THE GEOTHERMAL HEATING SYSTEM AT TAUPO HOSPITAL, NEW ZEALAND

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Keywords: *Geothermal; Direct use; Doublet system; Heat exchange; Heating system; Reinjection; Taupo; New Zealand.*

ABSTRACT

Taupo Township is located in the centre of Taupo Volcanic Zone (TVZ), in the centre north island of New Zealand, which has an abundance of natural geothermal resources. The Taupo Hospital sits in the south-east of the township, in the outflow margin of the Wairakei-Tauhara geothermal systems. The direct-use of geothermal energy in the hospital was commissioned in August 2010 to provide space heating and domestic hot water supplies. Previously, coal fired boilers that consumed around 340 tonnes/year of coal were used. By converting to geothermal energy, significant savings were made in terms of fuel and maintenance costs. Geothermal fluid production fluctuates depends on the season. Minimum production is during summer, being 59 tonnes/day and maximum production is during winter, being 279 tonnes/day. The geothermal and heat exchange system has now been running for more than three years and there has been good performance, with no issues pertaining to scaling and corrosion. This is due to a combination of good maintenance practices and the favourable chemical composition of the geothermal fluid.

1. INTRODUCTION

Utilization and optimization of geothermal energy for direct-use in a country that has abundance of geothermal resources has become a matter of great interest. With the crises and uncertainty surrounding fossil fuels, the use of geothermal energy has become more popular, and has the potential for significant growth. As one of the biggest geothermal energy sources in the world, New Zealand has an in-line growth for its geothermal direct-use and power generation (White, 2009).

Space heating using conventional geothermal systems has been ranked in second position after geothermal heat pumps, worldwide. Iceland, China, Turkey, France and Russia were the world leaders in the district heating list, while Turkey, Italy, United States, Japan and Georgia ranked first for domestic and commercial space heating (Lund et al, 2011).

District heating originates from a central source supplying hot water or steam through a network of pipes to individual dwellings or blocks of buildings. Whereas individual and building space heating originates from its own system, and often the capacity is much smaller than that of district heating (Gazo and Lind, 2010). The geothermal direct-use discussed in this paper is for space heating and domestic hot water supply in the Taupo Hospital building. Comparisons of direct-use of geothermal energy for some space heating from different systems around the world are presented in

Table 1.

Compared to other sources of energy, the use of geothermal energy for either district, individual or building space heating, requires high capital investment upfront. These costs include production and reinjection well drilling, system equipment such as down-hole and circulation pumps, heat exchangers, pipelines and distribution networks, flow metres, valves, and control equipment, and building retrofitting. However, the operating cost is lower, coming in at approximately 30-50% per annum of the cost of natural gas (Lienau, 1998 as cited in Lund, 2011).

Table 1: Some examples of space heating in the world

Country	City	Space area	Prod. wells	RI wells	Flow rate	T geo in	HE	Year built	Energy output	Energy saving
Turkey	Afyon [1]	513,683 m² (district)	3	1	42-61 l/s	93-99 °C	Plate	NA	NA	NA
USA	Oregon [2]	55,700 m² (university)	3	2	62 l/s	89 °C	Plate	1964	0.53 to 5.6 MWt	1,650 tonnes/ year oil
NZ	Taupo	4,205 m² (hospital)	1	1	2-9 l/s	100-105 °C	Plate	2010	183 kW (average)	340 tonnes/ year coal
	Rotorua [3]	NA (hospital)	4	2	2-7.5 l/s	128 °C	Shell & tube	1977	689.7 kW (Oct 2009)	NA

[1] Keçebaş (2011)
[2] Boyd (1999)
[3] Steins & Zarrouk (2012)

Taupo Township is located in the heart of the Taupo Volcanic Zone (TVZ), in the North Island of New Zealand (Figure 1).

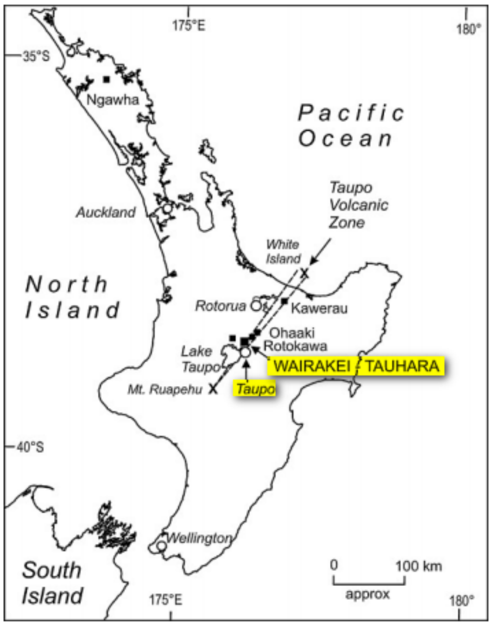
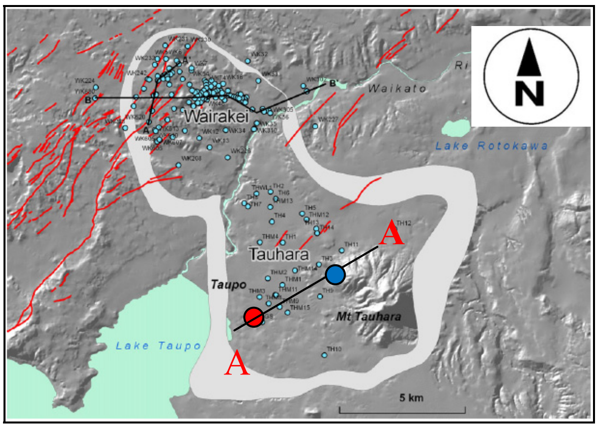


Figure 1: Taupo Volcanic Zone (from Hunt et al, 2009 as cited in Bignal et al 2010).

It has an abundance of geothermal resources, and also feeds in to several geothermal systems. Taupo sits within the Wairakei-Tauhara geothermal systems, which are delineated by the resistivity boundary shown in Figure 2. They are connected through the Waiora formation (Curtis, 1988 and Bromley et al, 2010). Even though they are related to each other, Allis et al. (1989, as cited in Hunt and Graham, 2009) acknowledged that the southern part of Tauhara consisted of a separated upflow region. This condition is confirmed by evidence that there is no pressure drawdown in this region, due to the Wairakei field activities.



Taupo Hospital TH3

Figure 2: Wairakei-Tauhara resistivity boundary (from Rosenberg et al, 2009).

Since many production and reinjection wells were drilled, stratigraphic knowledge of Wairakei-Tauhara has been evolving for over 50 years and has provided new insight into the geology of the rock formations beneath (Bignal et al, 2010). The geology formations and fluid states under the Tauhara field are described by Hunt and Graham (2009) in Figure 3.

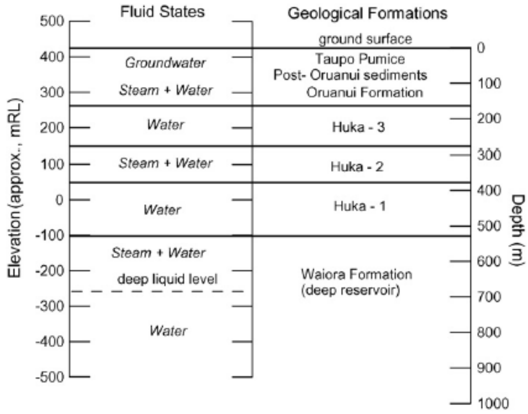


Figure 3: Geological rock formations (from Hunt and Graham, 2009).

Taupo Hospital is located in the central western part of the Tauhara geothermal field (see Figure 2), and the south-eastern part of Taupo Township (see Figure 4). In terms of the geothermal system, it is located in an outflow zone of the Tauhara system.

Figure 4: Location of Taupo Hospital (from Google Maps).

Allis (1982) suggested that TH 3 (shown in Figure 2) is the hottest well in the Tauhara geothermal field, and is possibly located in the up flow region of the system. Therefore the hydrology of the system can be modelled as shown in Figure 5 below.

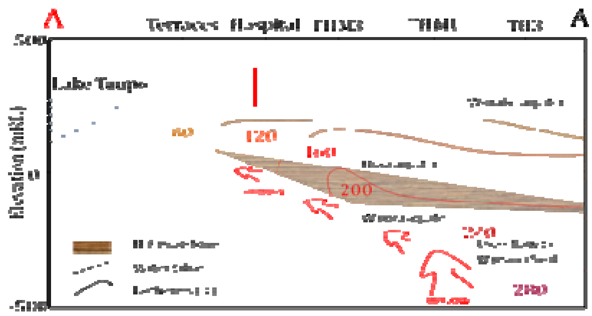


Figure 5: Tauhara hydrology model (NE-SW cross section of Tauhara field).

Based on the chemistry of the fluid taken from domestic wells and springs in Taupo, the waters can be categorized in one of two groups. One group being the steam-heated waters located in North Taupo and the other, the dilute chloride waters located in the Waipahihi area (Figure 4), which is close to Taupo Hospital (Henley and Stewart, 1983). The characteristics of the latter type of waters are a relatively high concentration of chloride and bicarbonate and a low concentration of sulphate. This occurs due to mixing between the deep chloride water with the fresh groundwater and flow that occurs naturally by gravity to Lake Taupo. Curtis (1988) supported the theory that hot waters utilised for domestic use in Taupo are supplied from the shallow aquifer, associated with the Tauhara field within the surficial pumiceous alluvium and breccias that contain fresh ground water. The fresh ground water is recharged by rainfall and then heated by the steam coming from the reservoir. Henley and Stewart (1983) also mentioned that the waters' pH is nearly neutral due to mineral-fluid equilibria.

This work provides an overview on the doublet geothermal system which provides direct-use space heating in Taupo Hospital, Waikato region of New Zealand, and then relates the system's production to local ambient temperature trends.

2. TAUPO HOSPITAL

The Taupo hospital is the main public hospital in Taupo Township. The hospital provides health services to the residents and visitors of the town consisting of a population of around 35,000. It was built in the year 1970s and has a capacity of 72 beds. Use of the geothermal system commenced in August 2010, supplying the main hospital with space heating and the maternity hospital with domestic hot water. Prior to that, the hospital ran a hot water heating boilers until 1983, then upgraded to a coal fired boiler with 2 × 100% duty with a maximum thermal load of 600 kW. The circulating fluid outlet temperature range was 80 °C to 85 °C and the heating system normally operated with a temperature difference of 5 °C. Therefore, the hot water circulation rate at maximum thermal output was 29 litres/sec. The two 100% duty main circulating pumps served the hospital heat exchange system and the two small circulating pumps delivered service hot water to the maternity hospital. All circulating water was returned to the common return header before making its way back to the coal fired boiler units.

A major operational difference between the coal fired heating system and the geothermal system is the delta T (temperature). The coal fired system operated at 5°C and the geothermal system operates at 20°C. Consequently, the circulating water flow rate required to meet the maximum thermal load was reduced to 7.2 litres/sec.

When the coal boilers were in use, the annual coal consumption was 340 ton/annum. With the North Island coal price in 2009 equal to NZD $150/ton (Denne et al, 2009), it meant that the hospital spent NZD $51,000/year on coal. The total cost of the geothermal heating system was NZD $287,000, by assuming the coal price above is stable, it can be simply calculated the return of investment is 5.6 years ($287,000/$51,000). There was also labour annual cost savings achieved by having the geothermal system, where the hospital needed to spend $13,000/year on weekends on-call boiler duty for the boiler operation.

The emissions impact, after the hospital converted to the geothermal energy, saved a significant amount of cost. Carbon dioxide equivalent emissions can be calculated as follow:

= 0.09 ton CO_2/GJ × Coal CV 23 GJ/ton × 340 ton /year
= 704 ton CO_2 equivalent/year × $20.00/ton
= $14,080.00 annual carbon tax

The Lake District Health Board (LDHB) viewed the carbon emission savings and resultant improvement in air quality, by way of reduction in smoke emissions and PM10 particles, in the Taupo area were considered of equal importance to economic considerations.

Aside from the fuel cost, the maintenance actions for the boiler were more complicated when compared to the geothermal heating system, such as the need to clean up the dirt caused by the ashes. The coal fired boilers are however still in place, and ready to be used anytime as a backup in the event of a problem with the geothermal system.

3. GEOTHERMAL WELLS

The locations of the production and reinjection wells are shown below in Figure 6. The distance between the two wells is approximately 60 m consisting of the pipeline material being mild carbon steel. There is also an old geothermal well drilled in 1966; this well was intended to supply heat for the hospital that was being built, however, since the fluid temperature was considered too low, which was around 70 ^{0}C to 75 ^{0}C, for the facilities needs then it was decided to abandon the well. To monitor the well condition, several downhole temperatures measurement were taken ever since (the temperature profiles are shown in Figure 10). The heat exchange system is located in the room adjacent to the coal fired boilers.

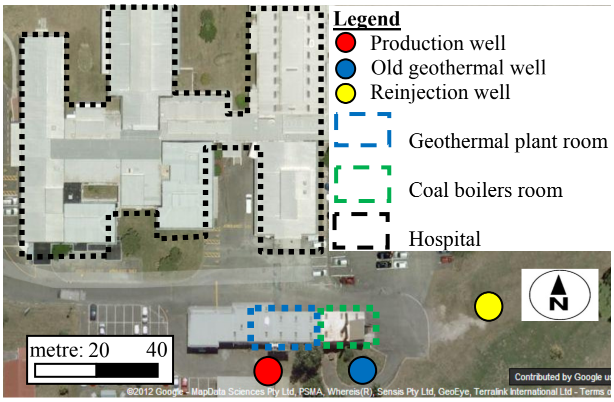


Figure 6: Taupo Hospital aerial photo (from Google Maps).

The process diagram showing geothermal and secondary fluid flows is given below in Figure 9.

3.1 Production well

The resource consents allow Taupo Hospital the use of geothermal fluids up to a maximum of 1,200 tonnes/day. This quantity was to also to serve the nearby Liston Heights Care and Independence Hospital and the Taupo Intermediate School, which will be connected into the system at a later date. To monitor this value, a flow metre with +/- 5% accuracy was installed in the system. Hospital staff are required to record this value on a daily basis, and report to Environment Waikato on a monthly basis. The production well (Figure 7) does not have the ability to discharge the geothermal fluid by itself; therefore, a down-hole pump was needed for the system.

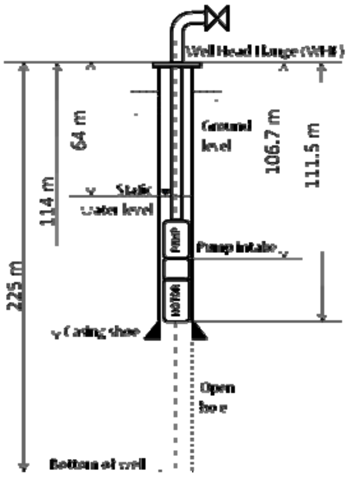


Figure 8: Schematic diagram of the production well.

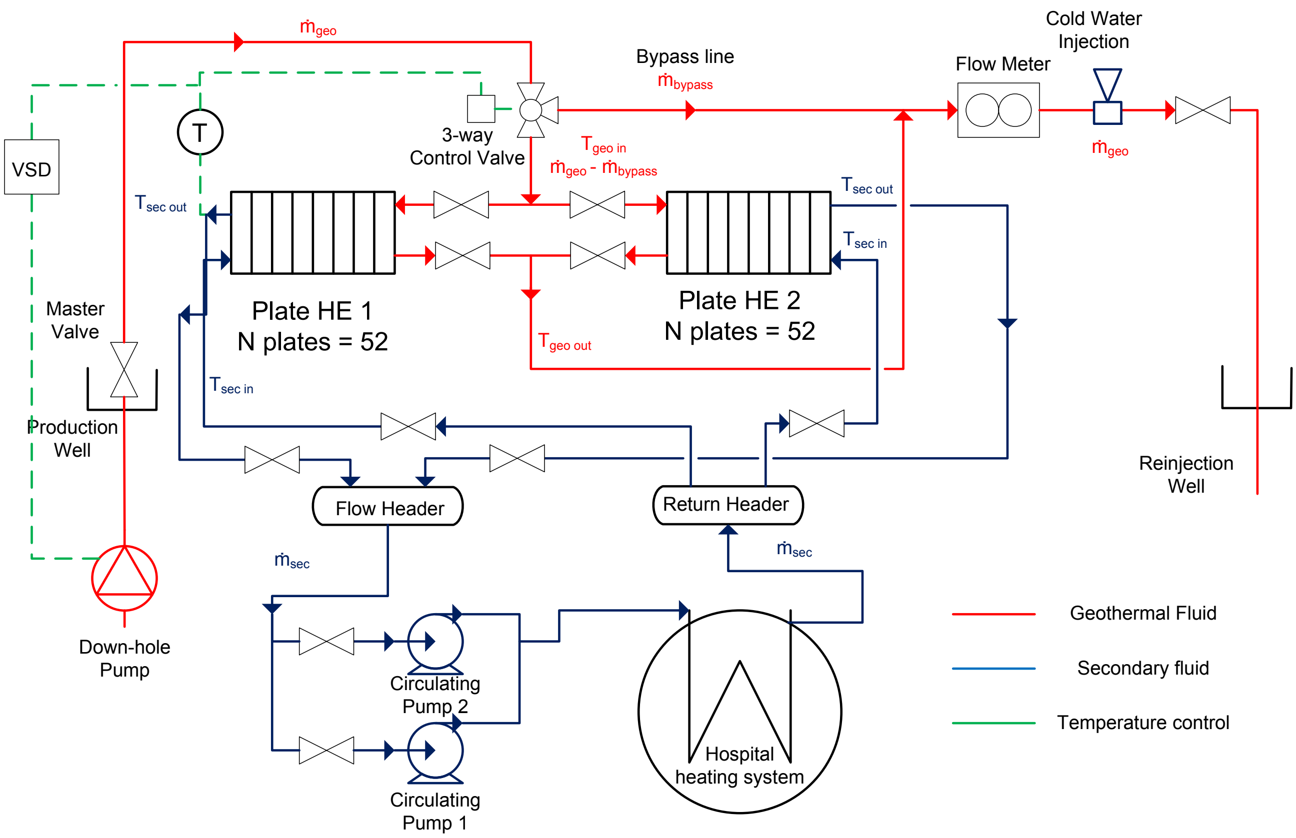


Figure 9: Schematic diagram of heat exchange system (from site visit observation).

There are two types of down-hole pump commonly used in geothermal wells: line shaft pump systems and submersible pump systems (Lund, 2011). The down-hole pump used in this well is an electrical submersible pump (ESP) made by Schlumberger. It is a REDA3100 which has 26 stages and can run at variable speed depending on the input given by a variable speed drive (VSD). The ESP is comprised of a multi-stage down-hole centrifugal pump, a down-hole motor, a seal section or protector between the pump and motor, and electric cable extending from the motor submersed in the well to the surface electricity supply (Gazo and Lind, 2010). The pump was installed with intake set at 106.7m below the well head flange (WHF), and was designed to have flow rate output vary from 2 to 9 litres/sec as shown in Table 2 below.

The production well head was designed to allow the later supply of another heating system - the additional geothermal fluid would be taken from the capped-branch in the wellhead. As the location of the production well is close to the plant room (about 5m away), this has the benefit of minimising the cost of the pipes, fittings, supports, and pressure drop occurring within the pipeline system. The insulation material used for the pipes is pre-formed fibreglass with a thickness of 50mm.

Before the production well was used for production, flow discharge test was carried out on July 16th, 2010. The flow rate was 12 litres/sec and the suction draw down level was calculated to be 105m below WHF. The down-hole temperature measurement profile taken on 20th of July 2010 is shown below in Figure 10. It can be inferred that the feed zone is at around 100 to 155m deep, where the temperature value showed the highest among the others. The hot water that flows from the higher elevation of Mt Tauhara is in this range, before it flows to Lake Taupo. There are also shown in Figure 10 temperature plots from time to time from 1966 to date (data provided by GNS Science-Wairakei). It can be inferred from the figure that from 1966 to 1978 the reservoir temperature had increased by 35 ^{0}C and after that the temperature has been reasonably constant.

Table 2: Actual pump performance

	Q l/s	Q l/min	H (1 stage) metres	H (26 stages) metres	F Hz	Rotation rpm	Power kW
Min geothermal fluid use	0.5	31	4.2	109.7	41	2,460	2.86
Avg geothermal fluid use	2	114	4.2	109.7	43	2,580	4.16
Max geothermal fluid use	4.1	249	4.2	109.7	48	2,880	5.98
Design limit	9	540	4.2	109.7	72	4,320	18.72

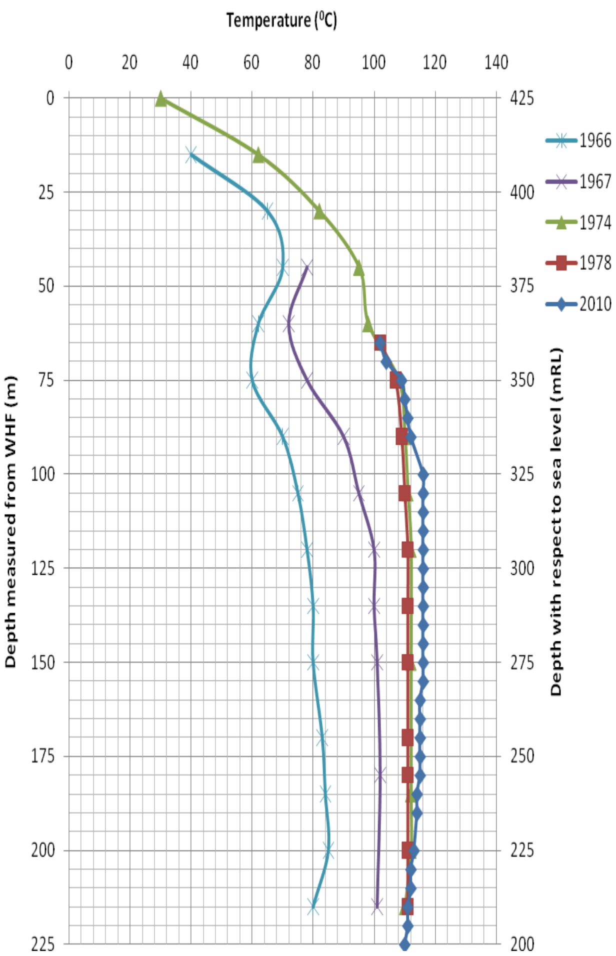


Figure 10: Production well temperature profile (mRL information from Google Earth).

Chemical analysis of the water produced carried out in 2010 is shown in Table 3, where little gas appeared in the result.

Table 3: Chemical analysis of production fluid (Lab No: 821094 v 1 Hill Laboratories)

pH	7.9	pH Units
Total Bicarbonate	580	ppm
Free Carbon Dioxide at 25^{0}C	14.1	ppm
Total Hardness (as $CaCO_3$)	35	ppm
Electrical Conductivity (EC)	225	mS/m
Approximate Total Dissolved Salt	1,510	ppm
Total Boron	7.1	ppm
Total Calcium	12.6	ppm
Total Copper	0.002	ppm
Total Iron	0.22	ppm
Total Magnesium	0.83	ppm
Total Manganese	0.109	ppm
Total Potassium	37	ppm
Total Sodium	540	ppm
Total inc	0.002	ppm
Chloride	330	ppm
Nitrate	< 0.05	ppm
Sulphate	86	ppm

The HCO_3 concentration of the fluid is not available on the list above, however, the type of geothermal fluid the Taupo Hospital produces can be inferred from a previous study of the nearest geothermal features. Henley and Stewart (1983) took several samples in the Terraces (located in the hospital 500m radius as shown in the Figure 4) called T4-T8. From ternary diagrams (after Giggenbach, 1991), it can be determined that the type of geothermal fluid is bicarbonate-chloride. This is because both bicarbonate and chloride are predominant while sulphate content is low (Figure 11). This is a signature of an outflow geothermal system, formed in the shallow margins of the system. However, this contradicts with Nicholson's (1993) suggestion that the formation was due to a condensation of vapour into the shallow groundwater aquifer.

At the initial phase of the geothermal system development in Taupo Hospital, a bubbler tube was installed on the production well to monitor the pump fluid draw-down of the well. However, it was removed from the well because it was blocked and not functional.

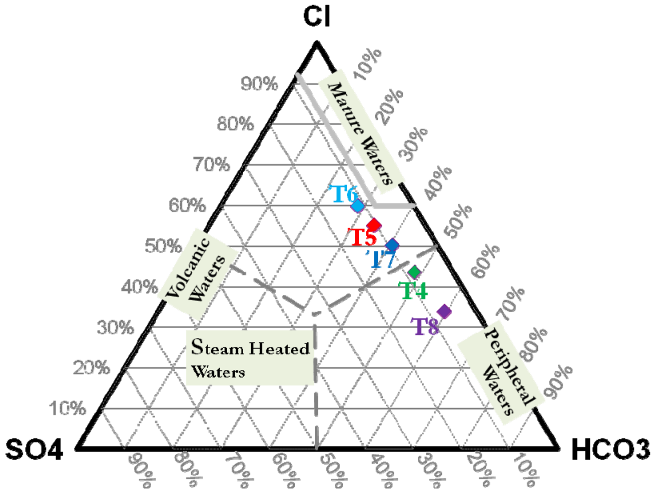


Figure 11: Triangular diagram of Cl-SO_4-HCO_3 (after Giggenbach, 1991).

Another important geochemistry analysis is the Na-K-Mg ternary diagram. After plotting the Cl, HCO_3 and SO_4 concentration into Figure 12, it is apparent that the water composition is categorised as immature waters.

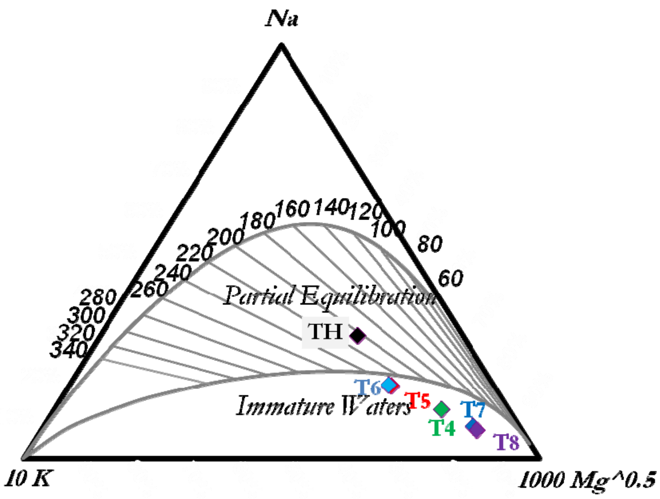


Figure 12: Triangular diagram of Na-K-Mg (after Giggenbach, 1991).

3.2 Reinjection well

Resource consents required 100% reinjection of geothermal fluid at about 80°C which is the same as the upper aquifer fluid temperature. The pipeline system was designed to route under the ground, so it will not interfere with traffic, and also to minimize the risk of the pipe being damaged. Another unique design of the system was fluid reinjection using a 3” pipe and flow to below the static water level in order to take advantage of the head difference (Figure 13).

This was due to negative pressure at the reinjection well head, hence even if the system loses pressure, reinjection can still continue with gravity.

An injectivity test using water from a fire hydrant was conducted for the completion test and results showed that the well was capable of taking a maximum flow of around 700 litres/min (11.67 litres/sec).

To reduce the risk of subsidence, the reinjection is targeted at the infield of the system, while to prevent thermal breakthrough, the fluid is reinjected into a shallower aquifer to that of the production well.

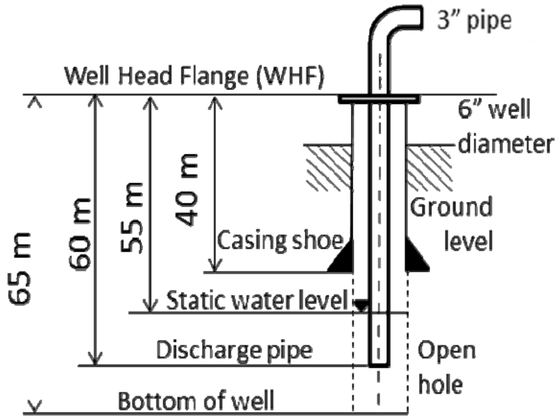


Figure 13: Reinjection well schematic diagram.

From the total geothermal fluid measured in the reinjection pipe by the hospital staff in a daily basis, the heat generated by the geothermal system can be calculated by using equation (1) below

$$Q = \dot{m}_{geo}(h_{in} - h_{out}) \quad (1)$$

Where Q is the heat in kW, $\dot{m}_{geo}$ is the geothermal fluid mass flow rate in kg/s, and h is the fluid enthalpy in kJ/kg.

The annual trend of the heat produced from the geothermal system can then be plotted in conjunction with the Taupo temperature trends gathered from Waikato Regional Council (WRC) as shown below in Figure 14. The curve is not smooth in particular periods of time, because of imperfection in the recorded data therefore extensive analysis could not be done.

The production data summary is shown below in Table 4. The heat minimum is produced in summer and the maximum in winter. This is because the hospital does not need much heat during the summer; it is only used for domestic hot water supplies and occasionally, when the temperature drops significantly during cold winter nights.

3.3 Monitoring well

No monitoring wells were drilled within the hospital. However, to monitor ground level changes due to the geothermal development as part of the consents, six ground Bench Marks (BM’s) were built in a 500 metre radius from the wells (Figure 4). Three are free standing BM’s and the other three are located on existing concrete structures. Intensive monitoring is also done in this area by Contact Energy as it has a plan to develop Tauhara II in the northern part of Tauhara Field. They monitor not only the subsidence level, but also perform checks on the water level every three months, and the chemistry and temperature levels every year (Farley, 2010).

In terms of water level changes, Bromley (2009) reported that since the water level monitoring in the vicinity of the hospital commenced around 1967, there have been no significant drops. This means that there was no pressure drawdown in the Taupo lake level aquifer. However, to continue monitoring the effects of the well's activities, static water level is monitored in both the lake level aquifer (100 to 130m) and in the shallow aquifer (40 to 65m). Pre commissioning static water levels were monitored in nearby wells of which included 106 Taupo View Road (shallow), 94 Invergarry Road (shallow), 54 Taharepa Rd, and Tauhara College (lake level) which are shown in Figure 13.

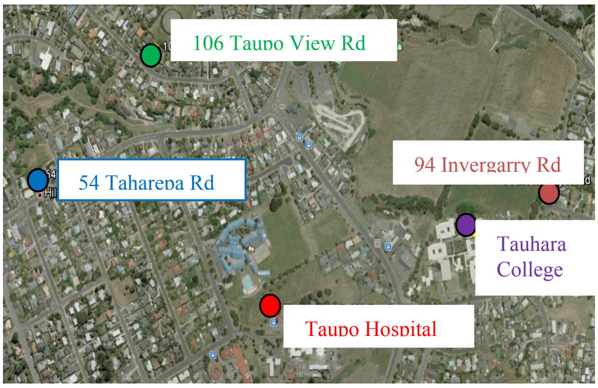


Figure 14: Static water levels monitoring locations.

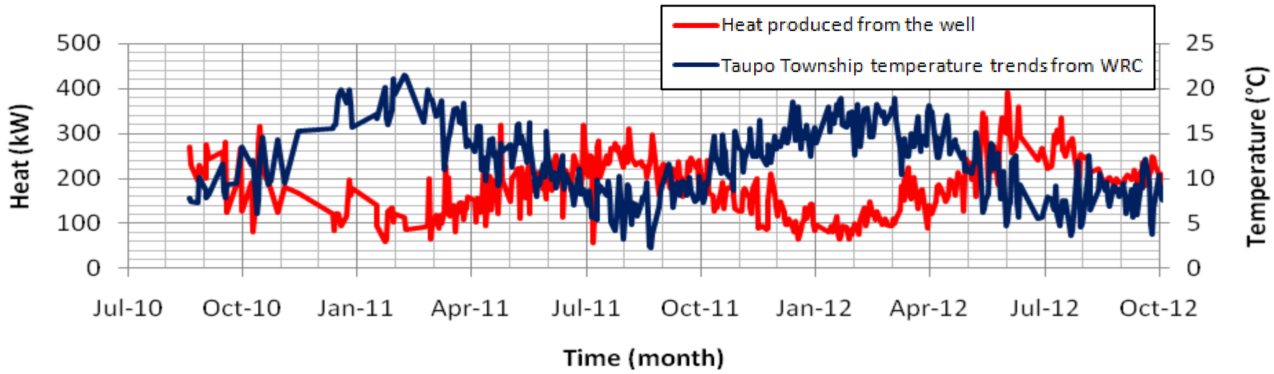


Figure 15: Production data from the geothermal system.

Table 4: Summary of production data

Time		$T_{geo\ in}$ °C	$T_{geo\ out}$ °C	$T_{sec\ in}$ °C	$T_{sec\ out}$ °C	m_{geo} m^3/day	m_{geo} litres/sec	Output kW
19 Jan 2011	Min	102	80	77	82	59	0.65	60
22 May 2012	Max	110	80	75	83	256	3.11	390
Average		103.4	80	73.2	83.2	172	2	183

3.4 Summary of wells

The summary information of the production and reinjection wells is presented in Table 6 below. The production well takes the fluid from middle aquifer, while the reinjection well discharges the fluid to upper aquifer. Both wells were drilled in non-pressurized aquifers, hence pressure containment casings such as surface and anchor casings were not needed. The geological condition beneath the hospital allowed the wells to be designed as open hole as it can act as a coarse filter to prevent debris from entering the well (Gazo and Lind, 2010).

4. HEATING SYSTEM

The Heat Exchanger (HE) as shown in Figure 16 installed for the space heating system in Taupo Hospital was a plate type HE with frame size M6-FG, made by Alfa Laval. Unlike the heat exchange system used in Rotorua Hospital where a shell and tube HE was used, the wells have more energy and the hospital has a greater bed and facility capacity (Steins and Zarrouk, 2012). A plate type HE is sufficient and suitable for the fluid temperature and pressure produced by the well in Taupo Hospital. While it produces a high fluid pressure drop across the plates, the plate type HE has a smaller unit size and lower capital cost, compared to a shell and tube HE (Thain et al, 2006).

Figure 16: Primary heat exchange system in Taupo Hospital.

The Taupo HE capacity was designed to produce 600kW with 100% redundancy. Only one HE operates at a time for a period of six months, while a second HE is on standby. The hospital staff flush the standby HE with clean tap water to remove any scaling deposited on the plate surface. The plate material was selected based on the chloride concentration from this region of the Tauhara field sample in 1996 which was 195 ppm. Compared to the chloride content in the 2010 sample (Table 3), it has increased to 330 ppm. This gives cause for concern with respect to the potential risk of pitting and crevice corrosion of the heat exchanger plates as these are made from 316 stainless steel. Table 5 below shows the specification of the main HE system used in Taupo Hospital.

Table 5 Heat exchanger specification

Type	Plate	
Plate dimension (H)	650	mm
Plate dimension (W)	230	mm
n plates	52	
HE surface area	7.77	m^2
Design pressure	1.6	MPa
Design temperature	180	^0C
Plate material	316 Stainless steel	
Pipe material	Mild steel	
Insulation material	Fibre glass	

4.1 Temperature control

The energy output of the geothermal system is regulated, so as to maintain the temperature exiting the HE in the range 77 °C to 82 °C. This is accomplished through the VSD unit by controlling the pump output flow rate. When necessary, cold fresh water is injected into the pipe exiting the HE to cool down the injected fluid. This only occurs during low summer load periods when very little thermal energy is required by the system. In such situations there is need to temper the exiting fluid temperature to less than 90 °C to protect the integrity of the cross linked plastic reinjection pipe which has a maximum operating temperature of 90 °C.

Table 6 Summary of geothermal wells

	Production Well		Reinjection Well	
Drill date	Jul-10		Jun-10	
Drill depth	225	m	65	
Production casing depth	114	m	40	m
Production casing diameter	150	mm	150	mm
Static Water Level	64	m below WHF	55	m
Liner	Open hole		Open hole	
Injectivity (J)			11.67	l/s
Discharge pipe			60	m below WHF

In addition to the submersible pump controlling the flow rate, there is also a bypass system, as shown schematically in Figure 9, which is used to control the mass flow rate entering the HE. Therefore, the temperature exiting the HE can be controlled. In doing this, a part of the fluid bypasses the bypass line to the reinjection line.

As no bypass mass flow rate data has been recorded, the specific amount of heat transferred to the secondary fluid cannot be calculated.

4.2 Temperature data

Figure 17 and Figure 18 show the temperature trends of the geothermal and secondary fluid system.

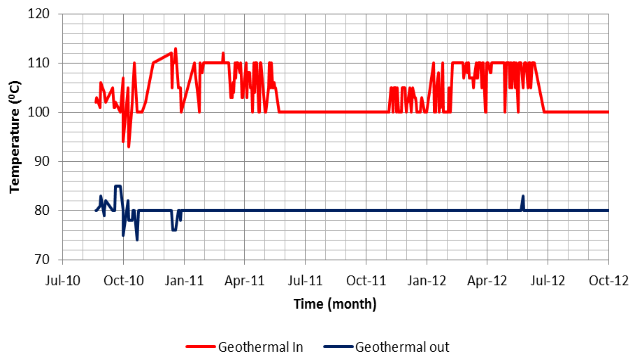


Figure 17: Geothermal fluid temperature trends.

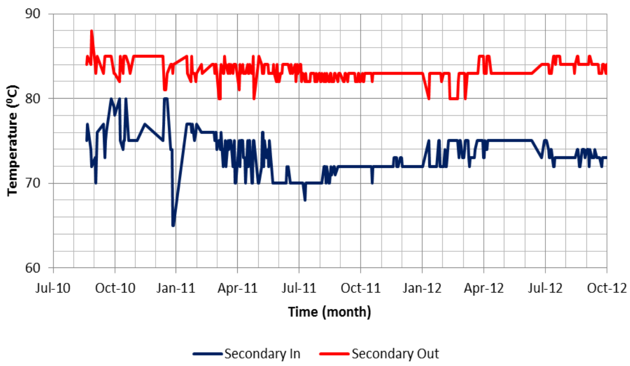


Figure 18: Secondary fluid temperature trends.

It can be inferred that the geothermal fluid temperature has been running constantly since the geothermal system was commissioned.

4.3 Maintenance

As part of preventive maintenance, Taupo Hospital maintenance team carries out a visual inspection on a daily basis of the geothermal system, including the heat exchanger. The geothermal system has been operating for three years and there has been no major technical problems reported in regards to any scaling or corrosion within the system. This is likely due to the geothermal fluid containing favourable chemistry, such as high bicarbonate, nearly neutral pH and relatively low silica and calcite concentrations.

4.3.1 Operational problems

In December 2012, the system suffered a submersible pump failure. This failure caused a significant impact to the system so that shutdown the system was required and the hospital must use the backup heating system which was running coal fired boilers for supplying the hospital facilities energy needs. The cause of the failure has been attributed to the pump operating at the bottom of its design output range of 2 litres/sec (172 tonnes/day) at minimum VSD frequency for long periods. The submersible pump operating characteristics had initially been selected to serve a much greater system heat load, which is 1,200 tonnes/day, that includes the hospital needs itself, Liston Heights Care and Independence Hospital and the Taupo Intermediate School. A replacement submersible pump is being procured with output characteristic better suited to the future long term output needs of the hospital.

5. CONCLUSION

Production data to date shows geothermal fluid consumption can service Taupo Hospital's needs without exceeding resource consent limits, including use during the peak winter season. In addition, there are no signs of decline in productivity of the production well.

Even though the location of the reinjection well is close to the production well, there is no evidence of thermal breakthrough. The produced geothermal fluid temperature is fairly constant around 100 °C - 105 °C, as the fluid is reinjected into a different aquifer to that of the production well. Reinjecting the fluid infield minimizes the risk of subsidence, as the amount of fluid produced is relatively small.

As Taupo Hospital sits in the outflow zone of the Tauhara field, the chemistry of the fluid does not cause scaling or corrosion. The pH is close to neutral and the fluid does not carry many minerals, as the bicarbonate is diluted through mixing with ground and chloride water. Another advantage of the hospital being located in an outflow zone, is it will not affect power generation. This is because it will not affect the deep fluid, which is what is used for large scale power production.

Taupo Hospital has made significant fuel and operating savings by switching from coal fired boilers to geothermal energy for space heating. It has also proved more reliable and efficient.

Another important benefit the hospital gained is energy independence, providing its own energy consumption. The high upfront capital cost for installation of the geothermal system will be returned in the near future.

ACKNOWLEDGEMENTS

The authors would like to gratitude Mr Peter Roy and Mr Chris Mcauley from the Lake District Health Board for their help, support and providing production data from Taupo Hospital. Mr Sebtiana Ady Chandra for accompanying me during the field data gathering, and Mr Kane Lynn from Waikato Regional Council for providing the Taupo temperature trends data.

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