DIRECT HEAT

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ABSTRACT

Potential resources and applications of earth heat in the form of geothermal energy are large. United States direct uses amount to 2,100 MWt thermal and worldwide 8,850 MWt above a reference temperature of 35^{o}C. Space and district heating are the major direct uses of geothermal energy. Equipment employed in direct use projects is of standard manufacture and includes downhole and circulation pumps, transmission and distribution pipelines, heat exchangers and convectors, heat pumps and chillers. Direct uses of earth heat discussed are space and district heating, greenhouse heating and fish farming, process and industrial applications. The economic feasibility of direct use projects is governed by site specific factors such as location of user and resource, resource quality, system load factor and load density, as well as financing. Examples are presented of district heating in Klamath Falls, and Elko. Further developments of direct uses of geothermal energy will depend on matching user needs to the resource, and improving load factors and load density.

INTRODUCTION

The technology of direct uses is in general well established. When viewed in terms of local and site specific conditions, however, this may not always appear to be the case. In many instances, there are institutional, legal, and environmental concerns that prevent the building of technically feasible direct use projects. A familiar technical solution such as fuel oil or electrical heating is often more acceptable than the less common geothermal option. Furthermore, the risk involved in buying fuel oil seems less than drilling for hot water for heating. The driving force of most direct use projects, however, is the economic advantage over alternative energy sources. In some instances, the advantages is there--in others not.

The purpose of this paper is to identify the principal elements of direct uses of geothermal energy. Local issues affecting the overall feasibility of direct use projects are not discussed, except perhaps incidentally. The paper concerns the technologies needed to bring geofluids from resource to user.

POTENTIAL

Tremendous potential exists in the United States for the development of geothermal energy. The low- and intermediate-temperature (<90 to 150^{o}C) geothermal resource base as reported in Muffler, 1978 and Reed, 1983, is estimated at 26,500 Quads. It is estimated that the wellhead thermal energy recoverable from these resources is 302 Quads.

Low-temperature geothermal resources occur in two types of geothermal systems--hydrothermal convection and conduction dominated, which are quantified in Table 1.

Table 1. Thermal Energy from Low-to-Intermediate Temperature Identified Geothermal Systems in the United States.[a]

System	Resource Temperature (°C)	No Systems	Resource[b] Base x 10^{15} Btu	Resource[c] x 10^{15} Btu
Hydrothermal-Convection	<90	1,123	190	30
	90 to 150	163	660	167
Conduction-Dominated to 3 km	<90	38	25,690	105
		1,324	26,500	302

a. Reed, 1983 and Muffler, 1978.
b. Resource base - geothermal energy in the ground.
c. Resource - energy that might be recoverable at the wellhead.

In hydrothermal-convection systems, upward circulation of water transports thermal energy to reservoirs at shallow depths or to the surface. These systems commonly occur in regions of active tectonism and above-normal heat flow, such as much of the western United States. In conduction-dominated systems, there exists high vertical temperature gradients in rocks that include aquifers of significant lateral extent. These conditions occur beneath many deep sedimentary bases throughout the United States (Reed, 1983).

The location of geothermal resources plays an important role in their applications. In the case of geothermal electric power plants, this aspect of feasibility is clear and all such plants are built at the resource site. In the case of district heating, however, this aspect of feasibility is less clear. Nevertheless, a geothermal resource within a town is more likely to be used than a distant resource. The co-location of a resource and a user becomes less important when energy costs dominate the feasibility of project. In Iceland, for example, where space heating must be used for most of the year, geothermal waters are being piped longer and longer distances.

District heating systems have received increasing attention in the United States in the past few years. An inventory identified a total of 1,277 hydrothermal sites within five miles of 373 cities in eight western states, with a combined population of about 6 - 7 million people (Allen, 1980). The total heat load of these cities (exclusive of industrial use) is estimated at 173,000 x 109^9 Btu/yr. In terms of installed thermal power this amount of energy corresponds to 15,000 MW, when assuming a load factor of 30%.

<u>Energy Use Distribution</u>

Compared with thermal energy from the combustion of conventional fossil fuels, geothermal energy resources have a much lower temperature. Temperatures of the order of 1500°C are readily attained in combustion, and this results in common working fluid and process temperatures of 500 to 1000°C. On the other hand, the highest known temperatures of workable geothermal resources are of the order of 250°C. These differences in temperature are critical inputs for evaluating how geothermal energy can best be used (Reistad, 1975).

Three main factors make direct applications have a significant potential in geothermal energy use. First, although electricity generation is technically feasible at low-to-moderate temperatures, there is a definite economic limit on the resource temperatures suitable for power generation. Secondly, the supplying of low-to-moderate temperature heating from high-grade fossil fuels results in poor thermodynamic performance. Matching geothermal resources to meet these heating requirements would result in much better use of worldwide energy resources. Thirdly, it appears that a large portion of the basic energy needs of modern industrial society is for low-to-moderate temperature heating.

The amount of direct heating that could be used to meet the basic energy requirements of an industrialized nation, and the temperatures that are required for such heating, were estimated by Reistad (1975). Although the data used are now out-of-date, the same trends in energy use distribution are likely to be exhibited by more recent information. An upper temperature limit of 250ºC was assumed for potential geothermal energy applications. All energy used in the United States below this temperature limit were estimated in 25ºC temperature ranges from 50 to 250ºC. It was found that a substantial amount of the total energy was used below 120ºC. Space heating at 50 to 75ºC application temperature was by far the largest single use, representing almost 50 percent of the total at temperatures below 250ºC. The results of Reistad (1975) are shown schematically in Figure 1, which illustrates the fractional energy use distribution with temperature (Tester, 1982). The thermal applications used to construct this figure represent 40 percent of the total energy consumption in the United States at the time. The relationship between resource and user was not considered in the Reistad (1975) study. However, it demonstrates the large potential for direct uses of geothermal energy, provided the resource and user are geographically matched.

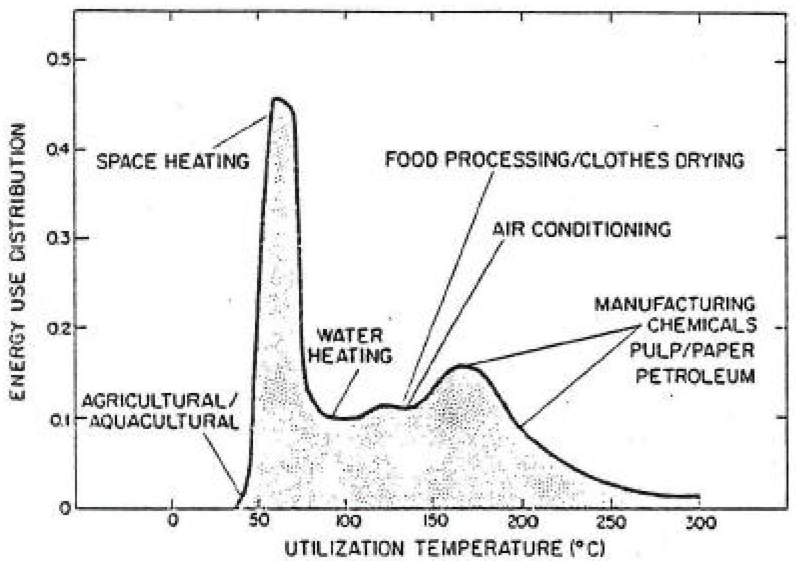


Figure 1. Energy use distribution with temperature.

SURVEY

Direct heat use of geothermal energy in the United States is recognized as one of the alternative energy resources that has proven itself technically and economically, and is commercially available. Developments include space conditioning of buildings, district heating, geothermal heat pumps, greenhouse heating, industrial processing, aquaculture, and swimming pool heating. Forty-five states have experienced significant geothermal direct use development in the last ten years. The total installed capacity is 7.2 billion Btu/hr (2,100 MWt), with an annual energy use of over 18,000 billion Btu/yr (5 million barrels of oil energy equivalent). These data are based on an extensive site data gathering effort by the Geo-Heat Center in the spring of 1988, under contract to the U.S. Department of Energy (Lienau, 1988). These energy use values are graphically displayed in Figure 2, showing the significant increase in the use of geothermal energy for direct use, especially after 1970. The annual compound growth rate for the industry from 1940 to 1970 was about 3%, from 1970 to 1985 about 13% and from 1985 to 1990 it is estimated at 6%. Of course the oil price shocks of the early 1970s and federal incentives account for the increase during the 1970 to 1985 period.

Figure 3 shows the projects on-line, separating heat pump installations from the other direct use applications. Most people think of geothermal energy as a western states resource; however, there are significant projects developing this resource for space conditioning and district heating where low temperature (40 to 70ºF) groundwater aquifers exist throughout the entire United States. Groundwater and earth coupled (vertical configuration) heat pump systems depend upon the average groundwater temperature. The recent phenomena of heat pump installations expects a growth rate of about 50 percent per year through 1990, according to the heat pump industry. Approximately 66,100 groundwater heat pump installations are presently installed.

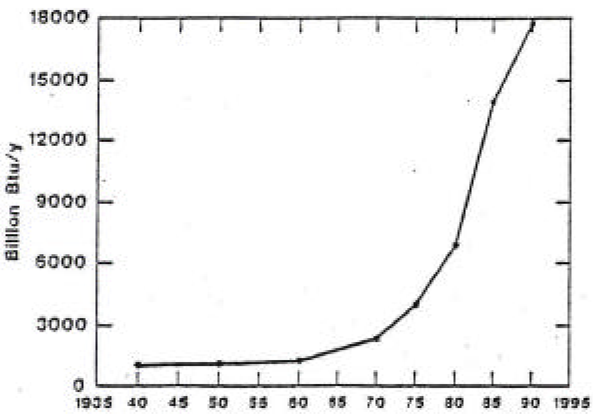


Figure 2. Direct use energy on-line from 1940 to 1990.

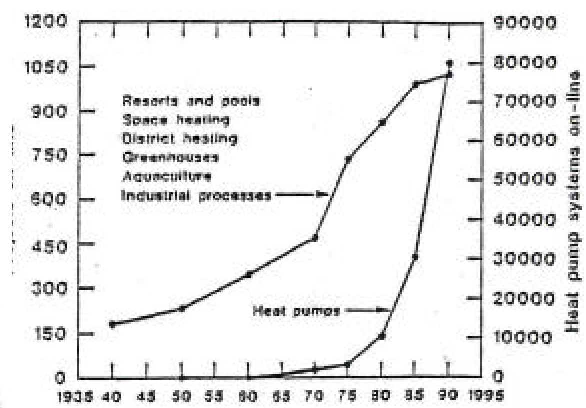


Figure 3. Direct use projects on-line between 1940 and 1990.

Table 2 gives the distribution of use according to application and Figure 4 shows the location of direct heat projects. The largest single application, the secondary oil recovery operations are in Montana, North Dakota, South Dakota and Wyoming.

Table 2. United States Geothermal Use by Application in 1990

Application	No. of Sites	Capacity (10^6 Btu/hr)	Annual Energy (10^9 Btu/yr)
Space and District Heating[a,b]	121	560.4	1,476.3
Geothermal Heat Pumps[a]	147	3,875.0	5,346.0
Greenhouses	36	163.1	396.0
Aquaculture	18	223.9	1,179.8
Resorts/Pools	114	233.5	1,452.3
Industrial	12	99.8	402.8
Enhanced Oil Recovery	4	1,163.9	8,156.2
		7,196.6	18,409.4

a. Includes Klamath Falls residential downhole heat exchanger systems (550), schools (7), apartment buildings (13), churches (4) and Reno/Moana residential downhole heat exchangers (300).

b. Two systems reported under construction, Mammoth Lakes (117 x 10^9 Btu/y) and Bridgeport (14.2 x 10^9 Btu/y). The city of Klamath Falls systems is undergoing reconstruction of the distribution piping.

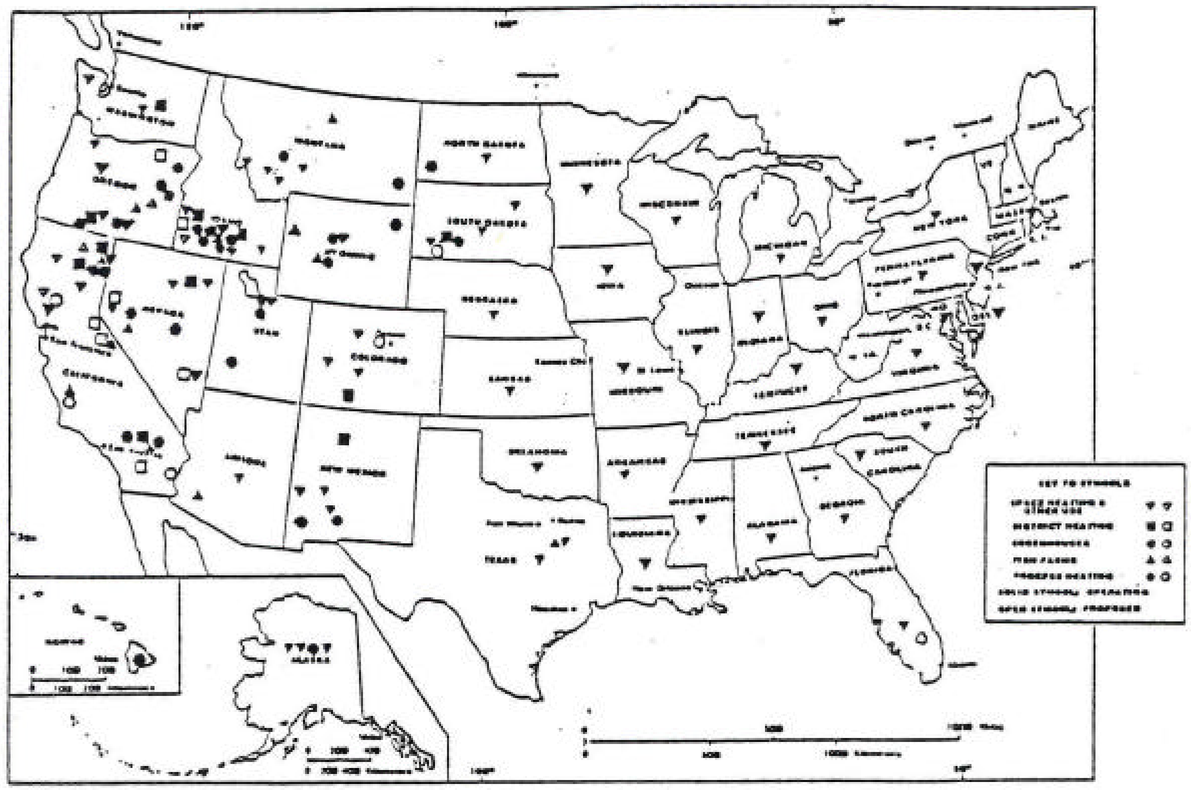


Figure 4.   Location of direct heat projects in the United States.

EQUIPMENT

Standard equipment is used in most direct-use projects, provided allowances are made for the nature of geothermal water and steam. Temperature is an important consideration; so is water quality. Corrosion and scaling caused by the sometimes unique chemistry of geothermal fluids, may lead to operating problems with equipment components exposed to flowing water and steam. In many instances, fluid problems can be designed out of the system. One such example concerns dissolved oxygen, which is absent in most geothermal waters, except perhaps the lowest temperature waters. Care should be taken to prevent atmospheric oxygen from entering district heating waters--for example, by proper design of storage tanks. The isolation of geothermal water by installing a heat exchanger may also solve this and similar water quality derived problems. In this case, a clean secondary fluid is then circulated through the used side of the systems.

The primary components of most low-temperature direct use systems are downhole and circulation pumps, transmission and distribution pipelines, heat exchangers, and various forms of heat extraction equipment. Fluid disposal is either surface or subsurface (injection). A peaking system may be necessary to meet maximum load. This can be done by increasing the water temperature or by providing tank storage. Both options mean that fewer wells need to be drilled. When the geothermal water temperature is warm (below 50ºC) heat pumps are often used. The equipment used in direct use projects represent several units of operation. The major units will now be described in the same order as seen by geothermal waters produced for district heating.

Downhole Pumps

Direct-use production wells consist of three main parts: surface casing (pump housing), the inlet portion, and the production casing between them. Surface casing diameter is usually two nominal pipe sizes larger than the pump bowls. For example, a production rate of 350 to 700 gpm requires an 8-in. diameter pump and a nominal surface casing diameter of 12 in.

The production well pumps are vertical lineshaft turbines with fluid coupling type variable speed drive units as shown in Figures 5 and 6. The variable speed drive provides for continuous operation of the pump to provide constant pressure at the wellhead and in the supply line under varying flow requirements. Pump discharge pressure is monitored by the fluid coupling control, which changes turbine shaft speed to maintain constant discharge pressure from no-low to full-flow conditions and eliminates the need for storage tanks required with intermittent pump operation. The actual design of the pumps evolved over the initial 16 years of operating the OIT geothermal heating system.

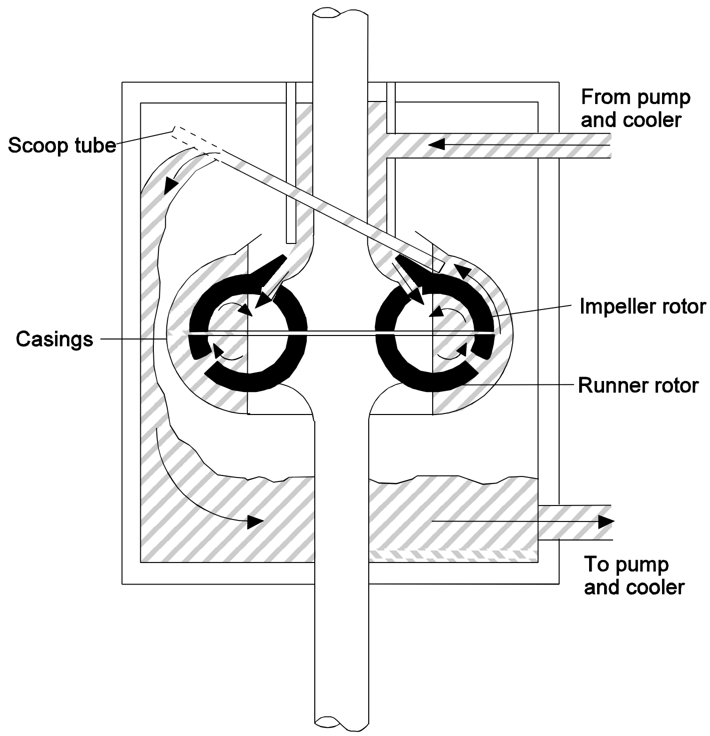


Figure 6. Fluid coupling (Culver and Rafferty, 1989).

In 1964, at OIT, direct-drive lineshaft vertical turbine pumps were originally installed with electric motors in 5 ft pits; this resulted in overheating of the motors. Open lineshaft water lubricated bearings, spaced at 10 ft intervals, developed problems due to hot water vaporizing in the bearing housing causing them to burn out.

In 1970, the pump system design was modified by adding variable speed fluid coupling drives, extending the motor to the surface for ventilation and using an oil lubricated enclosed lineshaft. The 13-stage pump was set at 450 ft in the 1,716 ft OIT Well No. 5, where the static water level was 358 ft below the surface. The pump was custom designed for a 5 in. differential expansion (lateral) between the lineshaft and the column. The start-up procedure is to lower the shaft to the bottom then raise it 5 in. to allow for expansion during the time to reach thermal equilibrium.

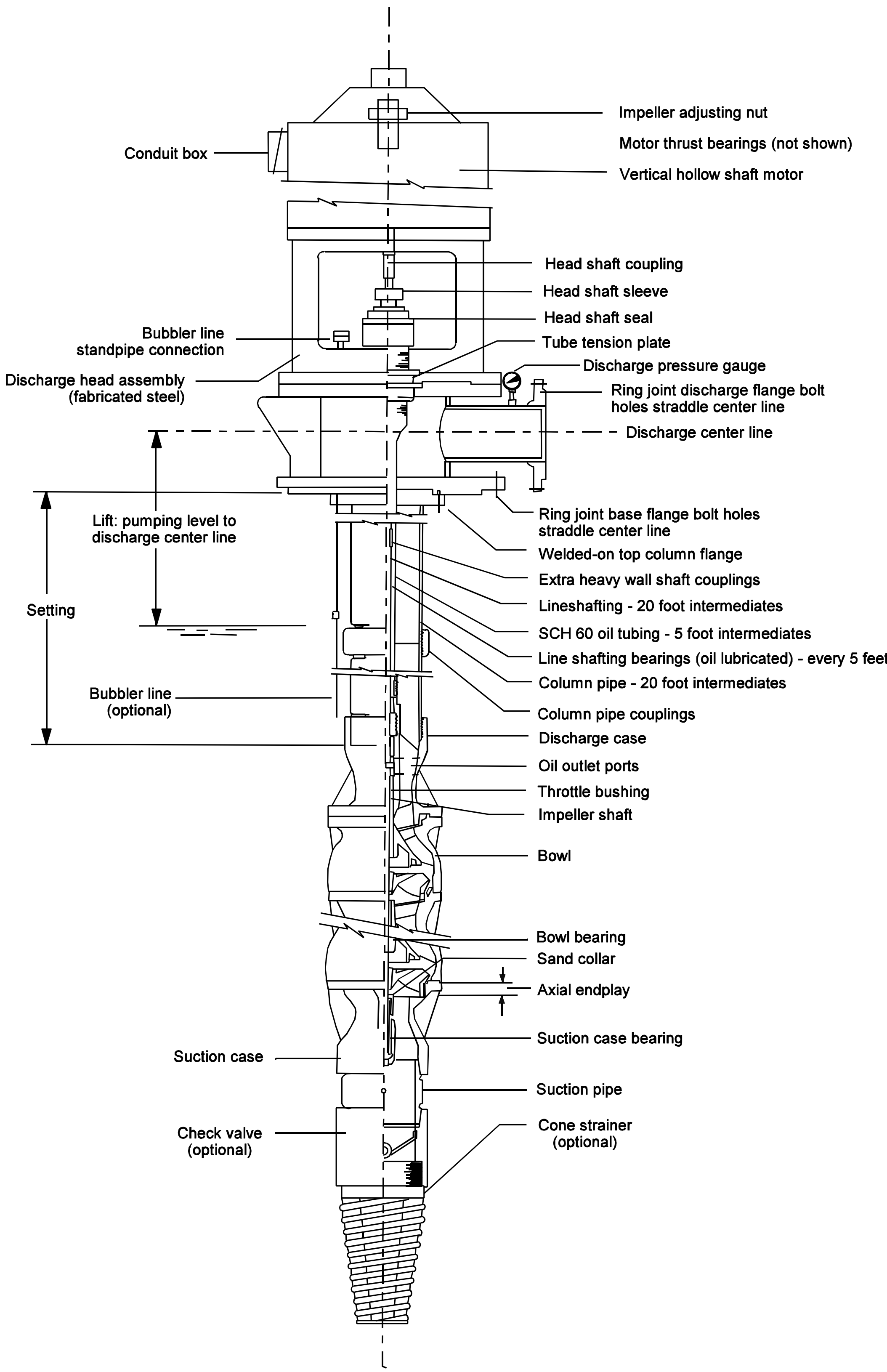


Figure 5. Typical lineshaft turbine pump with an enclosed oil-lubricated shaft (Culver and Rafferty, 1989).

The following materials, which have performed satisfactorily, are used for pump construction:

Column	Bowls	Bowl Bearings and Impellers	Pump Shaft	Impeller Lock Collets
ASTM A53 Grade A	ASTM A48 Class 35 Gray iron	ASTM 584 Alloy UNS Leaded red bronze	Type 416 SS	Type 316 SS

Turbine oil No. 68 is used for lineshaft lubrication.

Since 1970, the only serious problem has been with the main thrust bearing in the driver. This bearing has had to be replaced four times at a cost of about $1,200 per replacement. The column in No. 5 was replaced after 25 years of operation due to corrosion. Oxygen is prevented from contacting the inside of the column by maintaining a back-pressure with the variable speed drive. Start-stop modes of operation caused serious corrosion problems, with the introduction of oxygen, such as that experienced by the neighboring hospital well.

The life of the OIT vertical turbine pumps has been over 20 years and the design developed has been the basis for other installations.

Transmission and Distribution

The fluid state in transmission lines of direct use projects can be liquid water, steam vapor or a two-phase mixture. These pipelines carry fluids from the wellhead to either a site of application, or a steam-water separator. The temperatures the various transmission lines experience can range from ambient to about 200°C. Thermal expansion of pipelines heated rapidly from ambient to geothermal fluid temperatures causes stress that must be accommodated by careful engineering design. In low-temperature applications the thermal stress is less but nevertheless significant. The collection and transmission of geothermal fluids has been discussed by Rafferty (1989). The design principles adopted for geothermal steam and hot water lines are the same as used in conventional power and district heating systems.

The cost of transmission lines and the distribution networks (Figure 7) in direct use projects is significant. This is especially true when the geothermal resource is located at great distance from the main load center. All district heating systems have a distribution network. Although engineers have developed standard designs for hot water distribution in towns and cities, that holds less true for transmission lines. Therefore, many types of transmission lines are found in geothermal applications.

Carbon steel is the most widely used for geothermal transmission lines and distribution networks. Individual systems tend to differ in the form of insulation. Conventional steel piping requires expansion provisions, either bellows arrangements or by loops. A typical piping installation would have fixed points and expansion points about every 300 ft. In addition, the piping would have to be placed on rollers or slip plates between points. When hot water pipelines are buried they can be subjected to external corrosion from groundwater and electrolysis. They must be protected by coatings and wrappings. Concrete tunnels or trenches have been used to protect steel pipe in many geothermal district heating systems. Although expensive, tunnels and trenches have the advantage of easing future expansion and access for maintenance.

Supply and distribution systems can consist of either a single-pipe or a two-pipe system. The single-pipe is a once-through system where the fluid is disposed of after use. This distribution system is generally preferred when the geothermal energy is abundant and the water is pure enough to be circulated through the distribution system. In a two-pipe system the fluid is recirculated so the fluid and residual heat are conserved. A two-pipe system must be used when mixing of spent fluids is called for, and when the spent cold fluids need to be injected into the reservoir. Two-pipe distribution systems cost typically 20 to 30 percent more than single-piped systems.

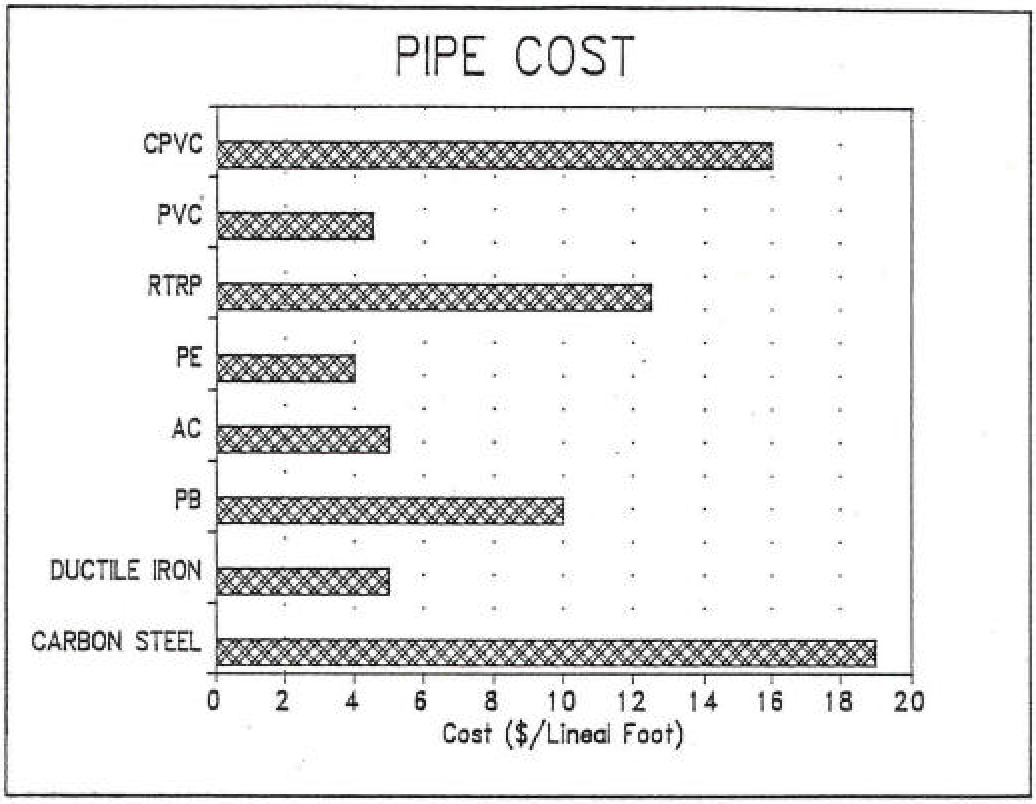


Figure 7. Pipe material costs (1989) for nominal 6 in. diameter.

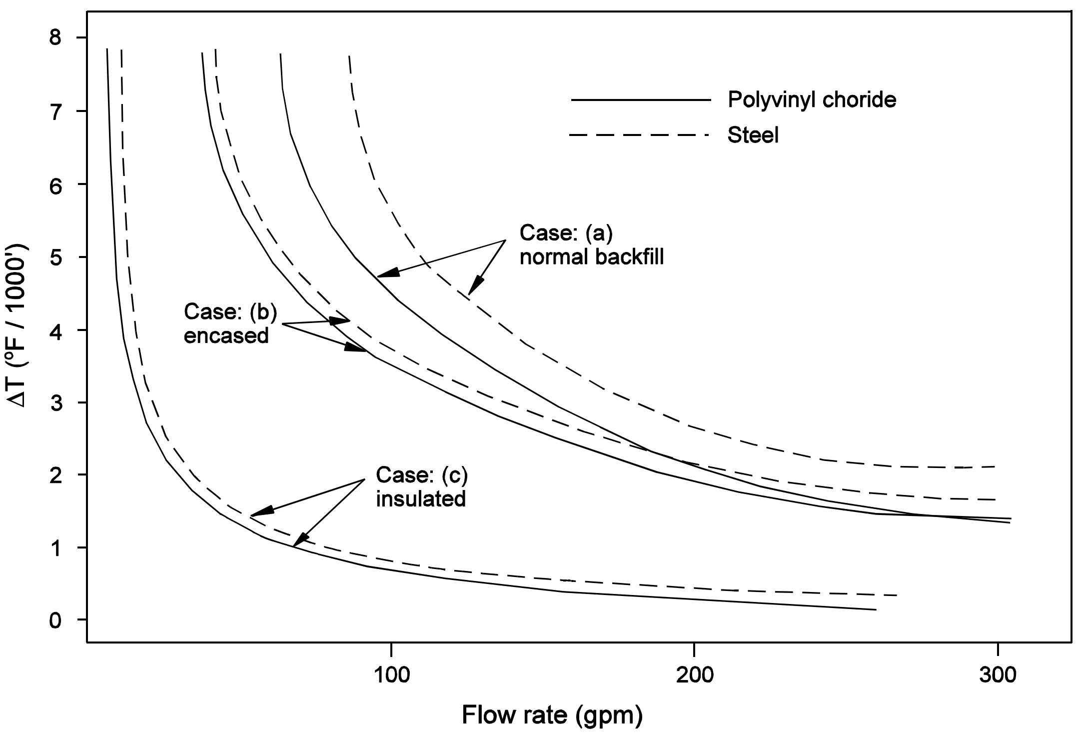


Figure 8. Temperature drop in flowing water (Ryan, 1981).

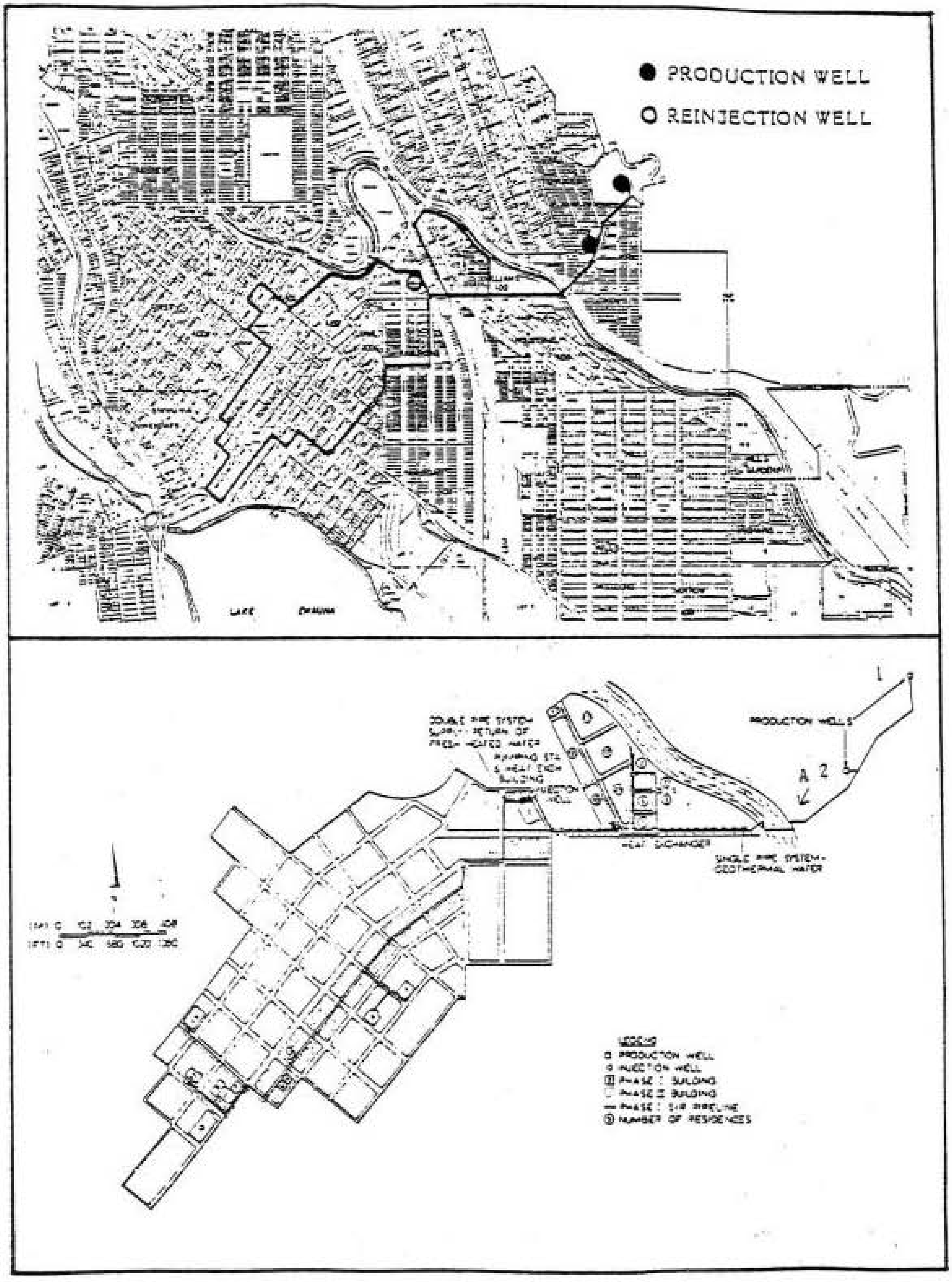


Figure 9. Proposed area to be heated by Phase I (Lienau, 1981).

The quantity of thermal insulation of transmission lines and distribution networks will depend on many factors. In addition to minimizing the heat loss of the fluid, the insulation must be waterproof and water tight. Moisture can destroy the value of any thermal insulation, and caused rapid external corrosion. Above ground and overhead pipeline installations can be considered in special cases. Considerable insulation is achieved by burying hot water pipelines. For example, burying bare steel pipe results in a reduction in heat loss of about one third as compared to above ground in still air. If the soil around the buried pipe can be kept dry, then the insulation value can be retained. Carbon steel piping can be insulated with polyurethane foam and fiberglass. Below ground, such pipes should be protected with a polyvinylchloride jacket; above ground aluminum can be used. Generally, one to three inches of insulation is adequate.

At flowing conditions the temperature loss in insulated pipelines is in the range 0.5°F/1000 ft. Pipe material does not have a significant effect on heat loss. However, the flow rate does have a significant effect. At low flow rates (off peak) the heat loss is higher than at greater flows. This aspect of geothermal pipeline design is illustrated in Figure 8. It shows the temperature loss as a function of the flow in a 6-in. pipe.

Several types of hot water transmission are used in the 22 geothermal district heating systems in the United States; some of these are discussed by Rafferty (1988).

A layout of the Klamath Falls distribution system appears in Figure 9. This system consists of two major portions: transmission line and distribution loop.

A description of the system, from Rafferty, 1989, follows:

"The transmission line employs two types of installation methods: direct buried and concrete tunnel. The entire 4,400 ft length is composed of 8-in. pre-insulated, Schedule 40 steel piping with a fiberglass jacket. From the production wells to Point A (Figure 9), this line is direct buried (Figure 10). Expansion joints are of the controlled flexing type with 304 SS carrier. After the passing under a state highway and across a canal bridge, the line enters the concrete tunnel. The tunnel is located for the most part under a sidewalk and was designed to accommodate a second 8-in. transmission line to provide for system growth (Figure 11).

All of the secondary loop is direct-buried piping. Approximately 4,400 ft of the total is 10-in. pre-insulated, Schedule 40 steel similar to the transmission line. Sizes less than 10 in. (8,280 ft) are pre-insulated FRP piping of the key-lock type mechanical joining.

A problem encountered with the city system was a failure of the joining system used on the fiberglass piping in the secondary loop. A detail of a typical joint is shown in Figure 12.

The failure of the system was the result of the lock ring portion of the joint becoming detached from the piping. The lock rings were attached, by the manufacturers, with an epoxy adhesive. This adhesive was evidently improperly manufactured or applied. In any case, failure of the epoxy permitted axial movement in the joint. Eventually resulting in leaks at these locations. The existing fiberglass material will be replaced entirely with ductile iron when the city secures funding for the construction."

Heat Exchangers

The principal heat exchangers used in geothermal systems are the plate, shell-and-tube, and downhole types. The plate heat exchanger consists of a series of plates with gaskets held in a frame by clamping rods (see Figure 13). The gasket material limits the maximum temperature that can be used. The primary and secondary fluids are usually passed through alternating passages between the plates in single-pass counter-flow, although other flow paths can usually be arranged by simple external piping. Stamping of the plates provides a variety of flow-path patterns. The counter-current flow and high turbulence achieved in plate heat exchangers, provide for efficient thermal exchange in a small volume. Plate heat exchangers are commonly used in geothermal heating situations worldwide. The plates are usually made of stainless steel, although titanium is used when the fluids are especially

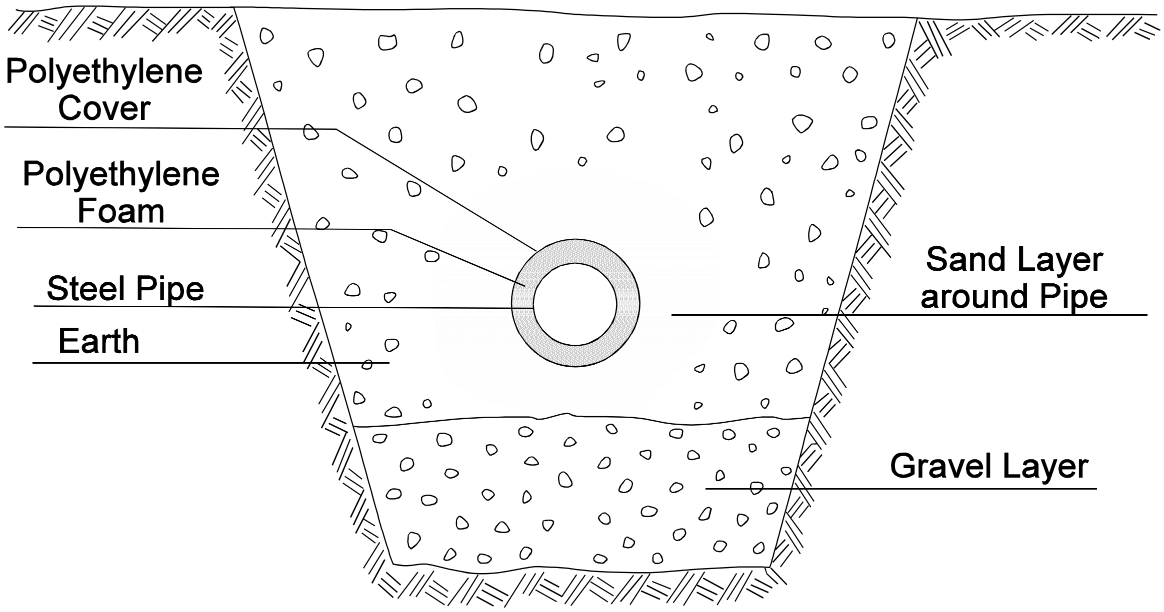


Figure 10. Steel pipe with polyurethane insulation and polyethylene cover.

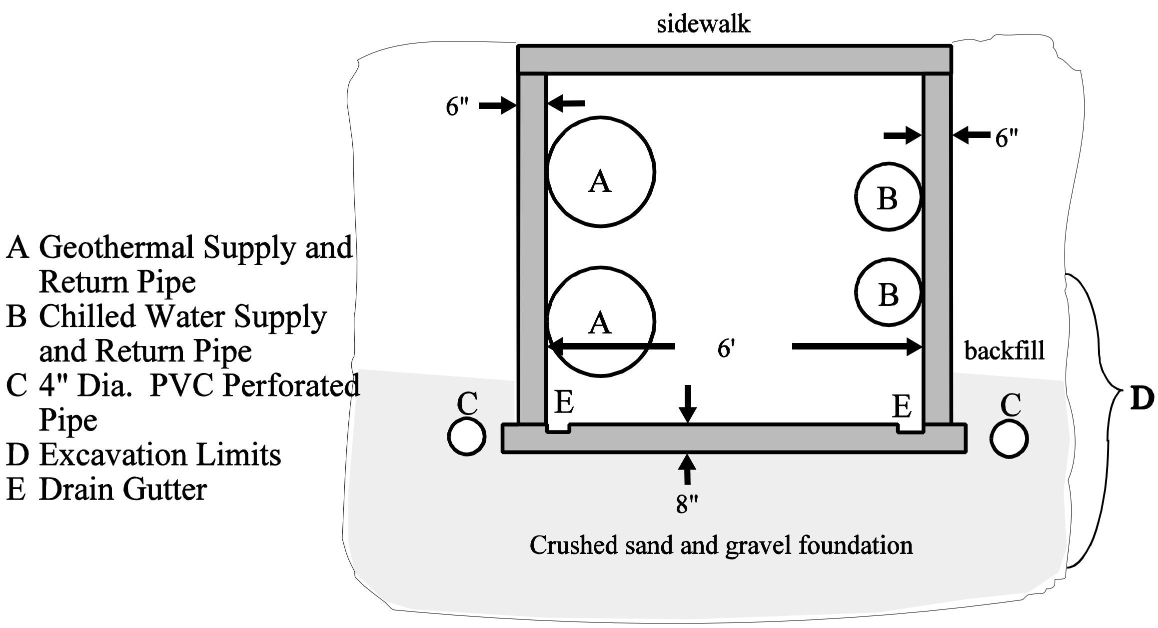


Figure 11. Tunnel construction detail (Lund an Lienau, 1980).

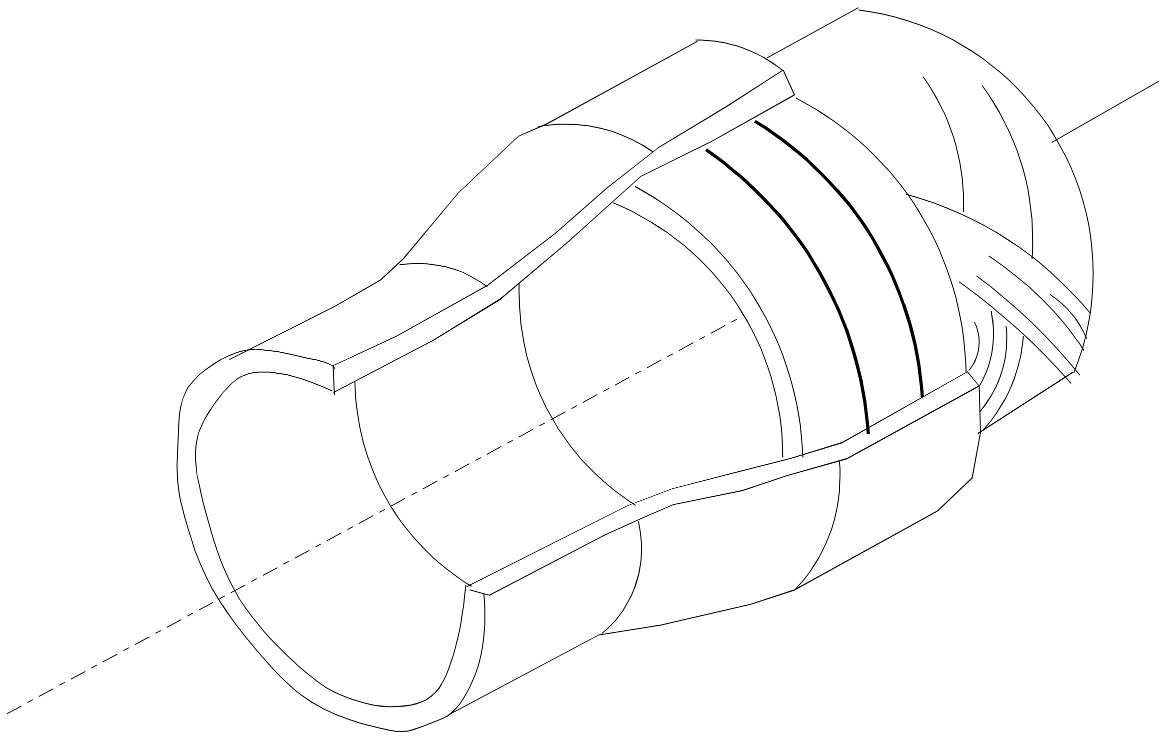


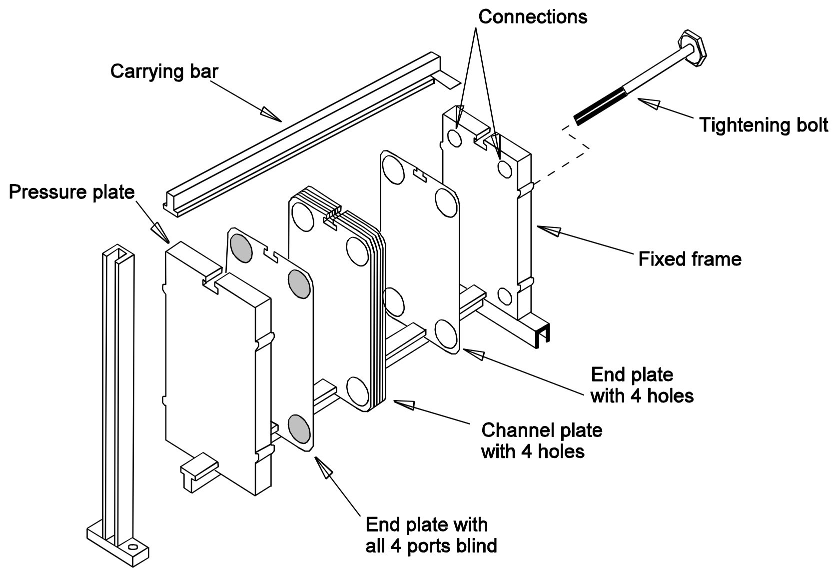
Figure 12. "Kwikey" connection system detail (Rafferty, 1989).

corrosive; for example, in several of the district heating systems in France. Plate heat exchangers are about 60 percent of the costs of shell-and-tube exchangers when compared at the same surface area (Ryan, 1981).

The plate heat exchanger is generally considered superior to the tube and shell type in application for geothermal liquid-to-liquid heat transfer where close approach temperatures are desirable and plate materials other than mild steel are required for corrosion resistance. They require little floor space, are easily cleaned, and are much more efficient. Of particular importance is the ease of changing exchanger surface area to accommodate changes in flow and temperature conditions by adding or removing plates.

Conventional shell-and-tube heat exchangers may be used for geothermal applications. This type of exchanger is readily available or may be custom designed to meet a specific need. Shell-and-tube exchangers consist of a series of tubes, normally carrying the geothermal water, surrounded by an enclosing shell, confining the secondary system water around the tubes. The tubes in this type of exchanger can be a U-tube configuration or a straight tube with removable heads at both ends to facilitate cleaning of the tubes.

About 1930, the first downhole heat exchanger (DHE), was installed in a geothermal well in Klamath Falls. The heat exchanger coil consists of two strings of pipe connected at the bottom by a reverse bend. The temperature of the well water and the predicted heat load determine the length of the pipe required. Based on experience, local heating system contractors estimate approximately "one foot of coil per 1,500 Btu per hour" required. The coil pipes are connected to the supply and return of the distributing piping and the entire system filled with city water.



Nature of fluid -plate heat exchanger

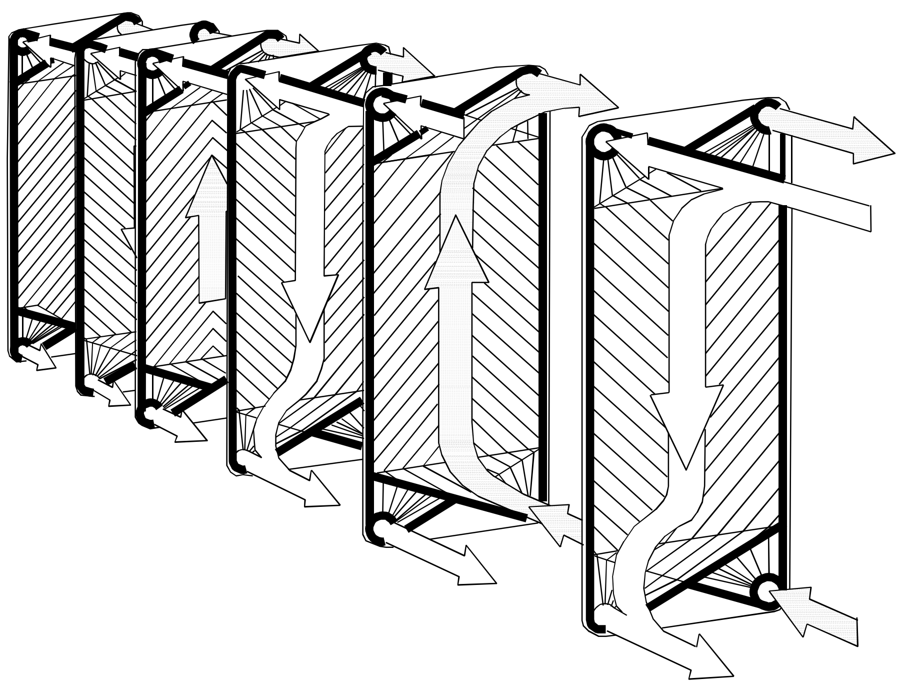


Figure 13. The plate heat exchanger (Culver and Rafferty, 1989).

Figure 14 illustrates a typical system. The heating coil is typically 2 in. in diameter and the domestic water coil is 3/4 in. in diameter. The "thermo-syphon" process (or gravity feed in standard hot water systems) circulates the water, picking up heat in the well and releasing the heat in the radiators. Circulation pumps are required in cooler wells or in larger systems to increase the flow rate. Thermo-syphon circulation will provide 2.9 to 5.1 psi pressure difference in the supply and return lines to circulate 16 to 24 gpm with a 10 to 20°F temperature change (Culver, 1978).

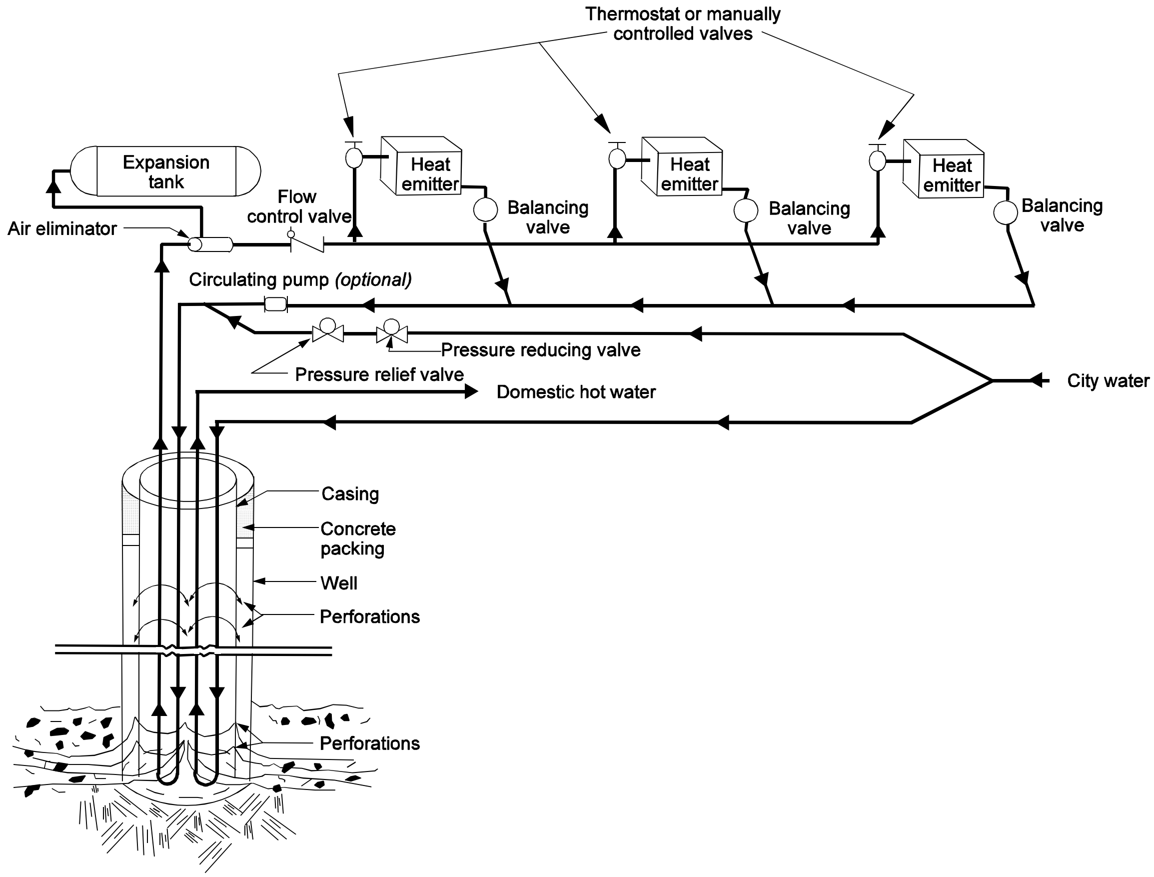


Figure 14. Typical hot-water distribution system using a downhole heat exchanger (Culver, 1978).

The largest output of a DHE is a Ponderosa School, where a 460 ft well contains two 2-in. and one 3-in. downhole heat exchangers. Two circulating pumps (7.5 hp each) with an estimated maximum flow of 525 gpm produce a capacity of 4.2 x 10^6 Btu/h (1.2 MWt) from the DHEs (Lienau, 1976).

The downhole heat exchanger system is economical, minimizes corrosion problems, conserves the resources, and eliminates the problem of waste-water discharge.

Three major types of heat convectors (emitters) are used for residential space heating: forced air, baseboard convection, and radiant panels illustrated in Figure 15.

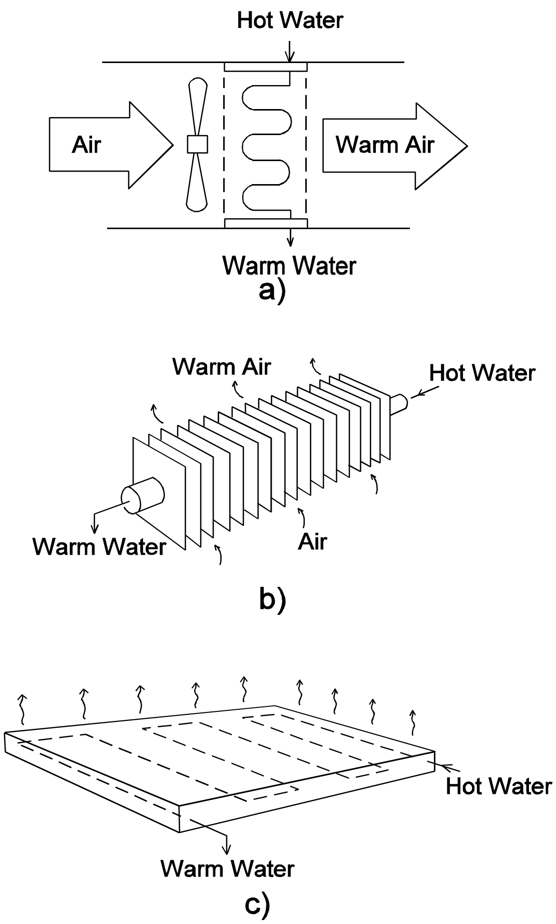


Figure 15. Convectors: (a) forced air, (b) baseboard finned tubed, and (c) radiant panel.

All can be adapted directly to geothermal or converted by retrofitting existing systems. Retrofitting existing systems may require larger fan coil units or additional baseboard convectors if the fossil fuel system required a high design temperature (above 200ºF) or the geothermal fluid has a low temperature (generally below 150ºF)(Lund, 1978). The details of each type of system are as follows:

Forced air. This system heats the incoming cold air by finned tube hot water coils and then distributes the heated air to the residence by ductwork to vents, usually located on outside walls. These units can economically use fluids of 120ºF and higher with temperatures above 160ºF being most efficient. One major advantage of forced air systems is the ability to incorporate air conditioning at a small additional cost. Retrofit would normally only require the placement of the finned tube hot water coil in the plenum of an electric or gas forced air furnace. The distribution system (ductwork) would not have to be modified.

Baseboard convection. This system uses hot water as the heat transfer medium where the hot water is distributed to convector units located at the base of outside walls. Fins attached to the piping transfer the heat to the room by means of natural convection. These units are economical above 140ºF with above 160ºF being the best range. The efficiency of the unit can be increased to use lower temperature water by placing a fan behind the unit to help circulate the air. Depending upon the temperature, retrofitting the system would require additional units or lengthening existing units.

Radiant panels. This system is located in floors, walls or ceilings and radiate heat to the room. Hot water is circulated in coils of pipe (usually plastic or copper) imbedded in concrete or plaster. Their main advantage is the uniform heat provided without a draft and the lower temperature fluid that can be used. Use of fluid temperatures as low as 100ºF is possible. The main disadvantage of this system is that it is difficult and expensive to repair if problems develop (especially leaks). This method is popular in garage and basement floors, and for melting snow on driveways and sidewalks.

Circulation pumps. Natural thermal convection is often adequate to provide water circulation in heating systems, especially those with downhole heat exchangers. A circulation pump may be required in the heating system to increase the flow of the fluid through the heat convector (to increase the heat transfer rate). This may be necessary for low-temperature geothermal fluids or in extremely cold weather. It will be mandatory when two or more residences share the same well to balance the heat load. Generally, a pump from 1/6 to 1/2 horsepower will be adequate.

Controls. Thermostatically controlled valves are desirable to control the heat within a residence. This is especially important with zoned heating systems, where each zone will have a thermostat.

Geothermal Heat Pumps

Like refrigerators, heat pumps operate on the basic principle that fluid absorbs heat when it evaporates into a gas, and likewise gives off heat when it condenses back into a liquid. A geothermal heat pump system can be used for both heating and cooling, as shown in Figures 16 and 17. In the heating mode, the evaporator acts as the heat exchanger transferring heat to the refrigerant. The refrigerant is then compressed, which changes it into a hot vapor. The hot vapor is then passed through a condenser, or the space conditioning heat exchangers, where the heat is transferred to air or water for space heating. At this point, the vapor changes to a warm liquid which is then passed through an expansion valve changing it to a cool liquid/vapor mixture to start the cycle over again. In the cooling mode (see Figure 17), the direction of flow of the refrigerant reverses. The refrigerant is a material such as freon, isobutane, that has a boiling point close to -0.4ºF. External energy is needed to operate the compressor, fans and hot water pumps.

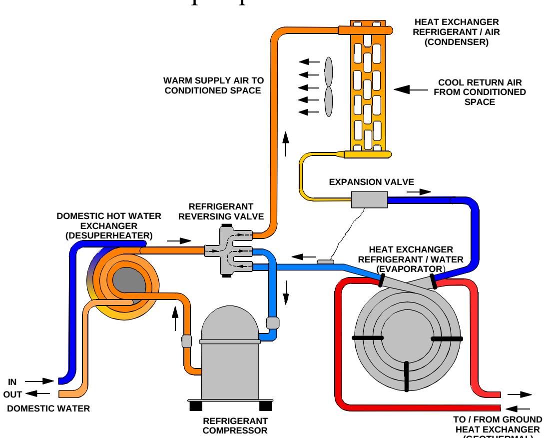


Figure 16. Heating cycle (source Oklahoma State University).

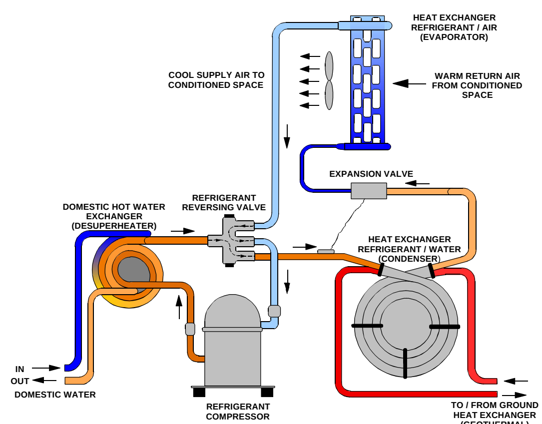


Figure 17. Cooling cycle (source Oklahoma State University).

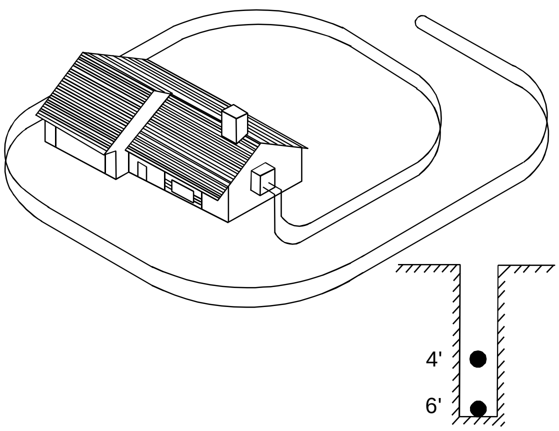
Two major types exist: earth coupled or water source. The earth coupled uses a buried earth coil with circulating fluid in a closed loop of horizontal or vertical pipes to transfer thermal energy to and from the earth. The water source uses a well or an open pond to provide an energy source or sink. Earth coupled systems have been used in northern Europe for many years, but were not used on a commercial scale in the U.S. until 1980. Earth coupling is used where insufficient well water is available, where the quality of well water is a problem, where drilling and casing of wells are expensive, or where disposal of well water is restricted.

In the horizontal mode of the earth coupled system, pipes are buried in trenches spaced a minimum of 5 ft apart and from 4 to 6 ft deep. This allows for minimum thermal interference between pipes; however, this system is affected by solar radiation. Solar radiation will effect the earth to a depth of about 15 ft, causing a cycling of soil temperatures, that lags in time and decreases with depth due to the insulating properties of he soil; however, the temperature is much more stable than for air source units. Moist soil will have greater temperature swings than dry soil. The loops can be placed in a double layer as shown in Figure 18. Vertical installation (Figure 19) of the coils are used where land space is limited or trenching would disturb the surface landscape, and drilling costs are reasonable. Holes are drilled approximately 150 ft deep and 15 to 20 ft apart.

Computer programs have been developed to calculate the length of horizontal earth coils for heating and cooling. Polyethylene pipes are the most popular in use, and along with socket fusion joining, are usually guaranteed for over 50 years.

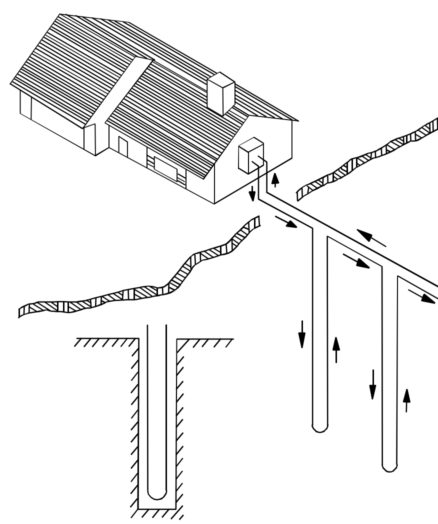
Whereas horizontal loops are affected by solar radiation, rain and wind; the vertical loops are controlled by the mean annual temperature of the area and the geothermal gradient, and thus, have a more stable temperature environment.

Water wells are usually used where one is already available, such as for domestic water supply. Normally a minimum diameter of 6 in. and a production of about three gallons per minute per ton of heat pump capacity is required. Three tons, a typical residential load, requires about nine gallons per minute. The 6-inch diameter well casing is required to place the pump and return line. The fluid can either be returned to the well by the return line, placed in an injection well, or disposed on the surface such as irrigation.



Earth Coil Type:	Horizontal -Two-Layer
Water Flow:	Series
Typical Pipe Size:	1 ½ to 2 inches
Practical Length:	210 to 300 feet of trench/ton
	420 to 600 feet of pipe/ton
Burial Depth:	4 feet and 6 feet

Figure 18. Series vertical ground heat exchanger (source Oklahoma State University).



Earth Coil Type:	**Vertical - Single U-Bend**
Water Flow:	**Series**
Pipe Sizes:	**1, 1 ½, & 2 inches**
Bore Length:	**165 to 200 feet/ton**
Pipe Length:	**230 to 400 feet/ton**

Figure 19. Two-pipe horizontal ground heat exchanger (source Oklahoma State University).

Refrigeration

Cooling can be accomplished from geothermal energy using lithium bromide and ammonia absorption refrigeration systems (Rafferty, 1989). The lithium bromide system is the most common because it uses water as the refrigerant. However, it is limited to cooling above the freezing point of water.

The major application of lithium bromide units is for the supply of chilled water for space and process cooling. They may be either one- or two-stage units. The two-stage units require higher temperatures (about 320ºF), but they also have a high COP (here taken as cooling output over source energy input). The single-stage units can be driven with hot water at temperatures as low as 190ºF and typically have a COP of 0.65 referred to primary energy. The lower the temperature of the geothermal water, the higher the flow rate required and the lower the COP. Generally, a condensing (cooling) tower is required, which will add to the cost and space requirements.

For geothermally driven refrigeration below the freezing point of water, the ammonia absorption system must be considered. However, these systems are normally applied in very large capacities and have seen limited use. For the lower temperature refrigeration, the driving temperature must be at or above about 250ºF for a reasonable performance. Figure 20 illustrates how a geothermal absorption process works (Witcher, 1980).

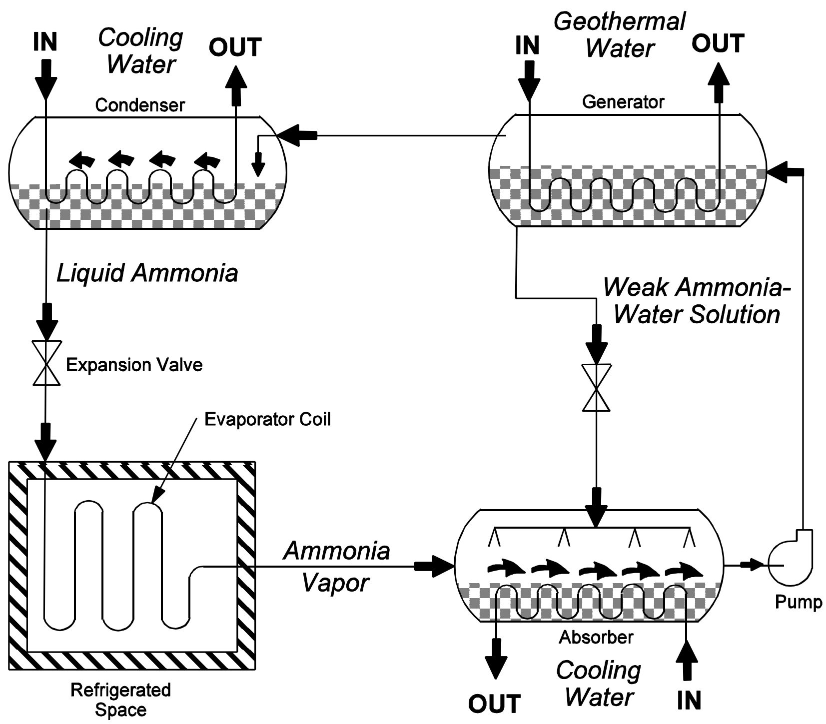


Figure 20. Geothermal absorption refrigeration cycle.

APPLICATIONS

Table 3 lists the principle direct use systems in the United States, which are discussed in the following section.

Space and District Heating

District heating involves the distribution of heat (hot water or steam) from a central location, through a network of pipes to individual houses or blocks of buildings. The distinction between district heating and space heating systems, is that space heating usually involves one geothermal well per structure.

An important consideration in district heating projects is the thermal load density, or the heat demand divided by the ground area of the district. A high heat density is required to make district heating economically feasible, since the distribution network which transports the hot water to the consumer is expensive.

Geothermal district heating systems are capital intensive. The principal costs are initial investment costs for production and injection wells, downhole and circulation pumps, heat exchangers, pipelines and distribution network, flowmeters, valves and control equipment, etc. Operating expenses, however, are in comparison lower and consist of pumping power, system maintenance, control and management. The typical savings to consumers range from about 30 to 50% of the cost of natural gas.

Elko District Heating Systems

A showcase of district heating developments are the two systems at Elko, Nevada. Elko Heat Company is a private company that has experienced considerable growth since it first began operating in 1982. The project started as a USDOE Program Opportunity Notice demonstration project consisting of three buildings: a laundry, bank, and hotel/casino. The system has grown to include 14 commercial buildings and a sewage treatment plant. This was accomplished by offering a preliminary estimate of customer needs to retrofit, educating about the reliability of the system (down less than one day per year) and charging its customers about 50 percent the price of natural gas ($1.00 to $1.25 per 1,000 gallons of geothermal fluids). The system supplies about 36.7 billion Btu/yr from its one geothermal well that produces 650 gpm at 170°F. The company has doubled the length of its delivery piping system and has reached the demand point where it will be necessary to drill a second well.

The Elko County School District in conjunction with the Elko Hospital, has been servicing the high school, junior high (heat pump system), gymnasium, school administrative offices, hospital, convention center, city hall and the municipal pool for about two years. One of the most impressive aspects of this system is the 100°F temperature drop through the closed loop servicing the buildings from two plate heat exchangers in parallel. An injection well was drilled, but is not used due to concern of contamination of domestic aquifers. Disposal of geothermal fluids is to percolation ponds, storm drains, and a golf course irrigation system.

City of Klamath Falls District Heating System

In 1977, a Federal (DOE/DGE) field experiment contract was awarded to the city of Klamath Falls to design, construct and initiate operation of a geothermal space heating district in the central business district of the city. This project was for a city-owned and operated system, initially to serve 14 city, county, state and federal office buildings, and 120 residences (Phase I) with subsequent expansion to an 11 block area adjacent to the initial secondary supply line (Phase II), and final expansion to commercial buildings on 54 city blocks (Phase III). The project included two production wells, an injection well, transmission lines, controls and retrofitting equipment for the government buildings.

A summary of the heat loads are as follows:

Phase I (14 government buildings)

Peak heat load	21.2×10^6 Btu/h
Geo-fluid flow	1,060 gpm

Phase II (11 commercial blocks)

Peak heat load	34.8×10^6 Btu/h
Geo-fluid flow	1,740 gpm

Phase III (54 commercial blocks)

Peak heat load	143×10^6 Btu/h
Geo-fluid flow	7,150 gpm

Table 3. Principle Direct Use Systems in the United States

Application	Resource Temperature °C	°F	Annual Energy (10^9 Btu/yr)
Industrial			
Enhanced Oil Recovery			
Amoco, WY	93	200	9480
Heap Leaching			
Round Mountain Gold Corp., NV	84	186	197
Pegasus Gold Corp., Florida Cary, NV	114	238	40
Food Drying			
Gilroy Foods, NV	132	270	86
Mushroom Growing			
Oregon Trails Mushrooms, OR	113	235	54
Geothermal Heat Pumps (Heating)			
Florida, all of state	24	75	839
Michigan, all of state	8	47	355
Indiana, all of state	12	54	335
Pools/Spas			
Payne's Fountain of Youth RV Park, WY	52	125	665
Hot Springs State Park, WY	57	135	478
Hunt's Ash Springs, NV	36	97	177
Aquaculture			
Hot Creek Hatchery, CA	16	61	201
Fish Breeders of Idaho, ID	32	90	174
Hyder Valley, AZ	41	105	140
Greenhouses			
Burgett Floral Greenhouses, NM	118	245	65
Utah Roses, UT	51	124	45
High Country Roses, MT	66	151	33
Troy Hygro, UT	110	230	30
Space Heating			
Residences (550 each), Klamath Falls, OR	93	160	96
Peppermill Casino, NV	53	127	63
Residences (300 each), Reno, NV	49	120	39
Merle West Medical Center, OR	88	191	24
District Heating			
Mammoth Lakes, CA	149	330	118
Litchfield Correctional Center, CA	77	170	79
Boise City, ID (two systems)	77	170	73
San Bernardino, CA	59	138	45

The total cost of the project was $2.58 million, consisting of 65% federal funds, and the remainder from city, county and state funds which are summarized below:

Item Description	Amount
Production wells (2)	$ 63,965
Primary pipeline	1,269,711
Secondary pipeline	790,966
Retrofit	249,890
Engineering & Administration	205,468
	$ 2,580,000

Since Phase I is a demonstration project funded primarily by the federal government (DOE), the economic analysis is based on Phase II. The pipe diameters in Phase I are sized to handle Phase II. Pipe tees were installed at the principal businesses along the 11 block commercial area, thus future hookup costs will be minimal.

For economic evaluation, the lowest cost existing energy source available to the downtown area (natural gas) was used for comparison. Cost of natural gas (1982) for commercial buildings is $\$5.67/10^6$ Btu. The first year geothermal unit energy cost is $\$5.84/10^6$ Btu, where the cost of capital is 8%, and operation and maintenance (O & M) costs will inflate at the economic inflation rate of 7%. District heating costs are, therefore, made up largely of capital charges (94%) which, after the system is built, do not escalate. A 20-year-life-cycle comparison and geothermal is shown in Figure 21, indicating a "break even" cost at under 5 years and a payback of under 8 years.

Customer geothermal energy price was two-thirds of the price of natural gas when the system operated from 1984 to 1985. In February 1985, the system was shutdown, and subsequently, it was decided that all the fiberglass piping would be replaced as discussed in the distribution section.

Since completion of the downtown loop and transmission line, two other small district systems have been tied into the main transmission line.

The Michigan Street system serves a residential area to the north of the transmission line. To deliver heat to this system, a fraction of the flow in the main line is shunted through a heat exchanger and then back into the line. Since there are only eight houses currently connected to the system, the impact on the temperature delivered to the main loop heat exchanger is small. As in the case of the main loop, this system employs a central heat exchanger and secondary loop to deliver heat to the customer (Rafferty, 1989).

The Mills Addition system is connected to the main transmission line only for emergency backup purposes. This system uses, as its primary source of heat, water which was previously wasted to the storm sewer. A number of existing geothermal systems in this area of the city were previously operated on a "pump and dump" basis. The Mills Addition system was implemented in an effort to collect this fluid, extract any useful heat and then deliver it to an injection well. Toward this end, the fluid is collected in a gathering system, passed through a heat exchanger and then delivered in a separate line to the injection well used by the main system. A secondary loop delivers heat to the customers.

Others that have experienced considerable growth are San Bernardino, California system and Warren Properties at Reno, Nevada (doubling in size). When completed, Mammoth Lakes district heating will be the largest development in the country. This is followed by the Litchfield Correctional Center at Susanville, California and the two systems in Boise, Idaho, the downtown commercial system and the Boise Warm Springs residential system.

The Peppermill Casino, Reno, Nevada, has the largest space and domestic hot water use followed by the 550 individual homes that utilize downhole heat exchangers in Klamath Falls, Oregon.

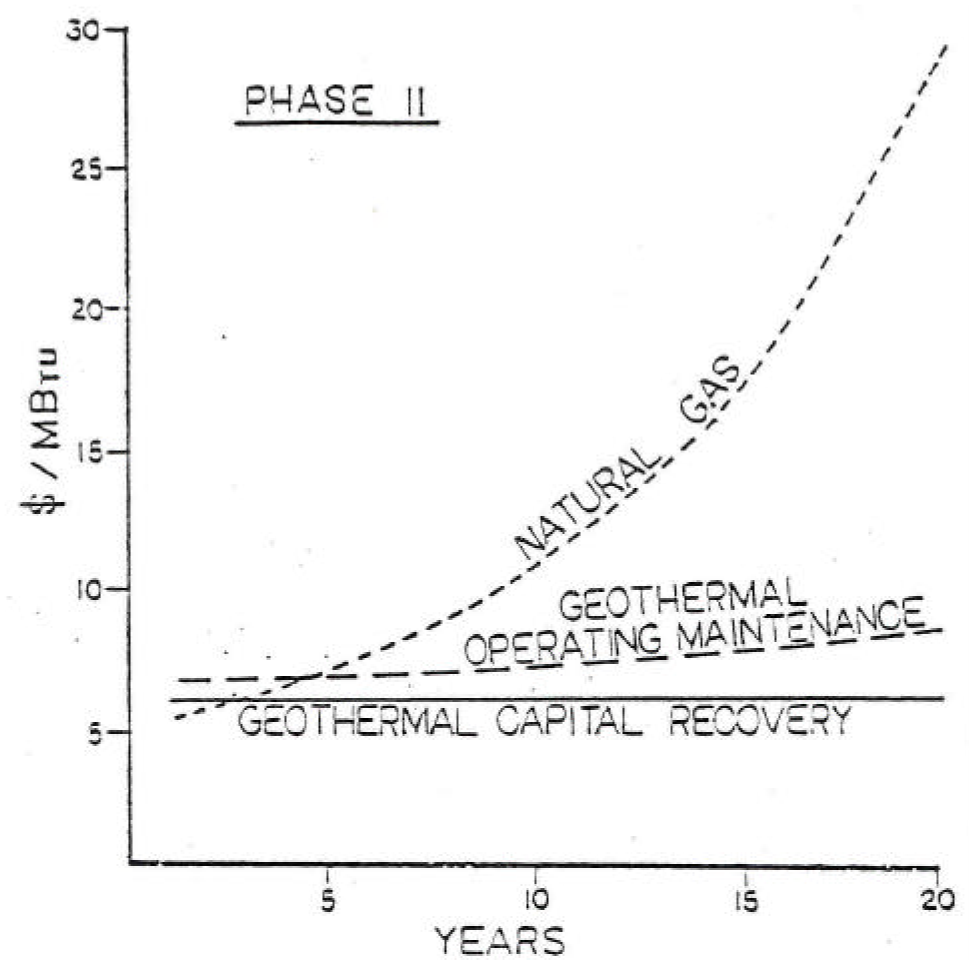


Figure 21. Phase II Unit Energy Cost Comparison (Lienau, 1981).

The potential for geothermal district heating in the United States is very large. An inventory identifies a total of 1,277 hydrothermal sites within five miles of 373 cities in eight Western states, with a combined population of 6,720,000 persons. The combined heat load for all cities (exclusive of industrial loads) is estimated at 1.3 x 10^{14} Btu/yr (Allen, 1980). Currently 20 geothermal district heating systems are operating (700 x 10^{9} Btu/yr) and 26 planned projects should increase the annual energy use by 1,690 billion Btu per year.

Greenhouses

A number of commercial crops can be raised in greenhouses, making geothermal resources in cold climates particularly attractive. Crops include vegetables, flowers (potted and cut), house plants and tree seedlings.

Greenhouse heating can be accomplished by several methods: finned pipe, unit heaters, finned coils, soil heating, plastic tubing, cascading, and a combination of these methods (Rafferty, 1989). The use of geothermal energy for heating can reduce operating costs and allow operation in colder climates where commercial greenhouses would not normally be economical.

Economics of a geothermal greenhouse operation depend on many variables, such as the type of crop, climate, resource temperature, type of structure, etc. An example is the raising of roses near Helena, Montana, where using geothermal energy in a 75,500 ft^2 greenhouse reduces heating costs by 80% and overall costs by 35%.

Greenhouses are one of the fastest growing applications in the direct use industry. A number of the existing greenhouse systems are expanding. For example, Troy Hygro, Newcastle, Utah, is building an additional 28 acres, which will result in a 100% increase in the total U.S. utilization for greenhouses. Other systems expanding are Utah Roses, Bluffdale, Utah; Flint Greenhouses near Buhl, Idaho (doubling in size) and a new experimental facility and commercial space with a geothermal delivery system is being constructed by Lake County, California.

Troy-Hygro Greenhouses will be the largest greenhouse energy user when the 28 acre facility is completed. Burgett Floral at Animas, New Mexico, has developed about 13 acres and the state with the largest total use for greenhouses is Idaho with 14 sites in operation.

Aquaculture

Aquaculture involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The principal species that are typically raised are aquatic animals such as catfish, bass, tilapia, sturgeon, shrimp, and tropical fish. The application temperature in fish farming depends on the species involved. Typically, catfish grow in 4 to 6 months at 64 to 75°F, trout in 4 to 6 months at 55 to 64°F and prawns in 6 to 9 months at 80 to 86°F. The benefit of a controlled rearing temperature in aquaculture operations can increase growth rates by 50 to 100%, and thus, increase the number of harvests per year. Water quality and disease control are very important in fish farming.

In the U.S. aquaculture projects using geothermal water exist in Arizona, Idaho, Oregon, and California. Aquaculture is one of the fastest growing applications for using low-temperature geothermal energy. Recently, four locations in Arizona began raising catfish, tilapia and bass using geothermal fluids with temperatures ranging from 80 to 105°F and a large facility is planned for raising sturgeon at Brooks Warms Springs, Montana.

Aquaculture projects at the Hot Creek Hatchery near Mammoth Lakes, California and the Fish Breeders of Idaho, Buhl, Idaho, are the largest aquaculture use sites.

Resorts and Pools

Geothermal energy used for swimming pools and spas is the earliest use of the resource. Natatoriums and large resorts developed at hot springs, located in both the eastern and western United States, were popular in the 1800s and were reminiscent of those in Europe. Many of these continue to be used today, and in some cases, elaborate facilities have been developed. For example, Fairmont Hot Springs Resort, a major new all-year resort near Butte, Montana, is using a 640 ft geothermal well (160°F) for space heating a 140-room hotel, mini-zoo, game room and restaurant in addition to large indoor and outdoor swimming pools. The resort also boasts a golf course, convention center and time-share condominiums.

The survey identified 114 resorts using geothermal energy, the largest being Paynes Fountain of Youth and Hot Springs State Park in Wyoming.

Industrial

Industrial applications mostly need the higher temperatures while space heating and agriculture predominantly use low temperatures. Examples of industrial uses include: enhanced oil recovery (200°F), heap leaching operations to extract precious metals (230°F), dehydration of vegetables (270°F), mushroom growing (235°F), and others worldwide such as pulp and paper processing (400°F), hay drying (363°F), timber drying (200°F), and diatomaceous earth drying (360°F).

Drying and dehydration may be the two most important process uses of geothermal energy. A variety of vegetable and fruit products can be considered for dehydration at geothermal temperatures. Dehydration processes involve either continuous belt conveyors or batch dryers, using low temperature air from 100 to 200°F. Blowers and exhaust fans move the air over coils through which the geothermal fluid flows. The heated air then flows through the beds of vegetables or fruit on conveyors, to evaporate the moisture. Geothermal Food Processors near

Fernly, Nevada, dehydrate onions, garlic, celery, and carrots using 270ºF geothermal fluid. This saves an estimated 86.0 billion Btu/yr which is equivalent to replacing 119 x 10^6 cubic feet of natural gas corresponding to a savings of about $350,000 per year. This plant has been operating since 1978.

When oil is produced, only about a third of the oil in the ground can be recovered by simply pumping production wells. Secondary recovery, the injection of water to move oil toward production wells, is often used to recover up to an additional third of the original oil. In the oil fields of North and South Dakota, Wyoming and Montana, geothermal fluid is produced with the oil from several deep zones. This fluid is often between 140 and 212ºF as it is produced at the surface, and this heat is extremely useful in the secondary recovery of additional oil. Efficient secondary oil recovery is a function of the temperature and chemical compatibility of the injected water compared to the oil formation. To calculate the benefit from the use of the geothermal fluid, a comparison is made between the geothermal water and the energy needed to heat surface water to the same temperature. The estimated benefit for secondary oil recovery in the four states is 8,156.2 x 10^9 Btu/yr; however, fluctuating oil prices may impact the degree to which it is utilized.

Large volumes of geothermal fluid are separated from oil production or are produced from other zones for use in secondary oil recovery. The injected water use in the four states mentioned above comes primarily from the Dakota Sandstone and the deeper Madison Limestone. Dakota aquifer water ranges between 140 and 170ºF and Madison aquifer water ranges between 160 and 212ºF.

New developments in 1988 are the use of geothermal fluids for enhanced heap leaching of precious metals in Nevada by heating the cyanide circuit. This represents an additional 300 billion Btu/yr of energy use or a 3% growth.

FEASIBILITY

The decision to invest in a geothermal project depends primarily upon the annual savings over an alternative fuel system, taking into account the project life, system maintenance, cost of money and fuel price projections. Direct use projects require a relatively large capital investment at the beginning, with small annual operating costs thereafter. Production wells, pipelines, heat exchangers and injection wells may cost much more than the initial investment of a fossil fuel system. However, the fossil fuel system must continue to pay for the oil, gas or coal at a high rate. The annual operation and maintenance costs for the two systems are similar. The two systems, one with a high initial cost, and the other with high annual costs, must be compared when evaluating the feasibility of direct use projects.

The economics of geothermal direct use projects are affected by several factors, including the location of user and resource, efficiency of heat extraction and annual load factor, cost of financing, amortization period and inflation rates. These factors can be grouped into three major considerations.

1. Locations and site specificity. Direct use projects are site specific because the resource location and characteristics must be compatible with the use. The relocation of new potential users and/or the retrofitting of existing potential users are important alternatives. Pipeline lengths for transmission and distribution are a significant cost of any geothermal project. The location of users near the resource can help reduce the cost of transmission lines. The depth of drilling determines the cost of production and injection wells. The trade-off between shallow and cooler wells using heat pumps, and deeper and hotter wells used directly, is also a consideration. Water quality affects system design and maintenance costs. In low-to-moderate temperature reservoirs, the water level determines the setting of downhole pumps and the associated costs of pumping. The rate of pressure and temperature depletion of these and higher temperature reservoirs used for direct uses, are site specific and prescribe how many make-up wells need to be drilled.

2. System efficiency and load factor. In a geothermal direct heat system, increasing the amount of heat extracted from the fluid will decrease the cost of energy. A more expensive heat extraction system is required in geothermal applications then commonly used in systems burning fossil fuels; but, this is offset by the reduction in the number of production wells required. Cascaded use in one way of increasing the amount of heat extracted from geothermal fluids. Users with a high thermal load density will require smaller distribution systems which will reduce costs. The load factor of direct use systems is the ratio of the average annual load to the peak load. As this factor increases, the economic feasibility increases. The load factor of district heating systems depends on the local climate mainly. Hot water storage can improve the load factor of district heating systems. The use of fossil fuel or electric heating peaking systems can help reduce the peak geothermal load, and thus, reduce the number of wells required.

3. Financing and fuel costs. As the rate of return or the cost of borrowed money increases, the economic viability of a project decreases. It is important that the economic life of a project be kept relatively short, 20 years or less, although most projects last much longer. Also, inflation rates for fossil fuels should be kept conservative (low) when comparing with a geothermal alternative. By using long life and high inflation rates, feasibility studies make geothermal energy look extremely attractive when in fact the project may well operate in the red for its entire life. By holding the economic life and inflation rates low, projects that have good economic feasibility will be even more attractive if the actual life proves to be longer or the inflation rate is higher.

The important components of a typical geothermal feasibility study are: (1) to prove the resource, (2) to ensure that the end use is compatible with the temperature and flow rate of the resource, and (3) to determine if the project is economically feasible. Life cycle cost analysis is the method generally used to determine economic feasibility. It should include capital investment, annual maintenance and operating costs, financing cost and taxes and insurance.

CONCLUSIONS

The contained heat energy beneath the United States could, in theory, provide most of the future low temperature energy needs of this Nation. The actual contribution will be determined by the effort--time, people, and funding--devoted to a broad research, development, and demonstration program with participation by federal, state, and local governments in cooperation with industry, universities, laboratories and the American people.

The United States direct use industry is and will continue to experience a significant growth rate. The largest growth should continue to occur in the use of geothermal heat pumps, and aquaculture, greenhousing and district heating will add to the expansion of the industry.

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Figure 5.   Typical lineshaft turbine pump with an enclosed oil-lubricated shaft (Culver and Rafferty, 1989).