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DIRECT USE R&D ASSISTANCE

FINAL REPORT

January 1988 - September 1990

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ABSTRACT

Progress in technology transfer and R&D of geothermal direct uses in three areas, by the Geo-Heat Center, are reviewed in this report. First, technical assistance was provided to 81 projects covering the entire development process from resource information to troubleshooting problems after a project has been completed. Second, applied research was conducted on: the performance of materials and equipment used in 13 geothermal district heating systems, wellbore/aquifer interaction and worldwide utilization of downhole heat exchangers, development of a U.S. direct-use site data base, and development of information on transmission/distribution piping and analysis of uninsulated pipe for geothermal district heating systems. Third, an overview is presented on a technology transfer program which included: publishing a Guidebook, topical papers, and quarterly Bulletin, advising and referrals on projects, presentations and tours, geothermal library, and reporting activities to the Geothermal Progress Monitor.

DIRECT USE R&D ASSISTANCE

1. EXECUTIVE SUMMARY

In recent years, developers have made appreciable strides in exploiting low-temperature resources; however, the enormous potential of these resources is greatly under-utilized. Geothermal energy is the nations's third largest energy reserve, and low-temperature resources are widely distributed throughout the United States. It is essentially non-polluting and offers one alternative to the environmental problems associated with the burning of fossil fuels.

To obtain increased utilization of the large direct-heat resource base, the Geo-Heat Center provided the direct-use industry with: 1) engineering, technical and development assistance, 2) research to aid in resource and technical development problems, and 3) information and educational materials to stimulate development. The program provided strong support to state energy offices, potential and existing users, the engineering consulting community, and the public. The main results arising from the program can be summarized as follows:

- Engineering and technical assistance was provided to 81 direct-heat projects. Requests for assistance covered the entire development process, including: resource information, review of consultant's designs, development of innovative efficient designs and troubleshooting problems after a project has been completed.
- Researched the performance of materials and equipment used in 13 geothermal district heating systems, including: production facilities, central plants, distribution, customer connections, metering, and disposal.
- Conducted wellbore/aquifer interaction research and worldwide utilization of downhole heat exchangers.
- Developed a U.S. direct-heat utilization data base to characterize how and where geothermal energy is used, the extent of that use, and growth trends.
- Developed information for the district heating industry on transmission and distribution piping relative to: costs, purchase considerations, existing materials performance, new products, and analysis of the use of uninsulated piping.

- Published the Geothermal Direct Use Engineering and Design Guidebook, 401 pages, to provide engineers with state-of-the-art and comprehensive technical information for the design of direct use projects.
- Published 28 topical papers to inform and educate the public and geothermal technical community on geothermal resources and their uses, including geothermal heat pumps.
- Published 8 quarterly Bulletins which reported on the progress and development of geothermal resources for direct utilization to 1,993 subscribers in the U.S. and 51 foreign countries.
- Answered 1,371 requests for advisement, referrals, and information packets on: resources/wells, space and district heating, equipment, aquaculture, greenhouses, geothermal heat pumps, electric generation and industrial applications.
- Provided 39 presentations to lay and technical audiences and 33 group tours of geothermal facilities.
- Maintained a geothermal library of over 4200 volumes, 3000 slides, and 20 video tapes for use by the technical community and public.
- Reported on 55 Geothermal Progress Monitor activities.

Although, the above program assisted many individuals and organizations in implementing direct-heat projects and increased awareness of the tremendous potential low-temperature geothermal energy offers, there is a continuing need to stimulate the conversion to, and utilization of these resources throughout the United States.

In the coming years, to provide technological support for development of low-temperature reservoirs and user assistance, the following are recommended:

- Evaluation and confirmation of low-temperature reservoirs near hundreds of population centers that have potential for district heating and other direct utilization.
- Develop improved testing techniques of production potential and injection strategies for low-temperature reservoirs.

- Geothermal heat pump analysis and use that includes: user feedback, resource data, R & D opportunities, and integrated resource planning.
- Technology assistance for direct use that includes: project technical and development assistance, research and development activities which will reduce the cost of developing, designing and operating low-temperature geothermal projects.
- Outreach and public education to inform and educate the public on the nature and distribution of geothermal energy, its beneficial uses, and the potential cost savings of geothermal heat pump installations.

2. TECHNICAL ASSISTANCE

2.1 Background

The technical assistance program was initiated in 1978. The original program could provide up to 100-man hours per project of engineering and economic evaluation in the form of preliminary feasibility studies to public, private and corporate entities. The program concept was to provide potential geothermal developers with enough information to make informed decisions on whether or not to proceed with a project, provide consulting engineers with conceptual designs and/or provide enough information to obtain funding for development. Of course, many requests were for assistance on specific portions of a project (i.e., pumps, heat exchangers or terminal equipment) and required much less than 100 hours of effort. In 1984, the time allowed per project was reduced to 64-man hours and in late 1986, further reduced to approximately 8 hours unless special permission for a greater amount of time was granted. The final report for the contract period of 1983 through 1988 noted that 54% of the program users were public entities and the remaining 46% individuals or small businesses.

2.2 Overview

During the period covered by this report (January 1988 through September 1990), technical assistance was provided to 81 projects. Appendix A provides information on technology type, assistance type and status for each of the 81 projects. Of these, 38 or 47½% are operational. In general, the 8 hours per project guideline has been adhered to although several program users have requested assistance more than once and have been accommodated.

Special permission for additional time was granted for a feasibility study at Henley High School. This resulted in the school district obtaining a grant and converting to geothermal space and domestic water heating.

Of the 81 requests for assistance, 27 or 34% were from public institutions (i.e., schools, cities, hospitals, etc.).

Requests for assistance cover the entire development process from resource information to troubleshooting problems after a project has been completed.

Review of consultants designs and/or discussions with consultants during the design phase of a project accounts for an increasing number of requests--25% of the requests during the 33-month period. Several of these were for single residences which is particularly pleasing. Typically, these have been installed by local plumbing or heating contractors not aware of some potential problem areas. When we are contacted to solve the problem, we must recommend sometimes costly modifications that could have been incorporated in the original design much easier and cheaper.

As might be expected with the reduction of time available per project, the assistance provided has been more of a troubleshooting and advising nature than in the past. There have been few opportunities to develop innovative efficient designs except through consultants advising. Most consultants prefer to use what has worked for them in the past and are not often open to truly innovative suggestions.

The troubleshooting nature of many requests for assistance has not been without what we think are some long-term benefits. Some of the problems have resulted in presentation of papers at national and international professional meetings. Publication of "A Materials and Equipment Review of Selected U.S. Geothermal District Heating Systems" was the outcome of troubleshooting in district heating systems. This nearly 400 page document details problems and solutions in 13 geothermal district heating systems and should prevent the occurrence of similar design problems in the future.

3. RESEARCH AND DEVELOPMENT ACTIVITIES

Research and development activities that were conducted during the project period included: 1) a materials and equipment review of selected U.S. geothermal district heating systems, 2) downhole heat exchanger wellbore/aquifer interaction research and worldwide utilization, 3) development of a U.S. direct-heat utilization data base, and 4) development of

information on transmission and distribution piping and analysis of uninsulated piping for geothermal district piping. The purpose of these activities was to provide information and data for the benefit of future geothermal system designers. The following are condensed reports of results taken from the final interim reports for each project.

3.1 A Materials and Equipment Review of Selected U.S. Geothermal District Heating Systems, by Kevin D. Rafferty, 1989.

Objectives

- To investigate the performance of materials and equipment in 13 geothermal district heating systems. Specific areas of investigation included equipment type and materials of construction for: production facilities, central plants, distribution, customer connections, metering, and disposal.
- To characterize components with the highest incidence of problems, which were to be documented and reported on the solutions employed. In addition, successful performance of various components and materials were to be highlighted.

Introduction

Most of the systems included in this review have logged a minimum of 5 years operating experience. As such, they have encountered many of the problems likely to occur as a result of fluid chemistry and initial design. Table 1 presents an introduction to the systems included in report.

As indicated, these systems are located generally in the western U.S. and particularly concentrated in the states of Nevada, California, Idaho and Oregon.

All of the systems have experienced equipment problems of one sort or another. Difficulties tend to be associated with one of the following areas: production facilities, central plants, distribution, customer connections, metering and disposal. Each of these areas is discussed in detail below.

Production Facilities

There is great variation in the depth and temperature of production wells employed for these systems. Depth ranges from only 275 feet at Pagosa Springs to 3030 feet at the Capital Mall in Boise. Temperatures of 138° to 218°F are employed. With one exception (Pagosa Springs), all of the projects employ pumps to produce the geothermal fluid. Several systems previously were able to operate for some of

Table 1. Information Summary - Systems Reviewed

<u>System and Location</u>	<u>Years Operated</u>	<u>Resource Temp. °F</u>	<u>Peak Flow (gpm)</u>	<u>Feet of Pipe</u>
Oregon Institute of Technology (OIT), Klamath Falls, OR	26	192	980	7,300
Klamath Falls City, Klamath Falls, OR	5	218	1,000	14,000
Susanville DOE, Susanville, CA	5	174	700	19,000
Susanville HUD, Susanville, CA	4	155	300	10,000
San Bernardino Water District, San Bernardino, CA	5	138	3,700	35,000
Pagosa Springs, Pagosa Springs, CO	6	140	600	15,000
New Mexico State University (NMSU), Las Cruces, NM	6	142	230	N/A
Boise City, Boise, ID	5	170	4,000	37,000
Boise Warm Springs Water District (BWSWD), Boise, ID	100	176	1,600	11,300
Boise Capital Mall, Boise, ID	6	169	750	6,000
Elko County School District (ECSD), Elko, NV	2	190	290	11,300
Elko Heat Company, Elko, NV	6	170	650	15,500
Warren Property, Reno, NV	6	210	710	26,500

the year on the artesian head generated by the well. At present, however, only the two Elko, NV projects and Pagosa Springs system have this capability.

Production well pumps, in general, have been the source of much system downtime. Specifically, difficulties have centered around shaft and bearing failures in lineshaft pumps. Two types of lineshaft pumps have typically been employed in geothermal applications: enclosed lineshaft and open lineshaft. Of these, the open shaft has been more subject to failure. In this design, the shaft and bearings are lubricated by the fluid flowing up the pump column. As a result, these components are exposed to the geothermal fluid.

Shaft materials of both carbon and stainless steel have experienced failure in this application along with bearing materials of bronze and various elastomers (rubber).

The nature of the failure of these components has been attributed to a variety of modes; however, two causes are most common:

- Deterioration of the bronze bearings as a result of fluids containing hydrogen sulphide, and
- "dry" running of the top bearings (those above the static water level) at start up.

This latter effect may be particularly important in view of the relative success of water lubricated pumps in artesian wells. The Boise City, Boise Capital Mall and Elko Heat Company systems have all operated water lubricated pumps successfully and all have artesian wells. The water levels in these wells are of sufficient height to maintain the bearings in a fully lubricated state, thus avoiding "dry" running.

The most successful shaft and bearing arrangement for direct use wells has been the enclosed shaft, oil lubricated design. This system isolates the shaft and bearings from the geothermal fluid and maintains the lubrication on a constant basis. One system (Susanville) experimented with a water-lubricated enclosed lineshaft arrangement initially; however, after several failures, oil lubricated models were installed (Templeton, 1988).

Of the 11 systems reviewed which use lineshaft pumps, 8 use oil lubricated designs. The Oregon Institute of Technology (OIT) system has successfully operated such pumps in 192°F, 800 TDS fluid for as long as 15 years without major overhaul.

The pumps (bowl assemblies) themselves have proven more reliable than the lineshaft/bearing portion of the system. Few failures of the bowl assembly have been experienced. The only system to experience numerous, recent failures of the pump was New Mexico State University (NMSU). This is due to the production of large quantities of sand in that location. The OIT system experienced several failures of the bowl assembly in the early years of operation. This was reportedly due to impellers becoming detached from the shaft (Wiltrout, 1988). A change was made to keyed rather than collet connections (impellers-to-shaft) and no further problems were encountered.

Regardless of the type of lineshaft design (oil or water lubricated), the bearings in the bowl assembly are water lubricated. Of interest is the fact that leaded red bronze bearings, while the source of numerous failures (as lineshaft bearings) in open lineshaft pumps, have demonstrated good performance in bowl assembly bearings.

The most successful design for production well pumps in direct use systems includes: enclosed lineshaft, oil lubricated equipment with bowl assemblies consisting of leaded red bronze bearings, stainless steel shaft, keyed impeller connections and enameled cast iron impellers.

Submersible pumps were employed in only one of the systems reviewed (NMSU). Numerous failures occurred and such pumps are no longer used.

Other pump problems of note include headshaft seal failures in Boise and deterioration of threaded pump column connections at NMSU.

All of the original pumps in the Boise Capital Mall and Boise City system included teflon packing in the headshaft seal. Several incidents of shaft scoring occurred and the teflon was replaced with graphite impregnated material (Osgood, 1988).

The NMSU operators have experienced ongoing problems with corrosion of carbon steel components in the system. One area in which this has been of greatest concern is threaded connections on well pump columns. Several solutions have been attempted including various coatings and the use of flanged rather than threaded connections. These efforts have been partially successful; however, carbon steel components continue to fail due to corrosion (Lockwood, 1988).

As indicated in Table 2, many of the systems employ variable speed drives of one type or another to regulate well pump output. The two most common are fluid couplings and variable frequency drives. The fluid coupling is a mechanical device installed between the electric motor and pump shaft. It is a relatively simple device which can generally be serviced by the local pump contractor. The only problem experienced by users of this equipment is periodic replacement of the thrust bearings.

Variable frequency drives are more energy efficient than fluid couplings. This efficiency, however, comes at the expense of much greater sophistication. Some operators have found it useful to purchase the optional self-diagnostic packages and factory operator training available from certain manufacturers (Fisher, 1988).

Table 2. Production Facility Information Summary

<u>Facility</u>	<u>No. of Well Pumps in System</u>	<u>Pump Type</u>	<u>Lube</u>	<u>Artesian</u>	<u>Variable Speed Drive</u>	<u>Frequency of Well Pump Failures</u>	
						<u>Early</u>	<u>Recent</u>
Oregon Institute of Technology	3	ELS	Oil	No	FC	High	None
Klamath Falls City	2	ELS	Oil	No	FC	None	None
Susanville DOE	1	ELS	Oil	No	VFD	High	None
Susanville HUD	1	ELS	Oil	No	VFD	High	None
San Bernardino	2	ELS	Oil	Yes	VFD	None	None
Pagosa Springs	0	-	-	Yes	None	None	None
New Mexico State University	1	ELS	Oil	No	None	High	Mod
Boise City	3	OLS	Water	Yes	None	High	None
Boise Warm Springs Water District	2	ELS	Oil	Yes	None	Mod	Mod
Boise Capital Mall	1	OLS	Water	Yes	MSM	None	High
Elko County School District	1	Surface	-	Yes	VFD	None	None
Elko Heat Company	1	OLS	Water	Yes	None	None	None
Warren Property	2	ELS	Oil	No	None	High	None

ELS - Enclosed Lineshaft
VFD - Variable Frequency Drive
MSM - Multi-Speed Motor

OLS - Open Lineshaft
FC - Fluid Coupling
MOD - Moderate

The remaining production facility problems relate mainly to controls and system design.

The Susanville Department of Energy (DOE) system was originally designed as a pumped storage system. The well produced into a large storage tank. From here a booster pump supplied water to the system. Higher than normal energy use (the booster pump was designed for peak system flow and throttled to control its output) and level control problems resulted in the redesign to a variable-speed well pump feeding directly into the system.

The OIT system also includes a well head tank. The three production wells produce into the tank which then feeds the campus system by gravity. The tank, which is vented to atmosphere permits oxygen to enter the system. This substantially increased the corrosion rate on the largely steel distribution system. In recent years, much of the distribution system has been converted to fiberglass piping. The tank remains vented to atmosphere.

The Boise City system regulates flow to its distribution system by cycling its three production pumps. In addition, a large pneumatic valve throttles the flow in response to supply line pressure. A number of problems surfaced with this design. Initially, pressure surges were experienced as

different pumps were cycled on and off. Subsequent modifications included the installation of pressure relief valves and removal of stages from pumps to allow for closer matching of head at certain flows. Finally, the main throttling valve, designed for the system peak flow (4000 gpm), was somewhat oversized for the actual flow during initial operations. This resulted in "hunting" of the valve and system pressure variation. Control modifications which effectively reduced valve travel by 50% successfully addressed this situation (Turner, 1988).

Central Mechanical Plant

Central mechanical plants are included in five of the systems reviewed for this project. The central mechanical plant contains the main heat exchangers, circulating pumps, expansion tanks and controls for systems which employ closed-type distribution systems. Closed systems are those in which the geothermal fluid does not flow through the distribution system to the customers. A closed loop is used to deliver the heat.

The equipment in these facilities has been quite successful with respect to fluid compatibility. No corrosion related failures have been reported.

Piping within mechanical plants consists of all steel in three of the systems, all copper in one and all fiberglass (epoxy adhesive joint) in the remaining plant. Isolation heat exchangers in all cases are constructed of 316 stainless steel plates and nitrile (Buna-N) gaskets. Control valves are typically of iron body, flanged construction with stainless steel trim.

Although no corrosion related problems have occurred, operational problems have surfaced.

The Klamath Falls system had difficulty with a pressure sustaining valve on the geothermal injection line. This valve, designed to regulate the peak system flow (800 gpm), exhibited erratic operation at the low flow under which the system was operated. Controls for the valve were disconnected and a manual valve is operated to perform this function (Colahan, 1988).

Similarly, the Pagosa Springs system is operated manually; though, it is extensively instrumented with sensors and motorized valves for automatic operation. The low load imposed on the system is such that manual control resulted in more stable operation.

The Elko County School District (ECSD) system also experienced problems with very low load operation. The unstable operation which occurred under these conditions was not possible to address through manual means since the system was designed to operate unattended. As a result, a small, low-load heat exchanger was installed. Controls were modified such that the two main heat exchangers were out of the loop at low flows and supply water temperature was controlled only through the small heat exchanger (Vietti, 1988).

Distribution System

Distribution networks for these systems fall into two general designs: open and closed. As discussed in the Central Plant section, the closed-type distribution system includes central heat exchangers while the open system delivers the geothermal fluid directly to the customer. This is an important distinction since the open type design exposes the entire distribution system to the geothermal fluid.

Table 3. Distribution Systems Equipment and Materials Summary

<u>System</u>	<u>Distribution Type</u>	<u>Geothermal Pipe</u>	<u>Non-Geothermal Pipe</u>	<u>Customer Branch Lines</u>	<u>Isolation Valves</u>
OIT	Open	FG,STL	—	STL	G,BF
Klamath Falls	Closed	STL	FG, STL	STL, CU	G
Susanville DOE	Open	AC,FG,PB	—	FG,PB,STL	BF
Susanville HUD	Open	PB	—	PB	—
San Bernardino	Open	AC,DI,PVC	—	STL,CU	G
Pagosa Springs	Closed	AC	AC	STL,CU	G,BF
New Mexico State University	Closed	AC	AC	STL,CU	G,BF
Boise City	Open	AC,FG	—	STL	BF
BWSWD	Open	AC,STL	—	STL	G
Boise Capital Mall	Open	STL,AC	—	STL	BF
Elko County School District	Closed	AC,STL	STL	STL	BF
Elko Heat Company	Open	AC	—	STL,SS	G
Warren Property	Closed	STL,CU	STL,FG	CU	G

FG - Fiberglass

PB - Polybutylene

PVC - Poly Vinyl Chloride

SS - Stainless Steel (304)

STL - Steel

DI - Ductile Iron

G - Gate

AC - Asbestos Cement

CU - Copper

BF - Butterfly

Open - No central heat exchangers, geothermal fluid delivered directly to customers.

Closed - Central heat exchangers.

As indicated in Table 3, a wide variety of piping materials has been applied to geothermal district heating systems. Of these, the most common is asbestos cement. This material, frequently used in municipal water systems, is familiar to

installers, relatively low cost, designed in such a way as to eliminate the need for expansion compensation devices and, as a non-metallic, is impervious to corrosion. Unfortunately, health related concerns regarding the asbestos content of this material have, for practical purposes, eliminated it from consideration for new projects. An important task for the future will be the identification of a substitute material capable of replicating the practical and economic advantages of AC pipe.

The San Bernardino system, which has to date employed largely pre-insulated AC pipe, recently installed a new extension using pre-insulated ductile iron piping which they manufacture themselves. Another system anticipating expansion is considering a fiberglass product which incorporates threaded connections (Mickelson, 1988).

Fiberglass piping has been used successfully in several systems. At Oregon Institute of Technology, the original direct buried steel piping was replaced with fiberglass piping after about 15 years. The original field installed asphalt coating, used to protect the pipe and insulation from moisture, failed and permitted exterior corrosion of the pipe to occur. The replacement fiberglass piping employed epoxy adhesive joints and was installed largely in concrete tunnels.

The Klamath Falls City system experienced a failure of the fiberglass portion of their system (7,000 lf). Interestingly, this failure occurred not in piping exposed to the geothermal fluid, but on the closed loop portion of the system. The piping system employed a "key lock" type joining system. This connection method consisted of a bell and spigot arrangement with a flexible "key" to lock the joint together. When assembled, a groove on the male portion of the fitting aligned with a groove in the female portion of the fitting. A flexible key was inserted into these grooves to lock the connection axially. The failure involved the epoxy, used at the factory, to attach the grooved rings to each section of pipe. This epoxy failed allowing the connection to slip and ultimately leak. The piping itself experienced no failure.

Ductile iron was originally selected for replacement of the fiberglass. Consideration was also given to retaining the fiberglass piping and repairing only the piping connections.

Aside from fiberglass and AC, the two remaining types of piping in common use for main lines are steel and polybutylene.

Steel has been used successfully in both the Klamath Falls system and Boise Capital Mall system for the conveyance of geothermal fluid. In addition, it is used in the ECSD,

Klamath Falls and Warren Property systems on closed distribution loops. In both the Klamath Falls and Capital Mall systems, this piping is installed primarily in concrete tunnels and building mechanical spaces in order to permit access.

The Boise Warm Springs Water District (BWSWD) system used a wrought iron alloy pipe for approximately 50 years. This pipe was removed during the system upgrade in 1982 (Griffiths, 1988).

Polybutylene was used successfully in the Susanville HUD system. This piping, in sizes of 2 to 8 inches, has been in service for five years and has not required any repair. The entire system was assembled using thermal fusion connections.

Although the experience with various types of main line piping has been generally good, problems have occurred in some systems with such items as valves and temperature crossovers.

Two types of valves have been employed for isolation duty on these systems: gate and butterfly. Gate valves are the most common. These valves in many cases have experienced stem leakage and seizure. In addition, they tend not to be capable of 100% shutoff after several years in service (Lattin, 1988). As a result, two system operators have switched to resilient seated gate valves for new construction.

Butterfly type valves appear to be better suited to geothermal applications. The rotary motion (rather than reciprocating) is less prone to leakage. In addition, the resilient lining protects the valve body from exposure to the geothermal fluid. Most geothermal applications employ seats and "O" rings of EPDM, and shafts and discs of 316 stainless steel in butterfly valves.

Only one system has thus far experienced problems with these valves. The Boise City system employed butterfly valves at various points around the system for temperature maintenance duty. These valves, installed between the supply and waste collection piping, were designed to divert a small flow of hot water to waste in order to maintain adequate supply temperature in the distribution system. In some valves, the resilient seat distorted in such a way as to cause an increase in resistance to movement of the disk. This resistance required the operator to apply more torque to open and close the valve. As a result, the geared operator on some valves failed.

These valves were replaced with automatic temperature activated valves which were installed in concrete valve boxes. Each valve station also included a water meter for monitoring

of flows. These installations solved the problems with the direct-buried manual valves and resulted in significantly reduced system flow requirements.

Customer Connections

The customer connection is the physical link between the building heating loop and the district system. In general, this connection contains isolation valves, metering (volume or energy), temperature and pressure instrumentation, and in some cases, a heat exchanger and/or temperature limiting valve. The components included in the customer connections vary according to district system type (open or closed) and sophistication.

The simplicity of the customer connections in most systems has resulted in few if any problems for most operators.

Customer branch lines, however, have been the source of some problems. In the Susanville HUD system, field insulated polybutylene lines were used for all customers. Compression type fittings were used to join this piping. After start-up, numerous leaks developed at these connections. It was later discovered that the fittings incorporated acetal components which were not recommended for use in continuously recirculating hot water systems. These fittings were replaced with brass and stainless steel components, and the leakage was eliminated (Templeton, 1988).

Exterior corrosion of steel service lines has occurred to a large extent in both the Elko Heat Company and the Boise City systems. The operators of these systems have taken two different approaches to the problem.

At Elko, type 304 stainless steel piping with welded connections is used for branch lines for new installations. Although considerably more expensive than carbon steel, corrosion problems have been completely eliminated (Lattin, 1988).

At Boise, several solutions have been applied. These involve the use of fusion bonded epoxy coating on all ferrous components to be directly buried in the soil, high potential magnesium anodes with test stations and selected backfill material (Turner, 1988).

Metering

Most district heating systems which serve more than a few customers, must employ some means for apportioning costs. In addition, many systems install wellhead meters to track total

production rates. In the systems reviewed for this report, both the equipment employed and the results obtained vary widely.

Wellhead metering is used in eight of the systems. All of these are of the volume type, measuring total gallons supplied. As indicated in Table 4, a variety of meter types are used. Only two of the systems report difficulties with this instrumentation. The OIT systems's paddle wheel type insertion meter was installed just down stream of a number of fittings. As a result, accuracy is questionable.

Table 4. Metering Summary

<u>System</u>	<u>Wellhead Metering</u>	<u>Type</u>	<u>Experience</u>	<u>Customer Metering</u>	<u>Type</u>	<u>Experience</u>
Oregon Institute of Technology	Yes	1. IPW	Fair	None	--	--
Klamath Falls	None	--	--	Yes	Energy	Good
Susanville DOE	Yes	Orifice	Good	Yes	Energy	Poor
Susanville HUD	None	--	--	Yes	Energy	Poor
San Bernardino	Yes	1. IPW	Good	Yes	Energy	Good
Pagosa Springs	None	--	--	Yes	Energy	Fair
New Mexico State University	Yes	Turbine	Good	Yes	Volume/ Turbine	Good
Boise City	Yes	Turbine/ Magnetic	Poor/Good	Yes	Volume/ Turbine	Good
BWSWD	Yes	Turbine	Good	Yes	Volume/ Orifice	Good
Boise Capital Mall	Yes	--	--	--	--	--
Elko County School District	None	--	--	Yes	Energy	Good
Elko Heat Company	Yes	Ultrasonic	Good	Yes	Volume/ Turbine	Good
Warren Property	None	--	--	Yes	Energy	Fair

1. IPW - Insertion Paddle Wheel

The original turbine meter at the Boise City System #2 well failed after a short period of operation. The turbine wheel from this meter was discovered lodged in the piping at the system disposal point some 14,000 feet away. The turbine meter was replaced with a magnetic flow meter. In addition, piping modifications were made to accommodate a sufficient straight length of piping upstream of the meter.

The turbine meter installed at the BWSWD production facilities has been in service for approximately 35 years. In that time, it has been rebuilt at the factory on only two occasions.

Customer metering is used on all but one of the systems. Meter output is one of two types: volume or energy. In general, volume metering has been less trouble prone than energy metering.

Volume meters are considerably less complex than energy meters, and hence, their greater reliability. Volume metering provides an incentive for customers to minimize flow requirements since billing rates are generally indexed to a specific Δt . Customers who design their systems for higher Δt (lower flow rate) increase their savings and help minimize district system flow requirements. Three of the systems use turbine meters for volume metering.

One system (BWSWD) uses orifice plates for metering purposes. A constant pressure is maintained in the supply system and as a result, various orifice sizes can be used to regulate customer flow rates. Of course, the orifice plate method controls only the peak flow rate and does not address the total gallons used. This method does not provide the incentive to minimize use as discussed above.

Energy metering has been demonstrated to be a useful technique or a persistent problem depending upon the system in question.

In Susanville, most of the problems have been traced to poor installation practices. Meters were installed in orientations not recommended by the manufacturer (such as horizontal meters in vertical position). Oversizing of the flow meter portion of the instrumentation also appears to be a problem there. The results at Susanville suggest that it is equally important to consider the average and minimum flow rates in addition to the peak flow rate when sizing these meters. This is particularly true for space heating applications.

At the Warren Property system in Reno, installation practices again have given rise to problems. In this case, the meters were installed in small concrete valve boxes at the edge of each property. These valve boxes tend to accumulate water particularly during the spring and summer months. This water penetrates the electronic integrating circuits and renders the display unreadable or in some cases, the entire unit inoperable. In the drier locations of the system, however, these meters have performed well.

One experience which seems to be common to most operations using battery-operated energy meters is that the "5-year" batteries seem to consistently last only 2-3 years. As a result, some systems favor AC power sources for the meters, or have switched to the less expensive 1-year batteries.

Disposal

Most operating systems currently use some type of surface disposal, though four employ injection wells. Of note is the fact that half (4) of those currently disposing on the surface are planning for or are in the construction phase of injection wells. This movement toward injection is a result primarily of regulatory issues.

The Susanville systems have been operated for several years under temporary surface disposal permits. During this time, attempts have been made to complete an injection well which would be capable of serving both systems. One existing well was found to be incorrectly completed and two subsequent wells drilled for injection were incapable of accepting a sufficient flow. The motivation for injection is regulatory pressure from the local water quality control board.

In Klamath Falls and Boise, extensive geothermal development has resulted in measurable reservoir declines. This is particularly true in Boise where wells which previously flowed artesian no longer do so. As a result, system operators are working diligently toward injection.

In both cases, regulatory pressure again plays an important role. At Klamath Falls, a city ordinance requires that all wells currently discharging to the surface cease to do so by 1990. In Boise, no specific regulations have been enacted; however, the State Department of Water Resources is closely monitoring the situation and has hired an outside consultant to evaluate the reservoir.

The OIT system is currently in the testing phase on their 2,000 ft injection well. As indicated in Table 5, the success of the well as an injector is still in question. Initial pump tests have not been encouraging.

For those systems currently operating injection wells, few problems have been encountered.

The Capital Mall system experienced some minor pressure fluctuations on start-up. These were traced to the main throttling valve on the outlet of the injection pumps. Adjustments to the valve controller successfully addressed this problem.

The three other systems with injection wells do not require injection pumps and have had no problems (Austin, 1988).

Table 5. Disposal Data

<u>System</u>	<u>Type of Disposal</u>	<u>Repository</u>	<u>Planning Injection</u>	<u>Injection Well Under Construction</u>	<u>No. of Unsuccessful Injection Wells</u>
OIT	Surface	Lake	Yes	Yes	1 ?
Klamath Falls	Injection	--	--	--	0
Susanville DOE	Surface	Drain Ditch	Yes	Yes	3
Susanville HUD	Surface	Drain Ditch	Yes	Yes	
San Bernardino	Surface	River	No	No	0
Pagosa Springs	Surface	River	No	No	0
NMSU	Injection	--	--	--	1
Boise City	Surface	River	Yes	No	0
BWSWD	Surface	Storm/Sanit. Sewer	No	No	0
		Irrig. Canal			
Boise Capital Mall	Injection	--	--	--	0
ECSD	Surface	Irrigation	No	No	0
Elko Heat Company	Surface	Pond & River	No	No	0
Warren Property	Injection	--	--	--	0

For the systems using surface disposal, the only common problem relates to pressure sustaining valves. These valves used to maintain a minimum back pressure on the system, have failed at four sites. The failures are generally related to embrittlement of valve diaphragms. Periodic monitoring and replacement has been successful in reducing the problem. Standard Buna-N material has demonstrated the shortest life. Ethylene propylene diene monomer (EDPM) offers improved performance and fluoroelastomer superior performance.

Conclusion

The systems reviewed in the course of this work have all experienced materials and/or equipment problems to some degree. For the most part, however, these difficulties have been overcome and the systems serve as a reliable energy source for their customers.

The experience gained from the combined 182 years of operation of these systems allows one to describe conceptually, the ideal geothermal district heating system from a materials and equipment perspective. In summary, this system would consist of:

- Production well pumps of the enclosed lineshaft, oil lubricated design with bowl assemblies containing enameled cast iron impellers with keyed shaft connections, leaded red brass bearings and stainless steel shafts.

- Production pumps equipped with a variable-speed drive (preferably a multi-speed motor or variable frequency drive).
- Production pumps feeding directly into the main production line (no wellhead storage tank).
- Open-type distribution system with asbestos cement piping (or some similar substitute).
- Butterfly valves (EPDM/316 SS trim).
- Automatic temperature activated valves for crossovers if used.
- Customer branch lines of a non-metallic material.
- Volume metering for billing purposes.
- Surface disposal if regulatory authorities permit.

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3.2 Downhole Heat Exchanger Wellbore/Aquifer Interaction Research and Worldwide Utilization, by Gene Culver, 1990.

Objectives

- To perform experiments that would provide insight into wellbore/aquifer interaction and thereby provide more information on which to base downhole heat exchanger design.
- To determine how widespread the use of DHEs is.
- To inform both current users and potential users of DHEs what is being done by whom throughout the world, to open lines of communication and cooperation.

Introduction

The use of DHEs for residential and small commercial space and water heating, and other applications has several desirable features. Systems are nearly or completely passive--little or no water or steam is produced from the well reducing or eliminating disposal problems, or the need for injection wells. Initial costs of pumps and installation are eliminated or reduced along with maintenance and pumping power. Residential and small commercial systems can operate with no outside energy consumption at all--a decided advantage where electricity is costly or not available.

DHE Wellbore/Aquifer Interaction Research

During the summer of 1989, a research program was setup by the Geo-Heat Center to investigate the interaction of a well with a downhole heat exchanger and the aquifer, and possible effects on nearby wells. The work was performed by M. G. Dunstall a visiting graduate student from the University of Auckland who donated his time and by G. Culver of the Geo-Heat Center. Computer modeling was attempted for the area of interest followed by a tracer dye and temperature logging program.

Computer flow modeling studies used an established groundwater flow package to which a random walk dye dispersion routine was added. Because the package was designed to simulate flow in a uniform porous media, it was not well suited to modeling the "dual-permeability" of the Klamath Falls reservoir. Assumptions made in the model and unknown reservoir parameters limited the results of this work to helping with design of the dye tests. Estimation of the required dye injection quantity was based on the computer model and several tracer dye transport equations.

The results of the first dye test showed that a nearby pumped city district heating well has considerable influence on the flow. A rapid breakthrough of dye occurred in this test indicating that there is a good hydraulic connection between the two wells. The dye concentration was, however, quite low, considering the breakthrough time, indicating that mixing volumes are high. Large flow rate variations occurred in the city heating system pumped wells during the remainder of the test period and this interfered considerably with subsequent tests. Better result may be obtained if testing is carried out in winter since natural flow in the reservoir is higher, due to draw off in downstream wells, and the pumped wells operate in a more stable condition.

A total of four tests were run under varying conditions of pumping and DHE loading. Despite the fact that fairly large dye loadings were used, no dye was detected in a monitor well only 84 ft away, and presumably, down hydraulic gradient from the DHE well.

The downhole heat exchanger supplied 500 kW of steady heat load during a twelve-day test. More heat was obtained during the first hour of the test, as heat stored in the wellbore was extracted. Temperatures in the well declined quickly during this period, but levelled off to steady values for the remainder of the test. At the completion of the test, the well quickly regained the temperature it had before testing began. The heat load of 500 kW was achieved with a lower inlet temperature than is usual, since once-through cooling was used. If fluid was recirculated after supplying the heat load, as in a closed-loop heating systems, it would probably have a steady output of around 300 - 350 kW.

During the test period, the monitor well showed a steady drop in temperature. This occurred before, during and after periods of downhole heat exchanger use. Similar temperature drops have been recorded in other Klamath Falls wells during summer months and are not attributable to heat loading of nearby wells, but rather to reduced hydraulic gradient slowing the flow rate through the aquifer.

DHE Utilization

To determine worldwide use, 50 letters were sent to persons in 35 countries known to have geothermal resources. Responses were received from 21 countries for a 60% return rate.

DHEs were reported being used in only five countries: USA, New Zealand, Austria, Turkey and Switzerland. The Swiss use is strictly in conjunction with heat pumps. Most certainly,

DHEs are used in conjunction with heat pumps in many countries who did not respond; probably because they are not called "geothermal" as they are in Switzerland.

The most typical design noted was the "U" tube; although, several coaxial DHEs are in use or proposed.

The country with the highest number of DHEs is the U.S. with over 800 direct use DHEs and an unknown, but large number in conjunction with heat pumps.

Turkey has some impressive DHEs. One serves an ammonia/water absorption machine providing 59.2 tons of cooling capacity. Another has been tested at 6 MWt. It is currently only partially utilized for greenhouse heating.

DHE research is currently being conducted in the U.S., Italy, Peoples Republic of China, and Japan for direct use and/or power generation. Workers in Switzerland, the U.S. and presumably other countries, are continuing research for use in conjunction with heat pumps.

Considering the large number of relatively shallow low-enthalpy geothermal resources worldwide, there are surprisingly few DHEs. It is somewhat surprising that they were not independently invented in several countries since they are such simple devices.

Currently, direct use DHEs supply about 40 MW thermal worldwide. The capacity of heat pump DHEs is unknown; but, certainly fairly large since the U.S. alone is estimated to have over 250 MWt.

Conclusions

Considering the number of relatively shallow low-enthalpy geothermal resources worldwide, there are surprisingly few where downhole heat exchangers are used--especially since in many applications, they would not require even small circulating pumps and could, therefore, be utilized where electricity is not available. While it is true that a given well will produce several times as much energy when pumped as it will with a DHE and certain hydrogeologic conditions provide higher outputs, there most certainly are many potential applications. It is even somewhat surprising that DHEs were not independently invented in several localities since they are such simple devices.

It may be they are in wider spread use--but simply known by a name so different that respondents to the letters didn't recognize them as the same or similar devices--or when used in conjunction with a heat pump are not considered geothermal.

Currently, not including heat pumps, DHEs supply about 40 MWt worldwide. This is not the installed capacity. In Klamath Falls, which has about 16 MWt being utilized, one well usually supplies one house; but, most could easily supply two and many three or four homes. In Reno, wells are probably utilized to near their capacity. The situation in other parts of the world is currently unknown.

In 1988, the estimated United States total geothermal heat pump capacity was 938 MWt for space heating. It was estimated that 25% of these used vertical earth-coupled DHEs for a capacity of 235 MWt.

Worldwide, it would seem, there are many potential uses for DHEs--particularly in developing countries. There is a considerable number of developing countries with shallow low-to-moderate temperature resources that could be used for direct heat applications. In developing countries, electricity may not be readily available or costly, and pumping equipment difficult to obtain and maintain. Since some DHE applications require neither electricity nor sophisticated pumps, they seem to be a method for utilization of those resources.

3.3 Development of a U.S. Direct-Heat Utilization Data Base, by P. J. Lienau, J. W. Lund and G. Culver, 1988.

Objectives

- To compile data and report the utilization of low-temperature geothermal resources for: space and district heating, geothermal heat pumps, greenhouses, aquaculture, resorts/pools, industrial processes, and enhanced oil recovery.
- To characterize how and where geothermal energy is used, the extent of that use, the economics and growth trends. Develop a computerized data base that will facilitate periodic updates.

Introduction

The use of low-temperature (40 to 300°F) geothermal resources for direct-heat applications has increased significantly since the late 1970s. The oil price increases of the 1970s revived interest in the use of geothermal resources as alternative energy source. Beginning in 1978, DOE initiated numerous programs that also caused significant growth in the industry. The use of geothermal heat pumps contributed to the growth, starting in 1980.

In 1988, at the request of DOE, an extensive survey was conducted to determine how and where low-temperature geothermal energy was used, the extent of that use, and the growth trends. Earlier documentation was reported at the 1985 International Symposium on Geothermal Energy (Kenkermath, 1985). The main differences between data reported in 1985 and the 1988/1990 surveys by the Geo-Heat Center were: 1) many unknown projects were identified in the 1988 extensive survey, 2) geothermal heat pumps were included in the later survey, 3) resorts were estimated with very limited technical data in 1985, and 4) there was a 24% increase in annual energy utilization from 1985 to 1990, excluding geothermal heat pumps, based on the 1988/1990 survey data. The recent interest in geothermal heat pump installations, expects to generate a growth rate for that sector of about 25% per year in the 1990s.

Direct Use Data Base

This study, identified 452 sites, which included approximately 130,000 individual installations, using geothermal energy for geothermal heat pumps, space and district heating, greenhouses, aquaculture, industrial processes, and enhanced oil recovery. The results are presented in Table 6, which was updated in 1990.

The data base includes: 1) site name, 2) location, 3) application type, 4) resource temperature, 5) maximum flow, 6) thermal capacity, 7) annual energy, 8) a description of the utilization, 9) reference, and 10) date data was filed.

The computerized data base is updated on a continuous basis. Currently there are 452 site entries in the data base and the principal direct use projects, their resource temperature and annual energy use are identified in Table 7, with the largest energy users listed first. Appendix B contains a listing of all identified low-temperature resource users by state.

Recent developments include two geothermal district heating systems under construction in eastern California: the Mammoth system which recently issued an RFP (request for proposal) and Bridgeport. The San Bernardino district heating system has 35 buildings connected with more expected. The Klamath Falls district heating system which had been shut down since 1985 due to leaking pipe connections in the FRP secondary loop was put back on-line in December 1990.

Table 6. Summary of U.S. Geothermal Direct-Heat Projects, 1990

Application	No. of Sites	Thermal Capacity (x 10 ⁶ Btu/hr)	Annual Energy (x 10 ⁹ Btu/yr)
Geothermal Heat Pumps ^a	147	5,010	5,666
Space and District Heating ^b	126	560	1,476
Greenhouses	36	183	464
Aquaculture	20	224	1,180
Resorts/Pool	114	234	1,452
Industrial Processes	12	100	403
Enhanced Oil Recovery ^c	<u>4</u>	<u>1,164</u>	<u>8,156</u>
	452	7,475	18,797

a. Includes residential and commercial geothermal heat pumps totalling over 110,000 units.

b. Includes two systems reported under construction: Mammoth (118 x 10⁹ Btu/yr) and Bridgeport (14 x 10⁹ Btu/yr).

c. Enhanced oil recovery located in four states (Reed, 1983).

There were significant developments in the industrial sector with the establishment of heap leaching of gold in Nevada at Round Mountain and Florida Canyon (Trexler, 1987). Over 57 acres of geothermally heated greenhouses have been built in eight western states. The largest was Burgett Floral, Animas, New Mexico, with 16 acres. Four aquaculture projects were started in Arizona, primarily at Hyder Valley, where tilapia, catfish and bass are raised (Fitzsimmons, 1988).

At the present time, earth-coupled and groundwater heat pump systems are being installed in great numbers. Ground-water aquifers in the range of 5° to 30°C are being used in these systems in just about every state in the nation (mainly in the midwest and east). Geothermal heat pumps utilize groundwater in wells or by direct earth coupling with vertical or horizontal heat exchangers. It is estimated that almost 60,000 groundwater systems and over 50,000 closed-loop, earth-coupled systems (2/3 of these are vertical installations and 1/3 horizontal) are being used. In 1989, there were over 10,000 earth-coupled and 8,000 groundwater systems installed in the United States, and in 1990, the total is estimated to reach 25,000 (Lund, 1988 and 1989). The estimated capacity of the heat pumps installed is 1,470 Mwt and the annual energy

Table 7. Principal Direct Use Systems in the United States

Energy Use Application	Resource Temp. (°F)	Annual (10 ⁹ Btu/yr)
<u>Industrial</u>		
Enhanced Oil Recovery MT, ND, SD, WY	170 - 200	8,156
Heap Leaching		
Round Mountain Gold Corp., NV	186	197
Pegasus Gold Corp., Cary, NV	238	40
Food Drying		
Geothermal Food Processors, NV	270	86
Mushroom Growing		
Oregon Trails Mushrooms, OR	235	54
<u>Heat Pumps (Heating)</u>		
Florida, all of state	75	839
Michigan, all of state	47	355
Indiana, all of state	54	335
<u>Resorts/Pool</u>		
Payne's Fountain of Youth, WY	125	665
Hot Springs State Park, WY	135	478
Hunt's Ash Springs, NV	97	177
<u>Aquaculture</u>		
Hot Creek Hatchery, CA	61	201
Fish Breeders of Idaho, ID	90	174
Hyder Valley, AZ	105	140
<u>Greenhouses</u>		
Burgett Floral Greenhouses, NM	245	105
Utah Roses, UT (two systems)	124	77
High Country Roses, MT	151	33
<u>Space Heating</u>		
Residences (550 ea.), Klamath Falls, OR	180-200	96
Peppermill Casino, NV	127	63
Residences (300 ea.), Reno, NV	130-208	39
Merle West Medical Center, OR	191	24
<u>District Heating</u>		
Boise City, ID (two systems)	170	130
Mammoth Lakes, CA (under construction)	330	118
Warren Properties, NV	196	72
San Bernardino, CA	138	58

utilization is 5.7×10^{12} Btu. The popularity of these systems is due to the recent promotion by electric utility companies and the availability of low-temperature resources throughout the country.

Methodology

The thermal capacity of a direct heat site was computed using actual fluid temperature drops and flow rates.

Data usually available for a direct heat site are the wellhead temperature and the maximum flow rate. If the outlet temperature is unknown, the thermal capacity is estimated using an assumed outlet temperature or an estimated value of the thermal capacity per unit area (Btu/ft²), if the heated structure's floor area was known.

Average annual energy was estimated using a site specific load factor. The load factor of a direct heat system is the ratio of the average annual load to the peak load. The load factor ranges from 9% in southern California to 25% in the northern states, and as high as 50% in Alaska.

In the case of geothermal heat pump wells, it was assumed that an average residence would require a temperature drop of 10°F at 8.0 gpm to meet the thermal capacity of a typical 1800 ft² home. When calculating energy use, load factors are considered for the heating mode only, since this extracts heat from the earth; whereas, the cooling mode returns heat to the earth, and is thus, not considered a geothermal use.

The thermal capacity of aquaculture projects and swimming pools, where possible, were calculated from flows and temperature differences. Often, the entire output of a thermal spring simply flows continuously through the pool; thus, in the case of swimming pools, the annual energy was adjusted by a utilization factor of 0.8 in northern states and 0.4 in southern states, to give a more realistic value of the beneficial heat. In addition, if the pool was only used a portion of the year, this value was further adjusted.

Much of the information on heat pumps was based on information provided by the International Ground Source Heat Pump Association (Ellis, 1988 and 1989), and from various state organizations. The average load factor is 12.5%.

Growth Trends

The potential is large for the growth of the direct heat industry in the United States. Based on historical data, presented in this paper, projected growth of each direct heat technology was constructed for a base case ("business as

usual") and a high case. The high case assumes extensive resource evaluation takes place, federal incentives are instituted and economic conditions change due to conventional fuel prices increases. The cumulative growth of six direct heat technologies, excluding enhanced oil recovery, are illustrated on Figure 1.

Figure 1. Projected growth for direct heat projects excluding enhanced oil recovery.

Geothermal heat pumps providing space heating and cooling will have the largest growth because the technology has applications nationwide and they reduce energy consumption by 30% when compared to air-source heat pumps. It is estimated that by the year 2010 vertical closed-loop units will have captured 15% of the air-source heat pump market--presently estimated at 800,000 units installed per year. This amounts

to a 24-fold increase or 17.2% growth per year over 20 years for the high case. The base case amounts to approximately a 4-fold increase or 7.5% per year over 20 years.

Space and district heating using resources greater than 120°F are estimated to have a potential annual energy use of 13.6×10^{12} Btu per year by 2010, assuming a 33% market penetration. This represents a high case growth of 12% per year. The base case growth is estimated at 2% per year, corresponding to the population growth rate.

Greenhouses can utilize geothermal temperatures as low as 100°F. There are many such resources, but limited information is known about them. Assuming federal programs are re-instituted to provide location and confirmation, technical assistance, etc., it is estimated that the high case growth would be about 10% per year or 2.4×10^{12} Btu by 2010, a 6-fold increase.

Aquaculture is one of the fastest growing industries. Catfish processing increased 21% in 1989. Only a very small part of that is geothermal; although, it is well known that growth rate and food conversion are greatly enhanced with geothermal aquaculture where water temperature can be maintained relatively constant. It is estimated the high case growth will be about 11% per year and the base case of about 8% per year.

Excluding enhanced oil recover, the major industrial uses of geothermal are gold heap leaching, food dehydration and mushroom growing. Of these, gold processing seems to have the most promise of substantial increased use. It is estimated the high case growth will be about 11% and the base case about 5%.

As oil prices rise, enhanced oil recovery use would increase and, perhaps, expand to other fields that co-produce hot water and oil. Geopressured-geothermal resources and oil producing business in the Gulf Coast, Los Angeles basin, San Joaquin Valley and other basins are possible fields.

Conclusions

The results of the federal programs of the early 1980s are encouraging. For many projects, commercial exploitation is now a reality and results of resource exploration are still being utilized. Much more work in the low- and moderate-temperature resource areas is needed. The economic conditions and competitiveness of direct-heat geothermal energy development have declined in recent years, and the cost and risk of resource evaluation and confirmation is constraining accelerated growth.

As a case in point, more direct use wells and projects were developed in California than other states. The California Energy Commission has a grant and loan program for local governments designed to reduce the risk of developing geothermal resources. This successful program, which began in 1981, has resulted in 14 operational projects saving approximately 5,000 TOE/yr and planned activities in the coming year could result in increasing this to 12,000 TOE/yr.

Also, the large increase in geothermal heat pump use is due in large part to incentives from electric utility companies. These incentives benefit both the user by reducing installation and heating costs, and the utility because of the load leveling effects of groundwater heat pumps.

As dependence on the import of crude oil increases, there is a need for a serious program to develop alternative energy resources and encourage energy conservation. There is an enormous potential of using geothermal resources for district heating. However, there is a need for federal support (cost share) of evaluation and the drilling phase for the exploitation of new geothermal reservoirs, thus mainly covering the drilling risk. This approach has proven to be very efficient in the European community (CEC, 1988) and California in triggering geothermal activity.

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3.4 Piping Materials for Geothermal District Heating System, by Kevin Rafferty, 1989.

Objectives

- To provide information to the district heating industry regarding transmission and distribution piping on: relative costs, purchase considerations, existing material performance, and new products.
- To analyze the use of uninsulated piping in geothermal district heating systems.

Introduction

Transmission and distribution piping can constitute a significant cost component in a geothermal system. For district heating systems, the cost associated with the distribution network is frequently 40 - 60% of the overall capital cost of the project. For this reason, it is important to select the least cost material which is suitable for the application. The information contained in this report is intended to provide a background for the selection of piping for direct buried service in low temperature (<250°F) geothermal district heating systems.

Historically, most piping (approximately 55%) in these systems was of asbestos cement construction. This material was very successful in terms of installed cost and chemical compatibility with the fluids. Unfortunately, concern regarding the health related aspects of asbestos cement products has rendered this product unusable from a practical standpoint. As a result, it is important to identify cost effective alternative piping materials for future project construction.

Finally, several new products have recently become available. The suitability of and cost associated with these products should be evaluated for geothermal application.

This report addresses only pre-insulated and bare piping products of 2" and larger, nominal size. Included are sections on existing installed piping by type, operator/designer preference with regard to material, performance of existing installed piping, cost considerations, and insulated versus uninsulated piping.

Piping Currently in Use

The following data was taken from a recent survey (Rafferty, 1989) of 13 operating geothermal district heating systems. The total main line (>2") piping included in the systems reviewed for that report amounted to approximately 260,000 lf.

Figure 2 provides a breakdown of the total piping by type. As indicated, asbestos cement (AC) material is clearly the most widely applied product with approximately 55% of the total piping in these systems. Steel and fiberglass are a distant second to AC. Only minimum quantities of polybutylene, ductile iron and PVC are in use. Of note is the fact that there is increasing interest in ductile iron. Its relatively low cost and simple installation techniques are similar to the now unavailable AC pipe. The PVC currently in use is all uninsulated piping in use on the collection network of one of the low temperature systems.

Figure 2. Existing Installed Piping (>2") Geothermal District Heating Systems

District heating systems can be designed as "open" or "closed" distribution networks. In the open design, the geothermal fluid is delivered directly to the customer. Waste or cooled fluid is collected in the return piping for delivery to the disposal facility. Closed systems, on the other hand, employ central heat exchangers to isolate most of the district system from the geothermal fluid. Heat is delivered to the customer via a "closed loop" of clean treated water.

The characteristics of open and closed systems are quite different. For example, closed systems generally employ insulated piping for both the supply and return piping; whereas, open systems use insulation only on the supply piping. More importantly, open systems expose all of the piping to the geothermal fluids and as a result, corrosion considerations are more critical to these designs. Finally, the cost of closed systems is generally much higher than open systems. This is the result of costs associated with the central plant and the more extensive use of insulated piping.

Figure 3 provides a breakdown of total piping with respect to quantities used in open and closed distribution systems. As indicated, open systems constitute most of the piping applications.

Figure 3. Comparison of Total Amount of Pipe Used in Open and Closed Geothermal District Heating

For the piping used in the closed distribution systems, Figure 4 provides a breakdown by type. Clearly, steel piping is the choice for this application.

Figure 5 provides a similar breakdown for piping used in open systems. Again AC pipe has obviously been the material of choice for applications in which the pipe must be exposed to the geothermal fluid. Asbestos cement far exceeded its closest competitor (FRP ~ 18%) for this application. The

previous popularity of AC, coupled with the fact that it is for practical purposes no longer available, underscores the need to identify a low cost alternative for this application.

Figure 4. Distribution of Piping Used in Closed Loop Geothermal Systems

Figure 5. Distribution of Pipe Used in Open Geothermal District Heating Systems

None of the geothermal district systems reviewed uses piping larger than 14". A breakdown of piping by size appears in Figure 6.

As discussed above, many of these systems employ uninsulated piping on the return (or disposal) side of the distribution system. As indicated in Figure 7, fully 27% of all distribution piping in these systems is uninsulated. The prospect for increased use of uninsulated material in future systems is discussed later in this report.

Figure 6. Size Distribution of Piping in Geothermal District Heating Systems

Figure 7. Comparison of Relative Amounts of Insulated and Uninsulated Pipe in Geothermal District Heating Systems.

Designer/Operator Preference

An important consideration in the selection of any piece of equipment is the opinion of those who have operating experience with it. Toward that end, a survey was taken of the individuals involved with the design and operation of several geothermal district heating systems.

Respondents were asked to provide preferences for pre-insulated and uninsulated piping based upon normal project limitations of time, budget and contractor skill levels.

Of the 21 survey sheets sent out, 16 were returned for a 76% response. Although this is a small number, it nevertheless represents a majority of geothermal system operators and designers given the fact that only 18 such systems are in operation in the U.S. All of the respondents are either full-time operators of existing geothermal district heating systems or designers of existing systems.

The results indicate that, fiberglass piping with epoxy adhesive connections is the most popular (33.3%) with the group. Despite its lack of availability, asbestos cement remains high on the list (18.5%) as well. Surprisingly, polybutylene is nearly as popular (14.8%) as asbestos cement. At present, only 1 system, Susanville HUD, contains pre-insulated polybutylene piping in the distribution network.

Two products previously unused in geothermal applications also are highlighted: ductile iron (11.1%) and threaded FRP (14.8%). Ductile iron is currently being used in the San Bernardino Water District system for mainline extensions. Threaded FRP piping has not, to date, been used in any district system. Approximately 2,500 feet of uninsulated 6" material was installed in a transmission line to a greenhouse project in California recently (Dellinger, 1989).

It is interesting to compare the results of this survey with the current stock of installed piping. Clearly the interest demonstrated by this group of individuals is in piping other than that which they currently have in their own systems.

Figure 8 compares the current installed piping stock (in percent by type) with the results of the survey of operators and designers. There is a definite shift away from asbestos cement to fiberglass and polybutylene materials.

Figure 8. Comparison of Survey Results (Interest in Piping by Type) to Existing Stock of Piping in Service

It is important to note that the survey failed to include some piping products which may be of interest for geothermal district heating applications. Two of the newer products in this group include slip joint (gasketed) fiberglass and slip joint steel. The design of this piping reduces both the skill and magnitude of labor required to assemble the piping system.

Performance of Existing Piping (Rafferty, 1989)

Mainline piping, in general, has been one of the more reliable areas of the system for most district heating operations. Isolated problems have occurred; however, no consistent failures with any particular piping material have been identified.

Asbestos cement piping has been quite successful in geothermal district heating applications. Occasional failures have occurred; however, most of these were related to poor installation techniques (bedding). In addition, leaks at piping connections related to poor lubrication or assembly techniques have occurred on some systems.

The single largest problem associated with AC systems has been with fittings. All of the AC piping designs employ ductile iron fittings. These fittings are generally left uninsulated. As a result, exterior corrosion has been a problem in some areas. This has been most pronounced in saddle tap fittings. Corrosion of this type has generally been addressed successfully through the use of stainless steel fasteners and fusion bonded epoxy coatings on ferrous components.

Steel piping has performed well in most geothermal applications. In only one instance has significant failure occurred. The OIT distribution system, originally installed in 1963, was a field insulated, direct buried design. After a period of approximately 10 years, the vapor barrier (asphalt impregnated fabric) deteriorated to the extent that groundwater was able to come into contact with the exterior of the pipe. This resulted in numerous failures due to external corrosion. Although portions of this piping remain, the system has been largely rebuilt with epoxy adhesive joint, pre-insulated fiberglass piping installed in concrete tunnels.

The remaining installations, in which steel piping is used, all employ newer pre-insulated products. This material has provided trouble-free service in all instances.

Fiberglass piping used in most geothermal applications has been of the epoxy resin, adhesive joint variety. One system employed a mechanical joint (key-lock) product. It was the mechanical joint system which experienced the most difficulty.

Much of the Klamath Falls City system's closed distribution network was constructed of a key-lock type mechanical joint fiberglass product. After the first year of operation, a number of leaks began to appear in the system. These leaks occurred exclusively at the mechanical connections and no failures were noted in the piping itself. The nature of the failure was related to a component in the connection which was epoxied onto each length of pipe at the factory. The epoxy used to attach a grooved lock ring to the pipe was either improperly prepared or was not suitable for the temperature of the application. This epoxy failed allowing the lock ring to slip (axially) on the pipe and result in leaks.

Initially, an attempt was made to repair these leaks; however, the frequency of occurrence quickly resulted in the necessity to shut the system down. All of the fiberglass pipe will be replaced.

The Klamath Falls system experience should not be considered an indictment of fiberglass material in general. Numerous applications of fiberglass piping have been successful in geothermal applications. Three major district heating systems employ substantial quantities of epoxy adhesive type fiberglass piping. No failures of piping have been reported in any of these systems.

Pre-insulated polybutylene (PVC jacket) piping was employed for main distribution lines in one of the systems reviewed. The entire distribution system was constructed of this material with butt fusion joining used throughout. This system has been in operation for approximately 6 years and no problems with the piping have been reported. Some difficulties were experienced at installation. Due to the flexible nature of the material, bending stress tended to be concentrated at locations where the jacketing and insulation were removed (at fittings). Special handling was required during installation to prevent kinking the pipe at these locations.

Until recently, ductile iron piping has not been used in geothermal systems, although fittings of this material have been extensively used in conjunction with asbestos cement pipe. The operators of the San Bernardino system have recently installed several thousand feet of ductile iron in their system. This pipe is internally lined with coal tar epoxy (distribution temperatures on the order of 130°F). Ductile iron was chosen primarily on the basis of economics and ease of installation in comparison to the previously used asbestos cement (Fisher, 1989).

PVC and CPVC have seen only limited use in district systems. In the few installations where these materials were installed, solvent weld type joining practices were employed. Both systems in which the pipe was used have experienced multiple joint failures. In one situation, this was likely the result of insufficient allowance for expansion. In the second case, the cause of failure is less clear. If PVC or CPVC materials are to be used for district installations, expansion allowances should be given careful consideration. In the case of PVC, gasketed pressure pipe may be an alternative.

Piping Cost

The cost of piping for a district heating project is influenced by a host of factors, including:

- Material type
- Size
- Joining method
- Purchase quantity
- Vendor
- Number of fittings
- Routing
- Existing utilities
- Funding source
- Temperature/pressure requirements
- Direct buried or tunnel installation

As a result, it is difficult to provide meaningful price information in a general report such as this. However, cost is an important factor and frequently the most important factor in material selection. To address this issue, data were drawn from a number of sources to develop the relative costs appearing in Figures 8 and 9. These sources (References 1-5) included recent project cost data, vendor quotes, and values from various construction cost estimating manuals. In the case of both figures, the relative costs are indexed to 6" asbestos cement pressure pipe which is currently the most common material found in U.S. geothermal district heating systems.

Fourteen different piping types are included in the cost data appearing in Figure 9. These include:

- AC - Asbestos cement pressure pipe, class 150
- DI - Cement lined ductile iron pipe, Tyton joint, class 50
- STL-S - Schedule 40 steel pipe with slip (gasketed) connections
- STL-W - Schedule 40 steel pipe with welded connections
- PVC-S - Schedule 40 PVC, solvent weld connections

- PVC-G - Class 160 PVC, gasketed connections
- CPVC - Schedule 40 CPVC, solvent welded connections
- PE - SDR 13.5 polyethylene, butt fusion connections
- PB - SDR 13.5 polybutylene, butt fusion connections
- FRP-M - Epoxy resin fiberglass, resin liner, keyed-mechanical joining
- FRP-EM - Epoxy resin fiberglass, resin liner, epoxy adhesive joining 150 psi/250°, military spec.
- FRP-E - Epoxy resin fiberglass, unlined, epoxy adhesive joining 150 psi/210°
- FRP-S - Epoxy resin fiberglass, resin liner, slip type gasketed joining
- FRP-T - Epoxy resin fiberglass, unlined, integral threaded connections

Figure 9. Relative Cost of Piping by Type

The cost data appearing in Figure 9 is divided into 3 sub-parts: pipe materials, installation and connection, and 15% overhead and profit.

The pipe material numbers include only values for 6-inch straight pipe. No costs have been included for fittings, valves, expansion loops or joints. The installation and connection values include costs associated with connecting the pipe for materials (lubricants, solvents, adhesives, joint insulation kits [steel pipe], etc.), and equipment (fusion machine, welder, heat blankets, etc.). Finally, a 15% construction overhead and profit adjustment is added to each material. No costs have been included for trenching, backfill and thrust blocks since these are highly site specific.

Figure 10 presents cost data (again relative to asbestos cement) for 90° elbows typical of that employed for each of the piping types. As indicated, the costs associated with fittings for many nonmetallic piping products are significantly higher than for steel and ductile iron materials.

Figure 10. Relative Cost of 90° Elbow Fitting by Type.

Uninsulated Piping

High capital costs are one reason development has lagged in the area of district heating. Much of this cost (40 to 60%) is associated with the installation of the distribution piping network. The use of uninsulated piping for a portion of the distribution offers the prospect of reducing the piping material costs by more than 50%.

Although the uninsulated piping would have much higher heat loss than insulated lines, this could be compensated for by increasing system flow rates. The additional pumping costs to maintain these rates would be offset by reduced system capital costs. Preliminary analysis indicates that it would be most beneficial to use uninsulated lines in sizes above about 6" in certain applications.

It is important before discussing the specifics of uninsulated piping to draw a clear distinction between heat loss (measured in Btu/hr lf) and temperature loss (measured in °F/lf). Heat loss from a buried pipeline is driven largely by the temperature difference between water in the pipe and the ambient air. The temperature loss which results from the heat loss is a function of the water flow in the line. As a result, for a line operating at a given temperature, the greater the flow rate the lower the temperature drop. In geothermal systems, the costs of energy is primarily related to pumping; this results in a low energy cost relative to conventional district systems and the ability to sustain higher energy losses (of the uninsulated piping) more economically.

Figure 11 illustrates the relationship of heat loss and temperature loss. The figure is based upon 6" pre-insulated (1.8" insulation, PVC jacket, FRP carrier pipe) and a 6" uninsulated pipe buried 4 feet below the ground and operating

at 170°F inlet temperature. Temperature loss per 1,000 feet is plotted against flow rate. As discussed above, the graph indicates a substantial increase in temperature loss at low flow rates.

Figure 11. Buried Pipeline Temperature Loss Versus Flow Rate.

The prospect for the use of uninsulated piping is greatest for larger sizes (>6"). This is related to the fact that in larger sizes the ratio of the exposed surface area (pipe outside surface area) compared to the volume (flow capacity) is reduced. This relationship reduces the heat lost per gallon of water passed through the line.

If the use of uninsulated piping is to be economically attractive, a high load factor (total annual flow divided by peak flow) is required. In many district systems, initial customer flow requirements amount to only a small fraction of the distribution capability. Many years are required for the system to approach full capacity. Under these conditions, the system is operated at very low load factor initially and the economics of uninsulated piping would likely not prove to be favorable.

Systems designed for an existing group of buildings or those which serve process loads are more likely candidates for the use of uninsulated piping.

Table 8 presents the results of an example of uninsulated pipe used for a specific case. The table is based on the following:

- * 6" fiberglass pipe line
- * 170° water temperature
- * 4 feet burial depth
- * soil conductivity = 10 Btu -in/h - ft² - °F

- * design velocity 5 ft/sec (450 gpm)
- * minimum flow = 15% of design (68 gpm)
- * minimum flow occurs at temperature above 60°F
- * between 0° (design temperature) and 60°F a linear reduction in flow occurs (from 450 to 68 gpm)
- * average well pump efficiency = .63
- * pumping level = 200'
- * well head pressure requirement = 40 psi
- * Electricity costs \$0.07/kwh
- * allowable temperature drop = 2°F
- * line length = 1,500'

Table 8. Uninsulated Piping Example Results

1	2	3	4	5	6	7	8
Outside air temp. °F	Hrs/yr	Flow gpm	Δt °F	Flow for 2° Δt	Excess flow gpm	Pump kw	Annual kwh
2	17	450	0.94	--	0	0	0
7	39	414	0.98	--	0	0	0
12	82	374	1.05	--	0	0	0
17	150	338	1.12	--	0	0	0
22	352	302	1.22	--	0	0	0
27	675	261	1.36	--	0	0	0
32	1132	225	1.52	--	0	0	0
37	1044	189	1.75	--	0	0	0
42	931	149	2.13	159	10	.873	813
47	826	113	2.70	153	39	3.460	2706
52	783	77	3.80	146	69	6.050	4743
57	658	68	4.12	140	72	6.300	4145
62	551	68	3.94	134	66	5.760	3173
67	468	68	3.76	128	60	5.220	2442
72	373	68	3.58	122	54	4.710	1758
77	313	68	3.40	115	47	4.130	1294
82	235	68	3.21	109	41	3.600	845
87	124	68	3.02	103	35	3.050	379
92	<u>39</u>	68	2.85	97	29	2.510	<u>98</u>
	8792						22396

22396 kwh @ .07/kwh = \$1,568/yr
 1500 lf • \$10/lf savings = \$15,000

Column 1 contains the outside temperature values. Column 2 contains the annual number of hours at each outside temperature. Column 3 provides the system flow requirement at each outdoor temperature. The temperature drop across the line for

each temperature appears in Column 4. The required flow to maintain a 2°F temperature drop appears in Column 5. Column 6 is the excess flow (above system requirements) to maintain a 2°F temperature drop. Column 7 shows the required well pump kw to provide the excess flow. Column 8 indicates the total annual kwh consumption for temperature maintenance for each outside temperature.

In this particular case, the elimination of insulation on the 1,500', 6" line would save approximately \$15,000 in capital costs. The first year cost of electricity to compensate for the lack of pipe insulation amounts to \$1,568.

Assuming the owner was financing the project at a 9% for 20 years and that electricity inflates at 7% per year, the simple payback on the insulation for the pipe is in excess of 15 years and has a net present value (20 yrs 9%) of -\$5,742.

Items Important to the Consideration of Uninsulated Piping

1. Cost of Pumping. This is influenced primarily by the overall pumping system efficiency, cost of electricity, well pumping level, well head pressure requirements, and pump capacity control (throttling valve, variable speed drive, etc.). As the unit cost of pumping increases, the attractiveness of uninsulated pipe decreases.
2. System Load Factor. The higher the load factor, the more practical uninsulated piping becomes. Higher system load factor reduces the quantity of excess water which must be pumped to maintain supply temperatures.
3. Allowable Temperature Drop. The more temperature which can be sacrificed, the greater the possibility to use uninsulated piping. Allowable temperature drop must be carefully balanced against resource temperature and customer needs. In the example, had a 3° rather than 2°F drop been acceptable, annual pumping costs for temperature maintenance would have been reduced from \$1,568 to \$369 per year for the line. A four degree drop would have eliminated excess pumping completely.
4. Proximity of Other Utilities. Close proximity to some telephone, electric or water utility lines may preclude the consideration of uninsulated lines due to temperature effects.
5. Disposal Method. It is apparent from the example that most excess flow requirements occur during the summer months. If surface disposal is employed, low surface

water flows (rivers) may influence the maximum rate of geothermal disposal based on chemical or thermal pollution.

6. Customer Contract. Allowance for lower temperature supply water during the warmer portion of the year could reduce the requirement for excess pumping for temperature maintenance.
7. Piping Type. The use of uninsulated piping would be less attractive with respect to steel and possibly ductile iron. These materials would likely require exterior protection if uninsulated. This would reduce the savings achieved through the use of uninsulated pipe.
8. Local Soil Conditions. Soils of high thermal conductivity or wet areas tend to increase heat loss from piping. These areas would reduce the potential for uninsulated piping.
9. System Water Temperature. Lower temperature systems may be better candidates for uninsulated pipe use.
10. Line Size. As discussed earlier, larger lines (>6") are more likely to yield positive results with respect to the use of uninsulated pipe.

Considerations in the Application of Various Piping Materials

Asbestos Cement

- * Regulatory restrictions
- * Epoxy lining
- * Temperature rating of gaskets
- * External protection of cast iron fittings
- * Interior lining of cast iron fittings
- * Coal tar epoxy <130°
- * Cement lining with seal coat <150°
- * Bare cement lining (w/o seal coat) <212°
- * Compatibility of cement lining w/geo fluid
- * Delivery time for unlined and bare cement lined fittings
- * Temperature rating and material used in repair fittings
- * Gaskets
- * Carbon steel fasteners (external corrosion potential)

Ductile Iron (Tyton Joint)

- * Internal coating (see asbestos cement fittings)
- * Gasket temperature compatibility
- * External protection at connections

Fiberglass

- * Connection method
- * Epoxy adhesive
- * Threaded
  - Integral
  - Non-integral
- * Mechanical
- * Slip coupling (gasketed)
- * Internal lining
- * Temperature suitability
- * Potential for formation of water vapor (flashing)
- * Fitting costs
- * Special equipment and skills (magnitude depends on connection method)
- * Factory representative at installation
- * Availability
- * Cost of joint kits (epoxy adhesive joints)

Steel

- * Potential for corrosion due to introduction of O_2 in system (from tanks, etc.)
- * Expansion compensation
- * Connection method
- * Welded
- * Mechanical
- * Slip joint (gasketed)
- * Fluid compatibility (pH, dissolved CO_2)
- * Quality of jacketing/joint connection kits (external corrosion)

Polybutylene

- * Temperature/pressure requirements (wall thickness-SDR)
- * Special equipment/skills for fusion bonding
- * Factory representative at installation
- * Fitting costs
- * Rigging techniques (lack of rigidity)
- * Availability
- * Joining method for valves, etc.

Polyethylene

- * Same as Polybutylene except for much lower temperature/pressure ratings

CPVC

- * Material and fittings costs
- * Connection method
- * Solvent weld
- * Gasketed (?)
- * Temperature rating of gaskets
- * Solvent weld joining requires careful allowance for expansion

PVC

- * Same as CPVC except for lower temperature and pressure ratings

Pre-insulated Piping in General

- * Necessity of pipe insulation
- * Jacket material
- * PVC
- * Fiberglass
- * Polyethylene
- * Other
- * Jacket thickness requirement
- * End seals
- * Rubber inserts
- * Mastic coating
- * Insulation thickness requirement
- * Cost of joint insulation kits

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4. TECHNOLOGY TRANSFER

The technology transfer program was designed to provide the general public, potential users, consulting engineers, local, state and federal agencies information on geothermal resources and their uses, including geothermal heat pumps. This information was distributed to educate the public on the nature and distribution of geothermal energy, its beneficial uses, and the potential cost savings of geothermal heat pump installation. Technical information on project designs, technology advances, new products and materials selection were

provided to potential users and designers of geothermal systems. The Geo-Heat Center acted as a clearinghouse of general and technical information on geothermal energy. This effort also acts as a catalyst for initiating direct heat projects and increased public awareness of geothermal energy.

The effort included: 1) publishing the Geothermal Direct Use Engineering and Design Guidebook, 2) publication of a quarterly Bulletin, 3) writing topical papers, 4) answering questions, advising, providing referrals and meeting with groups on direct use technology, 5) presentations at technical meetings and tours of Klamath Falls geothermal facilities, 6) maintenance of a geothermal library, and 7) reporting of project progress and development in the USDOE Geothermal Progress Monitor.

4.1 Geothermal Direct Use Engineering and Design Guidebook

The use of low-to-moderate temperature (40 to 300°F) geothermal resources for direct-heat applications increased significantly since the late 1970s. As a result of this growth, and the need for state-of-the-art information to assist designers of geothermal direct use projects, the Guidebook was published in 1989.

The Geothermal Direct Use Engineering and Design Guidebook, 401 pages, represented two years of cooperative effort by Oregon Institute of Technology, Idaho National Engineering Laboratory, University of Utah Research Institute, Battelle Pacific N.W. Laboratories, Radian Corporation and Washington State Energy Office. Its purpose is to provide engineers with comprehensive technical information for space heating and cooling of buildings, district heating, greenhouse heating, aquaculture and industrial processing using low-to-moderate temperature (40 - 300°F) geothermal resources. It covers geology, exploration, well drilling, reservoir engineering, materials selection, well pumps, piping, heat exchangers, space heating equipment, heat pumps, absorption refrigeration, applications, engineering cost analysis, regulatory codes and environmental aspects.

Since the Geothermal Guidebook's publication in April 1989, the 500 copies of the book have been distributed. A second edition is being prepared and will be available in 1991.

A "Geothermal Direct Use Directory of Services and Equipment" was prepared to supplement the Guidebook. The directory contains listings of companies that provide: 1) professional services, 2) well pumps, 3) variable speed drives, 4) plate heat exchangers, 5) piping, 6) absorption chillers, 7) geothermal heat pumps--small tonnage, and 8) geothermal heat pumps--large tonnage.

4.2 Quarterly Bulletin

The Center published eight quarterly Bulletins which informed the public, geothermal technical community, and international market on the progress and development of geothermal resources for direct uses. This periodical has 1993 subscribers in the USA and 51 foreign countries.

Articles featured included: geothermal heat pumps, downhole heat exchangers, industrial applications, greenhouses, district heating, geothermal resources, injection practices, materials and equipment, and utilization in other countries. Progress monitor activities were reported in a section titled, "Geothermal Pipeline." Articles were solicited from both domestic and international authors.

4.3 Topical Papers

Topical papers were produced to inform and educate the public and geothermal technical community on geothermal resources and their potential, status of direct use development, injection well testing and monitoring, equipment, computer programs to aid in design, and geothermal heat pumps. During the grant period, 29 topical papers were written and published in journals and conference proceedings. Appendix C lists the topical papers prepared by Geo-Heat Center staff.

4.4 Advising, Referrals and Information Dissemination

Answering telephone inquiries, questions, letters and meeting with individuals or groups was a major function of this program. In addition, information packets were distributed. In some cases, the inquiry was referred to someone more knowledgeable about a specific subject. Each request usually required 2 to 3 hours (8 hours maximum) on the average to research and respond with a telephone call or letter.

A total of 1371 requests were logged during the 33-month period. The profile of the inquiries for assistance are shown on Figure 12, which also indicates areas of most interest which included: resource/wells (23.4%), space and district heating (21.0%), equipment (10.5%), aquaculture (9.3%), greenhouses (8.3%), geothermal heat pumps (6.6%), electric generation (3.8%), and industrial (3.4%). Information packet (see Section 3.3) requests are included under the general category.

The Geo-Heat Center made available for distribution 110 publications. They are classified as topical papers (46, technical reports and books (20), and technical assistance feasibility studies (44). A "Publications Request Form" was

Figure 12. Profile of GHC requests for assistance and information.

maintained for the convenience of ordering. Included are geothermal site data base reports for the states of Alaska, Idaho, Montana, Oregon, Washington on a loan basis. Formal technical assistance feasibility reports were made available for direct heat projects in 10 western states.

4.5 Presentations and Tours

The Center provided 33 presentations for lay and technical audiences at conferences, industry organizations, and to community groups. The purpose of these talks was primarily to increase awareness of geothermal energy as a viable energy alternative. They included such topics as: resource distribution, case histories, system design, direct heat applications, developments and potential, materials and equipment, and economic considerations.

The Center had a unique opportunity to show the public and potential users examples of geothermal energy use. Tours provided the opportunity to inspect operating geothermal systems which included: a campus geothermal heating and cooling system, the city district heating system, a residential use with a downhole heat exchanger, commercial and industrial applications, including greenhouses and aquaculture. Each application is unique and use of equipment for various purposes was explained. During the period of this program, 33 groups, representing over 130 persons, utilized this service.

4.6 Geo-Heat Center Library

The Geo-Heat Center maintained a library dedicated to geothermal energy. Over 4240 items have been collected over a 17-year period. These include a collection of books, reports, resource maps, and equipment supplier catalogs. Volumes are cataloged according to title, author, subject and geographical area. The Center also maintains a library of 35 mm slides (approximately 3000) and video tapes (20) on geothermal applications throughout the world.

In addition to Geo-Heat Center staff, the library was used by the public, students and energy consultants. Volumes were also made available on a loan basis.

4.7 Geothermal Progress Monitor

The Center compiled progress and development information on geothermal projects and activities. A total of 55 items were reported in the Geo-Heat Center's monthly project progress reports to DOE. Selected items from these reports were then included in the "Geothermal Pipeline" section of the Geo-Heat Center's Quarterly Bulletin.

APPENDIX A

TECHNICAL ASSISTANCE SUMMARY

OIT Geo-Heat Center
January 1988 - September 1990 (33 months)

Key to Symbols

Technical Type: S - Space Heating & DHW   A - Aquaculture   H - Heat Pumps
                                 D - District Heating   P - Swimming Pools   E - Electric
                                 G - Greenhouses   I - Industrial   - General

Assistance Type: f - feasibility study   e - economics   p - piping
                                 l - letter report   r - resource   h - heat exchanger
                                 c - review consultant design   w - well   te - terminal equipment
                                 d - conceptual design   wp - well pump   re - referral
                                 z - troubleshoot

Status: O - Operational   UC - Under Construction   P - Proposed   T - Terminated

No.	State	Project Name and Address	Date Initiated	Tech. Type	Assist. Type	Res. Temp. (°F)	Project Status
1	UT	Monroe Hot Springs Resort Monroe	Jan. 88	S,G,P	l,c,h	170 wp,p,te	P
2	ID	Geothermal Water Park Boise	Jan. 88	P	l,c	170	T
3	OR	Merle West Medical Center Klamath Falls	Jan. 88	S	w	190	O
4	OR	Mitchell Residence Klamath Falls	Jan. 88	H	l,t	70	O
5	CA	Cal-Ore Building Fair Oaks	Jan. 88	S	r,w		T
6	ID	Magic Hot Springs Sun Valley	Jan. 88	A	l	176	P?
7	CO	Box Canyon Motel Ouray	Jan. 88	S	l,h	140	P
8	CO	City Pool Ouray	Jan. 88	P	l	125	O

9	CA	Community Center Lake Elsinore	Jan. 88	S	c,l,te	117	O
10	CA	District Heating Calistoga	Feb. 88	D	l,w	234	P
11	OR	Residence Geo. Well Klamath Falls	Feb. 88	S	w	185	O
12	OR	County Jail Klamath Falls	Feb. 88	S	w	180	O
13	CA	Ag Park Kelsyville	Feb. 88	G	e,c,l	152	O
14	OR	Dingman Residence Klamath Falls	Mar. 88	S	w	190	O
15	UT	Troy Hygo Newcastle	Apr. 88	G	e,te	224	O
16	Canada	Okanagan Comm. Futures Sunderland, B.C.	Apr. 88	G	wp		?
17	OR	Persons Residence Klamath Falls	Apr. 88	S	h	180	O
18	CA	High School Alturas	Apr. 88	S	w	170	O
19	UT	12a Greenhouse Cove Fort	May 88	G	te	345	T
20	OR	Rockford Ranch Lakeview	May 88	A	c	190	T
21	CA	Tilapia or Catfish Farm Paso Robles	May 88	A	r,c	110	T
22	CO	District Heating Pagosa Springs	June 88	S,A	c,l	140	O
23	CA	Greenhouse Project Sierra Valley	June 88	G	w,l	120	T
24	OR	Stevens Residence Haines	July 88	S	c,l	130	O
25	OR	Mini-District Heating Klamath Falls	Aug. 88	D	d,w	180	T

26	CA	10a Greenhouse Sierra County	Sept. 88	G	e,l	120	T
27	OR	Henley School Complex Klamath Falls	Sept. 88	S	f,w,te	130	O
28	CA	Modoc County Schools Alturas	Sept. 88	S	c,w,l	170	O
29	MT	Jericho Group Whitefish	Sept. 88	P	c,r	120	?
30	CA	Siskiyou County Jail Yreka	Nov. 88	S	c,te	60	O
31	MT	High Country Roses Helena	Dec. 88	G	w	151	O
32	ID	Boise Warm Springs Project Boise	Dec. 88	D	te	170	O
33	CO	Motel Alamosa	Dec. 88	S	te	110	P
34	NV	Catfish Aquaculture Jackpot	Jan. 89	A	d,w	107	O
35	MT	Spa Motel Hot Springs White Sulfur Springs	Jan. 89	S,P	d	135	O
36	OR	Brown Alcohol Plant Adrian	Jan. 89	I	c	168	T
37	HI	Hawaii Aquafarms Puma	Feb. 89	A	d,h,l		T
38	CA	Kelseyville Schools Kelseyville	Feb. 89	S	d,w,wp,e	91	P
39	CO	Aspen Greenhouse Aspen	Feb. 89	G,P	d	130	?
40	CA	40 Homes Ft. Bidwell	Feb. 89	S	e,c,l	205	UC
41	CA	Exp. Aquaculture Sierra Valley	Feb. 89	A	d,l	94	UC
42	ID	Motel Lava Hot Springs	Mar. 89	S	l,d	114	P

43	OR	Motel Government Camp	Mar. 89	S,P	d	170	P
44	CA	Pool Paso Robles	Mar. 89	P	l,d	104	T
45	NV	Tower Motel Reno	Mar. 89	S	d	130	P
46	MD	17 Duplex Units Olney	Mar. 89	H	w	55	P
47	CA	Mineral Water Company Calistoga	Mar. 89	I	wp	250	O
48	ID	District Heating Lava Hot Springs	Apr. 89	D	r	112	P
49	CO	Testing & Monitoring Ouray	May 89	D	c,l	156	O
50	WY	Hydroponic Greenhouse Thermopolis	May 89	G	h, te	130	P
51	MT	Swimming Pool Enis	May 89	P	d,h,p,c	198	T
52	CA	Heat Pump Dorris	June 89	H	c,w	54	T
53	CA	Hospital Greenville	June 89	S	p	134	O
54	OR	Old Fort Road Apartments Klamath Falls	June 89	S	d,h,l	217	UC
55	OR	Pediatric Clinic Klamath Falls	Aug. 89	S	w	98	O
56	OR	Belknap Hot Springs Belknap	Aug. 89	S	h	160	P
57	OR	Snow Melt for Flume Ouray	Sept. 89	I	d,l	94	P
58	ID	Shop Building Gooding	Sept. 89	S	l,te	130	O
59	OR	Business Building Klamath Falls	Oct. 89	S	d,h,w, wp	190	P

60	OR	Retail Building Klamath Falls	Oct. 89	S	c,l	180	P
61	CA	Indian Valley Hospital	Oct. 89	S	c,l	134	O
62	OR	Kent Residence Klamath Falls	Oct. 89	S	w,h	180	O
63	OR	Hunters Lodge Lakeview	Dec. 89	A	d,l	200	O
64	MT	Salari Residence Butte	Dec. 89	S	d	98	?
65	CO	Johnson Residence Carbondale	Jan. 90	S	l,te		?
66	CA	Aetna Springs Resort Pope Valley	Jan. 90	S,H	l	93	P
67	OR	City District Heating Klamath Falls	Jan. 90	D	c,p	210	O
68	CA	District Heating Twenty-Nine Palms	Jan. 90	D	c,w,l	140	P
69	TX	Pond Heat Loss College Station	Feb. 90	A	d,l		O
70	NV	Manzanita District Heating Reno	Feb. 90	D	d,w	190	P
71	OR	Snow Melt Klamath Falls	Feb. 90	I	l,w	130	O
72	CA	Brockway Springs Dev. Co. Kings Beach	Feb. 90	S	l,d	131	P
73	MT	Chico Hot Springs Pray	Mar. 90	S	f	113	?
74	CO	Swimming Pool Salida	Mar. 90	P	p	160	O
75	OR	MWMC Injection Well Klamath Falls	Apr. 90	S	c,w	190	O
76	CA	District Heating Mammoth	Apr. 90	D	l,c,d	330	P
77	NV	School Reno	May 90	S	c,w,h	190	UC

78	CA	College San Bernardino	July 90	S	f	137	P
79	ID	Greenhouses Garden Valley	Aug. 90	G	l,p	138	P
80	ID	Hill Residence Buhl	Sept. 90	S	d,te	160	UC
81	CA	Litchfield Correctional Susanville	Sept. 90	G	d	170	P

Appendix B
GEOTHERMAL DIRECT HEAT PROJECTS IN THE UNITED STATES

State	Site	App. Type	Res. Temp. (F)	Max. Flow (gpm)	Capacity (million Btu/h)	Annual Energy (billion Btu/y)
AK	Chena Hot Springs	S, G, P	135	222	3.3	15.5
	Manley Hot Springs	S, G, P	138	175	2.6	12.6
	Circle Hot Spring	S, G, P	140	130	2.3	11.0
	Melosi	S, P	131	130	1.3	7.2
	Bell Island	S, P	162	30	0.5	2.5
	Goddard	P	153	13	0.1	0.7
	Baranof	S, P	151	100	0.1	0.7
	Tenakee	P	109	22	0.1	0.7
	Ophir Creek	S	145	225	0.1	0.2
Total				1047	10.4	51.1
AL	All of State	HP	67	2500	13.0	11.8
AR	All of State	HP	63	7500	119.1	106.4
	Hot Springs National Park	S, P	139	250	1.2	6.9
Total				7750	120.3	113.3
AZ	Hyder Valley	A	105	4000	40.0	140.2
	Safford	A	105	1000	10.0	35.0
	Near Tuscon	A	80	800	8.0	28.0
	Hyder Valley	A	105	850	7.0	24.5
	All of State	HP	62	0	5.8	5.1
	Castle Hot Springs	P	131	340	0.5	2.5
	Buckhorn Mineral Wells	S, P	140			
	Safford	P	108			
Total				6990	71.3	235.3
CA	Hot Creek Hatchery	A	61	18850	25.6	201.7
	Pacific Aqua Farms	A	142	1700	48.5	170.0
	Mammoth Lakes (under constr.)	DH	330	1720	51.6	117.5
	Paso Robles Fish Farm	A	104	1000	10.0	70.0
	San Bernardino District Htg	DH, I	138	3700	43.8	57.6
	Aqua Farms International	A	92	1500	9.0	47.3
	Litchfield Correctional Center	DH	170	1200	21.0	46.0
	Murrieta Hot Springs Resort	P	140	300	8.3	43.6
	Arrowhead Fisheries	A	74	1570	5.5	38.5
	Warner Springs Ranch (Resort)	S, P	137	130	6.0	37.0
	Vichy Hot Springs	S	90	65	0.1	26.4
	Pan Hot Springs	P	90	0	7.3	25.5
	Ft. Bidwell (Indian Res)	S	205	1500	6.4	23.4
	Desert Hot Springs	S, P	200	350	2.3	20.0
	Calistoga Private and Commer	I, P, S	275	105	2.3	15.0
	Bridgeport (under constr.)	DH	200	644	6.4	14.1
	Nakashima Nurseries	G	120	2000	15.0	13.1
	Sycamore Hot Spring (Resort)	P	109	150	2.2	13.0
	Aqua Caliente Springs Resort	P	97	70	1.4	12.0
	Susanville District Heating	DH	170	300	5.3	11.5
	Konocti Harbor Inn	P	107	130	1.6	11.0
	Tsuji Nurseries	G	140	350	4.8	9.2
	Fountain of Youth Spa	P	137	0	1.2	8.4
	Lake Elsinore	P	120	80	1.2	8.4
	Glen Ivy Hot Springs (Resort)	P	106	165	1.2	8.0
	Town of Tecopia	P	118	0	1.0	7.0
	Kelly Hot Springs	A	200	650	0.8	6.6
	Paraiso Hot Springs (Resort)	P	115	700	10.4	6.0

App. Type Key: S = Space Heating, DH = District Heating,
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A = Aquaculture, P = Resorts/Pool.

GEOTHERMAL DIRECT HEAT PROJECTS IN THE UNITED STATES

State	Site	App. Type	Res. Temp. (°F)	Max. Flow (gpm)	Capacity (million Btu/h)	Annual Energy (billion Btu/y)
CA	Tassajara Buddhist Meditation	P	110	152	0.7	5.5
	Furnace Creek Ranch	P	89	350	0.8	4.9
	Furnace Creek Inn	P	89	350	0.8	4.9
	Avila Hot Springs	S, P	131	50	0.5	4.9
	Cedarville Elem. & High School	S	134	115	1.4	4.3
	Grover Hot Springs State Park	P	147	105	0.6	4.7
	Campbell Hot Springs	P	115	80	0.6	4.7
	Wilbur Hot Springs	P	152	30	0.6	4.7
	Harbin Hot Springs	P	120	53	0.6	4.7
	Whitmore Hot Springs	P	95	400	0.6	4.7
	Indian Springs School	S	127	300	2.0	4.5
	Esalen Institute	P	120	75	0.6	4.4
	Modoc High Sch. (under constr)	S	163	650	2.0	4.4
	California Hot Springs	P	126	50	0.7	4.3
	Keough Hot Springs	P	128	528	0.5	3.9
	Palm Springs Spa	P	106	35	0.5	3.5
	La Vide Mineral Springs	P	120	50	0.5	3.0
	Bashfords Hot Mineral Spa	P	145	0	0.4	2.8
	Orr Hot Springs	P	103	30	0.4	2.8
	White Sulphur Springs	S, P	85	39	0.4	2.7
	San Luis Bay Estates	P	106	60	0.5	2.6
	Surprise Valley Hospital	P	108	43	0.7	2.2
	LDS Church	S	128	90	0.9	2.0
	Shoshone Motel & Trailer Park	S	93	200	0.3	1.9
	Aqua Caliente County Park	P	90	0	0.3	1.8
	Drakesbad Guest Ranch	P	180	20	0.5	1.4
	Indian Valley Hospital	S	110	96	0.6	1.3
	Imperial Sea View Hot Springs	P	165	0	0.2	1.2
	Mono Hot Springs	P	107	53	0.2	1.0
	Democrat Hot Springs Resort	P	102	15	0.8	0.7
	Matilija Hot Springs	P	109	75	0.1	0.7
	San Juan Hot Springs	P	125	20	0.1	0.6
	Big Bend Preventorium	G, P	180	90	0.1	0.4
	Jacumba Hot Springs Health Spa	P	97	15	0.0	0.1
	Lake County Ag Park	G	152	400	0.3	0.0
	Rancho Farms (unused)	G	175	600		
	Twenty-Nine Palms (City of)	S, P	140			
	Hot Creek	P	200	4000		
	Reds Meadow Hot Springs	P	115	15		
	Calistoga DH (planning)	DH	223			
	Tecopia Hot Springs	S, P	108	200		
	Miracle Hot Spring	S, P	122	15		
	Arrowhead Hot Springs	S, P	190	500		
	Lake Elsinore DH (unused)	DH	134			
	Saline Valley Hot Springs	P	107			
	Modesto Memorial Hospital	S	78	905	5.0	
	Fales Hot Springs	S, P	142	300		
	Calistoga High Sch (unused)	S	200			
			Total	50083	326.0	1170.5
				=====	=====	=====
CO	Sand Dunes Hot Spring	A	118	500	13.3	81.2
	Glenwood Hot Springs Motel	P, S	130	2263	9.0	63.4
	Roaring Judy Fish Hatchery	A	65	1100	7.1	62.6
	All of State	HP	52	0	11.3	20.3
	Jones Splashland	P	106	310	2.8	19.0
	Pagosa Springs District Htg.	DH	140	800	7.5	16.4
	The Spa Motel	S, P	123	220	2.7	14.1
	Waunita Hot Springs Ranch	S, G, P	175	100	2.5	13.0
	Pagosa Springs Private Wells	S	120	675	5.0	13.0
	Steamboat Springs Health & Rec	P	104	140	1.7	11.8
	Ouray Municipal Pool	S, P	156	180	1.4	9.6
	Old Wright Well	G	160	120	1.6	7.2
	Jump Steady Resort	S, P	119	90	1.0	7.0
	Cottonwood Hot Springs	S	119	10	0.2	6.3
	Valley View Hot Springs	P	99	180	0.8	5.7
	4 UR Guest Ranch	P	135	50	0.8	5.3
	Salida Hot Springs(Poncha Spr)	S, P	160	200	0.8	4.9

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GEOTHERMAL DIRECT HEAT PROJECTS IN THE UNITED STATES

State	Site	App. Type	Res. Temp. (F)	Max. Flow (gpm)	Capacity (million Btu/h)	Annual Energy (billion Btu/y)
CO	Hot Sulphur Springs	S, P	111	60	0.7	4.9
	Indian Springs Resort	P	115	60	0.8	4.3
	Wiesbaden Motel & Health Res.	S, P	117	60	0.7	3.8
	Pinkerton Hot Springs	S, P	93	77	0.3	2.1
	Mount Princeton Hot Springs	P, DHW	132	175	0.4	1.8
	Twin Peaks Motel	S, P	110	15	0.2	1.1
	Box Canyon Motel	S, P	110	15	0.2	1.1
	Mount Princeton Area	S, P	132		0.3	0.6
	Cement Creek Ranch	P	78	70	0.1	0.4
	Health Spa	S, P	114	6	0.1	0.4
	Lope Hot Springs	P	132	20	0.1	0.4
	Dunton Hot Springs	P	107	25	0.1	0.3
	Glenwood Springs Vapor Caves	P				
	Trip Hot Springs	G, P	111			
	Ouray DH (under constr.)	DH	156	780		
	Canon City Area	S				
	Total			8301	73.5	382.0
DE	All of State	HP	57	6300	32.4	57.7
FL	All of State	HP	75	260000	1301.0	1264.9
GA	All of State	HP	67	7500	38.6	34.4
	Roosevelt Warm Springs Inst.	S, HP, P	88	800	1.1	3.4
	Total			8300	39.7	37.8
HI	Community Geothermal Tech Prog	I	347	110		
IA	All of State	HP	52	3800	36.9	65.9
ID	Fish Breeders of Idaho	A	90	6200	24.8	174.0
	Boise City Geo. Dist. Heating	DH	174	4000	29.1	66.2
	Idaho Capitol Mall	DH	169	750	28.0	63.8
	Simplot Aquaculture	A	104	800	8.4	55.2
	Warm Spgs. Water District	DH	176	1600	12.3	30.0
	Lava Hot Springs	S, P	112	1800	3.0	20.2
	Flint Greenhouses	G	112	570	9.1	19.9
	All of State	HP	102	1220	8.2	18.0
	Cal Flint Floral	G	160	490	7.5	16.4
	M&L Greenhouses	G	112	460	7.4	16.2
	Jack Ward Greenhouses	G	138	390	6.9	15.1
	Lunty Tropical Fish	A	90	400	2.0	14.0
	Warm Springs Greenhouses	G, S	180	240	6.0	13.1
	Fort Boise Veteran's Hospital	S	162	300	6.0	12.1
	Schutz's Hot Spring	S, P	176	600	3.2	10.8
	Edward's Greenhouses	G	117	265	4.9	10.7
	Bald Mountain Hot Springs	P	168	2	2.8	10.0
	Crook's Greenhouse	G	194	140	4.0	9.0
	Sligar's Thousand Springs Res.	P	200	140	1.3	7.7
	Ketchum District Heating	DH	158	1027	3.0	6.6
	Hunt Brothers Floral	G, S	117	200	3.0	6.6
	Jim's Hot Springs	P	151	60	0.8	5.3
	Heise Hot Springs	P	120	80	1.0	4.4
	Bliss Greenhouse	G, S, A	151	60	1.2	3.7
	Silver Creek Plunge	P	101	110	0.9	3.6
	Haven Lodge	P	148	50	0.5	3.5
	Donlay Ranch Hot Spring	G	130	72	1.2	3.2
	Warm Springs Resort	P	110	100	0.9	3.2
	Miracle Hot Springs	S, P	139	50	0.7	2.9
	Downette Hot Springs	P	112	80	0.6	2.5

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GEOTHERMAL DIRECT HEAT PROJECTS IN THE UNITED STATES

State	Site	App. Type	Res. Temp. (°F)	Max. Flow (gpm)	Capacity (million Btu/h)	Annual Energy (billion Btu/y)
ID	Banbury Hot Springs	S, P	131	80	0.8	2.3
	Robinson Bar	P	135	40	0.6	2.3
	Challis Hot Springs	P	127	40	0.5	2.2
	Indian Springs Natatorium	P	90	120	0.6	2.1
	Green Canyon Hot Springs	G, P	118	80	0.6	2.0
	Bear Lake Hot Springs	P	115	40	0.3	1.3
	Corral	S, G	167	31	0.6	1.2
	Bergdorf Hot Spring	S, P	113	162	0.4	1.2
	Del Rio Hot Springs	S, G	200	20	0.4	0.9
	LDS Church	S	93	80	0.4	0.9
	Riggins Hot Springs	G, S	113	50	0.4	0.8
	Express Farms	G	99	47	0.4	0.8
	Weiser Hot Springs	G, S, P	158	15	0.3	0.7
	Givens Hot Springs	P	120	650	0.2	0.5
	Stanley Dist. Htg. (proposed)	DH	140	290	0.0	0.0
	Hooper Elementary School	S	81			
	Twin Springs Resort	S, P	180			
				Total	24001	195.2
					=====	=====
						647.1
						=====
IL	All of State	HP	54	13300	159.0	283.9
IN	All of State	HP	54	50500	299.4	534.8
KS	All of State	HP	57	2500	17.3	25.8
KY	All of State	HP	59	6600	138.9	248.3
LA	All of State	HP	69	0	142.0	126.6
MA	All of State	HP	55	80	0.4	0.9
MD	All of State	HP	57	10100	73.7	131.8
MI	All of State	HP	47	44200	213.0	570.3
MN	All of State	HP	45	10700	56.7	152.0
MO	All of State	HP	57	12600	85.0	76.0
MS	All of State	HP	67	1200	6.1	5.6
MT	Enhanced Oil Recovery	I	200	9000	542.7	3803.0
	High Country Rose Greenhouses	G	151	207	8.4	33.1
	Warm Springs State Hospital	S	154	90	1.9	14.6
	Fairmont Hot Springs Resort	S, P	160	200	3.0	14.5
	Montana Rose and Foral	G	198	460	4.9	14.1
	Lolo Hot Springs	S, P	111	180	1.8	12.6
	Bozeman Hot Springs	S, P	131	977	2.0	5.8
	Broadwater Athletic Club & HS	S, P	153	100	1.4	5.6
	Chico Hot Springs	P	113	320	0.8	4.6
	Boulder Hot Springs	S, P, G	169	500	1.0	4.4
	Jackson Hot Springs Lodge	S, P	136	259	0.5	2.9
	Medicine Hot Springs	P	113	100	0.6	2.6
	Sleeping Child Hot Springs	P	113	530	0.7	2.5
	Barkell's Hot Springs	P	161	150	0.7	2.2
	New Biltmore Hot Springs	P	127	26	0.3	1.8

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GEOHERMAL DIRECT HEAT PROJECTS IN THE UNITED STATES

State	Site	App. Type	Res. Temp. (F)	Max. Flow (gpm)	Capacity (million Btu/h)	Annual Energy (billion Btu/y)
MT	Ennis Hot Springs	I	181	100	0.8	1.7
	White Sulfur Springs	S, P	136	460	0.5	1.3
	Camas Hot Springs	P	104	24	0.2	0.7
	Hillbrook Nursing Home	S, P	133	100	0.2	0.6
	Brooks Warm Springs	A	70	72000	0.0	0.0
			Total	85783	572.4	3928.6
				=====	=====	=====
NB	Northern Part of State	HP	52	3800	36.9	65.9
NC	All of State	HP	63	26500	144.7	129.3
ND	Enhanced Oil Recovery	I	170	1500	75.1	526.2
	All of State	HP	42	3800	29.7	79.2
		Total		5300	104.8	605.4
				=====	=====	=====
NJ	All of State	HP	55	3800	36.9	65.9
NM	Burgett Floral Greenhouses	G	245	250	30.0	104.5
	New Mexico State University	S, DHW	142	417	3.7	45.9
	Masson Southwest, Inc.	G	127	500	7.5	26.1
	Ojo Caliente Resort	P	115	60	0.5	2.0
	SWTDI (NMSU)	G	148	50	0.5	1.8
	Jemez Springs	S	165	0	0.6	1.3
	Beall & McCant	G	185		0.2	0.7
	J & K Growers	G	148			
	Truth or Consequences	P	113			
		Total		1277	43.0	182.3
				=====	=====	=====
NV	Round Mountain Gold Corp	I	186	3000	48.0	197.0
	Hunt's Ash Springs	P	97	9000	22.5	157.7
	Geothermal Food Processors	I	310	750	19.0	86.0
	Warren Properties	DH,DHW	212	710	33.0	72.3
	Warm Spring Resort	P	90	3240	8.0	63.0
	Peppermill Inn & Casino	S, P	132	1200	24.0	63.0
	Pegasus Gold Corp Florida Cany	I	238	400	4.6	40.0
	Reno-Moana Area (300)	S	120	0	18.0	39.4
	Walley Hot Spring Resort	S, P	160	130	4.6	27.9
	Elko District Heat	DH	170	650	9.8	21.4
	Elko County School District	DH,S,HP	190	300	7.2	15.7
	Hobo Hot Springs	A	106	100	2.0	14.4
	Warren Estates	DH	209	1000	3.6	7.9
	Moana Municipal Pool	P	127	109	2.6	7.7
	Caliente City Pool	P	175	150	3.4	7.4
	Carson Hot Springs	P	120	75	0.8	5.7
	Bowers Mansion	P	116	75	1.4	4.7
	Brockway Springs Resort	P	180	150	0.5	3.9
	All of State	HP	87	110	1.7	3.6
	Caliente Hot Springs Motel	P	115	40	0.4	2.4
	Medical Center	S	167	46	0.7	1.5
	Wabuska	A	270	1300	0.0	0.0
	Gerlach Hot Springs	P	200			
	Aqua Caliente Trailer Park	S	152	200		
	Baileys Hot Springs	P	160			
	Salem Plaza (proposed)	S,DHW	160			
	Elko Jr. High School	S	190	300		
	Steamboat Springs (Spa)	S, P	200	590		

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 A = Aquaculture, P = Resorts/Pool.

GEOTHERMAL DIRECT HEAT PROJECTS IN THE UNITED STATES

State	Site	App. Type	Res. Temp. (°F)	Max. Flow (gpm)	Capacity (million Btu/h)	Annual Energy (billion Btu/y)
(Break keys from prior page)						
NV						
				Total	23625	215.8
					=====	=====
						842.6
					=====	=====
NY	All of State	HP	47	3200	21.8	58.1
	E. Middle School & Cayuga C.C.	S, HP	125	60	2.0	4.5
				Total	3260	23.8
					=====	=====
						62.6
					=====	=====
OH	All of State	HP	53	40400	204.4	364.9
OK	Central Part of State	HP	62	280	1.4	1.0
OR	Klamath Residence (550)	S, DHE	180	0	43.6	95.5
	Oregon Trail Mushrooms	I	235	275	20.6	54.1
	All of State	HP	68	7100	30.0	52.4
	Oregon Institute of Tech.	DH	192	745	17.5	38.3
	City of Klamath Falls DH	DH	210	720	13.0	28.4
	Kah-nee-ta	P, DHW	126	450	4.5	27.6
	Merle West Medical Center	S	191	325	10.5	23.9
	Klamath County Jail	S	180	700	10.5	23.0
	Klamath Schools (7)	S, DHE	180	0	8.7	19.8
	Klamath Apartment Bldgs. (13)	S	180	0	6.5	14.2
	The Greenhouse	G	220	700	4.7	8.8
	Maywood Industries of Oregon	S	118	450	3.0	6.8
	Henley High Sch (under constr)	S, DHW	127	400	3.0	6.6
	Aq Dryers	I	200	60	3.0	6.5
	Liskey Greenhouses	G	199	500	2.7	5.9
	Belknap Hot Springs	P	160	50	0.9	5.5
	Jackson Hot Springs	S, P	111	264	0.7	4.4
	Klamath Swimming Pools (5)	P	180	0	1.1	4.3
	Breitenbush Hot Springs	S, P	212	900	1.2	3.9
	Klamath Churches (5)	S	190	0	1.7	3.9
	Klamath Co. Shops	S	118	113	1.6	3.6
	Radium Hot Springs	S, P	136	300	0.6	3.6
	YMCA	S, P	147	120	1.4	3.1
	Highway De-icing	I	190	0	0.4	2.5
	Baker Swimming Pool	P, HP	75	200	0.6	1.8
	Hot Lake RV Park	S, P	190	830	0.9	1.8
	Public Swimming Pool	P	180	20	0.8	1.8
	Hunters Hot Spring	S	202	78	0.8	1.7
	Cove Hot Spring	G	108	226	0.7	1.4
	Greenhouses	G	195	40	0.6	1.3
	Medical Hot Springs	S, P	140	100	0.5	1.1
	Austin Hot Springs	P	186	250	0.2	1.0
	Lakeview Residences	S	190	50	0.4	0.9
	Vale Residences	S	185	24	0.3	0.7
	Vale Slaughter House	S	150	20	0.3	0.7
	Jackson Greenhouses	G	111	100	0.3	0.5
	Olene Gap	S	189	300	0.1	0.1
	Langel Valley	S	147	20	0.1	0.1
	Adrian	I	168	150	0.0	0.0
	Summer Lake Hot Springs	S, A	109	20		
				Total	16600	198.0
					=====	=====
						461.5
					=====	=====
PA	All of State	HP	50	18900	109.0	194.3
SC	All of State	HP	67	17700	96.6	86.2

App. Type Key: S = Space Heating, DH = District Heating,
 HP = Heat Pump, G = Greenhouses, I = Industrial Process,
 A = Aquaculture, P = Resorts/Pools.

GEOTHERMAL DIRECT HEAT PROJECTS IN THE UNITED STATES

State	Site	App. Type	Res. Temp. (F)	Max. Flow (gpm)	Capacity (million Btu/h)	Annual Energy (billion Btu/y)
SD	Enhanced Oil Recovery	I	170	1000	47.8	334.9
	All of State	HP	47	3100	28.7	77.7
	Evan's Plunge	P	87	10340	5.2	36.2
	Philip District Heating	DK	155	300	8.4	17.8
	St. Mary's Hospital	S	108	385	5.6	11.4
	Lake Wagner Greenhouses	G	154	250	4.3	9.3
	Diamond Ring Ranch Heat./Proc.	S, I	152	170		
	Keeton Fisheries	A	154			
Total				15545	100.0	487.3
				=====	=====	=====
TN	All of State	HP	61	1300	27.6	24.7
TX	All of State	HP	67	5700	233.1	208.3
	Cotulla High School	S	109	600	9.9	13.0
	Stacy Park Pool	P	96	250	0.9	5.5
	Navarro College	G, A	126			
	Marlin Hospital	S				
Total				6550	243.9	226.8
				=====	=====	=====
UT	All of State	HP	60	5300	27.0	47.3
	Utah Roses	G	124	1200	20.4	44.6
	Como Springs Resort	P	82	540	1.1	37.8
	Utah Roses	G	190	400	10.4	32.0
	Tryo Hygro (28a. under constr)	G	230	480	12.0	30.0
	Crystal Hot Springs	P, A	140	1800	3.5	21.4
	Utah State Prison	S, DHW	178	500	7.0	15.3
	Saratoga Springs Resort	S, P	120	150	2.0	8.7
	Monroe Hot Springs	P, S, G	164	600	1.0	7.8
	Belmont Springs	P	131	3600	1.5	7.8
	Veyo Resort	P	98	120	1.0	4.2
	Pah Tempe	P, S	108	10000	0.4	2.4
	The Homestead	P	95	60	0.1	2.0
	Mountain Spa Resort	P	115	1268	0.5	1.7
Total				26018	87.9	263.0
				=====	=====	=====
VA	All of State	HP	59	6300	56.7	101.4
	Homestead Resort	S, HP, P	104	223	1.1	2.9
Total				6523	57.8	104.3
				=====	=====	=====
WA	All of State	HP	55	4400	22.6	49.9
	Sol Duc Hot Springs	P	128	50	0.5	1.2
Total				4450	23.1	51.1
				=====	=====	=====
WI	All of State	HP	46	21400	1135.2	304.2
WY	Enhanced Oil Recovery	I	200	8300	498.3	3492.1
	Hot Springs State Park	P	135	3120	54.6	382.6
	Paynes Fountain of Youth RV Pk	P	125	1220	15.2	106.5
	The Saratoga Inn	P	114	450	4.5	31.5
	Huckleberry Hot Springs	P, I	140	300	4.2	29.4
	Hobo Pool	P	118	120	3.0	21.0
	Jackson National Fish Hatchery	A	78	100	1.9	16.6
	Chief Washakie Plunge	P	111	150	2.0	13.6

App. Type Key: S = Space Heating, DK = District Heating,
 HP = Heat Pump, G = Greenhouses, I = Industrial Process,
 A = Aquaculture, P = Resorts/Pool.

GEOTHERMAL DIRECT HEAT PROJECTS IN THE UNITED STATES

State	Site	App. Type	Res. Temp. (F)	Max. Flow (gpm)	Capacity (million Btu/h)	Annual Energy (Billion Btu/y)
WY	Cody Athletic Club	P	102	250	1.5	10.5
	Bronze Boot Spa	P	102	208	1.2	8.8
	DeMaria Hot Springs	P	97	400	1.0	7.0
	Astoria Mineral Hot Springs	P	104	100	1.0	6.6
	Auburn Hot Spring	P	144	37	0.8	5.7
	Jackalope Plunge	P	86	800	0.4	2.7
	Frank Nixon Residence	P	118	35	0.3	2.1
	Steele Hot Springs	P	102	25	0.2	1.8
	Countryman Well	G, A	98	500	0.4	1.6
	Van Norman residence	S	124	0	0.0	0.6
	East Grand St. Bridge	I	47	0	0.2	
	I-80 16th St. off ramp	I	47	0	0.9	
Total				16115	591.6	4140.7
				=====	=====	=====
Z	Seven Other States	HP			8.2	10.8
Grand Total				876088	7474.2	18796.8
				=====	=====	=====

App. Type Key: S = Space Heating, DH = District Heating,
 HP = Heat Pump, G = Greenhouses, I = Industrial Process,
 A = Aquaculture, P = Resorts\ Pools.

APPENDIX C

Topical Papers Prepared

1. Culver, G. "Direct Use Reservoir Models - How We Think They Work." In Symposium on Subsurface Injection of Geothermal Fluids. Oklahoma City, OK: Underground Injection Practices Council, 1990.
2. Culver, G. "Case Histories of Vale, Oregon and Susanville, California." In Symposium on Subsurface Injection of Geothermal Fluids. Oklahoma City, OK: Underground Injection Practices Council, 1990.
3. Culver, G. "Geothermal Injection Monitoring in Klamath Falls, OR." In Symposium on Subsurface Injection of Geothermal Fluids. Oklahoma City, OK: Underground Injection Practices Council, 1990.
4. Culver, G. "Downhole Heat Exchangers." GHC Quarterly Bulletin, Vol. 11, No. 3, Klamath Falls, OR: Geo-Heat Center, 1989.
5. Lienau, P. J. DHE Operating Instructions. A computer program. Klamath Falls, OR: Geo-Heat Center, 1990.
6. Lienau, P. J. OPIPE. A computer program. Klamath Falls, OR: Geo-Heat Center, 1990.
7. Lienau, P. J. "Direct Heat." In Introduction to Geothermal Resources. Davis, CA: Geothermal Resources Council, 1990.
8. Lienau, P. J. "Geothermal Direct Heat Application Potential." In Interagency Geothermal Coordinating Council 1989 Annual Meeting. Washington, D.C.: Department of Energy, 1989.
9. Lienau, P. J. and K. Rafferty. Geothermal Heating System, Oregon Institute of Technology. Klamath Falls, OR: Geo-Heat Center, 1989.
10. Lienau, P. J. "Geothermal Greenhouse Development." GHC Quarterly Bulletin, Vol. 12, No. 3. Klamath Falls, OR: Geo-Heat Center, 1990.
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12. Lienau, P. J. and B. Lunis. "Geothermal Direct Use Engineering and Design Guidebook Available for an Expanding Market." GRC Bulletin, Vol. 18, No. 5. Davis, CA: Geothermal Resources Council, 1989.
13. Lienau, P. J. "Geo-Heat Center Programs." GRC Bulletin, Vol. 17, No. 8. Davis, CA: Geothermal Resources Council, 1988.
14. Lienau, P. J. "Direct Use Developments in the United States." GHC Quarterly Bulletin, Vol. 11, No. 1. Klamath Falls, OR: Geo-Heat Center, 1988.
15. Lund, J. W.; P. J. Lienau and G. Culver. "The Current Status of Geothermal Direct Use Development in the United States - Update: 1985 - 1990." International Symposium on Geothermal Energy, Vol. 14. Davis, CA: Geothermal Resources Council, 1990.
16. Lund, J. W. "Geothermal Agriculture in Hungary." GHC Quarterly Bulletin, Vol. 12, No. 3. Klamath Falls, OR: Geo-Heat Center, 1990.
17. Lund, J. W. "Geothermal Spas in Czechoslovakia." GHC Quarterly Bulletin, Vol. 12, No. 3. Klamath Falls, OR: Geo-Heat Center, 1990.
18. Lund, J. W. "Geothermal Heat Pumps - Trends and Comparisons." GHC Quarterly Bulletin, Vol. 12, No. 1. Klamath Falls, OR: Geo-Heat Center, 1989.
19. Lund, J. W. "Geothermal Utilization in Daghestan, USSR." GHC Quarterly Bulletin, Vol. 12, No. 1. Klamath Falls, OR: Geo-Heat Center, 1989.
20. Lund, J. W. "Unusual Direct Use Projects in Iceland." GHC Quarterly Bulletin, Vol. 11, No. 2. Klamath Falls, OR: Geo-Heat Center, 1988.
21. Lund, J. W. "Geothermal Heat Pump Utilization in the United States." GHC Quarterly Bulletin, Vol. 11, No. 1. Klamath Falls, OR: Geo-Heat Center, 1988.
22. Rafferty, K. "A Tale of Two Heat Pumps." GHC Quarterly Bulletin, Vol. 12, No. 4. Klamath Falls, OR: Geo-Heat Center, 1990.
23. Rafferty, K. "Geothermal Greenhouse Heating." GHC Quarterly Bulletin, Vol. 12, No. 3. Klamath Falls, OR: Geo-Heat Center, 1990.

24. Rafferty, K. "Piping Materials for Geothermal District Heating Systems." GHC Quarterly Bulletin, Vol. 12, No. 2. Klamath Falls, OR: Geo-Heat Center, 1990.
25. Rafferty, K. "What Works and What Doesn't - A Materials and Equipment Review of Selected Geothermal District Heating Systems." GHC Quarterly Bulletin, Vol. 11, No. 3. Klamath Falls, OR: Geo-Heat Center, 1989.
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28. Rafferty, K. "Elko, Nevada - Showcase of Geothermal District Heating." GHC Quarterly Bulletin, Vol. 11, No. 1. Klamath Falls, OR: Geo-Heat Center, 1988.
29. Rafferty, K. "Geothermal Heating Plants." In IEA District Heating, ed. O. C. Morck and T. Pederson, pp. 443-469. Copenhagen, Denmark: International Energy Agency, 1988.