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U-TUBE DOWNHOLE HEAT EXCHANGER PERFORMANCE IN A 4INCH WELL ROTORUA, NEW ZEALAND

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Abstract

Regulations resmcting the withdrawal of geothermal fluid from shallow wells in Rotorua have created interest in the Downhole Heat Exchanger (DHE) as a low impact alternative method of utilizing the resource. Adapting existing production wells to DHE use is of special interest.

A series of tests has been conducted on a U-tube DHE installed in a 4in. (100mm) diameter well which previously provided a steam / water mixture to heat the Works and Development Corporation workshops in Te Ngae Road, Rotorua. Flow rates and temperatures through the DHE have been varied to test their influence on the heat load obtained. The thermal response of the well has been observed during quench tests and periods of DHE operation. A study of fluid temperatures inside the heat exchanger tubes has resulted in a better understanding of the heat transfer processes involved in a typical Rotorua DHE / well system.

Introduction

Concern over inefficient use of Rotorua's geothermal resource prompted the government to establish the Rotorua Geothermal Task Force in 1983, to investigate ways of improving heating system performance to reduce draw off. In a review of engineering alternatives the Task Force recommended that the applicability of Downhole Heat Exchangers **(DHEs)** be assessed for Rotorua, since they extract heat from the reservoir without mass withdrawal (Task Force Report, 1985). Late in 1987 the Ministry of Energy established a research programme to evaluate the performance of a downhole heat exchanger (DHE) in a "standard" Rotorua 4in. (100mm) well and to develop their design within the confines of the 4in. (100mm) well.

DHEs are used extensively at Klamath Falls, Oregon USA, to heat homes and commercial buildings. U-tube exchangers are the preferred design, installed in wells typically 100-150m deep, often fitted with a slotted undersized casing to form a convection cell (see figure 1). The field is very permeable and has a good hydraulic gradient across it, resulting in a high cross flow of fluid at the bottom of the well. Convective circulation in the wells is strong and although the undisturbed fluid temperature is only 90-100 °C high heat loads (up to 1MW) can be sustained by individual wells (Culver and Reistad, 1978).

At Taupo, New Zealand, many houses have their own DHEs. A local school, Tauhara College, has three DHE wells which are connected to the schools heating system. The first is similar in construction to a Rotorua 4in. (100mm) well, and is fitted with a 25NB U-tube DHE. A 7 5/8in. (195mm) well has a slotted liner and DHE as used in Klamath Falls and an 8 1/2in. (215mm) well is fitted with a convection promoter pipe designed by the method of Allis and James (1979). The combined system produces only 150kW from a shallow reservoir with an undisturbed temperature of 180-194°C due to poor heat and mass transfer at the bottom of the wells, a consequence of the fields low permeability (Pan, 1983).

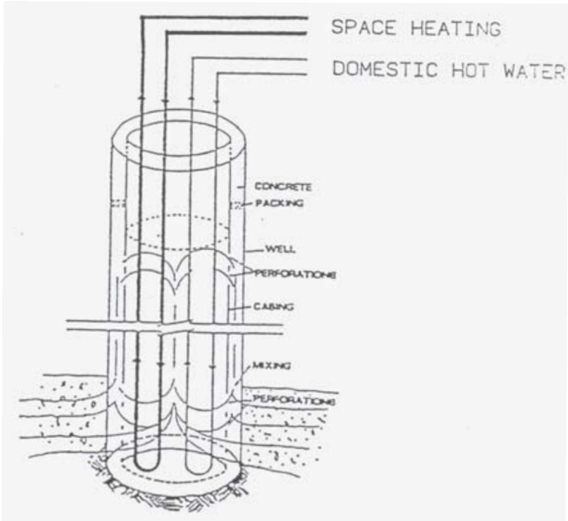

Figure 1 Typical DHE installation in a Klamath Falls well, Oregon USA (Culver and Reistad, 1978).

In Rotorua a simple 25NB U-tube DHE was installed to the bottom of a 123m deep 4in. (100mm) well to test performance under a range of operating conditions. A portable test facility complete with a circulating pump, flow controls, a plate heat exchanger and logging equipment was designed and constructed, to load and monitor the DHE. Once through cooling water is used to load the DHE through the plate heat exchanger. Flow and temperature monitoring and control of both streams is possible and temperatures can be continuously logged at eight points in the well. This rig is described in a previous paper (Dunstall and Freeston, 1988) and in more detail in a report to the Ministry of Energy (Dunstall and Freeston, 1989). This paper describes the results of the experiments with the simple U-tube design and suggests how performance may be improved. The effect of variation in flow-rate and return temperature on DHE output are investigated and a study of the DHE internal temperature profiles provides data on the effective heat transfer surfaces.

Well Description and Quenching tests

The well chosen for testing was a typical Rotorua production well with a "good" output. The well is 4in. (100mm) steel cased to a depth of 112m and has a drilled depth of 123m. The bottom hole temperature is around 160°C in an undisturbed condition. Firstly, a data-base of undisturbed temperature profiles was built up, then the well was quenched and its recovery from the quenched condition was monitored. Quenching flow was 1 l/s at 17°C for a period of 6-8 hours. The bottom hole temperature reached a stable 80°C during this time and the well profile showed an almost isothermal characteristic from the surface to the casing shoe (see figure 2). Re-heating of the well was rapid in the uncased region indicating good cross flow of geo-fluid. Heating of the fluid in the casing took considerably longer since re-heating in this region probably relies on conduction and eddy diffusion from the hot bottom zone.

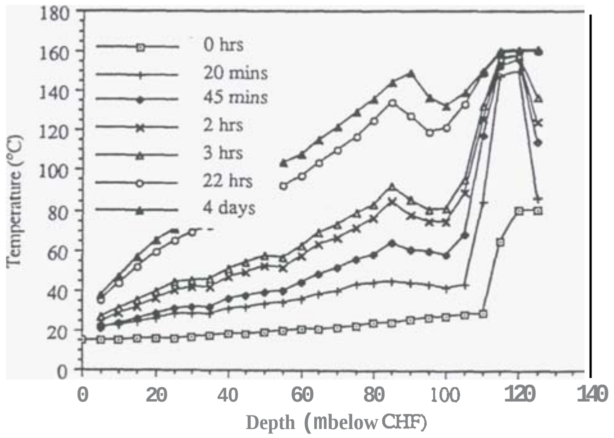

Figure 2 RR679 Heating after quenching

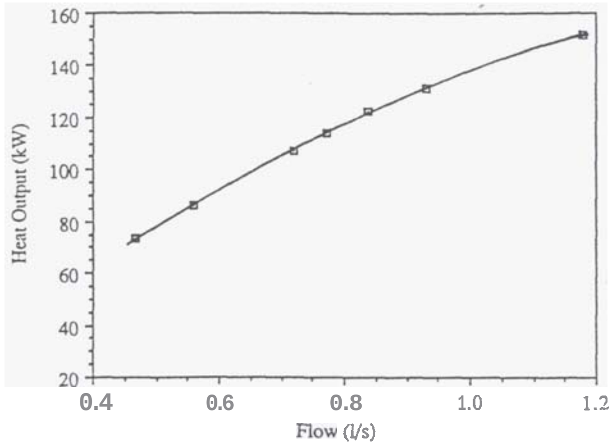

Figure 4 Heat Output vs. Flow Rate

The DHE was then installed in the well and connected to the test rig. Well profiles taken with the DHE running show a strong resemblance to the quenched profile (see figure 3), with a near linear increase in temperature in the cased portion of the well and a strong jump in temperature in the open hole portion of the well. The similarity is such that quenching a well and observing it heat up may give a well owner some idea of the potential heat output, should he be considering installation of a DHE, providing a cheap and simple performance assessment.

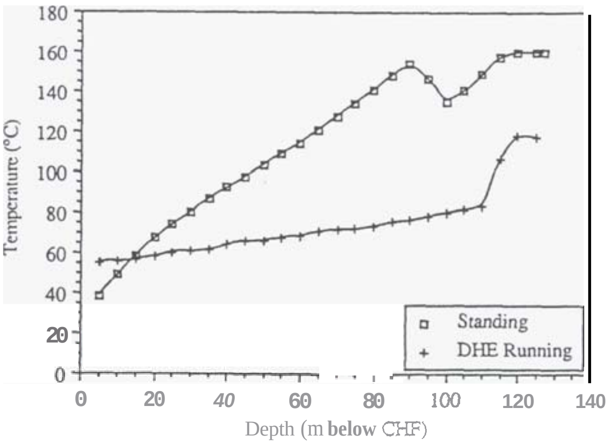

Figure 3 Downhole Temperature

If a number of existing DHE wells, with known outputs, could be quench tested and monitored during heat-up this data could be used to build up a data base, culminating in a DHE output potential prediction method.

Heat Output Tests

The **maximum** steady heat output of the DHE is currently limited to 150kW by the duty of the circulating pump and the heat transfer area of the plate heat exchanger used to load the DHE. At the *start* of the test programme a six day test was carried out with the pump flow rate and cooling water supply set at maximum. Immediately after start-up around 200kW heat output was obtained from the DHE at a flow rate of 1.2 l/s, flow temperature 44°C, and return temperature 83°C. After a period of several hours the output had dropped to 150kW, flow temperature 35°C, return temperature 66°C. The well bottom temperature reached a minimum of 111°C at this time and for the next six days the well and DHE conditions were invariant. This test was repeated two years later, after all other testing was finished, and conditions were found to be the same.

The effect of DHE flow rate (pumping rate) on heat output was investigated during the next series of tests. Cooling water flow rate was maintained at maximum so that the load on the DHE was as high as possible from the rig. The pump flow rate varied from 0.45 l/s to 1.2 l/s. Heat output was found to increase almost linearly with flow rate, tapering off slightly as the flow rate increases (see figure 4).

Numerical and model well experiments have shown that typical DHE output curves flatten off as the flow rate becomes "high" (see figure *5)*. Reservoir parameters and well / DHE configuration all play a part in determining what constitutes a high flow rate (Pan, 1983). From the output curve obtained here it appears that 1.2 l/s is a moderate flow rate for this DHE / well combination and that an increase in flow would yield a higher heat output. While heat output increases as the flow rate increases, the return temperature has a tendency to fall off, negating some of the gain. Costs of pumping also begin to rise sharply at higher flows, reducing the nett return. The likely increase in heat output would, however, almost certainly more than cover the increased pumping costs for moderate increases in flow rate.

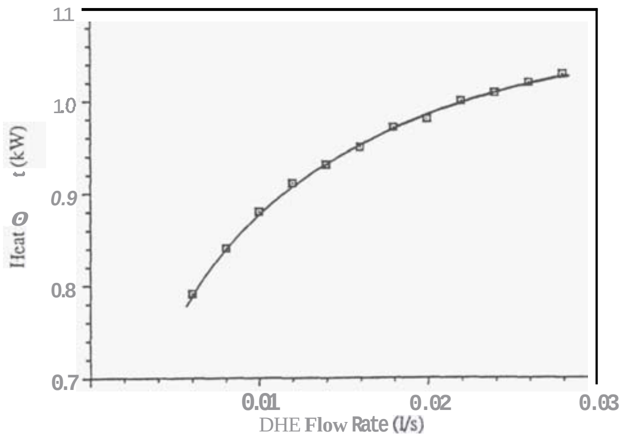

Figure 5 **Typical** *Output* **Curve for 3 DHE**
(taken from numerical data by Pan, 1983)

In order to assess the fall-off in performance due to return temperature declines another series of tests were performed with the return temperam held at 80°C for all flow rates. In order to maintain this return temperature the flow temperature was raised, sacrificing some heat load. For a given flow rate the heat duty was found to be very sensitive to the inlet (and hence outlet) temperatures. Once again the heat duty varied almost linearly with flow rate (see figure 6) and the heat duty obtained at a particular flow rate was around 20 kW lower than that obtained in the previous tests which had a lower return temperature. The inlet temperature is consequently around a constant 55-60°C for *this* series of tests. The flow temperature seems to control the return temperature over the range of flow rates tested and this is further explained in a following section.

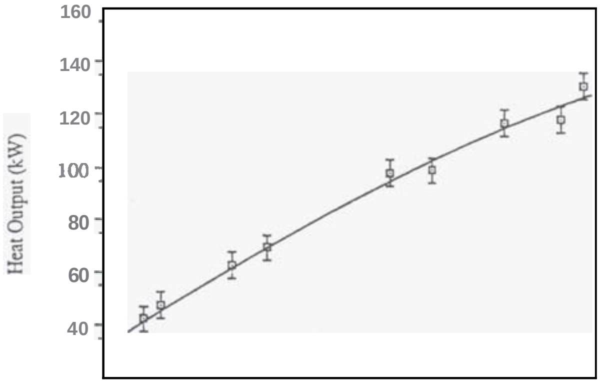

Figure 6 Heat Output vs. Flow Rate (80 deg C return)

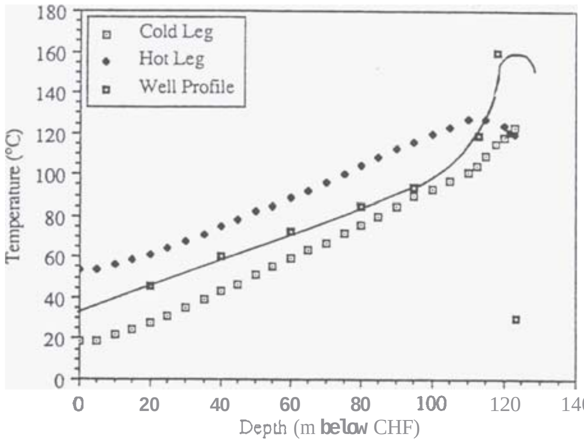

Figure 7 DHE internal temperatures (0.6 l/s)

Airlifting

It is well known that the circulation induced by the undersized casing in the Klamath Falls wells enhances heat transfer by exposing the full length of the DHE to hot fluid (Culver and Reistad, 1978) and for wells in reservoirs of low permeability that pumping can enhance heat output (Allis, 1981). Pumping fluid from a well lowers the hydrostatic pressure in the well and fresh hot fluid from the reservoir flows in at the bottom to replace that which was pumped out, raising the mean temperature of fluid in the well.

In an attempt to enhance heat transfer in the Rotorua well relatively cold fluid was withdrawn from the top of the casing with a small airlift pump. Temperature monitoring confirmed that fresh hot fluid flowed in at the bottom of the casing. This experiment was successful in enhancing the DHE output to a limited degree but large volumes of geothermal fluid would have to be extracted to substantially increase performance. The techniques primary disadvantage is that it withdraws mass from the reservoir, negating the DHEs principle advantage. Because the performance increase is small at low pump rates the method is probably best suited to the situation where an existing DHE cannot quite meet the required load, or for "boosting" during cold periods. It cannot be recommended as a standard technique to increase performance.

While the airlift gave only a slight increase in the number of kilowatts of heat produced it did improve the outlet temperature by 1-2°C. From the constant temperature return tests (80°C return) it was found that increasing the outlet temperature by 1-2°C could require a 5-10 kW reduction in heat duty, so at a given flow rate the airlift pump shows an effective improvement of 8-12 kW rather than the measured 2-4 kW improvement. This discrepancy is due to the test method, which involved allowing the DHE to reach a stable condition then bringing on the airlift. The resulting increase in outlet return temperature obtained with the airlift on does not figure in the heat load calculation.

Heat Transfer

The results of these tests led us to the conclusion that most of the heat transfer was probably taking place near the bottom of the well. Quench testing indicated that little heat transfer occurred through the casing and flow and return temperatures depend more on each other than on bottom hole temperature or flow rate. In order to investigate this a temperature probe was lowered inside the DHE tubes while the DHE was running, and the well temperatures were monitored. When the DHE was in a stable condition we measured the flow and return leg temperatures and well temperatures. This was done for a flow rates of 0.6 l/s and 1.2 l/s (see figures 7 and 8).

In both cases the DHE flow temperature increased until the point where the DHE return leg re-enters the casing. From here to the top of the well the return leg loses heat to the colder flow leg. At the higher flow rate a peak temperature of 83°C is reached with an outlet temperature of 60°C and a well feed zone temperature of 113°C. At the lower flow rate the temperature peaks at 127°C inside the DHE but this heat is lost on the return leg and the fluid exits at 54°C. The feed zone temperature is 135°C at this flow rate. Although a good approach to the reservoir temperature is obtained at the low flow rate the longer residence time also allows more re-equilibrium as the fluid returns to surface.

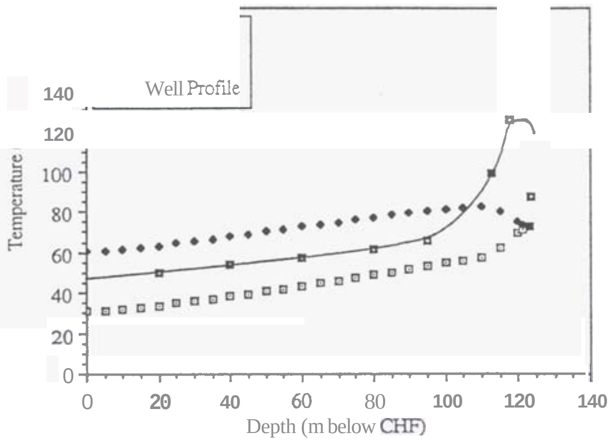

Figure 8 DHE internal temperatures (1.2 l/s)

A plot of the heat fluxes shows that the nett heat flux over the cased part of the well is almost zero, and that all of the heat lost in this section by the return leg is gained by the descending fluid in the flow leg (see figures 9 and 10). The heat flux, from the return leg to the flow leg, is the same at both flow rates and the temperature difference is approximately constant at 25°C (as for other tests).

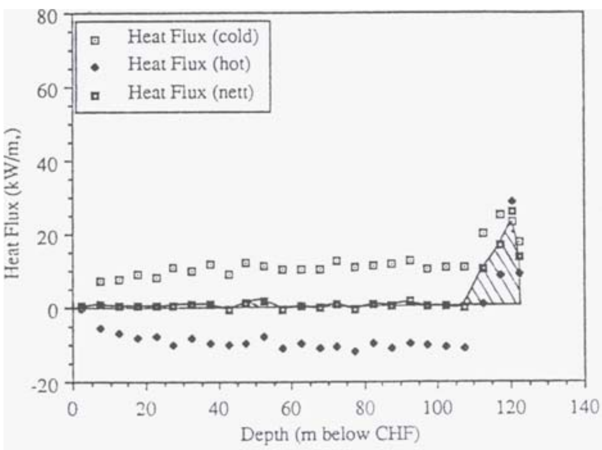

Figure 9 Heat Flux (0.6 l/s)

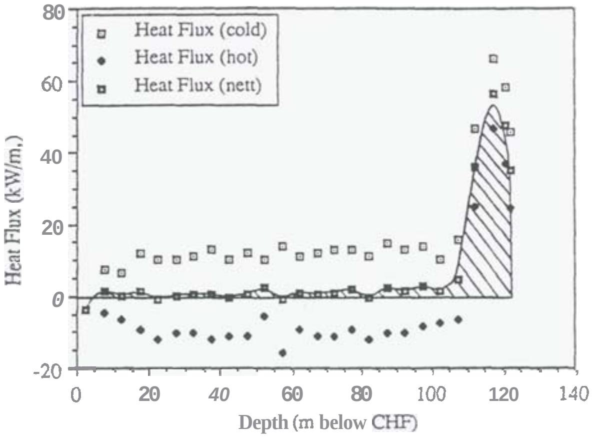

Figure 10 Heat Flux (1.2l/s)

If we were to insulate the return leg from the casing shoe to the surface we could expect a higher return temperature and higher heat output. In the case of the 1.2 l/s flow the maximum temperature reached is 83°C. Even with perfect insulation we may not achieve an 83°C outlet at the surface if the same 32°C inlet was used (for a heat output of 250kW) since the down-coming fluid would no longer be pre-heated. Arriving at the bottom of the well colder would, however, provide a higher driving force for heat transfer in the open hole region, enhancing heat output. Since almost all the nett heat transfer takes place in the open hole this area of the DHE is very important. Low finned tubing may increase performance if installed over the bottom 12m or so.

Annular DHEs

Annular DHEs have been shown to have a similar thermal performance to U-tubes on a model well (Pan, 1983). The results of the Rotorua experiments cast some doubt on their applicability to this type of well however. Normally an annular DHE has a higher output when fluid is pumped down the annulus, where it is heated, and returned via the relatively insulating pipe (Pan, 1983). If heat transfer is taking place over the length of the well this is desirable but in the Rotorua situation the inner pipe has no opportunity to gain heat from the well as the fluid moves upward. At the high flow rate, with our well configuration and the U-tube DHE design, 40% of the overall nett heat gain is via the bottom section of the return leg. Annular exchangers may cut off much of the positive heat transfer surface in this well.

Normally an annular exchanger is designed so that the flow resistance in the annulus equals the pipe resistance, to minimise pumping losses. From a heat transfer point of view it may be desirable to have a very small inner tube to return the fluid quickly to the surface after a slow mp down the well. It is intended to install an annular exchanger in Rotorua with a combination of several pipe / annulus area ratios to test this idea. It is intended to run the flow in both directions for comparison in each configuration tested. The annular exchanger, if it can compete thermodynamically with the U-tube, has the advantages of ease of installation, less corrosion problems and built in allowance for differential thermal expansion.

An annular design will also give us the opportunity to test a convection promoter tube, as was med unsuccessfully at Tauhara College, to increase the DHE output. If successful the tube will allow hot fluid to circulate to the top of the well before coming into direct contact with the DHE, resulting in more DHE area being exposed to hot fluid. Hotter geothermal fluid would then be first exposed to the final few metres of the DHE giving heat where it is needed most, at the exit. Wells in Klamath Falls have almost doubled in heat output when an undersized slotted casing was used to establish a convection path (Culver and Reistad, 1978).

Conclusions

1. The quench test provides a steady profile similar to that obtained with the DHE running and may be useful in predicting DHE performance before installation.

2. A circulation rate higher than 1.2l/s would increase DHE heat output, at the expense of outlet temperature and higher pumping costs.

3. The DHE outlet temperature is controlled by the inlet temperature for the range of flow rates tested because of heat transfer between the closely spaced tubes in the cased part of the well.

4. If a higher outlet temperature is required the DHE heat duty must be reduced or the flow rate increased.

5. Pumping cold fluid from the top of the well gives a slight increase in DHE performance.

6. Almost all the nett heat transfer to the DHE occurs in the bottom 12m of the well (in the open hole).

7. Experiments with annular DHEs and promoter tubes have the potential to greatly enhance the wells heat output.

References

The following articles were consulted during the preparation of this paper:

Allis, R.G. (1981); 'A study of the use of Downhole Heat Exchangers in the Moana Hot Water Area, Reno'. Geo Heat Centre, Oregon Institute of Technology. May 1981.

Allis, R.G. & James, R. (1979); 'A natural convection promoter for Geothermal Wells'. DSIR Wairakei, New Zealand, RGA-1, RJ-29.

Cosgrove, B. & Dunstall, M. (1988); 'Application of Downhole Heat Exchangers to the Rotorua Geothermal Field. Commissioning report to the Ministry of Energy, Contract No. 87/42. March 1988.

Culver, G.G. & Reistad, G.M. (1978); 'Evaluation and Design of Downhole Heat Exchangers for Direct Application'. Geo Heat Centre, Oregon Institute of Technology. December 1978.

Dunstall, M. & Freeston, D.H. (1988); 'Downhole Heat Exchanger Experiments - Rotorua Geothermal Field'. Proceedings of the 10th New Zealand Geothermal Workshop: Geothermal Institute, University of Auckland. November 1988.

Dunstall, M. & Freeston, D.H. (1989); 'Application of Downhole Heat Exchangers to the Rotorua Geothermal Field', Final report to the Ministry of Energy, Contract No. 87/42. April 1989.

Pan, H. (1983); 'Geothermal Downhole Heat Exchangers'. Masters Thesis, Department of Mechanical Engineering, University of Auckland. May 1983.

Task Force. (1985); `Technical Report of the Rotorua Geothermal Task Force 1983-1985'. December 1985.