricity supplied to the water source heat pumps. During summer, seawater serves as the heat sink of the thermal energy pumped out of the buildings. The main operating parameters are summarised in Tables 1 and 2 and the resulting energy balances are presented in Tables 3 and 4. The corresponding load factors are shown in Table 5.

The higher COP of the heat pumps during cooling operation is attributed to the prevailing lower temperature difference between the temperatures of the evaporators and the condensers. The net SPF (seasonal performance factor) of the system for all-year-round operation, taking into consideration the electricity consumed by the geothermal and seawater supplying submersible pumps, the water circulating pumps in the heat pumps and building loops, and the fans of the air handling units and the fan coils has been estimated at SPF=4.3. This value is approximately 50% higher than that of an air-source heat pumps. Electricity consumed by the heat pumps corresponds to 95% of electricity input and the remaining 5% corresponds to all pumps and fans. The prerequisite for this low power consumption to the pumps and fans is flow control by frequency modulators (inverters) and centralized energy management system.

Net annual energy savings of the geothermal-seawater energy system correspond to 13,150 MWh for heating (1,400 TOE), plus 7,500 MWh for cooling (800 TOE), totalling 2,200 TOE each year. The corresponding CO_2 emissions reductions have been estimated as 7,040 tons annually.

EXPECTED FINANCIAL PERFORMANCE: ENERGY COSTS TO THE END USER

The cost estimation of the proposed investment and its breakdown to major components of the project are presented in Table 6. Geothermal production network corresponds to 9% of the overall investment, the reinjection network to 8%, the seawater supply to 18%, the heat pumps to 35% and the building heating and cooling system to 31%.

The financial analysis of the project in terms of final energy (both heating and cooling) delivered to the end user, with or without reinjection, is presented in Table 7. The assumptions for the calculations are 5% cost of money (discount factor), and 20-yr amortization period of the investment.

Three different costs of energy have been calculated averaging both heating and cooling delivered to the building. The first one (0.0323 - 0.0337 $/kWh) corresponds to overall system costs including the amortization of the low-temperature heating and cooling system within the building itself.

Table 1. Heating and Cooling System of the New Terminal Building: Operating Parameters in Heating Mode

	Tin ºC	Tout ºC	Max. Flow m^3/h	Averave Flow m^3/h	Hours of Operation
Geothermal	42	10	75	58	5400
Seawater (winter)	15	9.64	700	212	2600
Evaporators	10	4.5	1119	434	5400
Condensers	45.5	40	1255	487	5400

Table 2. Heating and Cooling System of the New Terminal Building: Operating Parameters in Cooling Mode

	Tin ºC	Tout ºC	Max. Flow m^3/h	Averave Flow m^3/h	Hours of Operation
Evaporators	12.5	7	1119	559	2700
Condensers	39	33.5	1243	621	2700
Seawater (summer)	25	34.77	700	350	2700

Table 3. Heating and Cooling System of the New Terminal Building: Energy Balance in Heating Mode

	Power kW	Energy MWh	Energy %	Equivalent Energy MWh
Geothermal	2,787	11,551	62	12,960
Seawater	4,356	3,424	18	3,842
Geothermal & Seawater (approximately equal to the evaporators circuit)	7,143	14,975		16,802
Electricity	1,742	3,653	20	
Total Energy Input	8,885	18,826	100	
Thermal Losses	-871	-1,826	-10	
Heat Delivered to the Buildings (condensers circuit)	8,014	16,802	90	
Heat Pumps COP	4.6	4.6		

Table 4. Heating and Cooling System of the New Terminal Building: Energy Balance in Cooling Mode

	Power kW	Energy MWh
Cooling Energy Delivered to the Building (evaporators circuit)	7,143	9,643
Electricity	1,587	2,143
Thermal Losses	-794	-1,071
Condenser Circuit	7,937	10,715
Seawater	-7,937	-10,715
COP	5.0	5.0

Table 5. Load Factors of the Geothermal System, The Seawater System and the Heat Pumps

	Geothermal	Seawater	Heat Pumps
Heating	0.47	0.09	0.24
Cooling	-	0.15	0.15
Total	0.47	0.24	0.39

Table 6. Geothermal & Seawater Heating and Cooling System of the New Terminal Building: Capital Costs

	Amount	Cost Euros
Geothermal Energy Network		
Production Well	800 m depth, 8 in.	296,000
Piping and Fittings	2,000 m	180,000
Pumps and Inverters	1 submersible 70 hp	17,500
Miscellaneous *	10%	49,350
Total Without Reinjection		**542,850**
Reinjection Well	800 m depth, 8 in.	296,000
Piping and Fittings	1,000 m	90,000
Heat Exchangers	Ti Plate 100 m^2	45,000
Miscellaneous *	10%	43,100
Total With Reinjection		**1,016,950**
Seawater Network		
Seawater Wells	10 - 20 m each, 1,200 m depth total	162,000
Piping and Fittings	2,000 m	540,000
Pumps and Inverters	1 per well, 100 hp total	115,000
Heat Exchangers	Ti Plate 400 m^2	180,000
Miscellaneous *	10%	99,700
Total		**1,096,700**
Heat Pumps		
Heat Pump Units	8,000 kW	1,600,000
Pumps, Inverters, Etc.	Centrifugal 150 hp	37,500
Power Supply	2,600 kW net	65,000
Civil Engineering	Engine house 400 m^2	240,000
Miscellaneous *	10%	194,250
Total		**2,136,750**
Low-Temperature Heating & Cooling System of the Building		
Fan Coils, AHUs	8,000 kW	840,000
Piping and Fittings	40 km	800,000
Pumps, Inverters, Etc.	Centrifugal 170 hp	42,500
BEMS	100 units	80,000
Miscellaneous *	10%	176,250
Total		**1,938,750**

* Design study, works supervision and administration expenses

Table 7. Geothermal & Seawater Heating and Cooling System of the New Terminal Building: Energy Costs

(Euros)	Without Amortization	External Networks & Heat Pumps		Overall, Including Indoor System	
Reinjection		YES	NO	YES	NO
Investment	-	4,250,400	3,776,300	6,189,150	5,715,050
Operation & Maintenance	395,750	395,750	395,750	395,750	395,750
Amortization	-	341,063	303,020	496,633	458,590
Energy Costs $ per kWh	0.0150	0.0279	0.0264	0.0337	0.0323

The second includes only the amortization of the external system delivering heat or cool to the building, including the heat pumps and excluding fan-coils, air handling units (AHUs), air ducts, piping, etc. These values of 0.0264 $/kWh (without reinjection) and 0.0279 $/kWh (with reinjection) are competitive to natural gas and diesel sale prices prevailing in Greece. The corresponding energy costs for about a 10 MW_t district heating system of more than 1,000 dwellings in Traianoupolis near Alexandroupolis in North Greece utilising geothermal fluids of 53 - 92ºC temperature, have been estimated as 0.024 US $/kWh by Karytsas, et al. (2003).

The third value of 0.0150 $/kWh, which corresponds to the running costs of the system comprising mainly of the electricity consumption of the heat pumps, is approximately 40% lower than the sale price of natural gas and diesel oil in Greece.

CONCLUSIONS

A combined geothermal and seawater system coupled with water-source heat pumps can effectively provide heating and cooling to the new terminal building of the airport of Thessaloniki "Makedonia." The system is characterised by high energy efficiency and competitive costs.

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THERMAL MANIFESTATIONS IN NICARAGUA

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INTRODUCTION

In the Cordillera de los Marrabios, an active Quaternary volcanic range in western Nicaragua (Figure 1), several geothermal areas have been identified and characterized. In addition, field studies and scientific investigations have shown that significant thermal anomalies and permeable formations exist in the Nicaraguan Depression, a large NW-SE trending graben in the central part of the country. Exploration surveys, including drilling, have confirmed the presence of several thermal aquifers at different depths.

A number of articles, the latest in the July-August 2003 issue of the *Geothermal Resources Council Bulletin*, discuss Nicaragua's high-enthalpy geothermal fields that produce, or have the potential to produce, fluids appropriate for electricity generation. Here, we describe some of the lower temperature areas. They are associated with surface manifestations (i.e., hot springs, mud pots, gas discharges, zone of rock alteration, etc.) so abundant in the Nicaraguan Depression.

MASAYA-GRANADA-NANDAIME

The center of the Masaya-Granada-Nandaime area is in the southern portion of the Nicaraguan Depression, near the city of Diriomo, 45 km southeast of Managua (Figures 1 and 2). It is an active volcanic area that presents important surface manifestations and includes the Masaya Calera, the Apoyo Caldera (Laguna de Apoyo), and the Mombacho Volcano. Abundant hot springs and furmaroles are found north and south of the volcano; some are discussed below.

LA CALERA

Located north of the Mombacho Valcano, the La Calera hot springs produces 34ºC, Ca-SO_4 type waters that have minor amounts of chlorides. Several dispersed furmaroles are also found in this area. The springs flow at a rate greater than 1000 L/min. The waters are near saturation with respect to amorphous silica. Their sulfate content (470 ppm) suggest that the La Calera waters have mixed with condensed steam. The spring waters, however, are not acid. They have a pH of 7.6.

RIO MANARES RIVER - MELCATEPE

The Rio Manares-Mecatepe area is southeast of the Mombacho Volcano (Figure 2). There are several thermal springs in a zone with several swamps and small lakes. The springs are fed by the Manares River flowing from the northeast. Temperature of the waters varies between 38 and 48ºC.

The north-western shores of the Laguna Blanca in this area, shows some weak thermal springs. The temperature of the water is 36 - 38ºC. North of that lake, the Agnuas Calientes springs have temperatures of 38 to 40ºC. However, at the bottom of this swampy zone, 60ºC have been measured. Calcium is the main cation, and SO_4 and HCO_3 are the main anions in these thermal waters. There is some evidence that the waters mix with gases ascending from depth.

LAGUNA APOYO

Fluids from the Apoyo Caldera are discharging along a 4-km long track on the west and south-western banks of the Laguna Apoyo (Figure 2). The sodium-chloride waters have salinities of about 4000 ppm and temperatures of up to 97ºC. The observed correlation between chloride concentrations and temperatures, indicate that the fluids are a mixture of hot Na-Cl and cold diluted waters. Geothermometric data suggest that the hot waters originate at depth at a temperature of at least 220ºC.

The waters in the Laguna Apoyo are, in fact, equivalent to the thermal waters that surge along the banks of the lake, but they have been cooled and diluted to about half their original chloride concentrations. Probably, there is thermal upwelling at the bottom of the lake.

TIPITAPA

The Tipitapa area (Figure 3) is on the south-western shores of Lake Managua (also known as Lake Xolotlán), in the central part of the Nicaraguan Depression. It presents several thermal manifestations and some wells have encountered hot waters. A flow of andesitic lavas 12 km southwest of Tipitapa is the closest volcanic feature; the Masaya and Apoyo Calderas are 25-30 km to the southwest. Therefore, the origin of these manifestations is thought to be related to the NW-SE trending fractures of the Cofradía system.

At a place called Baños Termales ("thermal baths") close to the town of Tipitapa, a resort has been constructed. It has several hot water swimming pools and a restaurant to provide recreation as well as benefits from the waters' medicinal properties.

The Baños Termales waters have a Na-Cl-SO_4-HCO_3 composition and are relatively diluted, with approximately 285 mg/L of alkalinity (as HCO_3). The available data suggest that these 93ºC waters are stable in terms of their chemistry and temperature. They do not show evidence of mixing.

VALLE DEL RIO OBRAJE

The Obraje River valley area (Figure 3), about 10 km northwest of the Momotombo geothermal field, presents numerous thermal manifestations. Several wells show temperatures of about 40ºC. The river, at its headwaters, has a temperature of around 50ºC. It discharges into Lake Managua at an average rate of 90 L/s. In other words, some 2.84 x 10^6 m^3 of thermal, highly saline, $Na\text{-}SO_4$ type water flow into the lake every year.

SAN FRANCISCO LIBRE

On the northern banks of Lake Managua, at the San Francisco Libre area (Figure 3), there is a more than 2-km long zone of thermal manifestations (i.e., hot springs, geysers, hydrothermal alteration deposits, etc.). The temperatures of these manifestations varies between 45 and 89ºC. Along the shore of the lake, a shallow hot water table exists. It emerges at ground level; where, the rocks are fractured. Several fish kills have been observed near this area. It is quite possible, they were caused by hot fluids discharges from manifestations at the bottom of the lake.

To take advantage of the healing properties of the hot waters and muds, a Medicinal Center of Hydro and Mud Therapy has been built at San Francisco Libre with international financial support. The purpose of the center is to provide treatment to people of limited resources that suffer from illness like arthritis, migraines, rheumatism, muscular pains, obesity, scabies and allergies (Figure 2).

THERMAL SPA "AGUAS CLARAS"

The best thermal spa in Nicaragua is at "Aguas Claras." The facilities are being managed with tourism in mind. The owners have made improvements so that visitors can enjoy relaxing in the warm water baths. The spa is located at kilometer 69 on the Managua-Boaco highway (Figure 3).

The $Na\text{-}SO_4$ spring waters have a temperature of about 50ºC and a pH of 8.1. The Aguas Claras spa has six pools with natural thermal waters. A 6-in. diameter pipeline carries the spring's sulfurous waters directly to the pools by gravity flow. Besides the attraction of the hot pools, there are cold water pools, a restaurant, a bar, small ranch houses, as well as air-conditioned rooms. This make the place a required road stop when traveling between Managua, Boaco and Juigalpa.

FINAL REMARKS

Until recently, the development of Nicaragua's high-enthalpy geothermal resources for electricity generation has been the main focus of interest of the government and private sector. Lately, and because of health aspects associated with hot springs and their economic potential as tourist sites, some of the interest has shifted toward the development of a few surface manifestation areas. Some investments by government agencies and private groups have already been made, but much could be done considering the country's abundant low-temperature geothermal zones.

Figure 1. Volcanoes of the Cordillera de los Marrabios.

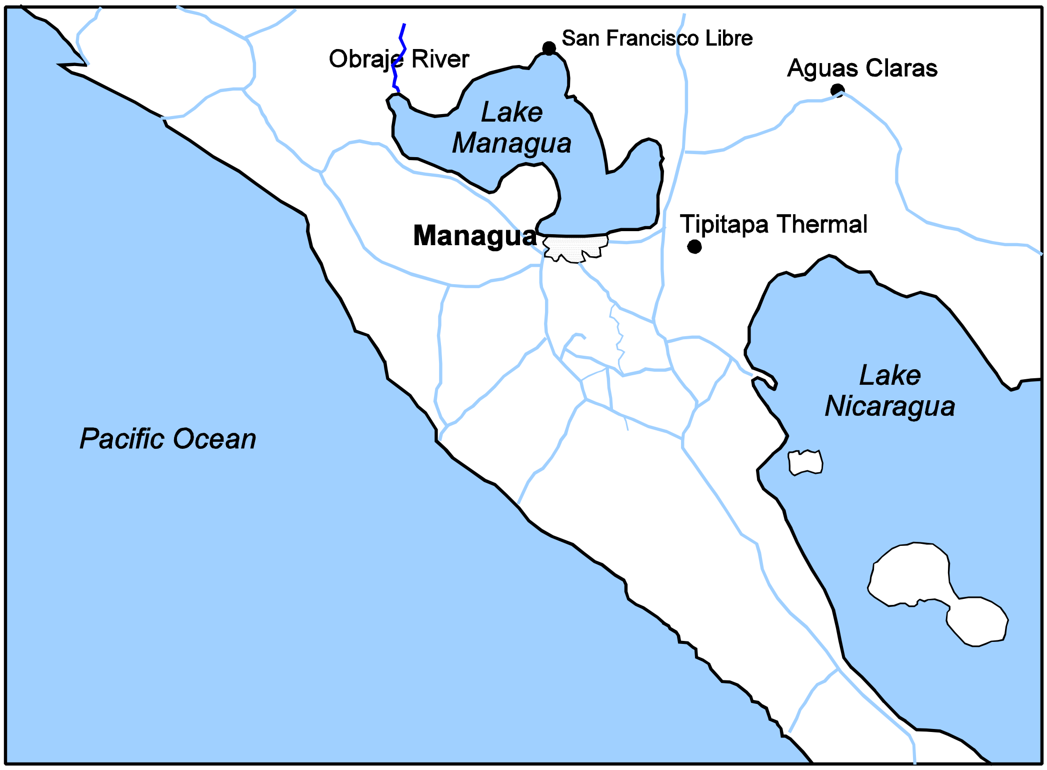

Figure 2. Details of the Masaya-Granada-Nandaime area.

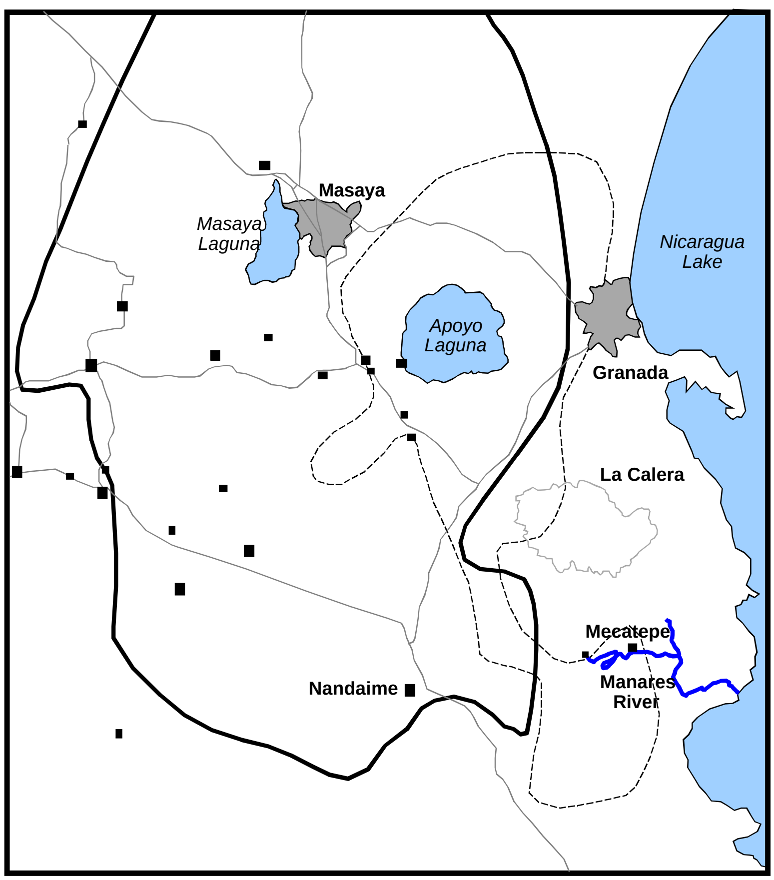

Figure 3. Location of other thermal areas mentioned in the text.

KEVIN RAFFERTY MOVES ON

Kevin Rafferty, the Associate Director of the Geo-Heat Center, resigned to try his hand at private consulting. Kevin started with the Center in 1979 while a student in the Mechanical Engineering Technology Program at Oregon Institute of Technology. Starting as a Research Assistant, he was responsible for conducting feasibility studies on geothermal projects throughout the western United States, and also assisted with research projects.

He graduate with a BSMET from OIT in 1981, and in 1983 was promoted to Research Associate. During the next 11 years, he was the senior mechanical engineer (PE) responsible for providing technical assistance to geothermal projects throughout the U.S., and training American and foreign technicians in current geothermal practices. He had extensive involvement in feasibility analysis, design, economic analysis, and operational review of existing low- and moderate-temperature geothermal systems, large tonnage heat pumps and small-scale geothermal power generators. He continued to conduct research.

In 1994, with the retirement of Gene Culver, he became the Associate Director with responsibility for oversight and management of the Center's Technical Assistance Program. The program offered technical design assistance to geothermal direct-use project developers throughout the U.S. He also became the resident expert on ground-source (geothermal) heat pumps, writing the "Geothermal Heat Pump Owners Information Survival Kit" as a key introductory document for homeowners, and with Dr. Stephen Kavanaugh of the University of Alabama, compiling an important design guide on "Ground-Source Heat Pumps" for commercial and institutional buildings, published by ASHRAE.

He was active with various ASHRAE Technical Committees, the Geothermal Resources Council, and with the National Groundwater Association. He participated in writing key chapters for various ASHRAE publications. He has presented over 50 papers at technical meetings such as GRC and ASHRAE, and provided training for engineers in the design of groundwater heat pump systems. Kevin produced key publications for the Center on aquaculture pond and greenhouse heating system designs, contributed many chapters to our 454-page "Geothermal Direct-Use Engineering and Design Guidebook," and articles to the Quarterly Bulletin. His most recent applied research project was on the testing and solutions to expansion problems with line-shaft well pumps.

He has received the GRC's "Best Paper" award on two occasions, and recently received the USDOE "Ring of Fire" award that acknowledged him "For outstanding and meritorious contribution to the expansion of geothermal direct-use applications and assistance to the geothermal community through the Geo-Heat Center." He was also noted for his love of finned-tailed Cadillacs (1957-64).