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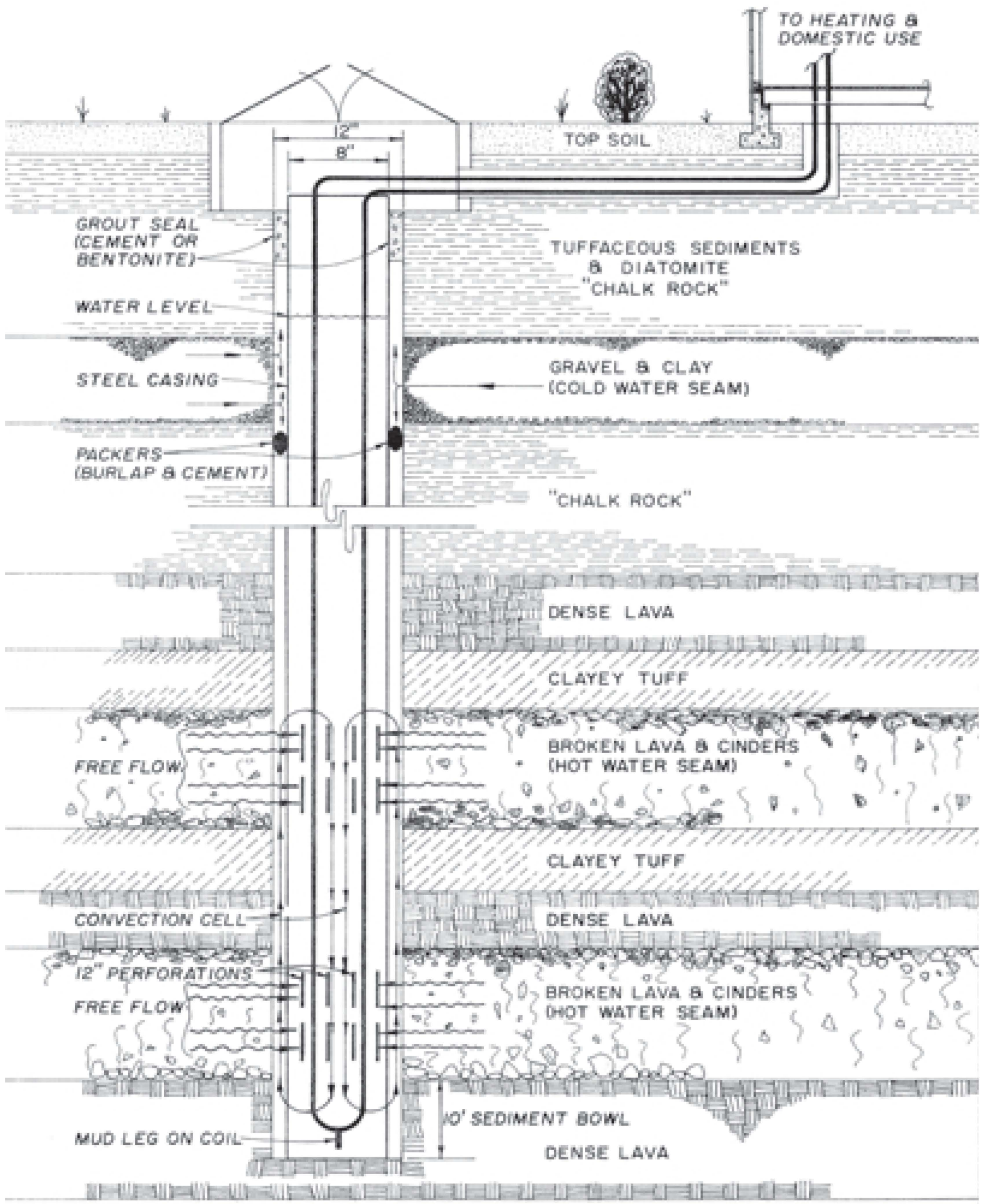

DOWNHOLE HEAT EXCHANGERS

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

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Cover: Typical downhole heat exchanger installation in Klamath Falls.

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DOWNHOLE HEAT EXCHANGERS

Gene Culver
John W. Lund
Geo-Heat Center

INTRODUCTION (Lund, et al., 1975)

The downhole heat exchanger (DHE) eliminates the problem of disposal of geothermal fluid, since only heat is taken from the well. The exchanger consists of a system of pipes or tubes suspended in the well through which "clean" secondary water is pumped or allowed to circulate by natural convection. These systems offer substantial economic savings over surface heat exchangers where a single-well system is adequate (typically less than 0.8 MWt, with well depths up to about 500 ft [150 m]) and may be economical under certain conditions at well depths to 1500 ft (450 m).

Several designs have proven successful; but, the most popular are a simple hairpin loop or multiple loops of iron pipe (similar to the tubes in a U-tube and shell exchanger) extending to near the well bottom(Figure 1). An experimental design consisting of multiple small tubes with "headers" at each end suspended just below the water surface appears to offer economic and heating capacity advantages.

In order to obtain maximum output, the well must be designed to have an open annulus between the wellbore and the casing, and perforations above and below the heat exchange surface. Natural convection circulates the water down inside the casing, through the lower perforations, up in the annulus and back inside the casing through the upper perforations. If the design parameters of bore diameter, casing diameter, heat exchanger length, tube diameter, number of loops, flow rate and inlet temperature are carefully selected, the velocity and mass flow of the natural convection in the well may approach those of a conventional shell-and-tube heat exchanger.

The interaction between the fluid in the aquifer and that in the well is not fully understood; but, it appears that outputs are higher where there is a high degree of mixing indicating that somewhat permeable formations are preferred.

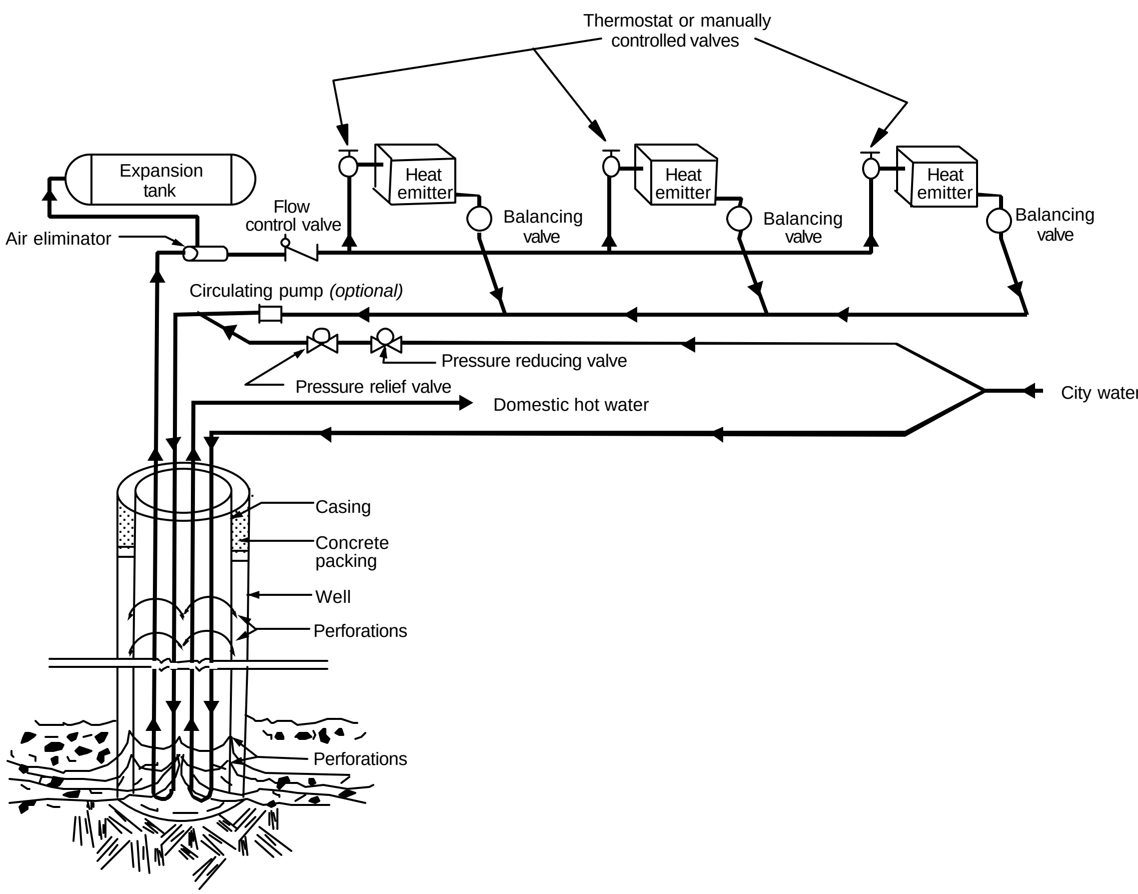

Figure 1. Typical downhole heat exchanger system (Klamath Falls, OR).

Considering life and replacement costs, materials should be selected to provide economical protection from corrosion. Attention must be given to the anodic-cathodic relationship between the exchanger and the casing since it is relatively expensive to replace the well casing. Experience in the approximately 600 downhole exchangers in use indicates that corrosion is most severe at the air-water interface at static water level and that stray electrical currents can accelerate corrosion. Insulating unions should be used to isolate the exchanger from stray currents in building and city water lines. Sealing the top of the casing to limit oxygen availability will also reduce the air-water interface corrosion.

DESIGN AND CONSTRUCTION DETAILS (Culver, 1987)

DHE outputs range from supplying domestic hot water for a single family from a 40-ft, 140°F (12-m, 60°C) well at Jemenez Springs, New Mexico, to over 1 MWt at Ponderosa Junior High School from a 560-ft, 202°F (170-m, 94°C) 16-in. diameter (40-cm) well in Klamath Falls, Oregon. DHEs are also in use in New Zealand, Turkey, Hungary, Iceland, Russia and other countries. A well producing 6 MWt has been reported in use in Turkey.

The wells in Klamath Falls are 10- or 12-in. (25- or 30-cm) diameter drilled 20 or more feet (6 m) into “live water” and an 8-in. (20-cm) casing is installed. A packer is placed around the casing below any cold water or unconsolidated rock, usually at depths of 20 - 50 ft (6 - 15 m), and the well cemented from the packer to the surface. The casing is torch perforated (1/2 in. x 6 in. [1 x 15 cm]) in the live water area and just below the lowest static water level. Perforated sections are usually 15 - 30 ft (4 - 9 m) long and the total cross-sectional area of the perforations should be at least one-and-a-half to two times the casing cross section. Since water levels fluctuate summer to winter, the upper perforations should start below the lowest expected level. A 3/4- or 1-in. (2- or 2.5-cm) diameter pipe welded to the casing and extended from surface to below the packer permits sounding and temperature measurements in the annulus and is very useful in diagnosing well problems.

“Live water” is locally described as a hot water aquifer with sufficient flow and permeability to wash away the fines produced in a cable-tool drilling operation or major lost circulation in rotary drilling.

The space heating DHE is usually 1-1/2- or 2-in. (4- or 5-cm) diameter black iron pipe with a return U at the bottom. The domestic water DHE is 3/4- or 1-in. (2- or 2.5-cm) diameter pipe. The return U usually has a 3 - 5 ft (1 - 2 m) section of pipe welded on the bottom to act as a trap for corrosion products that may fill the U preventing free circulation. Couplings should be malleable rather than cast to facilitate removal (Figure 2).

Other DHE types in use are short multiple tubes with headers at each end and straight pipes extending to near the well bottom with coils of copper or steel pipe at the ends. In Reno, Nevada, many DHE wells are pumped by small submersible pumps to induce hot water to flow into the well. Systems for use with heat pumps circulate refrigerant in DHE

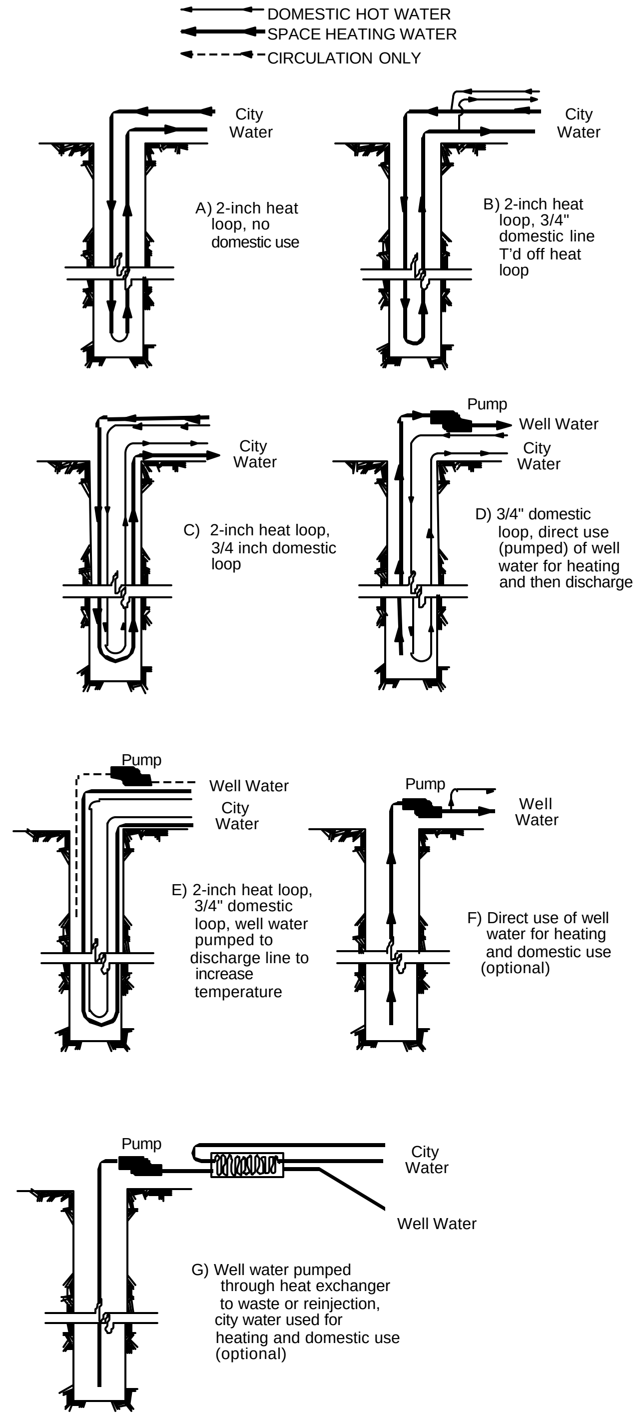

Figure 2. **Downhole heat exchanger systems (Klamath Falls, OR).**

pipes. A 20-kWt, 16-ft (5-m) prototype heat pipe system was successfully tested at least several months in the Agnano geothermal field in southern Italy (Figure 3)(Cannaviello, et al., 1982).

The first downhole heat exchanger, locally known as a coil, was installed in a geothermal well in Klamath Falls about 1930. The temperature of the well water and the predicated heat load determine the length of pipe required.

Based on experience, local heating system contractors estimate approximately 1 ft of coil per 1500 Btu per hr (1.4 kW/m) required as an average for the year. The "thermo-syphon" (or gravity feed in standard hot-water systems) process circulates the domestic 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 3 - 5 psi (0.2 - 0.35 bar) pressure difference in the supply and return lines to circulate 15 - 25 gal/min (1 - 1.5 L/sec) with a 10 - 20ºF (5 - 11ºC) temperature change.

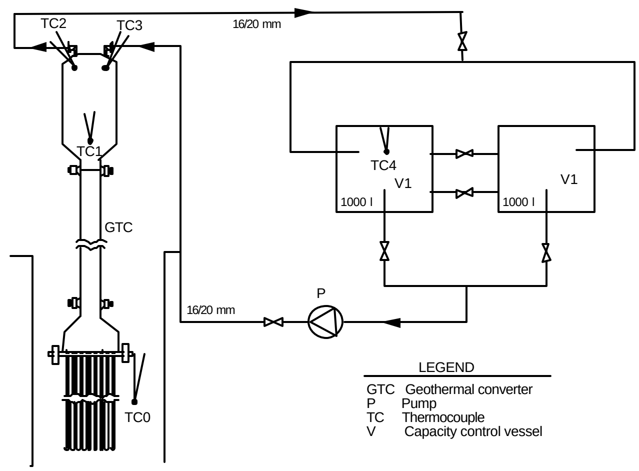

Figure 3. Experimental loop in Agnano, Italy.

There are several older or cooler wells that are pumped directly into the storm sewers or canal. In most cases, the well is pumped in order to increase the flow of geothermal waters and to raise the temperature of the well to a level locally considered satisfactory for use in space heating, about 140ºF (60ºC)(see Figure 2). In a few instances, mostly in the artesian area, well water is pumped directly through the heating system.

Considering life and replacement costs, materials should be selected to provide economical protection from corrosion. Attention must be given to the galvanic cell action between the groundwater and well casing since the casing is an expensive replacement. As indicated earlier, experience indicates that general corrosion is most severe at the air-water interface at the static water level and that stray electrical currents can cause extreme localized corrosion below the water. Insulated unions should be used at the wellhead to isolate the DHE form stray currents in the building and city water lines. Galvanized pipe is to be avoided since many geothermal water leach zinc and the anode-cathode relationship normally protecting steel in pipes reversed at 135ºF (57ºC)(Ellis, 1988).

Considerable success has been realized with non-metallic pipe, both fiberglass reinforced epoxy and polybutylene. Approximately 100,000 ft (30,000 m) of fiberglass reportedly has been installed in Reno at the bottom hole temperature up to 325ºF (163ºC). The oldest installations have been in about 10 years. The only problem noted has been National Pipe Taper Threads (NPT) thread failure in some pipe that was attributed to poor quality resin. The manufacturer has warranted the pipe including labor costs.

Although the thermal conductivity for non-metallic pipes is much lower, the overall heat transfer coefficient is a combination of the pipe thermal conductivity, film coefficients, and conductivity of any scale or corrosion products on both sides. Since the non-metallic pipe is smooth, does not corrode and scale does not stick to it, the overall heat transfer can be nearly as good.

Average DHE life is difficult to predict. For the 500 or so black iron DHEs in Klamath Falls, average life has been estimated to be 14 years; however, in some instances, regular replacement in 3 - 5 years has been required (Lund, et al., 1975). In other cases, installations have been in service over 30 years with no problems. Stray electrical currents, as noted above, have undoubtedly been a contributing factor in some early failures. Currents of several tens of milliamps have been measured. In others, examination of DHEs after removal reveals long, deeply corroded lines along one side of the DHE. This may be due to continual thermal expansion and contraction while laying against the side of an uncased well. Constant movement would scrub off protective scale exposing clean surface for further corrosion.

Corrosion at the air-water interface is by far the most common cause of failure. Putting clean oil, preferably turbine oil (because of environmental acceptability) as is used in enclosed-tube lineshaft pumps, or paraffin in the well appears to help somewhat, but is difficult to accurately evaluate.

For some reason, DHE wells are typically left open at the top. There appears to be no good reason they could not be sealed air tight. Once the initial charge of oxygen was used up in forming corrosion products, there would be no more available since there is essentially no dissolved oxygen in the water. Closed wells appear to extend the life of the DHE (Swisher and Wright, 1990).

Convection Cells

Although the interaction between the water in the well, water in the aquifer, and the rock surrounding the well is poorly understood, it is known that the heat output can be significantly increased if a convection cell can be set up in the well. Also, there must be some degree of mixing (i.e., water from the aquifer) continuously entering the well, mixing the well water, and water leaving the well to the aquifer. There are two methods of inducing convection.

When a well is drilled in a competent formation and will stand open without casing, an undersized casing can be installed. If the casing is perforated just below the lowest static water level and the near the bottom or at the hot aquifer level, a convection cell is induced and the well becomes very nearly isothermal between the perforations (Figures 4 and 5). Cold surface water and unstable formations near the surface are cemented off above a packer. If a DHE is then installed and heat extracted, a convection cell, flowing down inside the casing and up in the annulus between the well wall and casing, is induced. The driving force is the density difference between the water surrounding the DHE and water in the annulus. The more heat extracted, the higher the velocity. Velocities of 2 ft per second (0.6 m/s) have been measured with very high heat extraction rates; but, the usual velocities are between 0.04 and 0.4 ft per second (0.01 - 0.1 m/s).

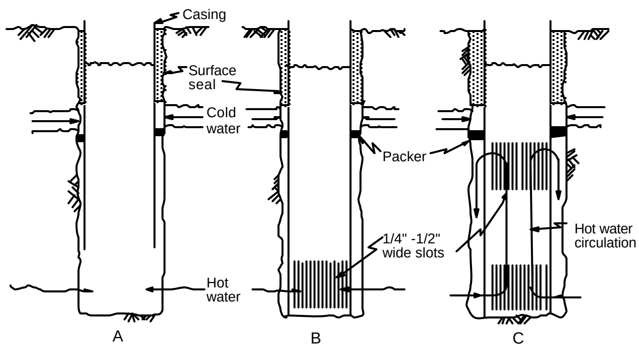

Figure 4. **Well completion systems for downhole heat exchangers (type c preferred).**

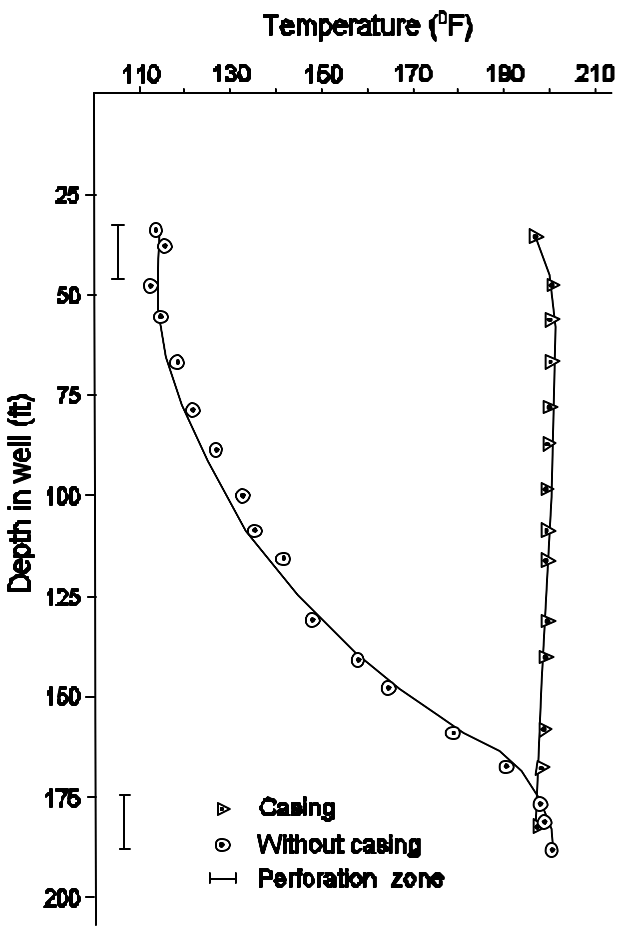

Figure 5. **Temperatures vs. depth for a geothermal well (with and without perforations).**

In Klamath Falls, it has been experimentally verified that when a well is drilled there is no flow in the wellbore. When the undersized perforated casing is installed, a convection cell is set up flowing up the inside of the casing and down the annulus between the casing and well wall. When a DHE is installed and heat is extracted, the convection cell reverses flowing down in the casing (around the DHE) and up the annulus. Similar circulation patterns were noted in New Zealand using convection promoters.

In New Zealand, where wells do not stand open and several layers of cold water must be cased off, a system using a convection promoter pipe was developed (Figure 6)(Allis and James, 1979). The convector pipe is simply a pipe open at both ends suspended in the well above the bottom and below the static water level. The DHE can be installed either in the convector or outside the convector, the latter being more economical since a smaller convector is used. Both lab and field tests indicate that the convection cell velocities are about the same in optimized designs and are similar to those measured in the undersized casing system. A summary of the New Zealand research is provided at the end of this section.

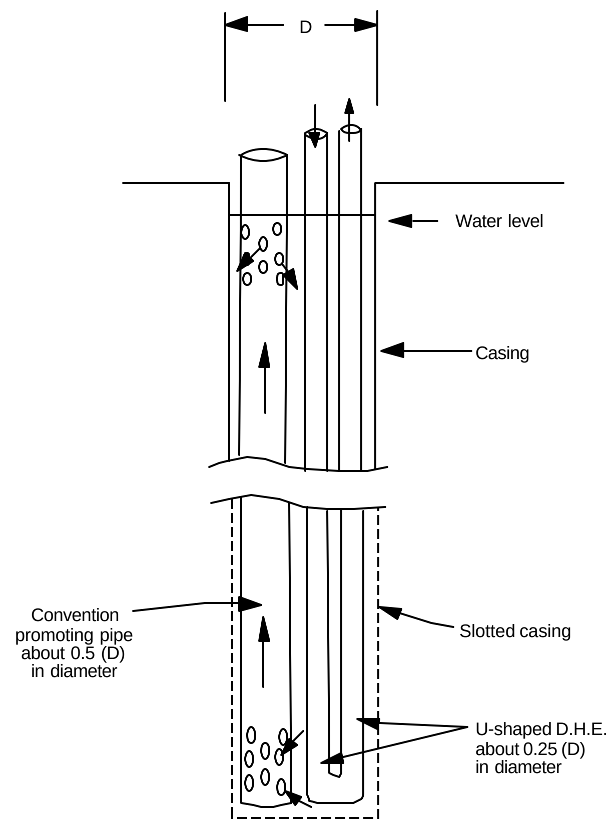

Figure 6. **Convector promotion and DHE (New Zealand type).**

Optimum conditions exist when frictional resistance due to wetted surfaces (hydraulic radius) is equal in both legs of the cell and DHE surface area providing maximum heat transfer. For the undersized casing and DHE inside the convector, this occurs when the casing or convector is 0.7 times the well diameter and 0.5 times the well diameter when the DHE is outside the convector. The full length U-Tube DHE is 0.25 times the well diameter in all cases. Partial length or multi-tube exchangers will have different ratios.

Maximum convection rates are obtained when the casing or convector pipe are insulated from each other. This maintains the temperature and density difference between the cell legs. Non-metallic pipe is preferred. Although corrosion products help insulate the pipe, scaling does not normally occur to any great degree since the casing or convector are the same temperature as the water.

Design Considerations

Downhole heat exchangers extract heat by two methods–extracting heat from water flowing through the aquifer and extracting stored heat from the rocks surrounding the well.

Once the DHE is extracting heat and a convection cell is established, a portion of the convecting water is new water entering the well–the same amount of cooled water leaves the well and enters the aquifer. The ratio of convecting water to new water has been termed the mixing ratio and is defined as:

$$RM = 1 - \frac{m\ add}{m\ total}$$

where:

Rm = Mixing ratio
m add = Mass flow of new water
m total = Total mass flow of convecting water

Note that a larger number indicates a smaller proportion of new water in the convection cell.

Mixing ratios vary widely between wells in the same aquifer and apparently depend on aquifer permeability. Also, as more heat is extracted, the mass flow rate in the convection cell increases; but, the mixing ratio appears to remain relatively constant up to some point, then increases with further DHE loading. This is interpreted as permeability allowing "new" hot water to enter the well or, more probably, allowing "used" cool water to sink in to the aquifer near the well bottom. At some combination of density difference and permeability, the ability to conduct flow is exceeded and the well rapidly cools with increasing load.

The theoretical maximum steady-state amount of heat that could be extracted from the aquifer would be when the mixing ratio equals zero. That is, when all the water makes a single pass through the convection cell and out the well bottom. Mixing ratios lower than 0.5 have never been measured and usually range from about 0.5 - 0.94 indicating little mixing. The theoretical maximum steady-state can be estimated if one knows the hydraulic conductivity and hydraulic gradient, and assumes some temperature drop of the water.

If K is the hydraulic conductivity (coefficient of permeability) and $\hat{I}h/\hat{I}l$ is the hydraulic gradient, by Darcy's Law, the specific velocity through the aquifer is given by:

$$v = K\, \hat{I}h/\hat{I}l$$

The mass flow through an area, A, perpendicular to the flow is therefore:

$$vAd = KAd\, \hat{I}h/\hat{I}l$$

where d is the density of water. The steady-state heat flow can be found by:

$$Q = KAdc(T_o - T_1)\, \hat{I}h/\hat{I}l$$

where:

A = Cross section of well in the aquifer or the perforated section
d = Density of water
c = Specific heat
T_o = Aquifer temperature
T_1 = Temperature of water returning to the aquifer

Multiplying the above by *Rm-1*, or about 0.4 to 0.5, one can determine the expected steady-state DHE output. The most important factor in the equation is *K*. This value can vary by many orders of magnitude–even in the same aquifer–depending on whether major fractures are intersected, drilling mud or debris partially clogs the aquifer, etc. The variation between aquifers can be even greater.

Based on short-term pump tests to determine hydraulic conductivity and an estimated 1% hydraulic gradient, the specific velocity in the Moana area of Reno is estimated at 1 to about 3 ft per year (0.3 - 1.0 m/yr)(Allis, 1981). The hot aquifer is generally encountered in mixed or interbedded layer of fine sand and silt stone. In Klamath Falls, on the other hand, where the hot aquifer is in highly fractured basalt and coarse cinders, specific velocity is estimated at 20 to 150 ft per day (6 to 46 m/day), perhaps higher in localized areas. Values of K in seven wells in Moana were estimated at 3×10^{-4} ft per second (1×10^{-7} meters per second). This implies a factor of 10 thousand to 10 million difference in the steady-state output. Indeed differences by a factor of 100 have been measured, and some wells in Moana have been abandoned because they could not provide enough heat even for domestic hot water.

Many DHE wells in Moana are pumped to increase hot water flow into the well. Pumping rates for residential use is limited to 1800 gallons per day (6800 L/day), and the pump is thermostatically controlled. This is designed to switch on the pump if the DHE temperature drops below some predetermined level, usually about 120ºF (49ºC). This method permits use of a well that would not supply enough heat using a DHE alone, yet minimizes pumped fluid and pumping costs. It is, however, limited to temperatures at which an economical submersible or other pump can be used.

Unfortunately, at the present time, there is no good design procedure. Culver and Reistad (1978) presented a computer program that appears to predict DHE output to within 10 - 15% if the mixing ratio is known. The problem is, there is no way of predicting mixing ratio except by experience in a specific aquifer and then probably only over a fairly wide range as noted above. The procedure was written in FORTRAN, but has been converted to HP-85 BASIC by Pan (1983), and later modified by Lienau and Culver as documented in Culver, 1990. The program enables optimum geometric parameters to be chosen to match a DHE to a load if one assumes a mixing ratio.

The program does not include a permeability variable nor does it take thermal storage into account. In wells with good permeability, thermal storage may not be a significant factor. Experience in Reno indicates that for low-permeability wells, thermal storage is very important and that with low permeability, a convection promoter can promote thermal storage and, thereby, increase non-steady-state output.

Permeability can be rather accurately estimated with relatively simple Hvorslev plots used in well testing. Relating the permeability thus obtained to mixing ratios typical in other permeabilities, could give an estimate of the mixing ratio one could use in the computer program. The problem is, there seems to be no middle ground data available, only very high and very low permeabilities, and precious little of that.

NEW ZEALAND EXPERIENCE WITH DOWNHOLE HEAT EXCHANGERS

Early Work by R. G. Allis and R. James (Allis and James, 1979)

The research of Allis and James was into the use of domestic wells, which were used for low-grade direct heating, and potentially powerful steam-water wells, which often had relatively cool water over most of their depth. Thermal convection was inhibited by the large aspect ratio (length to diameter ratio) of the well. The domestic wells could not use the Klamath Falls type downhole heat exchanger since the well had already been cased without perforations, and thus, heat could only be extracted over a very short length near the bottom. In a similar manner, deep high-temperature geothermal wells are sometimes difficult to discharge because of the great depth of cool water overlying the hot zone.

In their laboratory research, they found that, if a pipe (promoter) is inserted into their model of a well, natural convection will occur and the hot water will flow to the top of the well (Figure 7). The diameter of the pipe determined whether the hot water would flow up the pipe and down the annulus, or the reverse. The promoter pipe should at least be slotted on the lower end, especially if it rests on the bottom of the well.

The research also found that in domestic wells, the promoter pipe improved heat output by 60 to 120%, depending upon the diameter. The DHE in the annulus gave higher heat output from the DHE than if placed inside the promoter (Figures 8 and 9). The maximum flow (vertical) in the well occurs when the frictional pressure-drop in the promoter pipe equals that of the annulus. Thus, the promoter pipe should equal 0.5 the well diameter if the DHE is placed in the annulus and, should equal 0.7 the well diameter if placed inside the promoter. The DHE pipe should be 0.25 the well diameter (Figure 7). Using these recommended dimensions, the quantity of thermal energy available to the DHE is limited mainly by the existing bottom hole permeability. If the temperature of the well water is less than boiling (100ºC), then stiff plastic pipe can be used since it is a poor thermal conductor, and is also comparatively smooth.

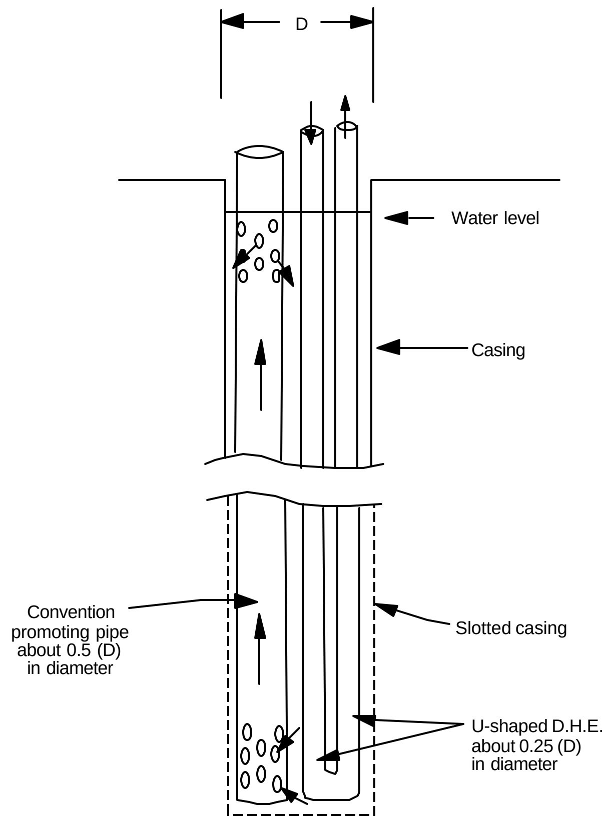

Figure 7. Scheme for optimizing the heat output of a DHE.

For potentially powerful (high-temperature) geothermal wells which are difficult to discharge, a 2-in. (5-cm) diameter pipe, positioned beneath the water level (Figure 10), should raise wellhead pressure (by promoting internal convection) to the point where controlled, spontaneous discharge is possible. This promoter pipe is placed approximately 160 ft (50 m) below the water surface and is slotted on both ends. Once the wellhead valve is opened and production conditions exist, the pipe should only slightly restrict vertical mass discharge which takes place both in the annulus and in the pipe.

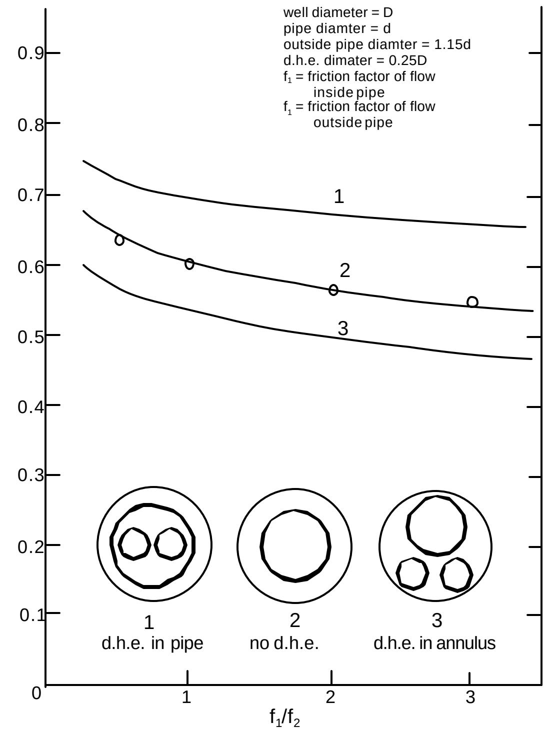

Figure 8. **Optimum diameter of the convection promoting pipe for varying friction factor ratio; in the three cross-sections, $f_2/f_1 = 2$. Refer to text for derivation of the 4 points and the curves.**

This method of stimulating vertical convection, and thus promoting uniform high temperature throughout the well column, is preferred instead of using a downhole pump or airlifting with the associated environmental problems of fluid disposal.

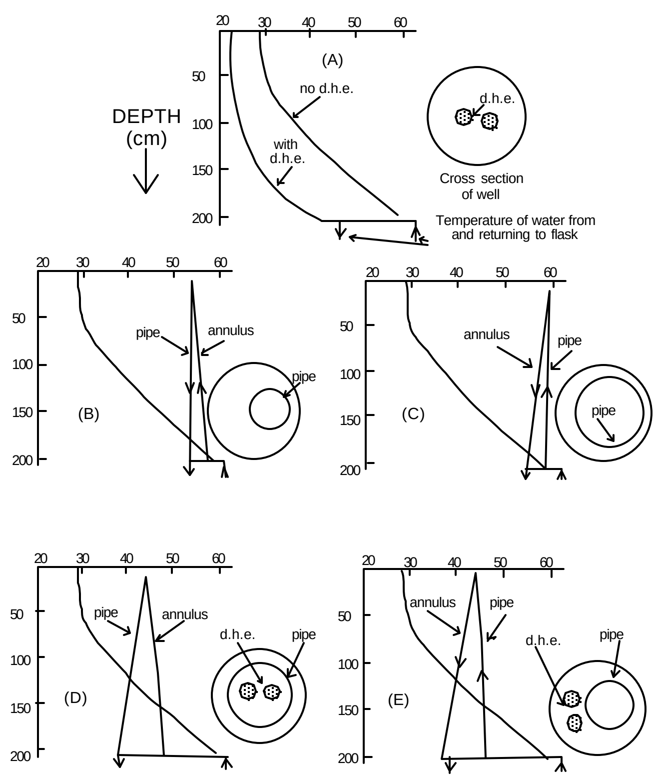

Figure 9. **Characteristic temperature and flow regimes observed in a laboratory model of a well; configuration of convection promoting pipe and/or DHE is shown in the cross-section in each case.**

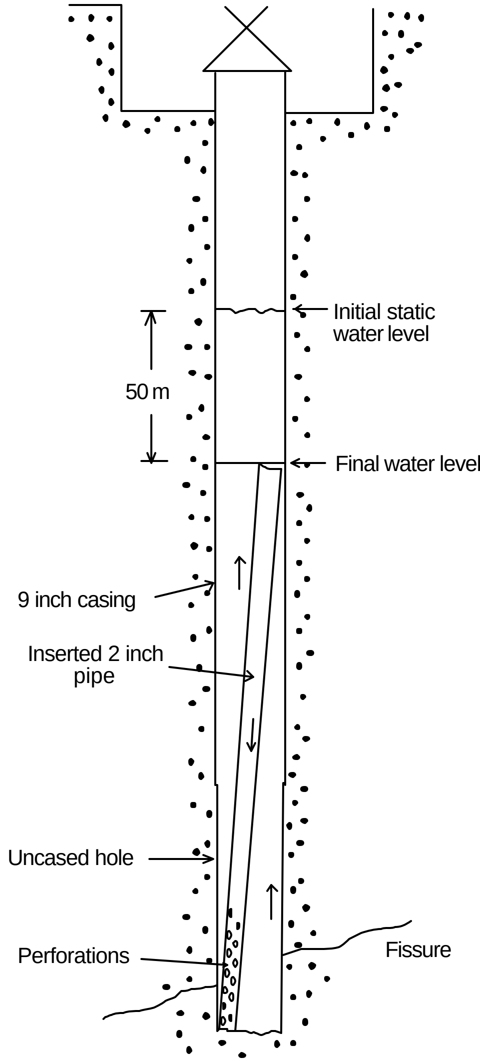

Figure 10. Scheme for promoting convection in a geothermal power well.

Experimental Work at the University of Auckland (Freeston and Pan, 1983)

The investigations of Freeston and Pan are based on both laboratory and field work in the Taupo area of New Zealand, and using results of work in the Moana area of Reno, Nevada (Allis, 1981). They looked at the heat transfer and flow mechanisms in the vertical convection cell of wells with DHEs. Conclusions were drawn from computer analysis and subsequent field testing. The work by Allis (1981) showed that in order to obtain 10 kW continuously for 24 hours (peak of 20 to 30 kW) from a DHE to supply a household from a 20-cm diameter well, 50-m deep in a reservoir where the hydraulic gradient was1%, a permeability of about 50 darcies (5×10^{-4} m/s) is necessary. Above 50 darcies, a promoter can be utilized; below, a small pump will be necessary. However, Allis did note that in wells with permeability below 50 darcies, the stored heat in the form of hot rock adjacent to the well may provide sufficient heat for days or even weeks. However, in the long-term, the well will cool off. The use of a convector pipe will not improve the long-term output of the DHE. A convector pipe only keeps the well water mixed and does not draw in fresh hot water. As mentioned above, these wells require some form of pumping to induce the required heat flow.

Based on their work and that of Allis, it was concluded that convective (vertical) flow must be favored instead of conductive (horizontal) flow between the promoters and the annulus, in order to maximize the output of DHEs. The relationship that best defined these conditions is:

$$D^o/L$$

where:

D^o = Diameter of the promoter pipe in cm
L = Length of the pipe in m

For $D^o/L < 1$, then conductive heat flow dominates.

For $D^o/L > 1$, then convective heat flow dominates.

Since heat flow should be convective, (1) long and small diameter promoters should be avoided as they do not generated significant circulation of the well fluid, and (2) it is best to have promoters with as large a diameter as possible, and use a low-conductivity material to get maximum vertical convection.

Field Work in Rotorua (Dunstall and Freeston, 1990)

A series of tests were conducted on a U-Tube DHE installed in a 100-mm diameter well which previously provided a steam/water mixture to heat a building in Rotorua. The field work was conducted to study the fluid temperatures inside the heat exchanger tubes resulting in a better understanding of the heat transfer processes involved in a typical Rotorua DHE/well system.

The DHE/well system consisted of a 123-m deep well cased to 112 meters with a bottom hole temperature of 160°C. A 25-mm diameter U-Tube produced a maximum output of 150 kW. The standing vs. DHE running (in operation) temperature profile of the well is shown in Figure 11.

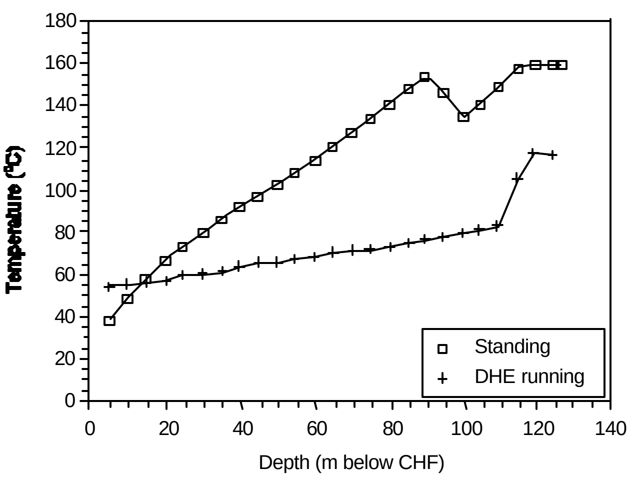

Figure 11. Downhole temperature.

The results of the test showed that the temperature increased below the uncased portion and thus, almost all heat exchange occurred at the feed zone. In the cased portion, heat was lost to the return leg (cold leg) of the DHE from the supply leg (hot leg) (Figure 12).

In order to prevent this heat loss, they recommended that either (1) the return leg from the casing bottom to the surface be insulated, or (2) that a smaller diameter return pipe be used, thus producing higher velocities inside it resulting in less heat loss.

The flow rate in the DHE was also varied from just above 0.4 L/s to 1.2 L/s (Figure 13). As was expected, the heat output in kW increased with flow rate; however, the typical output curve will flatten as flow rates become "high" (Figure 14). At "high" flow rates, the return temperature has a tendency to fall off, negating some of the gain, and pumping costs also increase. The likely increase in heat output would probably more than cover the increase pumping cost for moderate increases in flow rate. They concluded that the use of promoters would greatly enhance the well heat output.

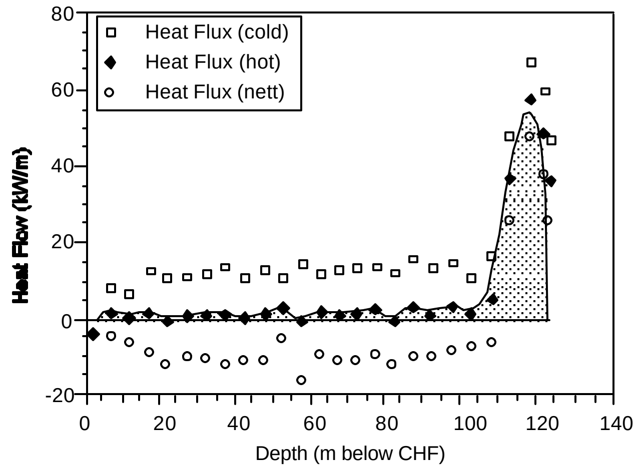

Figure 12. Heat flux (1.2 l/s).

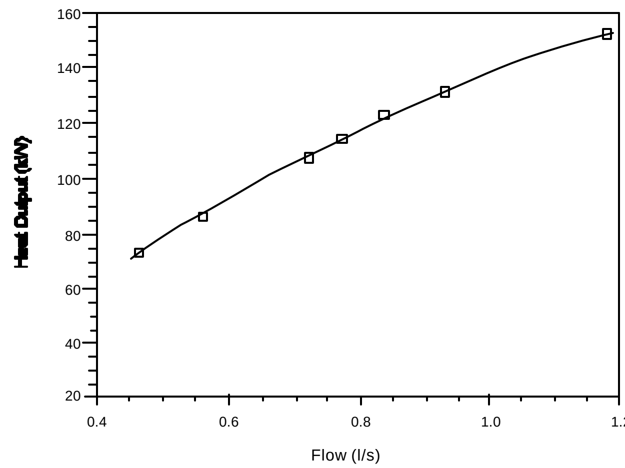

Figure 13. Heat output vs. flow rate.

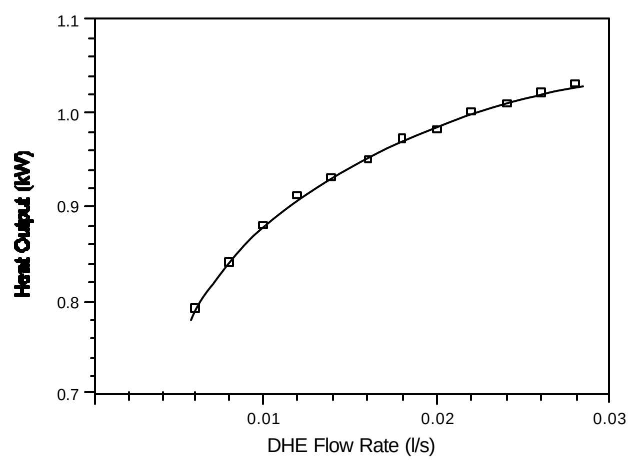

Figure 14. Typical output curve for a DHE (taken from numerical data by Pan, 1983).

Two different materials, copper and PVC, were used to construct two identical U-Tube DHEs, which were tested over a range of DHE flow and well aquifer cross-flow rates.

During most tests, a PVC convection promoter pipe was fitted in the well, to allow a bulk circulation of the well fluid. Various combinations of the DHE pipes inside and outside the promoter pipe were investigated. Some comparisons were made to results obtained during full-scale testing in a shallow Rotorua well.

The basic conclusion, as found by others, was that the output from the DHE increased with increasing cross flow in the aquifer at the well bottom and with increasing DHE flow rates. Both relationships appear nearly linear at low flow rates; but, the performance improvement tapers off as the flow rate increases (as was seen in the work by previous work by others discussed earlier). In larger diameter wells, the DHE supply (hot leg) temperature was less than the well temperature; therefore, there was no heat loss by conduction.

When a promoter pipe was installed, the bulk well circulation can be obtained in either a forward or reverse direction (Figure 15), with the forward direction (up the annulus and down inside the promoter pipe) yielding a higher heat output of the DHE by 10 to 20% (Figures 16 and 17). Thus, they recommended that the DHE return (cold) leg be placed inside the promoter pipe with the supply (hot) leg in the annulus to produce forward flow. Otherwise, forward flow may have to be stimulated by use of an airlift pump. It was also found that the heat output of the PVC DHE is quite high compared to the copper DHE, considering its thermal conductivity. This was due to the low percentage of the total heat transfer resistance represented by the tube and the face that no heat was lost in the return leg. Thus, they recommended that a hybrid DHE consisting of a copper supply and a PVC return leg be used to provide higher heat transfer rates, as compared to either of the single material DHEs

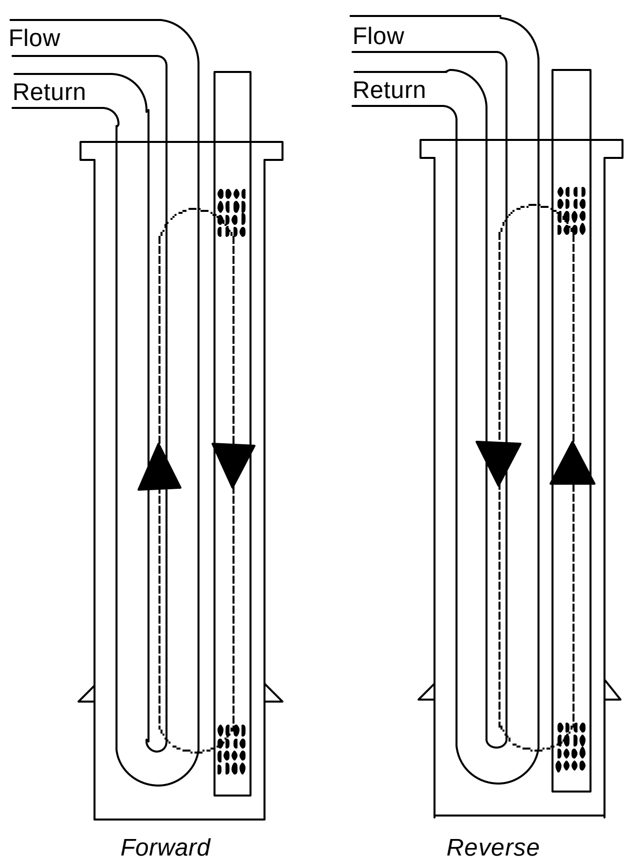

Figure 15. Circulation flow directions.

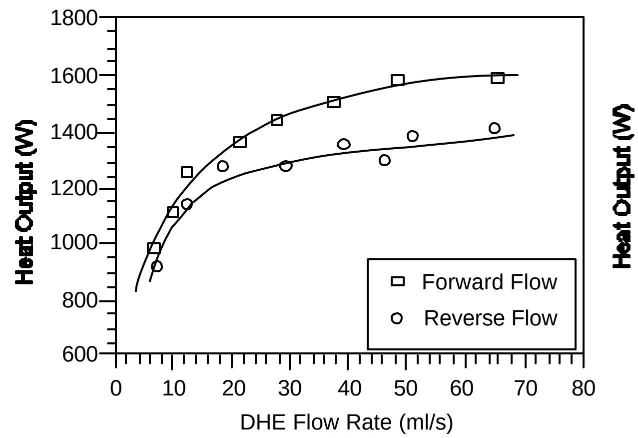

Figure 16. Heat output vs. DHE flow (32-mm promoter)(Cross-flow rate 25.8 ml/s).

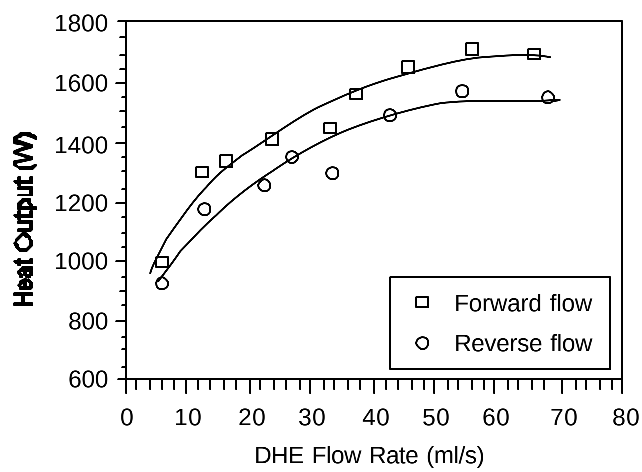

Figure 17. Heat output vs. DHE flow (32-mm promoter)(Cross-flow rate 31.4 ml/s).

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PHOTOGRAPHS OF TYPICAL DOWNHOLE HEAT EXCHANGERS AND HEATING SYSTEMS, KLAMATH FALLS, OREGON

Photographs by John Lund, Geo-Heat Center

Figure 1. Drilling a residential geothermal well with a cable drilling rig.

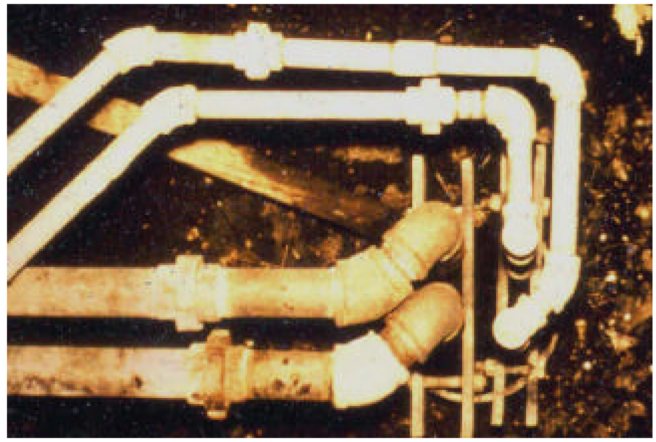


Figure 3. Looking down on a typical 8-in. (20-cm) diameter well casing with a 2-in. (5-cm) diameter space heating loop and a 3/4-in. (2-cm) diameter domestic hot water loop used for a single residence.

Figure 2. Placing a 2-in. (5-cm) diameter loop in a well.

Figure 4. Heating loop with mud leg at the U-tube return.

Figure 5. Installing the 3/4-in. (2-cm) diameter domestic hot water heating loop.

Figure 6. Heating system using forced air. DHE pipes enter at bottom right: forced-air heat exchanger at the top right (where a furnace used to be), expansion tank at top center, homemade shell-and-tube heat exchanger for the domestic hot water at the bottom center.

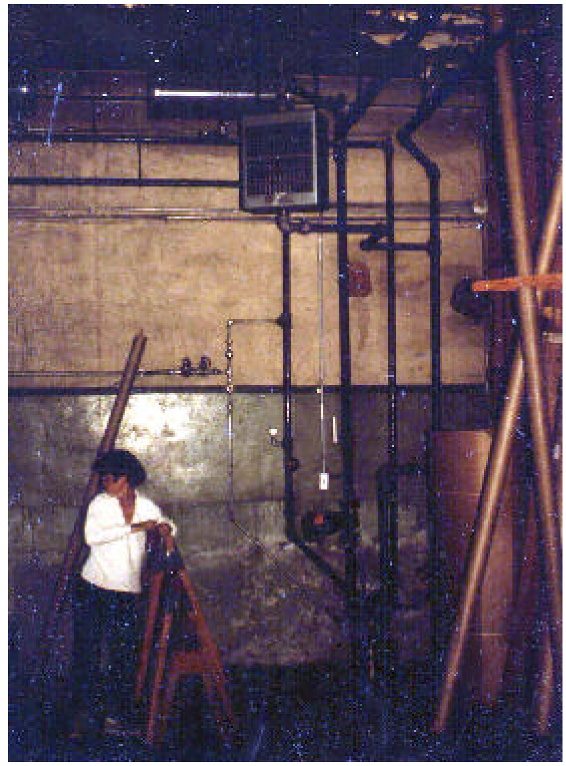


Figure 7. Commercial building heat system with two DHE heating loops entering the building at the bottom center; city secondary water entering through the pressure relief and pressure reducing valves on the left center; expansion tank at the upper center; and a finned-tubed unit heater at the top. The pipes run to other unit heaters throughout the building.

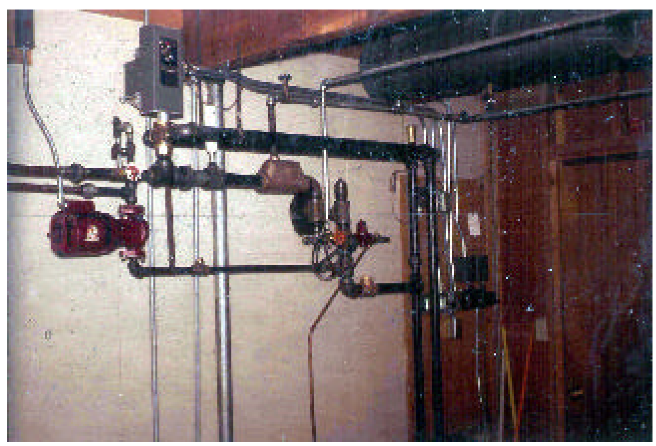


Figure 8. Residential heating system with a circulation pump. The DHE enters at the bottom right (large pipes) with the pump on the left; the thermostatically controlled valve at the upper center; and the expansion tank at the upper right.

INFORMATION FOR THE PROSPECTIVE GEOTHERMAL HOME BUYER

Kevin Rafferty
Geo-Heat Center

INTRODUCTION

This paper was written to assist new homeowners with geothermal heat in Klamath Falls. If you are not from the area, a geothermally-heated home may be something unfamiliar to you. This paper is intended to provide some background information to guide you through the purchase of a home equipped with a geothermal system.

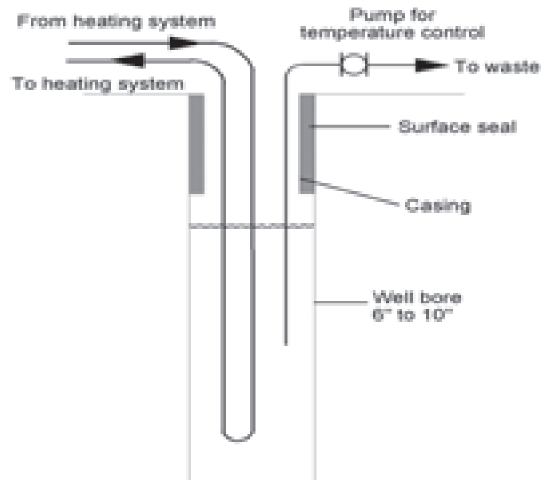
Geothermal energy resources and their use are not unique to the Klamath Falls area. Although our area is characterized by a high degree of development, many other areas of the western U.S. (Reno, NV; Boise, ID; Susanville, CA, for example) also have extensive geothermal resources and development. The geothermal hot water available here in Klamath Falls results from surface water circulating, through faults to a great depth at which the rock temperature is very high. Passing through this rock, the water is heated. Since hot water is less dense than cold water, it tends to rise toward the surface where it can be accessed through wells. Much of the geothermal water in town issues from a fault roughly oriented northwest to southeast between OIT on the north and Olene Gap on the south. The depth of hot wells in this area varies from just a few hundred feet to as much as 2000 ft. Temperatures are in the range of 100°F to 230°F with most home heating wells in the 150°F to 200°F range.

One aspect of geothermal that is somewhat unique to Klamath Falls is the use of the Downhole Heat Exchanger (also known as a DHE or a "loop"). This is simply a loop of pipe which is installed in the well and connected to the home's heating system. Water passes through the DHE, is heated and then passes through the homes heating system giving up its heat to the space. It is the returned to the DHE to repeat the process. This arrangement eliminates the need to pump water from the well (only heat is removed) and simplifies the system. It is limited to relatively small systems of the type that heat one home or a group of homes. It is also limited geographically. The performance of DHE's has been poor in other regions of the U.S. (notably Reno) where they have been tried.

The following paragraphs offer some more detailed comments on the systems and some suggestions for questions to ask of your agent or the existing homeowner which appear in **bold** type. There is little to be gained in having a well driller, plumber or Geo-Heat Center Staff inspect a system such as this. Asking the questions suggested below is a far more effective approach.

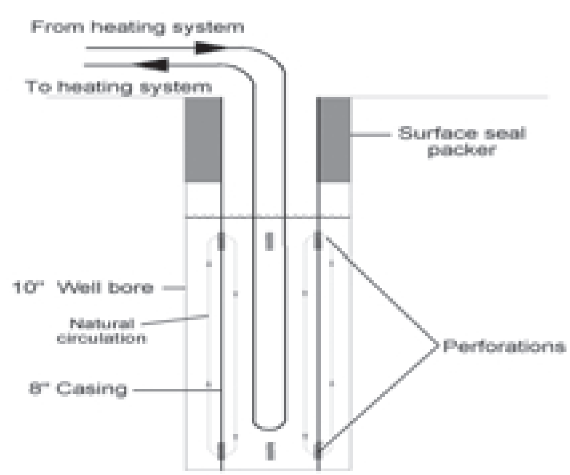
WELLS

There are two basic types of hot well construction. The older wells are simply a borehole in which a small amount of casing (20 ft to 100ft) is installed in the upper portion to seal off any cold water. The balance of the borehole is "open hole" - simply a cylindrical hole in the rock. In many of these wells, a small quantity of water was continuously pumped from the well to maintain temperature. This practice is no longer permitted under city ordinance (any water pumped from a geothermal well must be injected into another well).



Older Wells

Newer wells use a larger borehole diameter (12" or so) and a smaller diameter casing is subse-quently installed to the bottom of the well. Perforations are made in the casing just below the water level and near the bottom of the well. This leaves an annular space between the larger borehole and the smaller casing. The DHE is installed inside of the casing. As heat is removed from the well, the water around the DHE (inside the casing) is cooled and tends to fall to the bottom of the well. As this happens hot water entering the well rises up in the annular space. This natural movement of the water eliminates the need to pump water from the well to maintain temperature.



Newer Wells

Wells very rarely fail - at least to the extent that they are no longer useable. One condition that does occur from time to time in wells in the hillside area is referred to as a "cave in." The reality is a good deal less catastrophic than it sounds. Due to ground vibrations and natural erosion, an accumulation of soil and rock fragments can accumulate in the bottom of the well. Over a period of many years this material can build up and cut off or reduce the flow of hot water into the well thus reducing it's heating capacity. The remedy to this is to remove the DHE from the well, and have a driller "bail" the well. This is a procedure in which the driller lowers a tool called a bailer into the well to pick up the loose material that has collected in bottom. This procedure could be accomplished in a single day but most likely would require two days to complete. This is not a common problem. Of the 600 hot wells in Klamath Falls, probably less than 10 require bailing in any given year.

Buyers unfamiliar with geothermal often ask about the possibility of the geothermal resource cooling off over a period of years. This has not occurred in any well in the Klamath Falls area to our knowledge. The size of the heat source relative to the demands placed on it by the various uses is such that no detectable temperature change occurs.

DOWNHOLE HEAT EXCHANGER (DHE)

The DHE is usually constructed of ordinary carbon steel (sometimes called "black iron") piping. In most systems it is either 2" or 2 ½" diameter. If a domestic hot water heat exchanger is used, it is normally 3/4" or 1" in diameter. The length of the DHE varies with the depth of the well and the practices of the contractor at the time it was installed. A rule of thumb used in the past was that 1 foot of DHE was required for each 1500 Btu/hr of heating load.

The major concern with respect to the DHE is corrosion on the outside surface of the pipe. Because the pipe is submerged in hot water and exposed to air, corrosion is a natural occurrence. The result of this is that most DHE's will require replacement of the piping near the water line at intervals of 10 to 15 years. This is an average, with some wells causing failure of the pipe in as little as 5 years. Replacement of the piping requires the services of a water well pump company or a driller. A truck equipped with a tall "mast" and a winch is brought in and the piping is removed from the well and the corroded pipe replaced. This operation can normally be accomplished in 1 day. While the pipe is out of the well, it is a good opportunity to have a temperature log of the well performed. Time and equipment permitting, this is a service the Geo- Heat Center can perform at no cost to the homeowner.

Corrosion of the DHE piping, as mentioned above is a result of the exposure of the wetted pipe surface to the air. For many years, well owners poured old motor oil, paraffin and other substances down the well to coat the pipe in an attempt to reduce corrosion. For obvious environmental reasons this practice is not recommended. Recent research has indicated that simply sealing the top of the well to prevent the entrance of air (which is the fuel for the corrosion reaction) is a more effective strategy. This can be easily accomplished with the "foam in a can" type products often used for home weatherzation.

Obviously one of the pieces of information that you would want to request from the seller is the last time the DHE piping was serviced and/or replaced.

HOMES CONNECTED TO A MULTI-HOME SYSTEM

There are many systems in Klamath Falls in which several homes are connected to a single well. In most cases, these systems serve from 2 to 5 homes. There are several areas about which you should seek information.

Most multi-home systems involve a network of buried pipe to deliver the hot water to each home. This piping is usually uninsulated carbon steel pipe. Just as in the case of the DHE, external corrosion of this pipe is a common occurrence. Several of the systems have experienced leaks in the buried piping after approximately 15 years of service. Repair of these leaks requires first locating the leak and then excavating the site (the pipe is normally about 3 to 4 ft deep) and replacing the failed pipe. **For homes on such a system it would be advisable to determine the age of the system, whether there is an accurate layout of the buried piping and if there have been any failures to date.**

As a result of the need to periodically maintain the system, it is useful to have a formal agreement between the owners of homes connected to such a system. In this way, there can be no confusion as to the equitable distribution of costs when repairs are necessary. **You should determine whether such an agreement is in place and you may wish to have your attorney review the document.**

The agreement may also cover the distribution of costs associated with the operation of the main circulating pump. Some systems have a single circulating pump which delivers hot water from the well to all the homes connected to the system. This is the least complicated and most trouble free arrangement. A second design involves the use of a pump at each home. This design can result in the individual pumps "fighting each other" and the most water going to the home with the largest pump.

CONTROLS AND SEQUENCE OF OPERATION

Each geothermal system is unique and the specifics of it's installation are a reflection of the contractor responsible for it and the period in which it was installed.

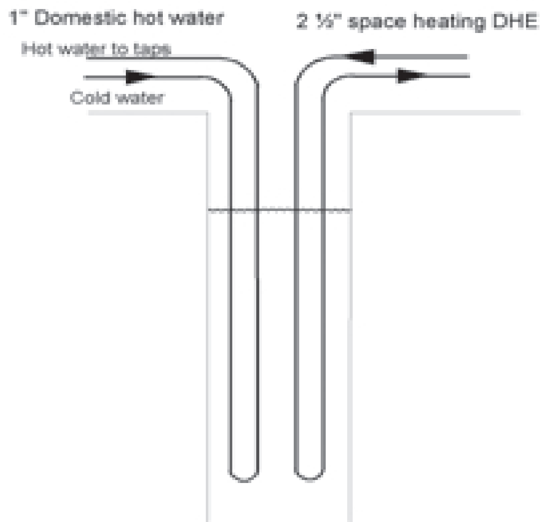
The simplest systems are the so called "thermosyphon" designs. These systems operate without the use of a circulating pump and rely only on natural convection to circulate the water through the piping. In most cases, the only controls are individual hand valves on the radiators or a main control valve that responds to the thermostat. These are the oldest systems and are generally found only in homes served by a single well.

Newer systems that use a pump to circulate the hot water, often have more complex controls. In addition, systems serving more than one home have the added complexity of controls to assure that the water is distributed evenly among the individual homes. Since no two systems are the same, it is important for the existing owner (who is the most familiar with the operation) to pass this information along to the new owner.

It is important that the seller provide a complete set of instructions (and preferably a diagram identifying the control and shut off valves) along with any periodic or seasonal adjustments that are necessary.

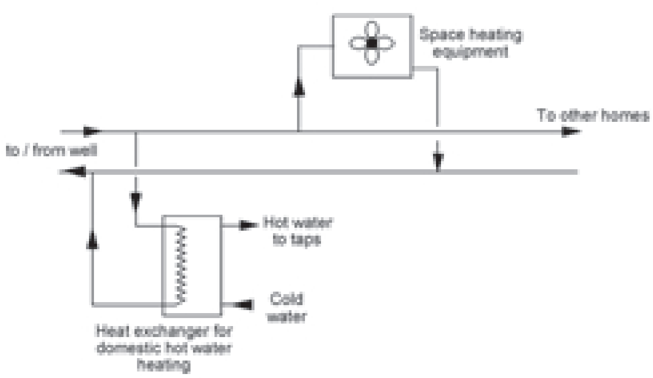
DOMESTIC HOT WATER

As discussed above, one method for heating domestic hot water is the use of a separate DHE specifically for that purpose.



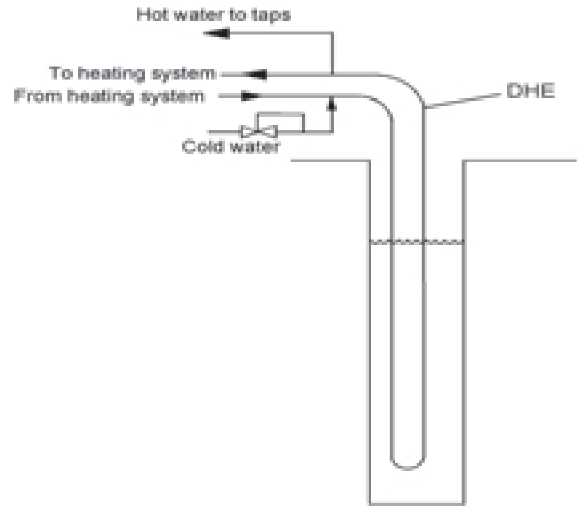
Separate Domestic Hot Water with DHE

The second approach to domestic hot water heating is the use of a heat exchanger. This is the design used on most systems serving more than one home. A heat exchanger is a device that transfers heat from one stream of water to another without the two streams mixing. For the heating systems in Klamath Falls, water from the DHE loop is passed through one side of the heat exchanger and cold city water is passed through the other side to be heated.

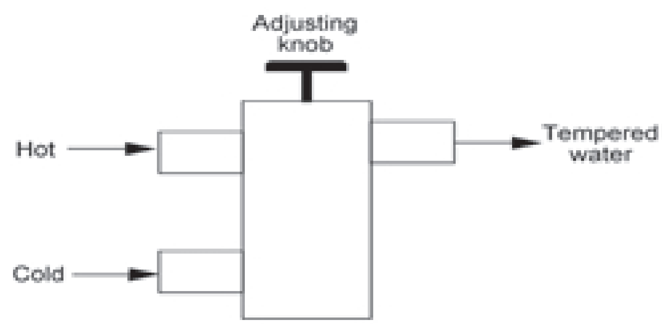


Multi-Home System

A third approach is to draw water directly from the space heating DHE. As hot water is drawn from the taps, cold water is admitted to the loop to make up the difference. This method was common in the earliest systems but is rare today.



With all three of these designs it is possible for the water at the tap to approach the well water temperature. In some cases, this would result in a temperature of 180°F or more. In most homes, plumbing systems have been equipped with a device called a tempering valve. This valve serves to limit the maximum water temperature delivered to the taps by mixing hot and cold water. If small children will be living in the home, it would be advisable to verify that a tempering valve is in place.



Tempering Valve

FOR MORE INFORMATION

If you have additional questions, please don't hesitate to contact the Geo-Heat Center at 541-885-1750 voice, 541-885-1754 FAX or geoheat@oit.edu.

LARGE DOWNHOLE HEAT EXCHANGER IN TURKEY AND OREGON

John W. Lund
Geo-Heat Center

TURKEY

Downhole heat exchangers have been used extensively in Turkey from 1981 to 1990. One of these installations is part of the geothermal district heating system in the city of Balçova near Izmir on the west coast of Turkey. These downhole heat exchangers are some of the largest in the world in terms of energy output. During the period 1981 to 1997, there were 11 DHE installations in Turkey, but now there are only five - two in Simav and three in Balçova. These five sets consist of multiple bundles of pipes in a well (Fig. 1). Typically, two to four sets of reverse bend loops are installed in each well, and these loops are then attached to a common header to supply heat to the building (Fig. 2).

Figure 1. **Downhole heat exchanger being removed from a well at Balçova.**

Figure 2. **Details of header pipe attached to the top of the DHE in Balçova.**

The wells in Balçova are 100 m (330 feet) deep and the heat exchanger pipes are about 10 m (33 feet) long (Fig. 3). Since the beginning of 1998, the three DHE in Balçova have the following characteristics:

Well No.	Output	Bottomhole Temp. °C	Cyclic Temp. °C	Flow Velocity in the Loop (m/s)	No. Loops
B-1	1 million kcal/hr 4 million Btu/hr 1.16 MWt (13.8 kg/s -219 gpm)	114 (237°F)	70/50 (158/122°F)	3.5 m/s (11.5 ft/s)	2
B-5	0.56 million kcal/hr 2.2 million Btu/hr 0.65 MWt (7.7 kg/s - 122 gpm)	124 (255°F)	70/50 (158/122°F)	1.9 m/s (6.2 ft/s)	2
B-7	0.40 million kcal/hr 1.6 million Btu/hr 0.46 MWt (5.5 kg/s - 87 gpm)	114 (237°F)	70/50 (158/122°F)	1.4 m/s (4.6 ft/s)	2

The well shown in Figures 1 through 3, had three loops of DHEs and could produce as much as 2 million kcal/hr (8 million Btu/hr) or 2.3 MWt at a flow rate of 2.0 m/s (6.6 ft/s).

Figure 3. **Downhole heat exchanger pipes used for one well at Balçova.**

At Seferhisar, a self flowing well produced 200 ton/hr, but sealed itself due to carbonate scaling in a short time. In order to avoid the scaling, a DHE was installed and tested. With a bleed rate of approximately 5 L/sec (79 gpm), the well produced 5 MWt. The DHE flow rate was adjust to maintain 70 to 80°C (158 to 176°F) water for use in heating greenhouses. The characteristics of the well was as follows (it is no longer being utilized) (Culver, 1990):

Depth:	250 m (820 ft)
Casing:	30 cm to 200 m (11 3/4 inch to 660 ft) 22 cm (8 5/8 inch) open hole to total depth slotted 60 to 200 m (196 to 660 ft)
Bottom Hole Temp:	153°C (307°F)
Shut-In Pressure:	2.5 bars (36 psi)
DHE:	4 loops 5 cm diameter to 187 m (2 inch diameter to 614 ft)

After 1990, other developments in geothermal energy utilization reduced the use of the DHEs. The main reasons were: (1) the availability of downhole pumps for high temperature, (2) the use of chemicals to prevent scaling and corrosion, and (3) based on tests, the output capacity of a DHE is only 1/7 compared to an artesian well or a well with a downhole pump.

OREGON

A model of DHE using multi-tube pipes feeding into a common header was tested in Klamath Falls. The four loops of 2.5-cm (1 inch) diameter pipes were 6.8 meters (22 feet) in length (Figs. 4 and 5) and had a flow volume of 1.7 L/s (27 gpm) through the DHEs. With a 13 L/s (205 gpm) of convection cell circulation, the output was 380 kW. As can be seen from the photographs the multiple tube unit was attached in a circular header which in turn was attached to two 5 cm (2 inch) diameter pipes. The circular header was smaller in diameter than the well casing; thus, it could be lowered in the well to below the upper set of casing perforations and the water line (Culver and Reistad, undated)(Figure 6).

Figure 4. **Details of the multiple loop installation with circular header.**

Figure 5. **Test project using multiple loops being lowered in the well.**

The largest DHE installation in Klamath Falls, supplies space heat and domestic hot water for a middle school. The well is 152 m (500 ft.) deep, 36 cm (14 in.) in diameter with 92°C (198°F) water. Two 5.6-kW (7.5-hp) pumps circulate 33 L/s through a 122-m long, 7.5 cm diameter (3 inch) and two 5-cm diameter (2-inch) DHEs (Fig. 7). The system will provide 1.2 MWt output.

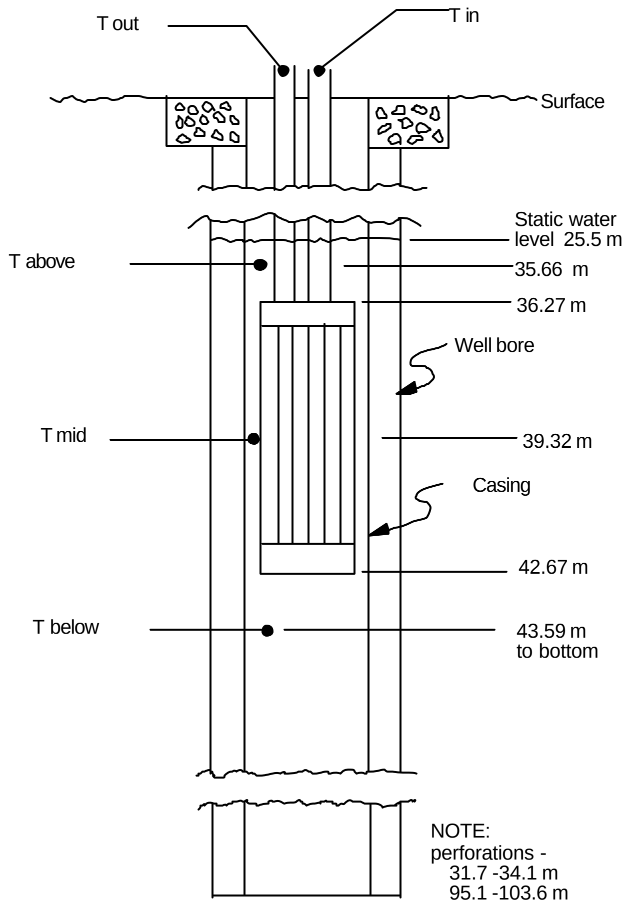


Figure 6. **Diagram of the multi-tube DHE installation in Klamath Falls (T = temperature measuring points).**

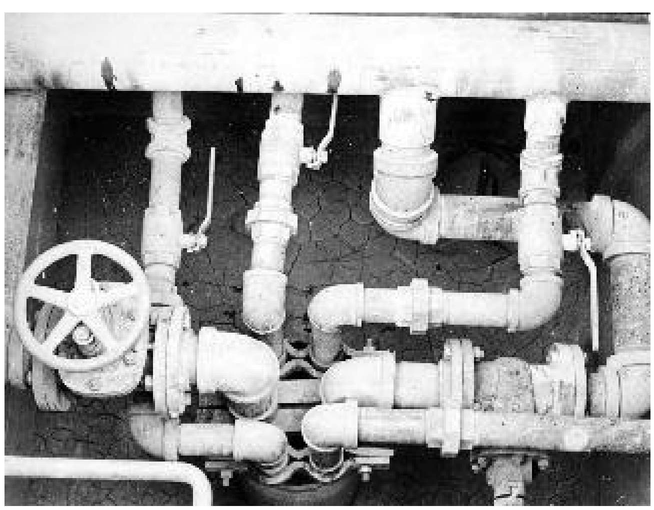


Figure 7. **Ponderosa middle school multiple DHE installation.**

CONCLUSIONS

The multi-tube DHE is more economical to install in shallow wells with high-static water levels; since, it can be installed with lighter equipment and has a high output for its short length, so does not require drilling beyond the hot aquifer when the aquifer is near the surface. The vertical convection in the well must also be high to provide adequate heat transfer to the loops. For energy outputs for large demands, the DHE is normally not adequate and thus, some form of pumping with a surface heat exchanger is necessary.

ACKNOWLEDGMENTS

The author would like to thank Dr. Orhan Mertoglu and Ms. Nilgün Bakir of Orme Geothermal, Inc., Ankara, for providing the information and photos of the Balçova project. Information on the Seferhisar installation is from Dr. M. F. Akkus of the Mineral Research and Exploration Institute, Energy Department, Ankara.

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EXAMPLES OF INDIVIDUAL DOWNHOLE HEAT EXCHANGERS SYSTEMS IN KLAMATH FALLS

John W. Lund
Geo-Heat Center

INTRODUCTION

The downhole heat exchanger (DHE), used extensively in Klamath Falls in over 500 installations, provides heating for one or more homes from a single geothermal well. The DHE eliminates the problem of disposal for geothermal fluids, since only heat is taken from the well. The heat exchangers consists of a loop of pipe or tubes (locally called a coil) suspended in the geothermal well through which "clean" secondary city water is pumped or allowed to circulate by natural convection. These systems offer substantial economic savings over surface heat exchangers where a single-well system is adequate. The maximum output of large installations is typically less than 2.73 x 10^6 Btu/hr (2.88 x 10^6 kJ/hr) or 0.8 MWt, with well depths up to about 500 feet (150 m), and may be economical under certain conditions at well depths of 1500 feet (450 m). However, typical DHE output for individual homes tends to be less than 250,000 Btu/hr (260,000 kJ/hr) or 0.07 MWt.

In order to obtain maximum output, the well must be designed to have an open annulus between the well bore and the casing, and perforations above and below the heat exchanger surface - just below the water surface and at the hot aquifer. The cross-sectional area of the annulus and the casing should be about equal, with the area of the perforations twice this area. Natural convection circulates the water down inside the casing, through the lower perforations, up in the annulus and back inside the casing, through the upper perforations, with new geothermal water mixing with the old (Fig. 1).

If the design parameters of the bore diameter, casing diameter, heat exchanger length, tube diameter, number of loops, flow rates and inlet temperature are carefully selected, the velocity and mass flow of the natural convection cell in the well may approach those of a conventional shell-and-tube heat exchanger. Based on experience, local heating system contractors estimate approximately 1 foot of DHE pipe per

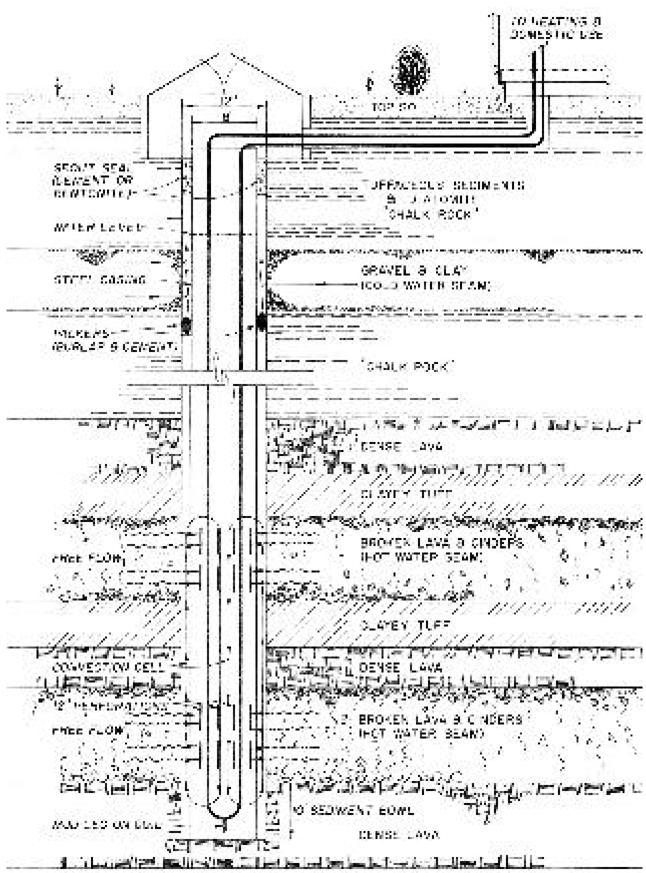

Figure 1. Typical downhole heat exchanger (DHE) installation.

1,500 Btu/hr (1.4 kW/m) as an average output. Thermo-syphon circulation will provide 3 to 5 psi (0.2 to 0.35 bar) pressure difference in the supply and return lines to circulate 15 to 25 gpm (0.9 to 1.6 L/s), with a 10 to 20ºF (6 to 11ºC) temperature change. Circulation pumps are required in cooler wells or in larger systems to increase the flow rate and system heat output.

The following description are of two systems in Klamath Falls, illustrating a basic installation and a more complex one. Both installations, located in the "Hot Springs" area of the city, have a well that supplies heat to two homes, but the design would be similar for just one home using the well.

BASIC INSTALLATION

This basic installation uses a well to provide heating for two adjacent homes using three DHEs. The well is 200 feet (60 m) deep, a temperature of 196º F (91ºC) at the top, 204ºF (96ºC) at the bottom, and a static water level of 75 feet (23 m) below the casing top. It was drilled in 1954 and cased to the bottom with a 10-inch (25-cm) diameter casing. The casing is torch perforated just below the water surface and at the bottom of the well in the live water area. The perforations are about 0.5 inches (1.2 cm) wide and 6 inches (15 cm) long for a total distance of about 15 feet (4.6 m). The casing is sealed with cement from the surface down to 21 feet (6.4 m), and then the annulus is open below this point providing about a 1-inch (2.5-cm) clearance.

Originally there were four heat exchangers in the well, two 2-inch (5-cm) diameter closed-loop pipes for space heating and two 3/4-inch (2-cm) diameter open loop pipes for domestic hot water heating - one set for each home. After 19 years of service, the black iron pipe DHEs were replaced due to corrosion at the water line. The two 2-inch (5-cm) diameter heating pipes were replaced with a single 2.5-inch (6.4-cm) diameter heating loop which is now shared by both homes. The present configuration is shown in Figure 2. Several pounds of paraffin, place in the well annually, were used to prevent corrosion at the air-water interface. In addition, a steel cap on top of the casing also helps prevent the introduction of air into the well, which is the recommended solution to prevent corrosion since paraffin can pollute the aquifer. The DHEs, which were replaced in 1974 (Fig. 3), are still in service.

Figure 2. **Well with three DHEs, a single 2-inch (5-cm) pipe used for space heating and two 3/4-inch (2-cm) pipes used for domestic hot water.**

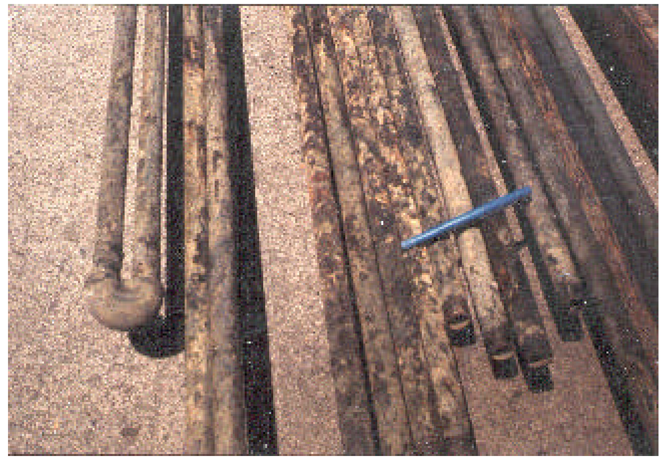

Figure 3. **Corrosion and pitting of DHE replaced in 1974. Note the reverse loop at the bottom of the heat exchanger.**

The space heating system consists of baseboard hot water radiators on a two-pipe system with flow control valves on each heating unit. A motorized valve on the return leg of the heating loop controls the flow via a thermostat (Figure 4). Recently, a solid state controller hooked to a storage battery

Figure 4. **Two loops from the DHE entering the home from the well–one for space heating and the other for domestic hot water.**

was installed, in case of a Y2K power failure, as seen in Figure 5. A 10-gallon (38 liter) expansion tank is connected to the high point in the heating system and a pressure reducing and relief values are part of the cold water supply line used to fill the domestic hot water loop and to initially fill the heating loop. Note that there is no hot water storage for the domestic hot water, and that there is no circulation pump on the space heating loop, as just the flow through the respective DHE is adequate. The entire system is diagramed in Figure 6.

Figure 5. Motorized control valve, solid state controller and expansion tank - the pressure reducing and pressure relief valves in the foreground.

The original cost for the well and DHEs in 1954 was about $2,400, and the estimated cost at today's prices is $10,000 for the well and casing and $3,000 for the three DHEs. The annual O & M costs are only for the electricity to run the motorized valve and the equivalent annual cost of replacing part of the DHE on about a 20- to 25-year interval, amounting to probably less than $100 per year.

The estimated annual heating and domestic hot water costs for the two homes at about 4,500 square feet total (420 square meters) of heated space using natural gas would be about $1,600 per year or $2,400 per year for electricity (the common alternatives in Klamath Falls), plus $5,000 for the capital cost of two furnaces and hot water heaters. This would give simple payback of about 5.5 and 3.5 years respectively and at 7% interest on investment of about 7 and 4 years respectively at today's cost. Deeper wells will obviously make the payback period longer -- the simple payback period for a 500-foot (150-m) deep well would be approximately 13 and 8 years respectively. Thus, deeper wells need more customers or a high heating demand to justify the investment.

COMPLEX INSTALLATION

A second home, approximately one mile (1.6 km) away, has a much more complex heating system, which also has a well shared by a neighbor.

A 375-foot (114-m) deep well was drilled in 1981. The bottomhole temperature was 204ºF (96ºC) and the static water level at 220 feet (67 m) below the surface. The well was completed with an 8- inch (20-cm) diameter casing to 130

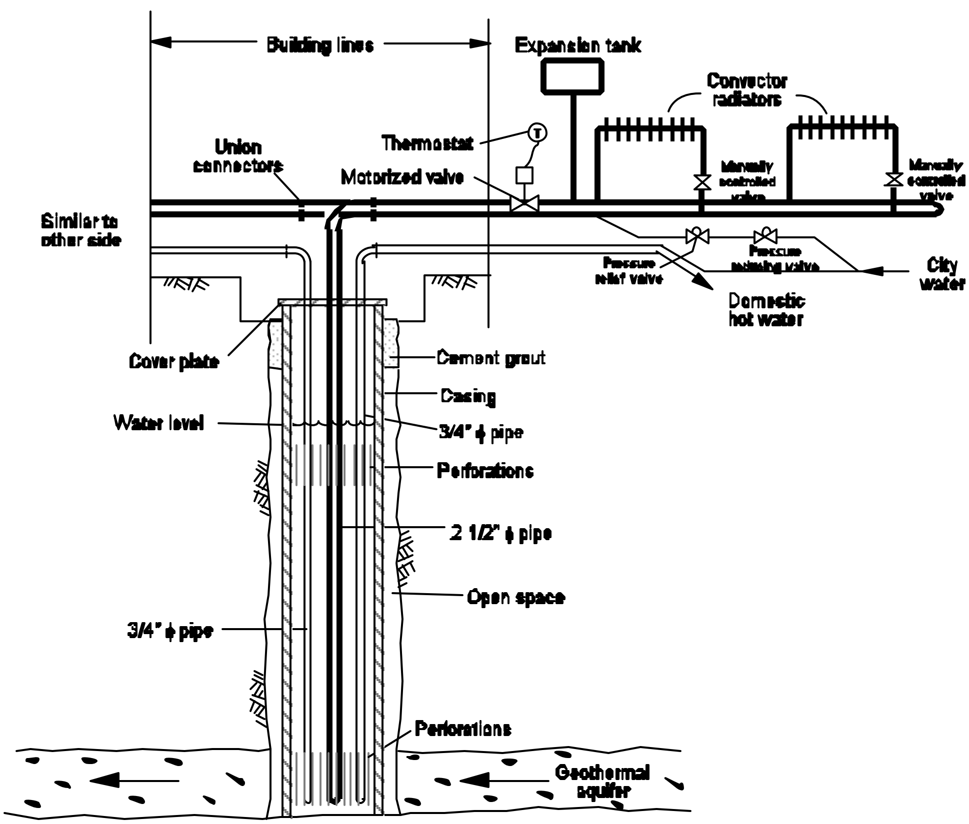

Figure 6. Diagram of the entire system for the basic installation.

feet (40 m) and a 6-inch (15-cm) diameter liner from top to the bottom. This allowed about a 1-inch (2.5-cm) clearance between the casing and annulus below the water surface. The 8 inch (20 cm) casing was sealed with a cement-bentonite mixture fromthe land surface to 130 feet (40 m). The 6 inch (15 cm) casing was perforated from 235 to 255 feet (72 to 78 m) and from 355 to 375 feet (108 to 114 m) below the surface. Geothermal water was first encountered at 250 feet (76 m), thus, as in most instances in Klamath Falls, the aquifer is subartesian.

A single 2.5-inch (6-cm) DHE 357 feet (109 m) long was placed in the well and then teed off at the top of the well to provide a supply to each home (Fig. 7). A 2-inch supply line was run into the house where a 1/4 hp (0.2 kW) circulation pump controlled by a thermostat was inserted on the return leg of the DHE to provide adequate heat supply. The other house is supplied from the tee at the well by a 2-inch (5-cm) diameter pipe. The closed loop supply from the DHE is circulated to three different uses: (1) for space heating by a forced air unit (a previous gas fired furance), (2) for heating domestic hot water, and (3) an for heating an outdoor spa of about 500-gallon (1,900-liter) capacity. The domestic hot water uses the original gas water heater as a storage tank, which is in turn supplies heated water through a shell-and-tube heat exchanger. The flow in the circuit between the shell-and-tube heat exchanger and the water storage unit is assisted by a second 1/4 hp (0.2 kW) circulation pump controlled by a thermostat (Fig. 8). The spa water is heated by another shell-and-tube heat exchanger, with flow controlled by a thermostat. Heated water can also be supplied to an outside faucet to provide heated water for rapidly filling the spa, when needed.

Figure 7. **Well head with a single DHE and two supply lines.**

The system has the standard water supply from city water through pressure reducing and pressure relief valves. The expansion tank is located at the high point in the system in the ceiling. The heated water supplied by the DHE to the house can reach about 175ºF (80ºC) and the pressure is about 8 psi (55 kPa) (Fig. 9).

Figure 8. **The interior mechanical system showing the domestic hot water shell-and-tube heat exchanger on the right and the water storage tank on the left. The pipes from the DHE enter at the top- center of the photograph. Circulation pumps can also be seen in the center top.**

The cost to drill the well and install the downhole heat exchanger with piping to the houses in 1981was almost $12,000 of which $2,000 was for the DHE and associated piping. Each owner paid half this amount. The mechanical system in the house cost about an additional $2,000. In 1990 the owner had to repipe the supply line and do some minor repairs for about $1,000. The original DHE is still in service. At today's prices, the well and DHE would cost $18,000 and the mechanical system each about $3,000. The total area for the two houses is about 5,000 square feet (465 square meters) with high beam ceilings, which would cost around $2,000 and $3,000 per year to heat with natural gas and electricity respectively (including the spa at each house). The annual O&M cost, mainly to run the circulation pumps would be about $300. The alternative capital cost of furnaces and water heaters using either natural gas or electricity, would be about $6,000 total. This would give a simple payback of 10.5 and 6.5 years respectively. At 7% interest on investment, the payback period would increase to 21 and 9 years respectively.

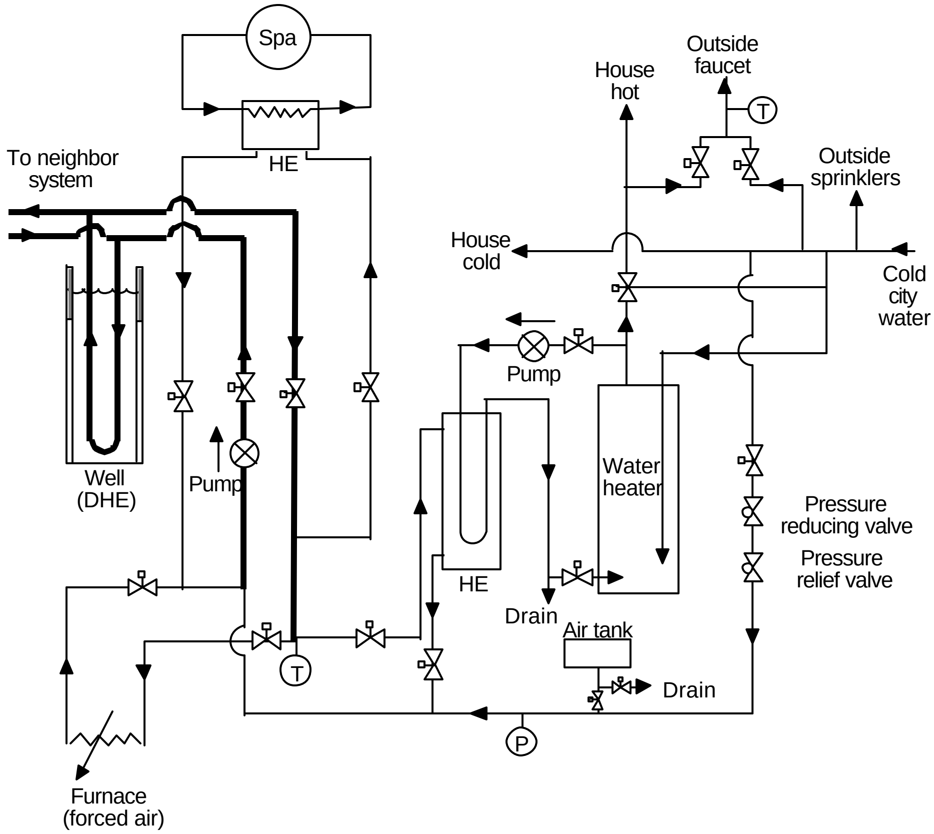

Figure 9. Diagram of the entire system for the more complex installation.

At the time of the installation of the system, there were both state and federal tax credits available for alternate energy home heating and cooling systems. The Oregon tax credit was 25% of the installation cost, up to $1,000. The federal tax credit was 40% of the cost up to a maximum credit of $4,000. Thus, each homeowner probably took a $5,000 credit, reducing the simple payback to approximately 8 years compared to natural gas and 5 years compared to electricity.

The main differences between this system and the basic installation, is that it has circulation pumps and provision for domestic hot water storage along with spa water heating. It does not require separate DHEs for domestic hot water, but instead has shell-and-tube heat exchangers in the homes. As can be seen, but comparing with the basic example, the payment period increases to the point where it may not be economical due to the deeper well, unless long term investment or rises in natural gas and electricity prices are anticipated. The alternative energy tax credits did make the system economical to install, and was the main reason for drilling the well in 1981.

GEOTHERMAL PIPELINE

Progress and Development Update
Geothermal Progress Monitor

MEETINGS

International Geothermal Days - Oregon 1999, October 10-16, 1999, Klamath Falls, OR

The Oregon 1999 program is being organized by the International Summer School on Direct Application of Geothermal Energy of Macedonia and staff of the Geo-Heat Center. Expert presenters from the U.S. and Europe will be joined by speakers from Latin America and Pacific Rim countries. Three main topic areas will be covered: Small Scale Power Projects, Geothermal Heat Pumps and Direct Utilization of Geothermal Energy. Two evening workshops will focus on application software for Geothermal Heat Pumps and HEATMAP (a district heating program).

The conference will also feature field trips to provide participants with a complete overview of geothermal development opportunities. The first excursion will take participants to nearby Medicine Lake (Glass Mountain) in northern California to view sites of 49.9 MWe power plants proposed by Calpine Corp. and CalEnergy Co. Inc (Oct. 10). The second excursion will provide participants with an in-depth tour of geothermal direct-use sites in and around the Klamath Falls area, including OIT's heating system, and the Klamath Falls City district heating/snow melt system, greenhouses and an aquaculture project (Oct. 13). An optional field trip on the last day of the conference will include stops of a number of district heating, binary and hybrid geothermal power generation projects in Oregon and California on the way to the Geothermal Resources Council (GRC) Annual Meeting in Reno, Nevada (Oct. 16).

For more information, including program, costs and accommodations, contact the Geo-Heat Center or the program can be viewed on the GHC web site at: <www.oit.edu/other/geoheat/iss/issindex.htm>.

Geothermal Resources Council Annual Meeting, Oct. 17 through 20, 1999, Reno, NV

The Geothermal Resources Council (GRC) Annual Meeting will be held at the Reno Hilton Hotel. The meeting will feature a thematic opening session, special and technical sessions on a broad range of geothermal resource and development topics, workshops, field trips and the Geothermal Energy Association Trade Show.

Two special GRC workshops are scheduled prior to the meeting: (1) Applications of High-Temperature Electronics in Geothermal Drilling (Oct. 14-15), and (2) Advances in Geochemical Methods for Geothermal Applications (Oct. 15-16).

Four field trips of northern Nevada geothermal manifestations and development sites will be held either before or after the meeting: (1) Dixie Valley and Stillwater power plants (Oct. 16), (2) Steamboat and Brady's Hot Springs power plants (Oct. 17), (3) Wabuska, Empire and Soda Lake binary power plants (Oct. 21), and (4) Colado and Humboldt House geothermal resources with epithermal gold deposits.

For more information contact the Geothermal Resources Council, Davis, CA (phone: 530-758-2360) or email: <grc@geothermal.org>, or view the program on their web site: <www.geothermal.org>.

Geothermal Heat Pump Projects in Iowa and California

The "nation's largest" lake-coupled, geothermal heating-cooling system recently began operating at what will be the Great River Medical Center, a new hospital facility under construction in West Burlington, IA. In February, two 150-hp pumps began drawing water through plastic piping at the bottom of a 15-acres, artificially made lake next to the hospital site. The pumps move more than 5,000 gpm of water through a 100-mile-long piping system, which carries it through more than 800 heat pumps that help regulate temperatures in office, patient, and treatment rooms in the hospital, two new medical buildings, and two existing facilities. All total, the geothermal system will provide heating and cooling for approximately 707,000 sq. ft. of building space. (The Air Conditioning, Heating and Refrigeration News, May 24, 1999).

Feather River College in Quincy, CA recently installed a ground loop heat pump system for the college's three office buildings, the library, the gymnasium and three classroom buildings, a total of 53,000 sq. ft. of enclosed space. The system has enabled the college to trim its heating and cooling energy by 421,000 kilowatt hours, which amounts to an annual savings of about $50,000. The entire project cost $512,000, with a grant for $35,000 from the Geothermal Heat Pump Consortium and funding from the California Community Colleges. (source: California Energy Commission, Aug. 11, 1999).

Yellowstone Deal to Keep Geyser Faithful

President Clinton announced a $13 million deal on August 21st, to buy 9,300 acres of land to better protect Yellowstone National Park and make sure the "Old Faithful remains faithful for year to come." The White House said the U.S. Forest Service will acquire title to, or conservation easements on, 9,300 acres of the Royal Teton Ranch north of Yellowstone, and will acquire geothermal rights to the entire 12,000-acre Montana ranch. The purpose will provide a critical winter range for Yellowstone bison, which in some years face starvation because of inadequate food supplies in the park, and preserve important migration corridors for elk, antelope, bighorn sheep, grizzly bears and other wildlife. It will also remove a threat to the underground springs that feed Yellowstone geysers. The land will be owned and managed by the Gallatin National Forest. The deal to buy the land was made with help from the nonprofit Rocky Mountain Elk Foundation, based in Missoula, Montana. (by Steve Holland, Reuters).

Washington, D.C. - Coalition Critiques Baron Restructuring Bill

On September 1st, sixteen member groups of the Sustainable Energy Coalition sent a detailed critique of the draft electric utility restructuring legislation, the Electricity Competition and Reliability Act, to its primary author Rep. Joe Baron (R-TX), chairman of the House Commerce Committee's Subcommittee on Energy and power. The group warned that "unless restructuring is carefully crafted, negative impacts on environmental quality and human health are likely to be one of the unintended consequences" noting that "the draft is missing a number of critical provisions that we believe are essential for inclusion in a final bill." The group further called for a redraft of the bill to include the following topics: (1) Public Benefits Trust, (2) Renewables Portfolio Standard, and (3) Emissions. For details, contact Eric Wesselman: 202-332-0900.