GEOTHERMAL UNDER STREET HEATING SYSTEM

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ABSTRACT

In 2008 the Rotorua District Council made a block of Tutanekai Street, nearest to the lake, a pedestrian only precinct and the many restaurants located on the block set up "al fresco" dining facilities. The area is named Eat Streat. This move was a great success and widely used by local people and the many tourists who visit the city. Encouraged by this success it was decided in 2012 to further enhance this aspect of the city experience, by providing better shelter and under street heating, using geothermal energy as a heat source, so that outside dining could be carried out for a longer period each year. As the natural geothermal features of the City are a major tourist attraction this move was aimed at showing the environmental benefits of geothermal by tapping the energy using a down hole heat exchanger.

The down hole heat exchanger (DHE) used on the project was of novel spiral flute coaxial tube design, with the key design aims being to promote greater turbulence of the circulating water and to maximise the heat transfer surface area of the unit. The unit has a maximum diameter of 80mm and can be installed in a 100mm dia. bore.

The bore was drilled at the corner of Tutanekai Street and Pukaki Street with the DHE installed at a depth of 120metres and located in a permeable zone encountering geothermal fluid at 130°C. The DHE was output tested using cold mains water as a heat sink and found to be capable of a sustainable output of around 135kW.

Technical details of the DHE system and its performance in meeting the under street heating load are provided in the paper.

1 BACKGROUND

1.1 Rotorua Geothermal Field Management

In the mid 1980’s, the Rotorua geothermal field was under severe stress and this resulted in Government action to rectify this situation. Fluid withdrawal from the reservoir in early 1980 was around 30,000 tonnes/day with only about 1000tonnes/day being reinjected. Action taken included a complete ban on any fluid extraction within 1.5 km radius of the Pohutu Geyser, curtailment of many production bores outside the exclusion zone and the implementation of a consenting process requiring reinjection of all production fluid within a given time frame. As a consequence of these measures by 2000 geothermal fluid extraction had reduced to around 9,000 tonnes/day with most of the extracted fluid being reinjected back into the reservoir.

Management of the Rotorua geothermal field is the responsibility of the Bay of Plenty Regional Council and they are required to achieve sustainable management of the resource by ensuring its efficient use and development, whilst at the same time maintaining and enhancing its amenity value. To help achieve these objectives Bay of Plenty Regional Council have developed the concept of a strategic equilibrium, where water levels associated pressures in the aquifer fluctuate above a defined geothermal aquifer water level. Thus field monitoring becomes a balance between inflows into and outflows from the reservoir.

Between 1986 and 1990 the outflow from Kuirau Park lake increased to 1,380tonnes/day and in the 2005 Field Monitoring report this flow was reported to be at around 2160tonnes/day but subject to variations governed by natural rainfall and lunar gravitational pull tidal effects. This outflow along with natural geyser activity at the Whakarewarewa geothermal reserve is at a level last experienced in the 1960's.

The measures adopted in the 1980's to curtail the decline and restore the natural geothermal activity of the Rotorua geothermal field have been successful. In view of this situation Rotorua District Council have indicated greater amenity use be made of this resource.

1.2 Efficient utilisation of the resource.

As part of the Governments action to remedy the decline in the Rotorua geothermal field, a Task Force was established to investigate and quantify the draw off from the field and to look into how this energy was being utilised. The Task Force report into the results of their investigation are detailed in *(Oil and Gas Division Ministry of Energy)* report.

A key recommendation made by the Task Force was that future tapping of the field be undertaken in an efficient and sustainable manner and suggested greater use be made of thermal energy extraction using down hole heat exchangers.(DHE)

As downhole heat exchangers (DHE) only extract heat from the reservoir their use on the field will not affect fluid outflows and can therefore be seen as a sustainable and effective means of exploiting the resource.

In 1992 Auckland University Geothermal Institute carried out a detailed performance analysis (*Dunstall M G)* of the U-Tube type of down hole heat exchanger which had been installed in an existing bore on the Rotorua geothermal field. As a result of this work a number of recommendations were made into how the output performance of a geothermal DHE can be improved. These recommendations were: -

- DHE to be located in a zone of greatest geothermal fluid hydraulic gradient and therefore offering greatest geothermal fluid flow past the DHE;
- Maximise the DHE heat transfer surface area;
- Create turbulent circulating water conditions within the DHE;
- Increase residence time of the DHE circulating water within the zone of greatest geothermal fluid flow;
- Insulate the DHE return leg to avoid surrender of heat in circulating water to the surrounding geological formation.

The DHE used on the Eat Streat project incorporates the first three of these recommendations in its design.

2 EAT STREAT PROJECT - DOWN HOLE HEAT EXCHANGER

The novel design and basic dimensions of the DHE used on the Eat Street project are shown in the following diagrams. Figure 1 and 2. It is made using coaxial 316 stainless steel tubes into which a spiral flute is rolled into the outer tube to create four separate flow paths retained by the central tube. The ends of both coaxial tubes are flared and welded to form a sealed containment. The circulating water flow pipe passes down the length of the inner tube and is seal welded to it as shown in the diagram and a return pipe connection made also through the inner tube at the top of the DHE. The DHE was made by Vaportec Ltd., of Napier, who hold patent rights to the spiral flute manufacturing capability. Trade name Spirex.

A key feature of the design is its 80mm diameter, which enables the unit to be installed into a 100mm diameter bore casing. The unit has a heat transfer surface area of 3.5m² and a liquid volume of 8 litres compared with a 25mm diameter U-Tube heat exchanger's 1.25m² and 7.5litre liquid volume.

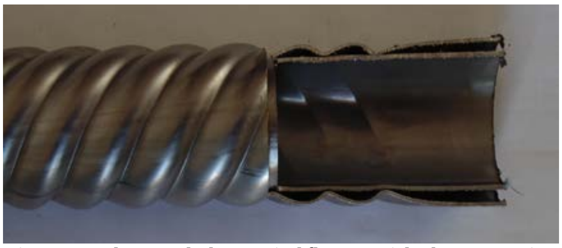

Figure 1 Photograph shown spiral flute co-axial tube construction technique

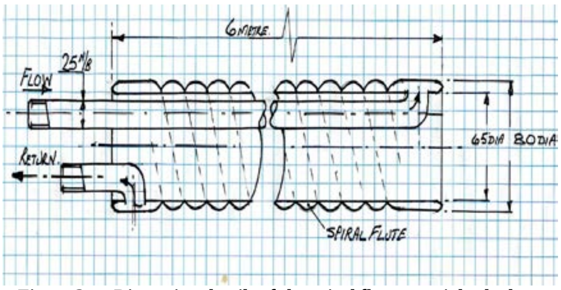

Figure 2 Dimension details of the spiral flute co-axial tube heat exchanger.

The spiral nature of the fluid flow path within the heat exchanger promotes turbulent flow conditions thus aiding heat transfer.

3 GEOTHERMAL UNDER STREET HEATING SYSTEM

3.1 Eat Streat heating system

In 2008 the Rotorua District Council made a block of Tutanekai Street, nearest to the lake, a pedestrian only precinct and the many restaurants located on the block set up "al fresco" dining facilities. The location is named Eat Streat. This move was a great success and widely used by local people and the many tourists who visited the city. Encouraged by this success it was decided in 2012 to further enhance this aspect of the city experience, by providing better shelter and under street heating, using geothermal energy as a heat source, so that outside dining could be carried out for a longer period each year. As the natural geothermal features of the City are a major tourist attraction this move was aimed at showing the environmental benefits of geothermal by tapping the energy using a down hole heat exchanger and to demonstrate the thermal output potential which can be sustainably achieved by these units. Figure 3 below shows extent of the Eat Streat enhancements undertaken by RDC

Figure 3 Photograph showing extent of work carried out by RDC on the Eat Streat project

Provision of comfort space heating to enable "al fresco" style dining is provided by a radiant under street heating system. This system circulates geothermally heated water at between 55 to 60°C through an array of small diameter (15mm dia.)PEX -type plastic pipes embedded in a 100mm thick concrete slab cast over the required heated area of the street which has a surface area of around 800m². The heated area is divided into 4 equal sized sectors each with its own circulating water flow control manifold. The slab is insulated on its underside to prevent heat loss to the ground. Heat input rate required to maintain the concrete at between 25 to 28°C is estimated to be around 150watts/m² requiring a max sustainable heat input of 120kW.

In this open air situation ambient air temperature will dominate at about 1.8metres above floor level. However at the seated person height (0.6m) a good degree of temperature comfort is expected be obtained from a radiant ground heating system in all but the most inclement weather. Essential, however, that the seated dining areas have good wind and wet weather shelter. The street heating system was designed by Central Heating New Zealand Ltd.

3.2 Geothermal DHE and system interface heat exchanger

Geothermal energy for the street heating system is provided by a DHE located in a bore drilled at the junction of Tutanekai Street and Pukaki Street. The 100mm dia. bore is cased to 80 metres with an open hole section to 130metres. Permeable conditions were encountered from 100 to 120metres and a DHE, as described in Section 2, is located at depth of 110metres. Flow and return pipes (25n/b 316 stainless steel) connect the unit to the well head flange. The geothermal fluid temperature at the depth that the DHE is located is 130°C.

A schematic diagram of the geothermal street heating system as installed on the Eat Street Project is shown in Figure 4.

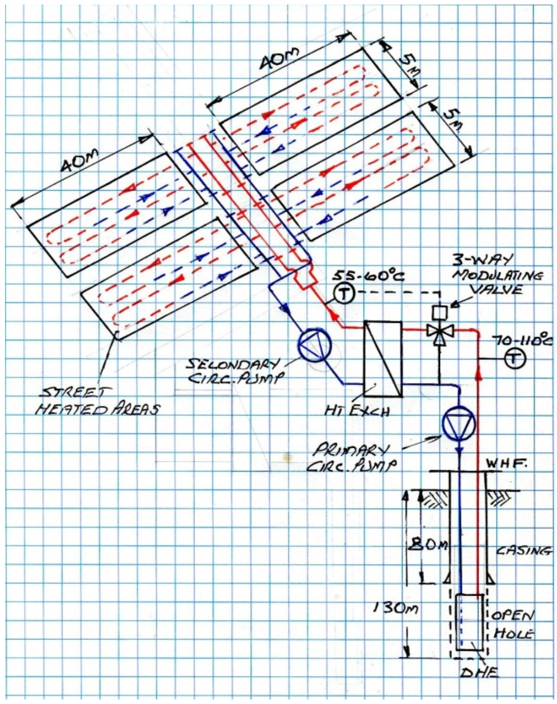

Figure 4 Schematic diagram of geothermal street heating system.

At the surface the DHE flow and return pipes are connected to the system interface plate heat exchanger and mains pressure water (4bar-g) is circulated at a rate of 1.25litres/second around the primary geothermal circuit. Heat input into the secondary street heating circuit is controlled at between 55 to 60°C by means of a three-way modulating valve located on the primary circuit flow line. The control valve diverts any excess geothermal heated water back to the reservoir. Figure 5 shows the above ground heat exchanger module, at time of commissioning. Flow and return pipelines to the secondary street heating circuit can be seen in the lower left hand side of the photograph and the wellhead surface casing can be seen on the centre right hand side.

Figure 5 Above ground geothermal heat exchanger module

4 DHE ENERGY OUTPUT TEST.

On completion the sustainable thermal output of the DHE was tested with the secondary side of the above ground heat exchanger connected to a cold mains water supply. After passing through the heat exchanger the heated water was discharged to a nearby storm water drain. The temperature of the cooling water for the duration of the test remained constant at 15.5°C and its flow rate measured using the bucket and stopwatch method at 1.47litres/second. The output test which was carried out over a two day period with an overnight system shut down. The overnight shutdown, of 14 hours duration, was to ascertain the in-ground geothermal system's ability to recover after a period of sustained operation. On restarting the DHE was operated for a further 8hours until reasonably constant thermal output conditions were established. The DHE output test was carried out on the 13th and 14th February 2014.

DHE primary flow and return temperatures together with the secondary inlet and outlet circulating water temperatures were continuously monitored using temperature recording data buttons set to record temperatures at 15 minute intervals. At the conclusion of the test the temperature data gathered on the data buttons was down loaded and analysed to provide a graphical plot of the respective primary and secondary system temperatures over the duration of the test period. The thermal output test results are shown in the following Figure 6.

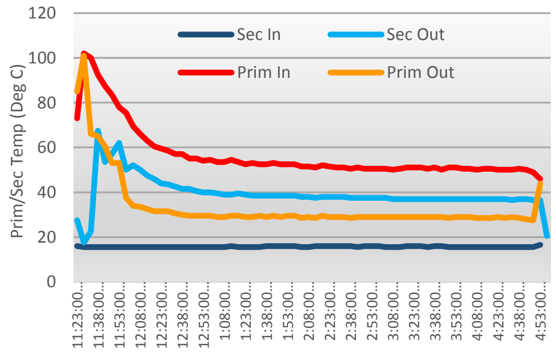

Figure 6 Primary and Secondary Flow and Return Temperatures 13 Feb 14.

From the primary temperature results and knowing the primary fluid flow rate (1.25 litre/sec) the DHE thermal output (kW) over the test period can be calculated. These results are shown on a time related basis in Figure 7 and 8. From these graphs it can be seen that the sustainable thermal output of the DHE is around 135kW. At this level of primary (kW) heat input the heat input rate per square metre of concrete is around 160 watts/m².

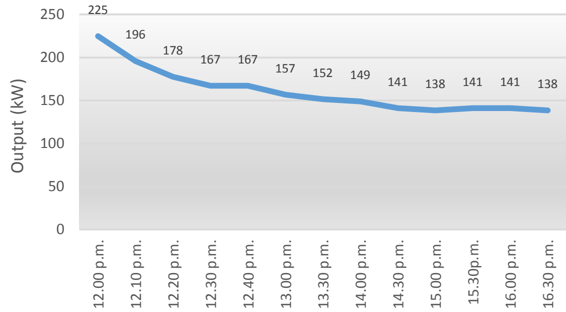

Figure 7 DHE Thermal Output 13 Feb 14

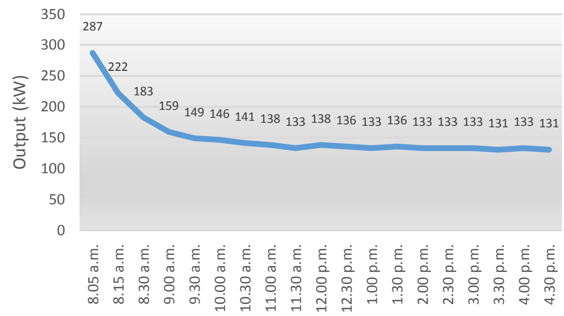

Figure 8 DHE Thermal Output 14 Feb 14

5 STREET HEATING PERFORMANCE

At time of writing this paper a full performance analysis of the street heating system had yet to be carried out. This task was being delayed until wind and weather protection measures had been put in place and the street heating system circuit commissioning is finalised to fully utilise the 135kWth output from the geothermal DHE.

During the first two winter months of operation of the system (2014) only around 94kWth of the geothermal DHE sustainable output, of 135kW, was being utilised by the street heating system. As a result, the concrete slab temperatures have been around 22 deg C, which is lower than expected. Further commissioning work is planned to optimise the performance of the street heating system and maximising the thermal output of the DHE.

Several measures are arranged such as the removal of a temperature limiting valve at each heating zone so that the full 60°C flow temperature is available to the heating circuits. The removal of this valve and relocation of the zone circulating pumps will also improve flow to each of the systems 48 heating circuits through reduced pressure drop. This improvement will increase the energy distributed to the system and the performance of the system. In addition to this the heated area is being covered by screens that will improve overall patron comfort in wet weather.

6 CONCLUSIONS

Delivering a thermal output of 135kW, the spiral flute design of DHE has shown it is suitable for greater use in tapping the geothermal energy of the Rotorua field in a sustainable and environmentally acceptable manner.

The small diameter of this type of DHE enables it to be installed in a 100mm diameter bore, thus reducing the cost of the installation.

ACKNOWLEDGEMENTS

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