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DESIGN OF A CONVECTION CELL FOR A DOWNHOLE HEAT EXCHANGER SYSTEM IN KLAMATH FALLS, OREGON

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ABSTRACT

Downhole heat exchangers extract heat by two methods which are extracting heat from water flowing through the aquifer and extracting stored heat from the rock surrounding the well.

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 of the well water, and water leaving the well to the aquifer. There are three methods of inducing convection: 1) casing perforations, and 2) "pumping and dumping" and 3) installing a promoter pipe.

The promoter pipe is simply a pipe that is open at both ends that is placed in the well. The promoter pipe can be either placed along side or around the DHE, with the first being the more economical since a smaller promoter can be utilized. To set up a convection cell using a promoter pipe the locations of the perforations are important. The proper location of the perforations in a promoter produces the convection cell necessary to increase the temperature of the water over the length of the promoter. The top perforations are usually place below the lowest static water level and the lower perforations are placed in the location of the live water zone.

This paper will present three examples of downhole heat exchanger systems and how they were originally designed and then redesigned. The first system utilizes a promoter pipe which has perforations in three different locations and the second system utilized cased perforations, but the water level decreased and a promoter pipe was installed. The third system did not have perforations in the casing but was open at the live water area only. The three systems have been analyzed that were not getting the expected output from their systems. Solutions used to increase the output of the systems will be discussed.

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 500 ft and may be economical under certain conditions at well depths to 1500 ft (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.

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.

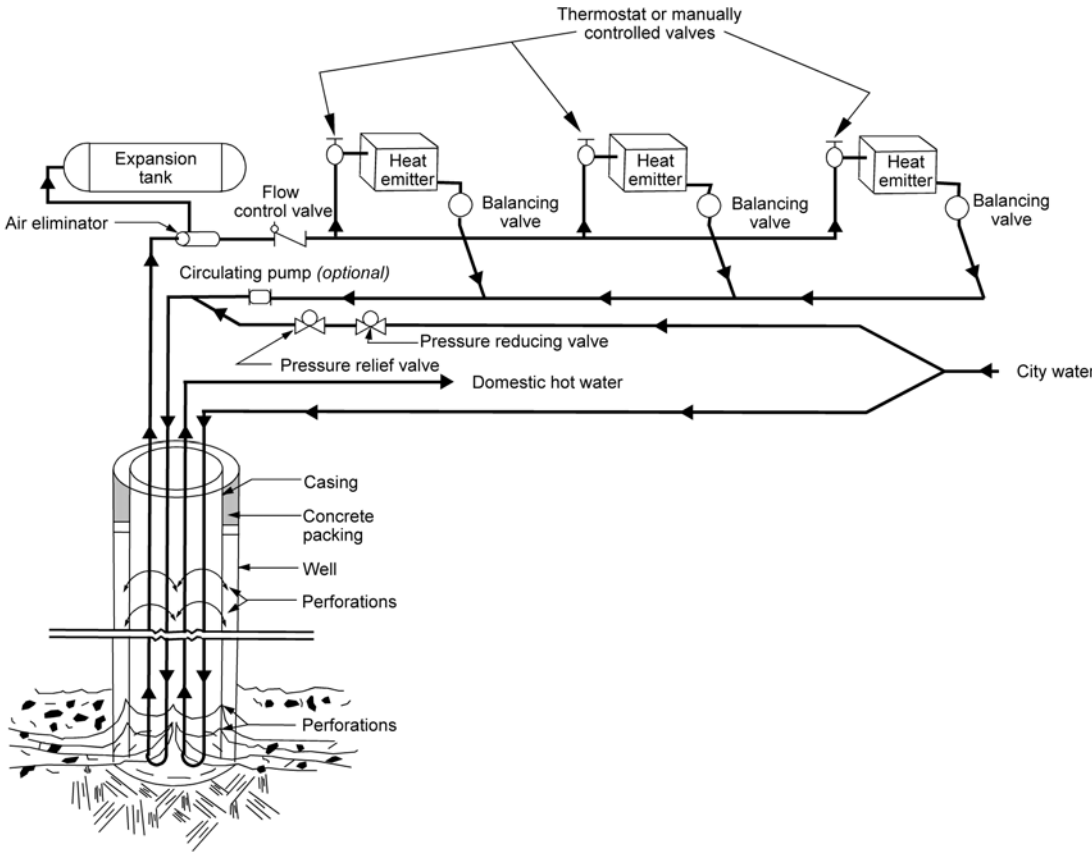

Figure 1: Typical downhole heat exchanger systems in Klamath Falls, Oregon.

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.

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. 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 vertical 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 in the past: 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 2). 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 2 ft/s have been measured with very high heat extraction rates; but, the usual velocities are between 0.03 - 0.3 ft/s.

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.

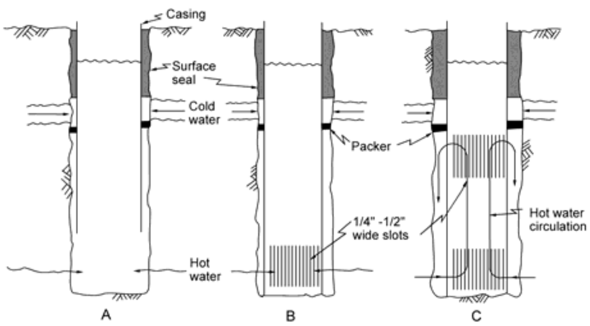

Figure 2: Well completion systems for DHE (type c with the vertical convection cell – preferred).

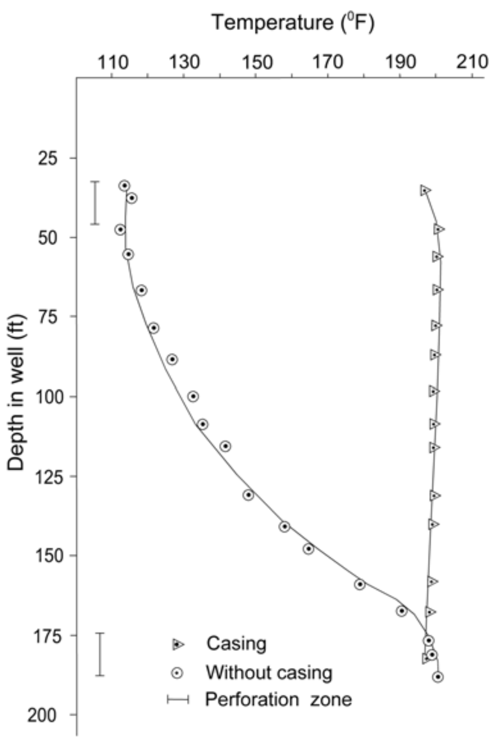

Figure 3: Temperature vs. depth for a geothermal well (with and without perforations).

In Klamath Falls, it has been experimentally verified that when a well is drilled there is no flow in the wellbore (see Figure 3). 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.

The convector pipe is simply a pipe open at both ends suspended in the well above the bottom and below the static water level (Figure 4). 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.

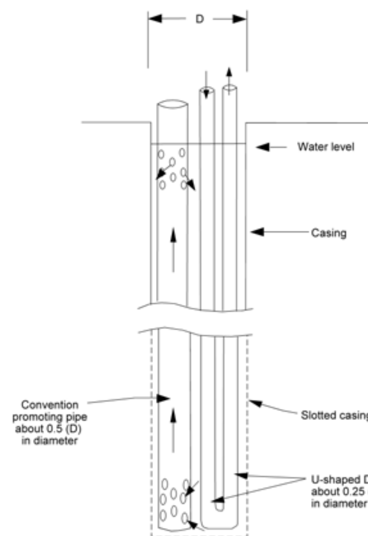

Figure 4: Convector promoter and DHE (New Zealand type).

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).

FIRST SYSTEM

The first well system was originally completed in 1929 as either a type A or B as shown in Figure 2. It has a 10-in diameter hole with a 8-in casing. The type was determined from the temperature probe completed in September 2008 (Figure 5) since we were not able to find a well log from the original drilling. The well had been losing temperature over time and was having trouble heating the two homes connected to the system.

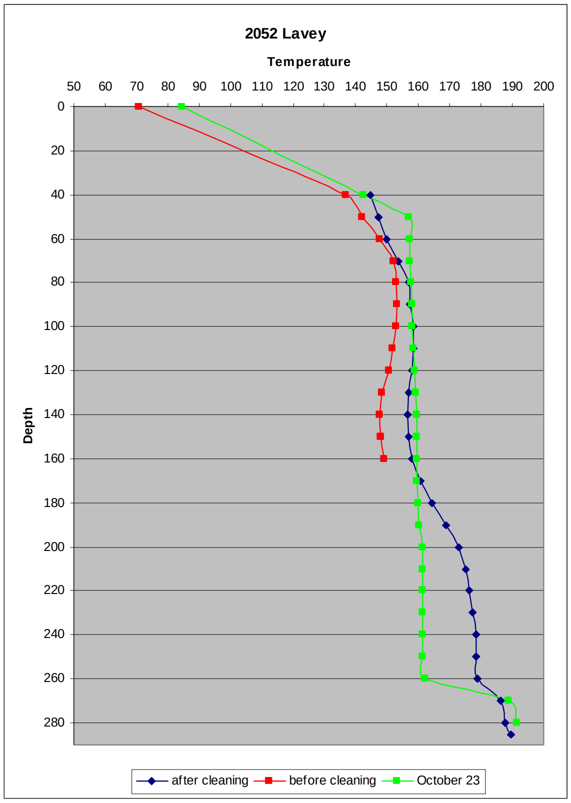

Figure 5: Temperature vs. depth profile of System One well before and after the operation of the promoter pipe.

The well was cleaned out in September to remove all the lose materials in the well since our first temperature probe stopped at 160 ft and the owner knew the well was deeper than that. From the temperature probe we were able to determine that there was no convection cell which did not allow the hotter water to circulate and that a promoter pipe should be installed to help with the circulation of the hot water. The perforations should be placed at the live water zone and just below the lowest static water level on the well. According to the new well log the static water level was at 56 ft.

The promoter pipe (Figure 6) that was installed in the well had three tee openings. There were located at 1) 50 feet below the top of the casing, 2) 30 feet from the bottom of the well and 3) 10 feet from the bottom of the well. Eight inch perforations were also placed at the top and bottom of the second tee opening. There were also 4 loops of ¾-in PEX tubing installed in the well for use as Downhole heat exchangers for the homes. Figure 7 shows the installation of the promoter pipe along with the PEX downhole heat exchanger.

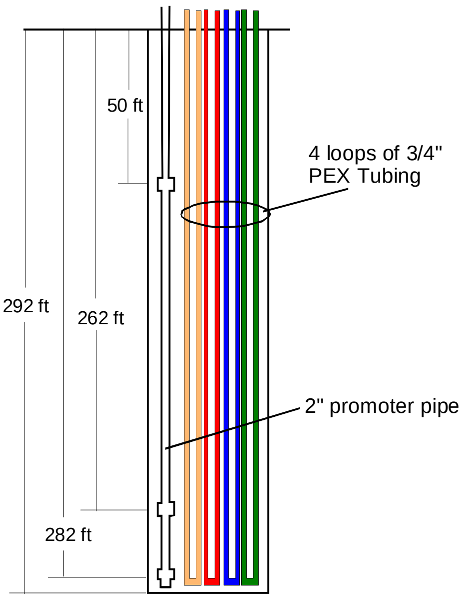

Figure 6: Schematic of System One well.

Figure 7: Placing the promoter pipe and PEX tubing into the well.

Another temperature probe was completed in October 2008 to see how the system was performing. The system was in operation at the time of the temperature probe. As can be seen from Figure 5, the temperature from the top tee to the second tee the temperature is constant, which shows that a convection cell has been obtained. This was probably due to the fact that the system was in operation and not from the promoter pipe since the top tee is unfortunately above the water level of the well. If the water level happens to increase enough to cover the first tee then the temperature curve from 50 ft to 262 ft should shift to the right.

SECOND SYSTEM

The second system had an 8" well drilled in 2002 to 370 ft. The well was originally cased with a 6-in casing and perforated with the lower perforations located in the "live water" zone 10 to 20 ft from the bottom of the well and the perforations in the upper part of the casing (170 to 190 ft from the top of casing) placed at the estimated lowest static water level. Static water at the time was 170 ft. below the casing and the temperature coming into the home was 175°F. Temperature probes were completed after the well was drilled and after the casing was installed as can be seen in Figure 8 and shows that a convection cell was obtained in the well.

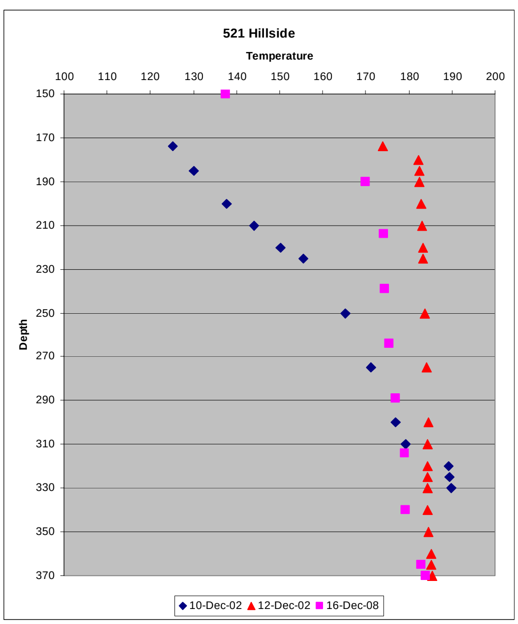

Figure 8: Temperature vs. depth profile of the Second System before and after casing installation and after installation of the promoter pipe.

After 6 years of operation, during the early part of 2008, the owner of the system reported that he was having trouble heating his home. The temperature of the DHE entering the home was down to 130°F. At that time it was determined that the water level in the well dropped to 188 ft and has apparently dropped below the top level of the perforations in the upper level, causing the convection cell of the well to decrease or disappear all together thus decreasing output temperature of the DHE. The home owner put water down into the well for 4 hours to raise the level of the water into the well. This seemed to help and the temperature into the house did increase. The temperature again decreased in the later part of 2008 and we were able to determine that the water level has again dropped below the bottom part of the upper perforations.

It was then decided to insert a 2-in promoter pipe into the well to get a convection cell started. The perforations in the 2-in promoter pipe were torch cut 1/2-in X 3-in, spaced approximately every 12 inches alternated in three areas along 18' of two lengths. The promoter pipe perforations are now placed from approximately 336 ft to 316 ft and 210 ft to 190 ft as shown in Figure 9. The length of the DHE was also extended another 21 ft. After the promoter was placed in the well another temperature probe was completed and as seen in Figure 8 it shows that convection cell has returned. As a result of this improvement, the home's DHE incoming temperature is approximately 170°F.

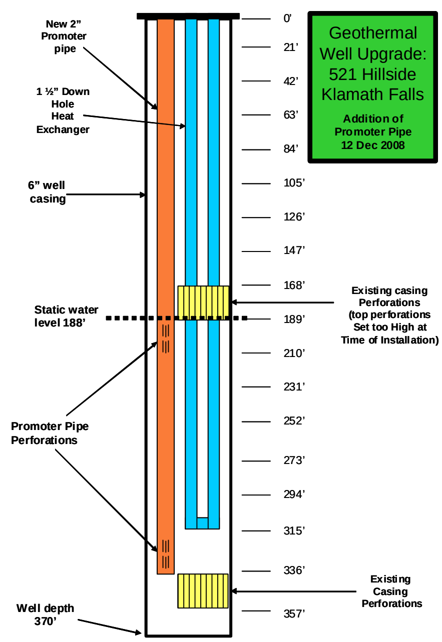

Figure 9-.Schematic of System Two well.

THIRD SYSTEM (LUND ET AL., 2008)

The third system, at time of completion, was cased with a 12-in diameter casing from the surface to 219 ft and then with a 10-in casing from 210 ft to the bottom at 354 ft. It only had perforations at the bottom to allow for hot water inflow from the fractured basalt aquifer as can be seen in Figure 10. Due to the way this well was completed there was no natural convection cell generated. This well was considered a "pumper and dumper" for they used a suction pump to bring the heat from the bottom of the well and then discharged to the storm sewer.

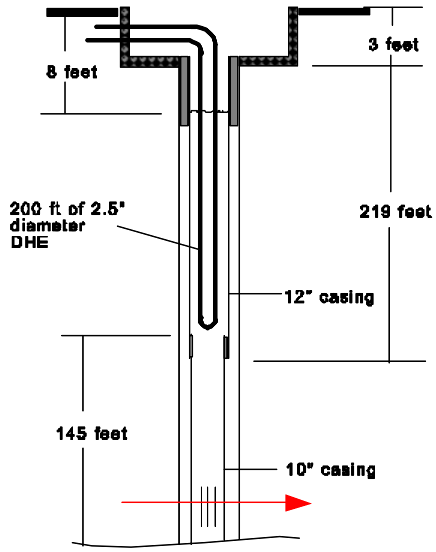

Figure 10: Schematic of System Three well..

System Three 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. The problem was researched and discussed and there were several options on how to fix the problem. The options were rip the casing to produce the necessary openings for a convection cell, install a smaller perforated casing inside, lengthen the downhole heat exchanger or install a promoter pipe. It was decided the best solution was to install a 4-in diameter promoter pipe then the estimated 200 ft of downhole heat exchanger pipes would not have to be removed.

In early March, 2008, 354 ft of 4-in diameter promoter pipe was installed. Very few problems were encountered getting the pipe passed the downhole heat exchanger and the casing size change. Approximately 1-in diameter holes were torch cut in the pipe 7 to 10 ft off the bottom and 15 to 20 ft from the top (Figure 11). The casing was hung from a plate at the casing top – which is about 3 ft 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. The static water level was about 8 ft below the surface. Before the top holes were cut, we measured the water temperature inside the promoter pipe as show in Figure 12 the following day. The problem with the well is readily shown, with only about 154°F for the first 150 ft and then increasing to 192°F from 225 ft 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 11: Cutting the 1-in diameter perforations in the promoter pipe for System Three.

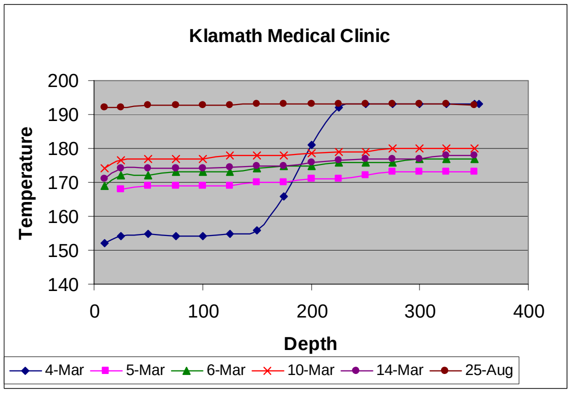

Figure 12: Temperature vs. depth profile of System Three well before and after the operation of the promoter pipe.

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 171^{o}F over the entire well depth and obviously creating a convection cell bringing hot water up from the bottom (see Figure 12). Subsequent reading produced similar results as shown in Figure 12. 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 28^{o}F and the highs around 50^{o}F. Another temperature probe was completed in August which shows the temperature has increase from 175^{o}F to 192^{o}F.

CONCLUSIONS

As can be seen from the three systems described above the design and placement of the convection cell system is very important to the operation of the downhole heat exchanger. The three systems have been completed differently and the results have varied greatly. System One will probably encounter problems in the future unless they decide to lower the location of the top tee or the water level increases. One of the owners has replied that the temperature coming in to his home is adequate, but not has high as he expected considering the temperature at the bottom of the well. When System Two was completed the perforations should have been placed lower that they were for they were placed just below the water level. With the installation of the promoter pipe the system seems to be operating in a satisfactory matter at this time and the owner is pleased with the temperature coming in to his home. The less costly option for System Three was the installation of the promoter pipe and they have reported they are getting very adequate and uniform heat into the building now.

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.

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.

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

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.

Lund, J. W., T. Boyd, B. Hackman, and B. Huffman, 2008. "Use of Promoter Pipe with Downhole Heat Exchangers in Klamath Falls, Oregon." Proceedings of the New Zealand Geothermal Workshop and NZGA Seminar 2008.

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.