TESTING AND MODELING OF DOWNHOLE HEAT EXCHANGERS IN SHALLOW GEOTHERMAL SYSTEMS

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INTRODUCTION

At the present time, over 400 downhole heat exchangers are being used in relatively shallow wells for extraction of geothermal energy at Klamath Fall, OR. Despite the large number of installations, the exact nature of the flows and hence, the optimal heat exchanger designs have not been determined.

Figure 1 shows a typical installation of a downhole heat exchanger (DHE) as presently used for extracting geothermal energy from the shallow, low-temperature geothermal resource at Klamath Falls, OR (Culver, et al., 1974). It consist of (i) the well bore, generally 15 to 36 cm in diameter and drilled with a cable rig, (ii) a casing sealed to the well bore at the top end for a distance of about 6 m and perforated at two levels, at the hot water strata level (well bottom) and just below the standing water level, and (iii) an unfinned U-shaped heat exchanger made from bare steel pipe.

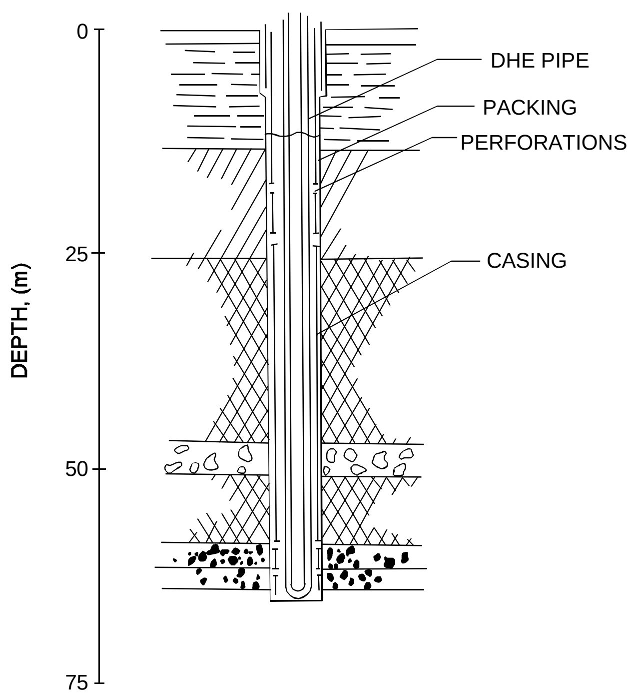

Figure 1. Typical DHE installation.

This paper reports the results of work on (i) characterizing flows in wells with perforated casings (as in Figure 1) with and without DHEs installed, (ii) determining energy extraction rates for conventional DHEs in both cased and uncased wells, and (iii) modeling of DHE systems to predict effects of heat exchanger and well variable changes.

FLOW CHARACTERIZATION

The flow characterization work has been done mainly by measurement of temperature and velocity profiles. Current work includes the use of dyes. Figure 2 shows the temperature as a function of depth for a typical well both before and after the installation of the perforated casing. The uncased temperature profile is probably somewhat indicative of the ground's temperature profile. The small top-to-bottom temperature difference indicates the existence of large, vertical water movements in the cased well which tend to keep well temperatures nearly constant with depth.

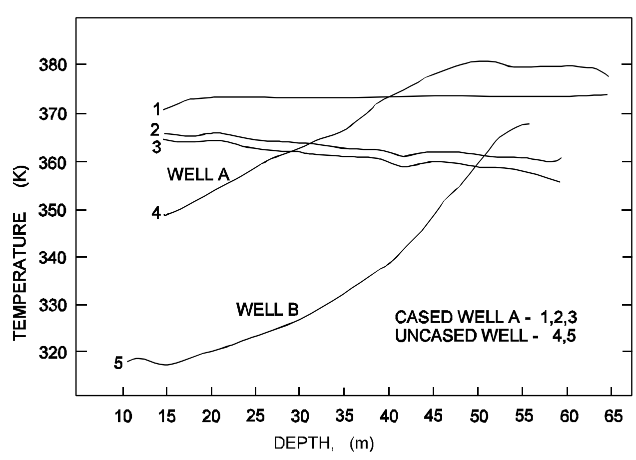

Figure 2. Measured temperature profile of cased and uncased wells. (Values are inside the casing of the cased well.)

Flow measurements were also made for both cased and uncased wells with a spinner (turbine meter). Before the wells were cased, the velocity was measured as either zero or very low (at the limit of sensitivity for the spinner). After the casing was installed, vertical upward flows over 1 kg/s were observed. Hot film anemometer measurements of the flow indicated an even larger flow of about 3 kg/s, much larger than the spinner measurements, but in better agreement with analytical models to be discussed later. The low reading of the spinner is explained at least partially by the fact that it posses a resistance to flow in the well.

These temperature and flow measurements indicate that a significant natural convection (thermosyphoning) is established by installation of the casing with perforations just below the water level and at the hot water aquifer level. The apparent driving mechanism of this thermosyphoning is the hot fluid at the well bottom and the cooling through the well walls.

ENERGY EXTRACTION RATES FOR CONVENTIONAL DHEs

Although it has been known for many years that the use of a perforated casing somewhat smaller than the wellbore increased the output of a DHE, there has been no information reported regarding the relative improvement. In order to quantify the improvement, obtain information about the convection cell with regard to energy balances within the well, and provide data for model evaluation, tests were run on DHEs installed in a well before and after casing.

Figure 3 shows the energy extraction rates achieved from both the cased and uncased well tests for a 64 m loop of 5-cm black iron pipe and a 65.5 m deep well. As expected, the DHE in the cased well was able to produce a significantly higher output than in the uncased well. At the highest output, DHE energy extraction from the cased well was 175 percent that of the uncased well, about 500 kW. However, it must be remembered that energy production would not be that high in the normal mode of operation since the inlet temperature for the test was lower than it would usually be and the ΔT across the DHE was 63ºC, much more than in actual operation.

Observation of the well fluid temperature at several depths inside the cased well revealed that with sufficient cooling, the convection cell reversed direction (see Figure 2, curves 2 and 3), going down the inside of the casing and up the outside–just the opposite of when there is no DHE present in the cased well (curve 1 of Figure 2).

MODELING OF THE WELL AND DHE

Analytical models of the cased well, with and without a DHE were made.

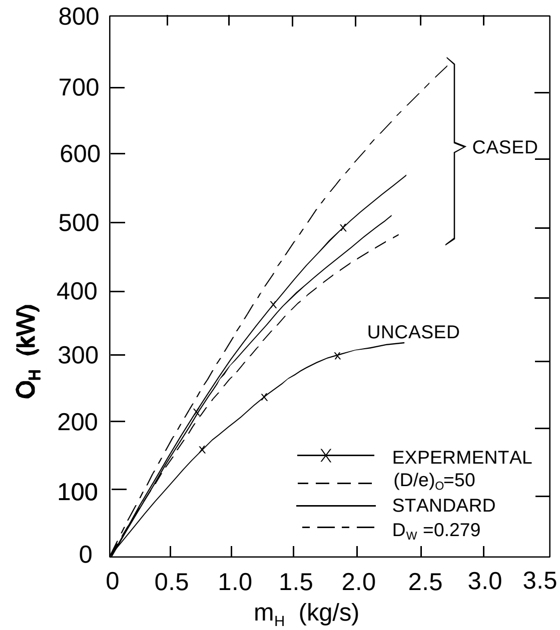

Figure 3. Experimental & model results for energy extraction as a function of flow rate through the heat exchanger. For well in Table 1.

The model for the cased well without a DHE was made to determine if thermosyphoning between the inside and outside of the casing due to the temperature gradient of the well is sufficient to account for the large observed flow rates. The model developed is quite sensitive to several assumed variables, the roughness of the well wall, the well temperature gradient, the exact well diameter, and time (because of conduction to the ground), but for reasonable values of these, predicts flows around that observed.

The model for the cased well was extended to include a DHE with flow inside the casing downward. For this model, the well temperature gradient and time (due to conduction thru the well walls) have very little influence, so the main assumed variables are the roughness of the well wall and the well diameter. Figure 3 presents the model results for the "standard" case (see Table 1) and variations of the roughness and well diameter about the "standard" values.

Comparison of the model predictions and the experimental results presented in Figure 3 illustrates how well the model predicts the energy extraction rates. The comparisons of Figure 3 show that the thermosyphoning can account for the energy extraction rates that are experimentally measured. Furthermore, they show that the modeling can predict the output within about 15% for reasonable estimated parameters. Consequently, the authors feel that thermo-syphoning is the major mechanism for heat transfer in the wells and furthermore, that while it must be recognized that application of this model has some uncertainty due to the selected values of well diameter and well wall roughness, the model allows the effect of design variables or design constraints of specific applications to be evaluated.

Table 1. "Standard" Well and DHE Variables

General Characteristics	
Well Diameter = 0.254 m	
Heat Exchanger Tube Diameter = 0.060 m	
Static Water Level = 14 m	
Perforation Levels:	
17 to 22 m and 57 to 65 m	
Temperature at Bottom of Well = 100°C	
Standard Parameter Sets	I
Casing Diameter	0.203 m
$(D/e)_o$ (1/ Relative roughness of the annulus)	100
L for cased well	50 m

Parametric analysis of the influence of design variables and constraints have been conducted. The variables considered include:

1. Well characteristics, length, diameter, casing diameter, and source temperature;
2. Heat exchanger design variables, diameter, number of loops and length; and
3. Heat exchanger fluid (water) variables, mass flow rate and inlet temperature.

The many results available from this analysis are too numerous to present here, but will be available soon from the authors or through another publication. Here, they will be treated in a qualitative sense only.

In general, increases in source temperature and well diameter both provide increased energy extraction rates. The length L and well casing diameter on the other hand both have an optimum value where the maximum energy extraction rate occurs. The influence of the casing diameter is particular interesting: in usual applications where the well is 0.254 m in diameter, the casing is 0.203 m; the parametric analyses show that roughly 50% higher heat transfer rates can be expected with a smaller casing. The length is not nearly as controllable as the casing diameter since it is dictated to a large extent by the depth of the hot water strata. However, in some instances, locating the top perforations at a lower level could prove beneficial.

The influence of the heat exchanger design variables is harder to generalize since there are trade-offs between tube diameters and number of loops in parallel. For the heat exchanger length (less than total length of the well), however, changes are almost directly proportional to changes in the energy extraction rate.

Increasing mass flow rate through the heat exchanger increases the energy extraction rate, but also increases pressure drop and decreases outlet temperature. Increased pressure drops will require larger circulation pumps and lowered outlet temperatures will affect process design. Decreasing the inlet temperature markedly increases the energy extraction rate but also decreases the outlet temperature.

The present models appear to be fairly accurate in the range for which they have been experimentally verified. The models do, however, neglect any mixing of cold fluid at the well bottom with warm (new) fluid that goes up the outside of the casing. Dye tests are presently underway to estimate the amount of mixing.

ACKNOWLEDGMENT AND DISCLAIMER

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REFERENCES

1. Culver, G. G.; Lund, J. W. and L. S. Svanevik, 1974. "Klamath Falls Hot Water Well Study," UCRL-13614, Lawrence Livermore Laboratory, Livermore, CA.