USE OF PROMOTER PIPE WITH DOWNHOLE HEAT EXCHANGERS IN KLAMATH FALLS, OREGON

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SUMMARY - Downhole heat exchangers (DHE) consists of a system of pipes or tubes suspended in a well through which "clean" secondary water is pumped or allowed to circulate by natural convection to provide space heating of buildings. The DHE eliminates the problem of disposal of geothermal fluid, since only heat is taken from the well. DHEs are used extensive in approximately 600 wells in Klamath Falls, Oregon. Corrosion has been a problem for the DHE pipes, especially at the air-water interface, with the use of cross-linked polyethylene (PEX) pipes currently being investigated to solve this problem. In order to increase the heat output from a well using a DHE, a vertical convection cell is developed by perforating the casing at the bottom of "live water" flow and just below the lowest static water surface. Where these perforations have not been provided, typical of older wells, pumping and dumping water to the storm sewers in Klamath Falls has been utilized. This disposal of geothermal water had lowered well water throughout the City. A City ordinance in 1990 stopped the "pumpers and dumpers" to correct this water level decline thus, alternate solutions had to be found. Using experience from Rotorua, New Zealand with convection promoter pipes, an experimental project with initiated at the Klamath Medical Clinic where a pump had been utilized to increase the vertical temperature in the well and the pumped water wasted to the storm sewer. A 10-cm diameter promoter pipe was installed in the well that had cooled in the upper portion due to lack of vertical circulation after the pump had been shut down. The promoter pipe increased the water temperature in the upper portion of the well and thus the DHE provided adequate heat to the Clinic. This solution for the "pumpers and dumper" will be tried elsewhere in the Klamath Falls area.

1 INTRODUCTION

The downhole heat exchanger (DHE) 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, thus eliminating the problem of disposal of geothermal fluid, since only heat is taken from the well. 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 150 m and may be economical under certain conditions at well depths to 450 m (Lund, et al., 1975; Culver and Lund, 1999).

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 shallow wells. 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 at the well bottom for the inflow aquifer and just below the lowest static water 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. However, this balance is often difficult to achieve, and is usually done by trial and error or based on local experience.

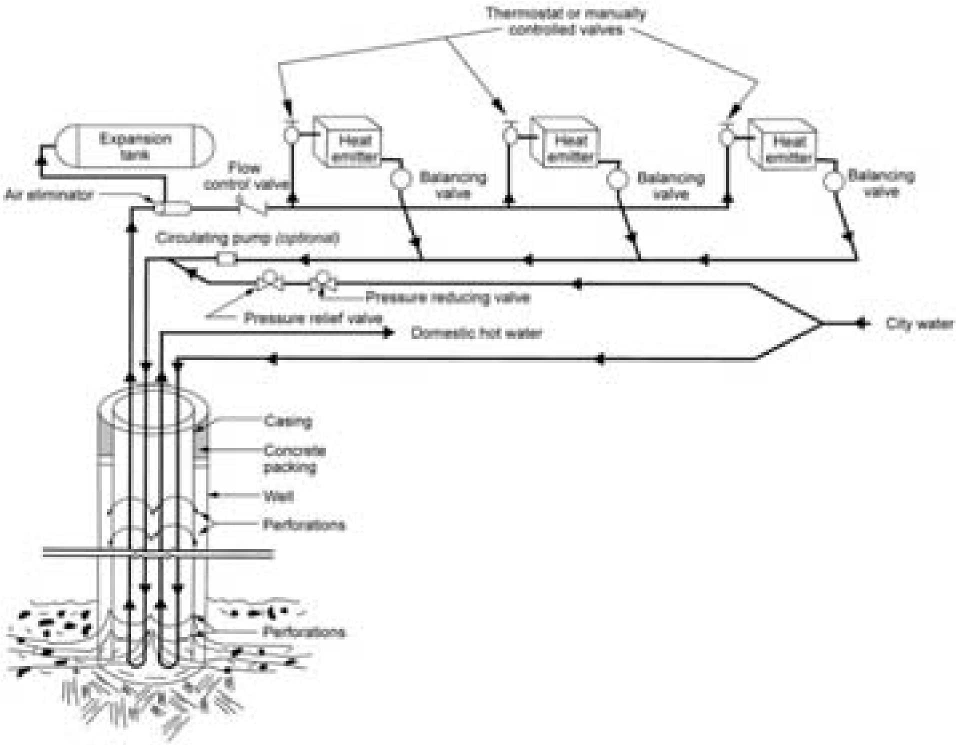

Figure 1: Typical downhole heat exchanger systems in Klamath Falls, Oregon

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 vertical fluid mixing in the well bore indicating that somewhat permeable formations with high flows are preferred.

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 in Klamath Falls indicates that corrosion is most severe at the air-water interface at static water level and that stray electrical currents can accelerate corrosion. Currents of several tens of milliamps have been measured (Lund, et al., 1976a). Insulating unions can 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. Average DHE life is difficult to predict. For the 600 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; Lund, et al., 1976b). In other cases, installations have been in service for over 30 years with no problems, especially in capped artesian wells. Stray electrical currents, as noted above, have undoubtedly been a contributing factor in some early failures. 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. Galvanized pipe is to be avoided since many geothermal water leach zinc and the anode-cathode relationship normally protecting steel in pipes reversed at 57°C

(Ellis and Conover, 1981; Ellis, 1998). More recently, a cross-linked polyethylene pipe (PEX) has been tried in wells to overcome the corrosion problem (Chiasson, et al., 2005; Chiasson, et al., 2007).

Corrosion at the air-water interface is by far the most common cause of failure (Figure 2). 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). An alternate solution has been 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. This practice has been mostly stopped due to the potential pollution of the ground water.

2 DESIGN AND CONSTRUCTION DETAILS (CULVER AND REISTAD, 1978)

DHE outputs range from supplying domestic hot water for a single family from a 12-m, 60°C well at Jemez Springs, New Mexico, to over 1 MWt at Ponderosa Junior High School from a 170-m, 94°C 40-cm well in Klamath Falls, Oregon. They have been used in the Moana area of Reno for many years (Allis, 1981). 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 (Lund, 1999).

Figure 2: Corrosion and pitting of DHE replaced in 1974. Note the reverse loop at the bottom of the DHE.

The wells in Klamath Falls are 25- or 30-cm in diameter drilled 6 or meter into “live water” and an 20-cm casing installed. “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. A packer is placed around the casing below any cold water or unconsolidated rock, usually at depths of 6 - 15 m, and the well cemented from the packer to the surface. The casing is torch perforated 1 x 15 cm in the “live water” area and just below the lowest static water level. Perforated sections are usually 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 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.

The space heating DHE is usually 4- or 5-cm diameter black iron pipe with a return U at the bottom. The domestic water DHE is 2- or 2.5-cm diameter pipe (Figure 3). The return U usually has a 0.9 – 1.5 m section of pipe (called a mud leg) 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 pipes. A 20-kWt, 5-m prototype heat pipe system was successfully tested at least several months in the Agnano geothermal field in southern Italy (Cannaviello, et al., 1982).

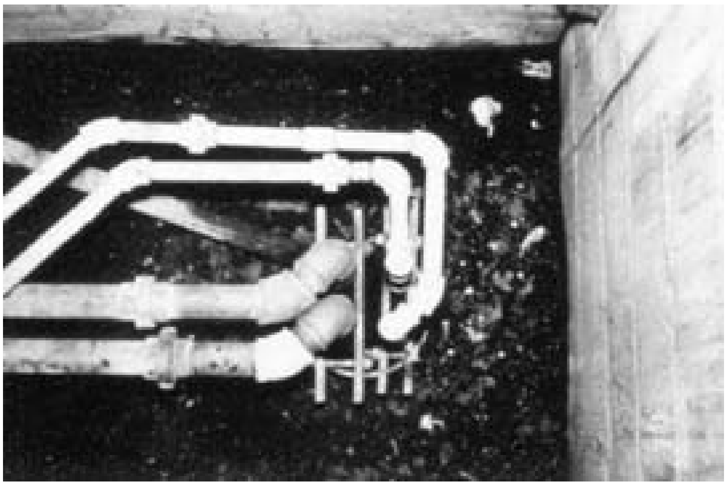

Figure 3: Looking down a typical 20-cm diameter well casing with a 5-cm diameter space heating loop and a 2-cm diameter domestic hot water loop used for a single residence in Klamath Falls.

The first downhole heat exchanger, locally known as a coil, was installed in a geothermal well in Klamath Falls about 1930, designed and installed by a local plumber, Charile Lieb (Geo-Heat Center, 2002). 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 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 to the radiators in the building. Circulation pumps are required in cooler wells or in larger systems to increase the flow rate. Thermo-syphon circulation will provide 0.2 - 0.35 bar pressure difference in the supply and return lines to circulate 1 - 1.5 L/sec with a 5 - 11^{o}C temperature change.

There were several older or cooler wells in Klamath Falls that were pumped directly into the storm sewers or canal. In most cases, the well was 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 60^{o}C (Figure 4). In a few instances, mostly in the artesian area, well water was pumped or allowed to flow directly through the heating system. This process of "pumping and dumping" has been stopped by City ordinance in 1990 as described later in this paper.

Various types of non-metallic pipe such as PVC, polybutylene and fiberglass reinforced epoxy (FRP) have been tried as DHE, most do not perform well in temperatures near boiling. 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. As mentioned early, PEX pipe is now being tested in Klamath Falls

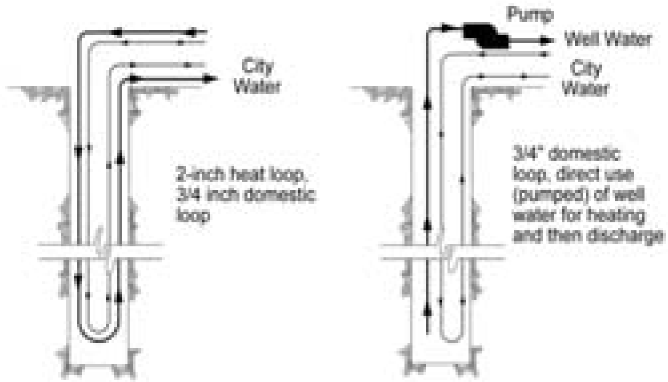

Figure 4: Diagram of a typical space heating and domestic hot water loop (left) in a well, and a well with a pump (right) for increasing the vertical circulation in the well and dumping to the storm sewer ("pumper and dumper")

3 CONVECTION CELLS

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, the former being most significant.

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: 1) casing perforations, and 2) "pumping and dumping".

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 at the hot aquifer level, a convection cell is induced and the well becomes very nearly isothermal between the perforations (Figure 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 is induced, flowing down inside the casing and up in the annulus between the well wall and casing. 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 0.6 m/s have been measured with very high heat extraction rates; but, the usual velocities are between 0.01 - 0.1 m/s.

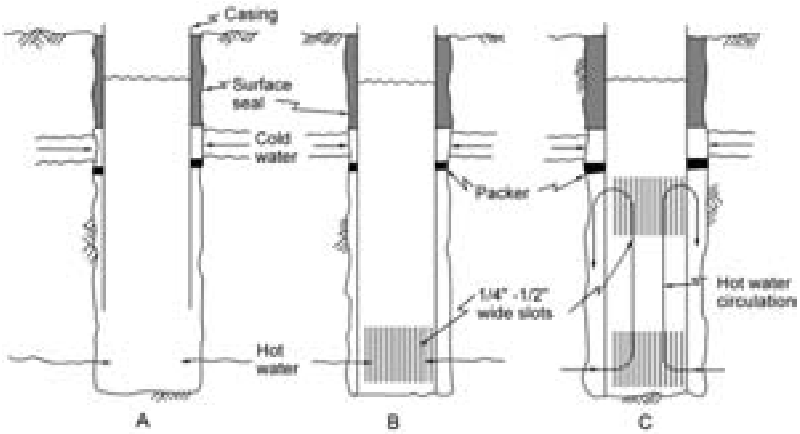

Figure 5: Well completion systems for DHE (type c with the vertical convection cell – preferred)

In Klamath Falls, it has been experimentally verified that when a well is drilled there is no flow in the wellbore (see Figure 6). 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.

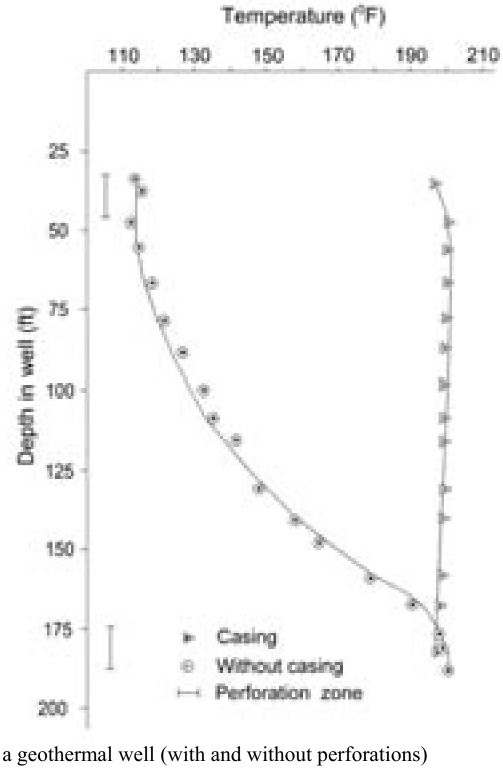

Figure 6: Temperature vs. depth for a geothermal well (with and without perforations)

In New Zealand, where high temperature wells (up to 160°C) do not stand open and several layers of cold water must be cased off, a system using a convection promoter pipe was developed (Figure 7) (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 can be found in the following references: Allis and James, 1979; Freeston and Pan, 1983; Dunstall and Freeston, 1990; Hailer and Dunstall, 1992.

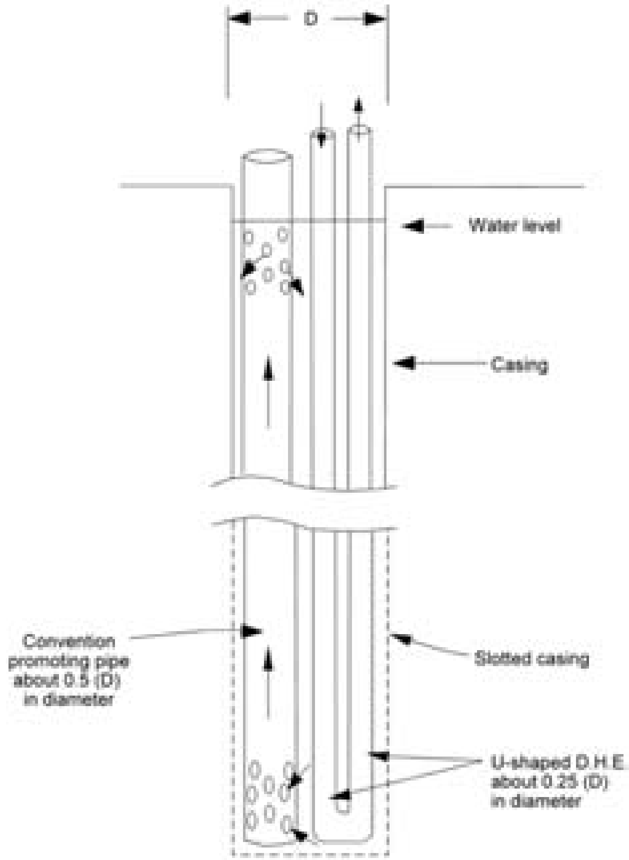

Figure 7: Convector promoter and DHE (New Zealand type)

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.

4 EXPERIMENTAL WORK IN KLAMATH FALLS

4.1 BACKGROUND

Many of the earlier wells drilled in Klamath Falls were not completed with the two sets of casing perforations that would generate the convection cells to maximize the output of the downhole heat exchangers (DHE). To provide for this vertical convection of the hotter water from the bottom of the well, they were equipped with a small suction pump that pumped water from the well to the storm sewer – locally referred to as "pumping and dumping." This pumping provided approximately the same energy transfer to the downhole heat exchanger as the convection cell. Approximately 60 wells in the City had these pumps, and could be identified by the steam rising from the storm water grates adjacent to the well. In addition, larger users, such as Oregon Institute of Technology, who could not generate enough energy from a downhole heat exchangers, pumped water for the plate heat exchangers in the various buildings on campus, and dumped the waste water to surface drainage.

Unfortunately, there was a noticeable decline in the static water surfaces in geothermal wells in the area, averaging about 30 cm per year, which of course, was a concern to well owners. This decline affected the performance of approximately 400 wells with downhole heat exchangers used for residential heating. As a result, the City passed an ordinance in 1985 which prohibited surface disposal of geothermal fluids by July of 1990 (Lienau, 1989). A well owner had to either drill an injection well or use a downhole heat exchanger without pumping the water if they wished to continue using the geothermal fluids for heating. For some well owners, this meant shutting down their system, as they could not afford to drill an injection well, as their well without pumping could not deliver the required heat. Oregon Institute of Technology had to drill several injection wells before two satisfactory ones could be completed.

By the early 1990s, water level had stabilized and in many cases rose to earlier level, as a result of the City ordinance. Then, in September of 1993 two earthquakes of 5.9 and 6.0 magnitude occurred at an approximate depth of 12 km and 25 km north west of the center of Klamath Falls (Lienau and Lund, 1994). This area of the epicenters is the western extension of the Basin and Range physiographic region of horst and graben structures with high angle normal faults which extends eastward to Salt Lake City. The earthquakes damaged at least 300 structures, some of which had to be demolished. Most of the Klamath Falls geothermal wells tap into flows from one of these normal faults along with east side of the community. Water levels in the geothermal wells rose in zones of compression and fell in zones of extension caused by the earthquakes. Increases up to 90 cm, and decreases up to 2.1 m were recorded (Lienau and Lund, 1994). The Klamath Medical Clinic geothermal well on Main Street started an artesian flow of approximately 2 L/s about 1.5 months before the earthquake and increased to 9.5 L/s after the earthquake with no apparent change in temperature. Since this was a natural phenomena, the City allowed this flow along with discharges from several other wells in the neighborhood (such as the City swimming pool well) to continue flowing to the storm sewer. The artesian level dropped below the casing top with time, thus a suction pump was installed to bring up heat from the bottom and then the water was discharged to the storm sewer (Figure 8). Finally, in 2008, the City served notice to these well owners that they also would have to cease dumping their hot water to the storm sewer.

Figure 8: Klamath Medical Clinic well flowing (artesian) after the 1993 earthquake

4.2 THE KLAMATH FALLS MEDICAL CLINIC WORK

We at the Geo-Heat Center received a call from Pacific Plumbers of Klamath Falls (see coauthors), who had been hired to solve the problem for the Klamath Medical Clinic. We met and discussed several options, such as ripping the casing to produce the necessary holes for a convection cell, installing a smaller perforated casing inside the existing one, lengthening the downhole heat exchanger, or installing a promoter pipe. The present casing only had perforations at the bottom to allow for hot water inflow from the fractured basalt aquifer, thus no natural convection cell was generated. Since the well was cased with a 30-cm diameter casing from the surface to 67 m and then with a 25-cm casing from 64 to the bottom at 108 m and only had one downhole heat exchanger of 6.4-cm diameter, there would be room for a 10-cm diameter promoter pipe. This was then selected as the best solution, as we would not have to remove the estimated 61 m of downhole heat exchanger pipes.

It should be noted that the Klamath Medical Clinic was having trouble heating the facility even when the pump was running. This was especially true for cold mornings and warm afternoon where the system had to adjust to the changing weather conditions. Klamath Falls this past winter had heavy snow falls and night-time temperatures a low as -15^{o}C with averages around -7^{o}C and average highs typically up to 4^{o}C with maximum up to 10^{o}C. The Clinic has a floor area of 1,115 m^{2} and an estimated peak heating load of 252,000 kJ/hr plus the domestic hot water heat load.

Promoter pipes had been tried on a limited scale in Klamath Falls previous, but not documented to any extent (see Chiasson, et al., 2005; Chiasson, et al., 2007). The Geo-Heat Center offered their services to design and monitor the results of the promoter pipe installation. In early March, 2008, 108 m of 10-cm diameter promoter pipe was installed. Very few problems were encountered getting the pipe passed the downhole heat exchanger and the casing size change. Approximately 2.5-cm diameter holes were torch cut in the pipe 2.1 to 3.0 m off the bottom and 4.6 to 6.1 m from the top (Figure 9). The casing was hung from a plate at the casing top – which is about 90 cm below street level. We elected to hang the casing off the bottom, as setting it on the bottom might bury the lower holes in fines sloughed into the bottom, thus preventing the circulation cell from working (Figure 10). The static water level was about 2.4 m below the surface. Before the top holes were cut, we measured the water temperature inside the promoter pipe as show in Figure 11 the following day. The problem with the well is readily shown, with only about 68°C for the first 46 m and then increasing to 89°C from 69 m to the bottom. Thus, the downhole heat exchanger was only exposed to the cooler temperature which is marginal for this type of installation, and since there was no convection cell, would cool even more with heating demand.

Figure 9: Cutting the 2.5-cm diameter perforations in the 10-cm diameter promoter pipe for the Klamath Medical Clinic

Figure 10: Looking down on the Klamath Medical Clinic well with the 6.4-cm diameter heating loop, the 2-cm diameter domestic hot water loop and the open promoter pipe suspended from steel plate

The top holes in the promoter pipe were then cut and the pipe installed. We then measured the water temperature profile the next day and received encouraging results. The promoter pipe was working and providing around 77^oC over the entire well depth and obviously creating a convection cell bringing hot water up from the bottom (see Figure 11). Subsequent reading produced similar results a shown in Figure 11. The slight variations are due to variations in heating demand for the building, lower readings on cold days and higher reading on warm days. The readings were taken from March 5 through March 14 (all around 1:00 PM) where the low temperatures were around -2^oC and the highs around 10^oC.

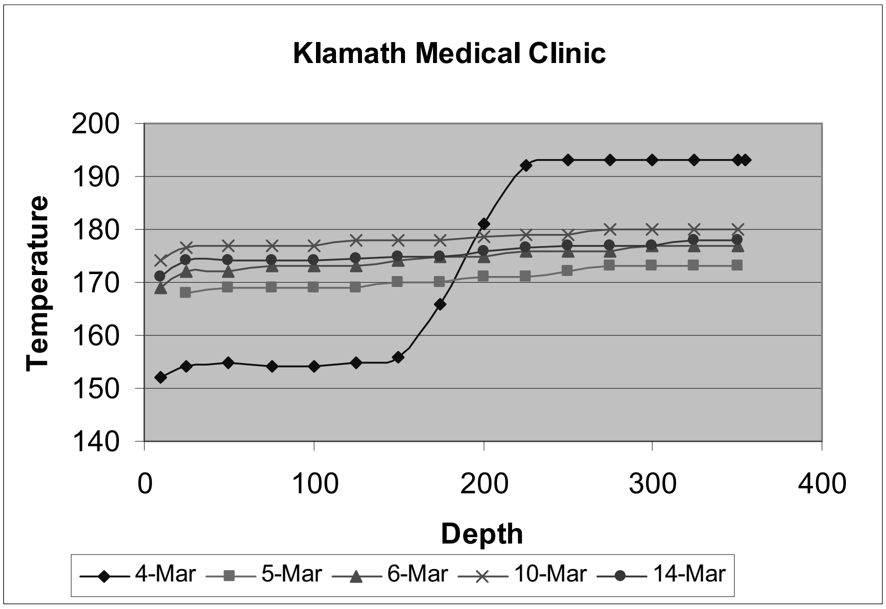

Figure 11: Temperature vs. depth profile of the Klamath Medical Clinic well before and after the operation of the promoter pipe

5 CONCLUSIONS

The Medical Clinic has since reported very adequate and uniform heat in the building with distribution water temperatures to the forced air heating system varying from 78 to 81^oC. Thus, the promoter pipe, as researched and developed in Rotorua, New Zealand, appears to be successful in Klamath Falls in solving a geothermal water disposal problem. Several other well owners are also considering this installation as a solution to their well configuration. Where it may not work is in small diameter wells with several downhole heat exchangers allowing room for only a small diameter promoter pipe. Whether a 2.5- to 5.0-cm diameter pipe will work adequately, has yet to be tested. Future monitoring of the Medical Center well and testing other installation will be undertaken by the Geo-Heat Center in the future. The labor and materials for this installation cost around $10,000. The geothermal heating and domestic hot water systems are estimated to save $7,000/year.

6 ACKNOWLEGEMENTS

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7 REFERENCES

Allis, R. G., 1981. "A Study of the Use of Downhole Heat Exchangers in the Moana Hot Water Area, Reno, Nevada." Geo-Heat Center, Klamath Falls, OR.

Allis, R. G. and R. James, 1979. "A Natural Convection Promoter for Geothermal Wells." Geo-Heat Center, Klamath Falls, OR.

Cannaviello, M.; Carotenuto, A. C.; Reale, F.; Casarosa, C.; Latrofa, E. and L. Martorano, 1982. "An Advanced System for Heat Transfer from Geothermal Low- and Medium-Enthalpy Sources." *International Conference on Geothermal Energy, Florence, Italy*, Vol. 2, pp. 63-80.

Chiasson, A. D., G.G. Culver, D. Favata, and S. Keiffer, 2005. "Design, Installation and Monitoring of a New Downhole Heat Exchanger". GRC *Transactions*, Vol. 29, Davis, CA.

Chiasson, A. D. and R. Swisher, 2007. "Continuing Advances in PEX Downhole Exchangers for Direct-Use Heating Applications," Geo-Heat Center *Quarterly Bulletin*, Vol. 28, No. 2, Klamath Falls, OR.

Culver, G. G., and G. M. Reistad, 1978. "Evaluation and Design of Downhole Heat Exchangers for Direct Applications," Final Report under contract No. EY-76-S-06-2429, prepared for the U.S. Energy Research and Development Administration, Oregon Institute of Technology, Klamath Falls, Oregon.

Culver, G. G., 1990. "DHE." Report prepared for USDOE, Geo-Heat Center, Klamath Falls, OR.

Culver, G.G. and J. W. Lund, 1999. "Downhole Heat Exchangers", Geo-Heat Center *Quarterly Bulletin*, Vol. 20, No. 3, Klamath Falls, OR

Dunstall, M. G. and D. H. Freeston, 1990. "U-Tube Downhole Heat Exchanger Performance in a 4-Inch Well, Rotorua, New Zealand." *Proceedings of the 12th New Zealand Geothermal Workshop*, pp. 229-232.

Ellis, P. F. and M. F. Conover, 1981. "Materials Selection Guidelines for Geothermal Energy Utilization Systems." Radian Corporation, Austin, TX.

Ellis II, P.E. 1998. "Materials Selection Guidelines." in the *Geothermal Direct-Use Engineering and Design Guidebook*, Geo-Heat Center, Klamath Falls, OR.

Freeston, D. H. and H. Pan, 1983. "Downhole Heat Exchanger." *Proceedings of the 5th New Zealand Geothermal Workshop*, pp. 203-208.

Geo-Heat Center, 2002. "A Tribute to Charlie Leib – Grandfather of Klamath Falls Geothermal Development," Geo-Heat Center *Quarterly Bulletin*, Vol. 23, No. 1, Klamath Falls, OR.

Hailer, S. and M. G. Dunstall, 1992. "Downhole Heat Exchanger Experiments in a Laboratory Scale-Model Well." Proceedings of the *14th New Zealand Geothermal Workshop*, pp. 93-98.

Lienau, P. J., 1989. "OIT Injection Well," Geo-Heat Center *Quarterly Bulletin*, Vol. 11, No. 4 (Summer), Klamath Falls, OR.

Lienau, P. J. and J. W. Lund, 1994. "Ground-water Anomalies Associated with the Klamath Basin Earthquakes of September 20-24, 1993," Oregon Geology, Vol. 56, No. 1 (January), Department of Geology and Mineral Industries, Portland, Oregon.

Lund, J. W., 1999. "Large Downhole Heat Exchanger in Turkey and Oregon," Geo-Heat Center Quarterly Bulletin, Vol. 20, No. 3 (September), Klamath Falls, OR.

Lund, J. W.; Culver, G. G. and L. S. Svanevik, 1975. "Utilization of Intermediate-Temperature Geothermal Water in Klamath Falls, Oregon." *Proceedings of the 2nd U.N. Symposium in the Development and Use of Geothermal Resources, San Francisco, CA*, Vol. 2, p. 2147-2154.

Lund, J. W., Silva, J. F., Culver, G. G., Lienau, P. J., Svanevik, L.S., and S. D. Anderson, 1976a. "Corrosion of Downhole Heat Exchangers," report prepared for the Energy Research and Development Administration (ERDA) and Idaho National Engineering Laboratory (INEL), Geo-Heat Utilization Center, Klamath Falls.

Lund, J.W., Culver, G.G., and P. J. Lienau, 1976b. "Groundwater Characteristics and Corrosion Problems Associated with the Use of Geothermal Water in Klamath Falls, Oregon," Geo-Heat Utilization Center, Klamath Falls, OR.

Swisher, R. and G. A. Wright, 1990. "Inhibition of Corrosion at the Air-Water Interface in Geothermal Downhole Heat Exchangers." *Geo-Heat Center Quarterly Bulletin*, Vol. 12, No. 2, pp. 10-13.