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DOWNHOLE HEAT EXCHANGER EXPERIMENTS - ROTORUA GEOTHERMAL FIELD

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ABSTRACT

The need for research for the application of downhole heat exchangers (DHE) in the Rotorua Geothermal field has arisen from the increased use of DHEs for heating and the limited performance information available to assist effective and efficient design.

An experiment was designed in which two 4 in. diameter wells located at the Works depot in Te Ngae Road have been used. RR679 is fitted with a 'U[1] tube DHE and well RR520, approximately 15 m away, is monitored for interference effects. The design and installation of the test facility is described and results of some experiments presented. A theoretical model of the installation is also presented which enables studies to be made of the major well and DHE design parameters.

1. INTRODUCTION

Downhole heat exchangers (DHE) are used extensively at Klamath Falls for the space heating and hot water supplies for domestic and institutional buildings. Heating loads vary from a few kilowatts to just over one Megawatt (Culver and Reistad, 1978). Generally these DHEs are of the simple 'U' tube type installed in wells, typically 100 m to 150 m deep, which are lined (Figure 1). The undisturbed reservoir temperature is about 90°C and the reservoir is in fractured sedimentary rocks with excellent permeability. A reasonable hydraulic gradient exists across the field producing a cross flow at the bottom of the well which, together with the formation of an annulus by the liner, creates a convection cell. The well fluid rises in the liner and descends in the annulus enhancing heat transfer.

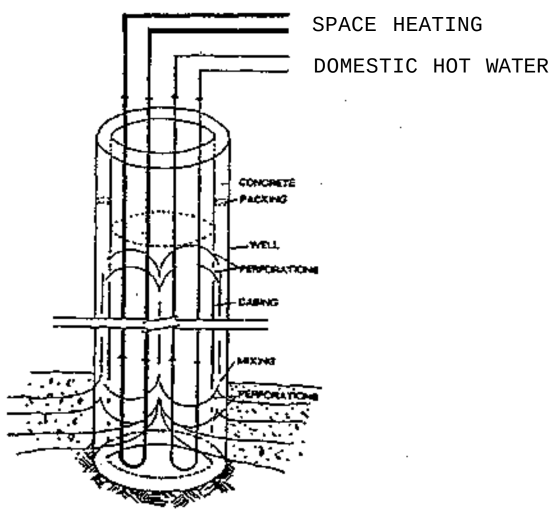

FIGURE I

At Taupo (NZ) a number of households also have their own DHEs supplying their heating and hot water needs. At Tauhara a system utilising three wells, one of 7-5/8 inch diameter, one of 8-1/2 inch diameter and one of 4 inch diameter provides heating for a high school. All three wells are completed differently. The 4 inch well is cased to 80 m and completed with an open hole to 200 m with a 1 inch diameter DHE. The 7-5/8 inch diameter well uses a design similar to the Klamath wells with a liner down to the bottom, perforated below the water level and at the bottom of the well; the 8-1/2 inch diameter well uses a promoter tube designed using the method suggested by Allis and James (1979). All three DHEs are connected to a common manifold and fed through a "peaking" boiler to supply additional heat energy for short periods when needed. Under normal running conditions, without the boiler, this system produces about 150 kW, sufficient to maintain the school buildings at a reasonable temperature. In this case, however, the reservoir has low permeability and there is little heat and mass exchange taking place at the feed point of the well (Pan, 1983).

The downhole heat exchanger has a number of advantages amongst which are:

(a) no mass withdrawal from the reservoir;

(b) clean water circulating through the load, so deposition and corrosion can be controlled;

(c) no waste water disposal problem;

(d) low capital cost and low maintenance.

However there are some disadvantages:

(1) the heat loads that can be supplied are limited. The largest heat loads serviced by a DHE known to the authors are 1.03 MW at Klamath Falls and two deep wells in Turkey which supply over 1 MW (Kural, 1985).

(2) There is a temperature drawdown in the well which results in a change in well water level locally, those changes are functions of the DHE load and the reservoir characteristics.

The Rotorua Geothermal field is a resource which, in recent years, has come under stress due to the extensive extraction of geofluid for domestic and commercial purposes. Establishment of research and monitoring programs by N.Z. Government departments has resulted in a control of the use of the fluid. A review of engineering alternatives, Task Force Report (1985) recommended further research into DHE performance.

The main objective of the experimental program was to evaluate the performance of DHEs in a "standard" Rotorua 4 inch diameter well and to develop their design to optimise this performance. The interference effects on nearby wells were also considered to be part of the project. Secondly, as part of the overall research program on DHEs, the influence of design parameters was to be investigated using a Fluid Mechanics and Heat Mass Transfer computer package PHOENICS. This paper reports some of the work on these two topics.

2. EXPERIMENTAL METHOD

2.1 Research Wells

In searching for a suitable research well certain preferences were developed. Utilising a well on Government property minimised operational problems and operational costs. Two wells (RR679, RR520) located at the Works Depot, Te Ngae Road, were targeted because of their proximity to workshops and their favourable output behaviour. Dispensation was given for their use as research wells, with RR679 being chosen for use in this research contract because of its good proximity to the Depot Plantroom. A monitoring program was initiated on RR679 and the surrounding well RR520.

Temperature profiles were recorded for RR679 in its heat-up phase after cleaning and after numerous test quenching runs (Figure 2), as well as monitoring of water level variations. Temperature profiles and water levels were recorded for RR520 (Figure 3) in its steady state conditions once completely cleaned.

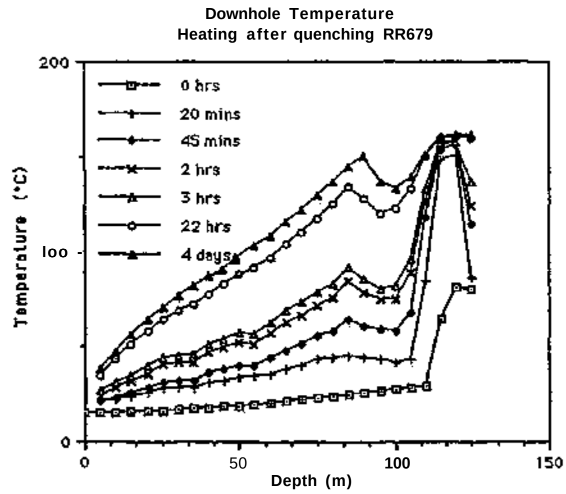

FIGURE 2

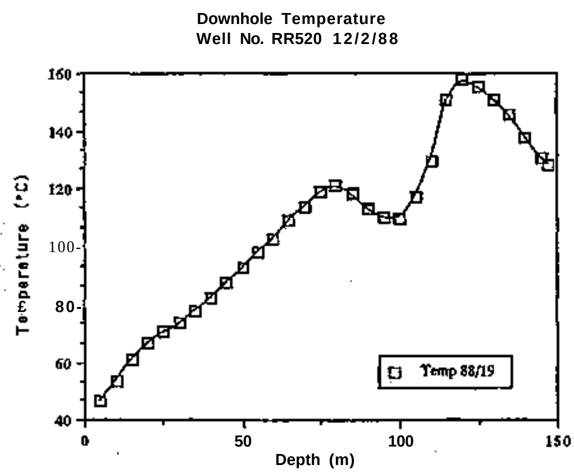

FIGURE 3

Currently RR520 is being periodically monitored to observe if the DHE operation affects its steady state condition. The research well RR679 is continually monitored during operation in accordance with set research procedure - thermocouple wires are suspended at fixed depths relaying continuous temperature readings to a multi-channel data logger during system operation.

2.2 Test Facility

The DHE designed and installed is a standard TJ' tube design made from 25 mm diameter mild steel (ms) medium grade tubing. A silt trap is located at the bottom for isolation of sediment, sockets join the pipe lengths together and are staggered to allow for thermal expansion, and a 20 mm thick ms capping plate, bolted to the well head, supports the DHE at the surface. A 20 mm diameter ms medium grade tube is suspended alongside the DHE for the thermocouple wiring. This tubing is systematically drilled in 6 m lengths in an effort to promote steady state conditions.

The test rig is a flat welded steel frame with a web grating floor. The outside dimensions have been limited to allow the rig to be placed inside a normal lightweight utility vehicle. Lifting lugs are provided at each corner, and the grating allows for easy assembly and disassembly of the test equipment.

The test rig (Figure 4) houses an instrument cabinet, a DHE circulating pump, a cooling load plate heat exchanger (PHE), an expansion tank with make-up water supply, balance (control) valves, and inter-connecting 25 mm ms piping.

The multi-stage circulating pump currently provides a duty of 1.2 1/s flow against a 50 m head pressure. This characteristic can be altered by either adjusting the impeller configuration of the pump or adjusting the flow control valve. The pump draws 1.5 kW power which equates to around $1,000 annual operating charge for continuous operation on domestic tariff.

The PHE was initially sized for 150 kW based on conservative temperature drop and flow rate conditions. Initial heat duty results show a 210 kW heat load is actually being produced on system start-up. Allowance for a heat duty beyond 200 kW can easily be provided through the addition of heat exchanger plates.

The balancing valves have been placed in the DHE circuit to alter both the flow and temperature characteristics of the system. These valves are intended to be replaced with automatic control valves in the future.

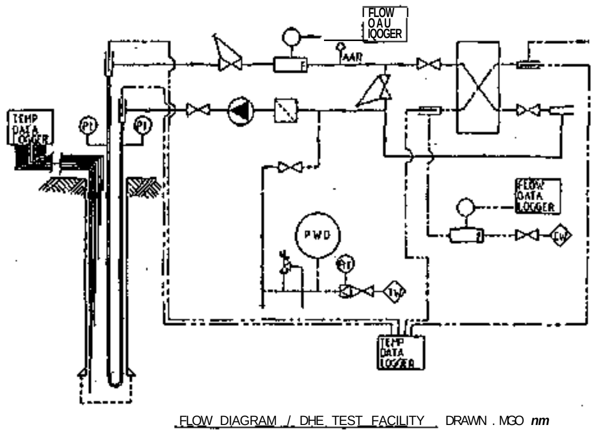

FIGURE 4

2.3 Instrumentation

Two areas require independent monitoring:

(a) Well behaviour
(b) DHE operating system.

The method currently used for monitoring well behaviour is as described above.

In monitoring the DHE operating system there are four independent areas of instrumentation:

(i) temperature
(ii) flow
(iii) pressure
(iv) control.

For temperature, resistance temperature detector (RTD) probes are located at five points in the system. They monitor the temperature changes across the PHE and the temperature control (by-pass) valve. During operation the readings are recorded at set intervals on data loggers.

For measuring flows two vortex shedding flowmeters are located within the system. One measures the circulating flow in the DHE system, and the other measures the cooling water flow rate. During operation the readings are recorded at set intervals on data loggers. As a calibration or back-up measure there is facility to use a manual 'bucket and stopwatch' method of flow rate measurement.

Pressure needs to be measured at the wellhead and across the control valves. At the wellhead, pressure gauges are fitted to the flow and return points of the DHE A differential pressure transducer is connected between the two lines to measure automatically the pressure drop. Both the positive pressure readings and the differential pressure values are able to be logged at set intervals during operation.

Monitoring control valve settings is more for the purpose of establishing varied operating conditions. A monitor instrument can record the pressure drop and flow across a control valve, enabling these parameters to be set at known intervals for studying the resulting DHE system behaviour.

The principal method of collecting field data during an extended operating period is from data loggers being used. Two are 2 channel 'Squirrel' data loggers collecting the vortex flowmeter readings; one is a 4 channel 'Squirrel' data logger directly reading the temperature from the DHE RTD probes; and one is a 20 channel Digitec 2000S' data logger collecting the geothermal well's thermocouple temperature readings. Unfortunately to date this is unservicable so we have logged temperatures manually using a digital thermometer.

The data loggers used are compatible with an ''Epson' field personal computer (PC). Data can be transmitted to the PC's internal memory storage through an interface program. The data is then transmitted to a IBM PC for floppy disk storage and manipulation within spreadsheet programs.

3. TEST PROGRAMME

Firstly the DHE circuit was commissioned. Upon the TJ'-tube DHE being successfully installed in the research well, a pressure test was conducted. Town water was supplied at 5.5 bar pressure with the outlet pressure stabilising at 11.5 bar (the increase being due to thermal expansion). Initially a gradual loss in pressure was noted from the stable condition. Retesting after approximately two weeks indicated that the pipe joints seemed to self-seal with minimal pressure losses.

Once the DHE heating circuit was started, duty readings were recorded for comparison with the designed values, The measured duty of the pump correctly matched the design duty of 1.2 1/s flow against 50 m head pressure for a completely open circuit (by-pass shut, flow control valve fully open). A heat load rating was taken across the PHE with start-up conditions typically measuring as below:

(a) DHE Circuit

Flow rate		=	1.21/s
Temperatures:	flow	=	44°C
	return	=	83°C
Heat Load		=	196 kW

b) Cooling Circuit

Flow rate		=	1.21/s
Temperatures:	flow	=	19°C
	return	=	59°C
Heat Load		=	202 kW

The difference is attributable to the 'rounding-off of the values shown.

Once the system has been operating for several hours a steady state condition is reached, with the measured heat output being around 150 kW. These heat values for start-up and steady state conditions correlate well with the designed performance values (Figure 5).

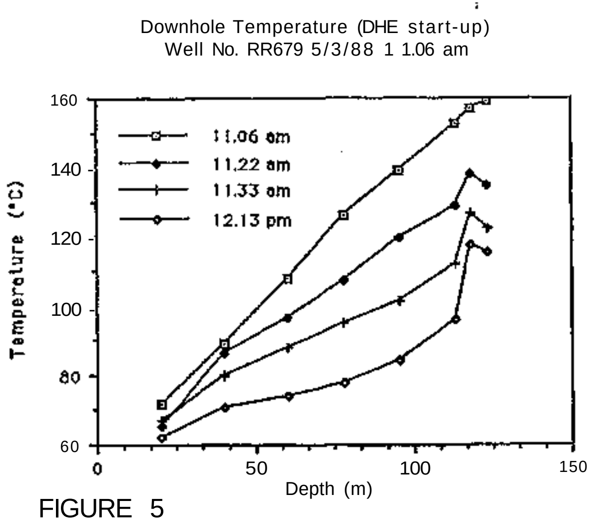

FIGURE 5

Temperature profiles taken when research well RR679 is in a steady state static condition, and in a steady state operating condition shows the feed zone (open hole area) drops from 162*C to 118*C. This is for the DHE circuit operating at maximum output. Cooling of the well approaches an even temperature gradient over time. This is due to the DHE piping circulating through a standing column of water.

Reheating of the well is a slower process, showing a rapid recovery of bottom hole temperature and slower recovery of the standing column within the well casing. This column relies on natural well circulation to regain the static equilibrium condition (Figure 6).

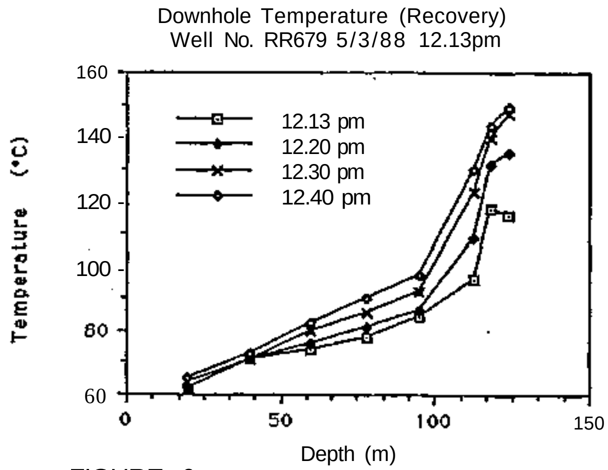

FIGURE 6

A six day test was carried out and demonstrated the rapid, temperature drawdown of the well when the DHE was put on line, reaching a bottom hole temperature of about 1J3°C after only 3 hours. The temperature at 24 hour intervals over the next 6 days is recorded in the table below:

Table 2

Day	1	2	3	4	5	6	7
Temp. at 118m (°C)	113.2	111.5	111.2	111.3	111.6	111.6	111.3
DHE in CO	36.6	35.4	35.4	35.4	35.4	35.4	35.4
DHE out	67.8	66.0	65.4	65.4	66.0	66.0	66.0

This data was obtained with a flow rate of 1.18 kg/s, the pressure drop through the DHE stabilised at 380 kPa. From the data above the steady output was 151.6 kW. Further work is underway which looks at the variation of heat load and pressure drop as a function of DHE mass flow.

On shutting down the DHE, the bottom hole temperature returned to 146°C after 2-3/4 hours, which was consistent with the early commissioning runs (Figure 6). The temperature at 120 m and 145 m in Well 520 was monitored over this period. The temperature data is not of sufficient quality to make definitive conclusions however there is trend in which the temperature of Well 520 appears to decrease with time stabilising at about 0.5 to 1.0 degree below the initial value after about 4-1/2 days of DHE operation.

3.1 Discussion

These tests demonstrate the viability of utilising a DHE in Rotorua 4 in diameter wells where there is a good cross flow. The output measured would be able to service about 12 homes with heating and domestic hot water. However it is necessary to reflect that the tests reported here are only the first stage of the programme. No attempt has been made to optimise either temperatures or mass flows. The future programme looks at varying some of these parameters.

Neither has any attempt been made to investigate the affects on inducing circulation within the well. It is well known that such a circulation enhances the heat transfer performance of the exchanger. In Klamath Falls (Culver, 1978) outputs were almost doubled when undersized casing was used to provide a path for convection in the well however at the Tauhara (Taupo, NZ) installation, referred to earlier, a promoter tube had little effect on output. In order to obtain effective well circulation with the techniques described above a reservoir with high permeability and a good cross flow across the bottom of the well is necessary.

4. ANALYTICAL METHOD

A computer package PHOENICS has been used to look at the flow and heat transfer process of the well and DHE system. The general equations of mass momentum and energy are solved using finite difference methods. A set of boundary conditions are specified for a two dimensional model of the Rotorua system described above. The well, 120 m deep x 100 mm diameter, was modelled using a 20 x 7 cell grid with the DHE piping considered to consist of the cells numbered 3 and 5 across the mesh, connected near the bottom of the grid. The package uses 'phases' to identify the individual fluid paths. Volume fractions were used to constrain the access of phase 2 (DHE fluid) to only the cells representing the piping whereas phase 1 (well fluid) was permitted access to all cells (Figure 7). Heat transfer to the DHE fluid could then occur by permitting 'mixing' of the phases within the DHE cells. For the DHE side, since the flow is turbulent, a high heat transfer coefficient was specified. On the well side only conduction heat transfer was modelled; circulation within the well is not modelled.

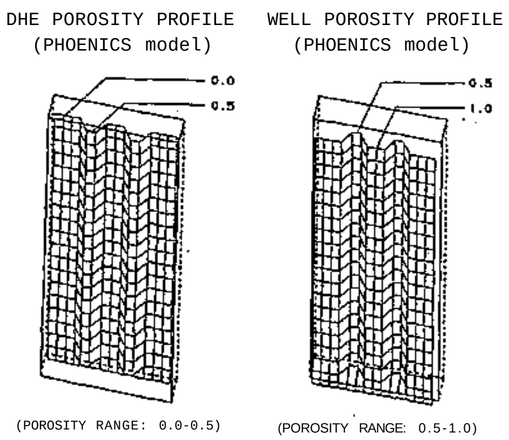

FIGURE 7

A measured well temperature profile representing the well temperature from the experimental rig was selected as an input so that the interaction between the legs of DHE could be investigated. Results from the model are consistent with those of the experimental rig. Maximum temperature of the DHE fluid is reached at about the point where the return leg enters the casing. Above this point heat is lost to the well over the DHE return leg, only about 60% of the total heat exchanger area is effective (Figure 8).

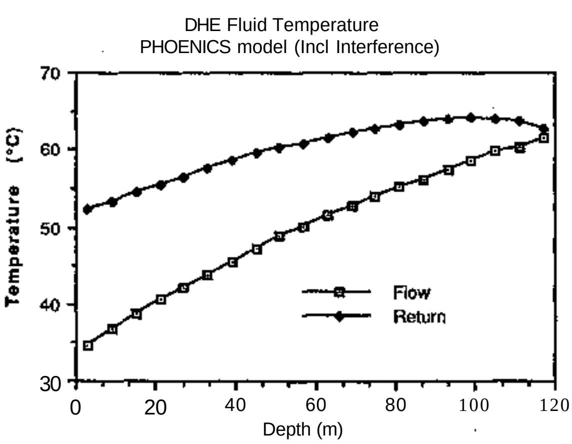

FIGURE 8

Using a purely conductive model results in relatively large temperature gradients across the well (Figure 9) particularly in the upper part of the casing where the DHE legs have a high temperature difference. If circulation due to convection is small, as seems likely, then we could expect a radial temperature distribution which leads to some doubt about temperature measurements in these wells. This point needs further consideration and is being investigated experimentally in a laboratory scale model of a well.

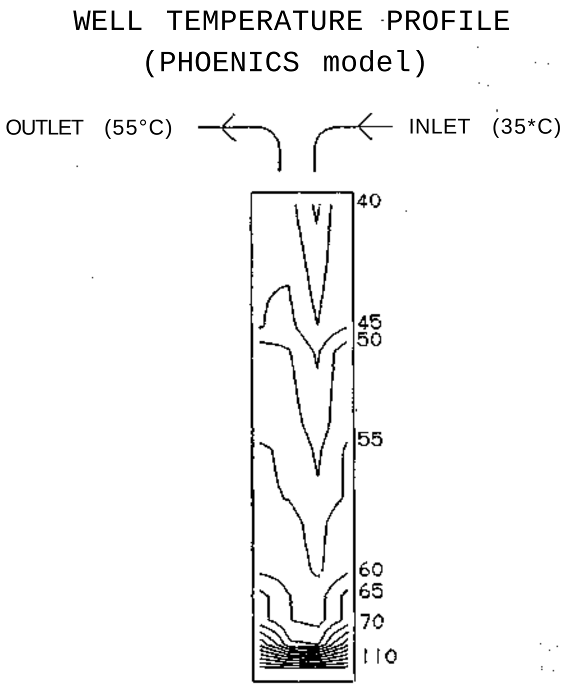

FIGURE 9

This preliminary attempt at using PHOENICS encourages further work. Of particular importance is the influence of cross flow on the DHE performance and the introduction of a convection cell formed by a promoter tube or by extracting a small quantity of fluid at the well head. Both these phenomen require the model used so far to be modified.

5. CONCLUSIONS

1. This installation would provide enough heat energy for 12 homes i.e. 150kW.
2. The 6 day test indicated that the system reached equilibrium after only a few hours and was able to give a continuous output over the test period.
3. Long term temperature and water level drawdown effects need to be carefully evaluated in the surrounding wells.
4. Variations in load as a function of DHE flowrate need to be determined in order to minimise pump running costs.
5. The analytical approach will assist the understanding of the heat and mass transport processes taking place within the well and between the three major components, well, reservoir and DHE.

REFERENCES

Culver, G. and Reistad, G. M. (1978). Evaluation and design of downhole heat exchangers for direct application (final report). GHC, Klamath Falls, Oregon.

Allis, R. G. and James, R. (1979). A natural-convection promoter for Geothermal Wells. DSIR Wairakei, NZ, RGA-1, RJ-29.

Pan, H. (1983). Geothermal Downhole Heat Exchangers. M.E. thesis, University of Auckland, NZ

Kural, H. Personal communication.

Task Force (1985). Technical Report of the Rotorua Geothermal Task Force 1983-1985.

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