ROTORUA GEOTHERMAL FIELD – EXPLORING METHODS TO MEASURE HEAT AND FLUID USE

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ABSTRACT

The Rotorua Geothermal Field is unique in that is one of the few high temperature systems in New Zealand that is predominantly tapped for individuals direct use, rather than for large scale energy generation. The wells are shallow, typically less than 150m depth (with most about 80 – 120m deep), for small scale use (typically 50 to 200 tonnes/day), and temperatures range from 90°C to 200°C.

To manage geothermal resource allocation, a model was developed in 1994 by Bay of Plenty Regional Council (BOPRC) resulting in a policy limiting discharge to waste to protect surface features. All other abstraction required to be reinjected back to source.

The management policy is to be reviewed and the model updated to corroborate allocation limits. Information needed includes temperature, pressure and flow of the resource from consented wells (wells with the right to abstract fluid/steam).

As such BOPRC has developed a pilot flow testing programme to determine the current actual (rather than consented) use of geothermal fluid and energy from the Rotorua Geothermal Field.

The flow testing programme has evolved through a range of field trials, seeking to overcome issues that many Rotorua wells exhibit, such as slug two phase flow, scaling, condition of welhead and casings and urban setting; difficult access, enclosed areas, and the ability to dispose of excess test fluid safely.

Advancing a method that is relatively accurate, affordable, robust and that is easily transferable across multiple wells with different characteristics has been critical. The trials undertaken have led to the development and refinement of a method that includes fitting a separator loop with inline meter near the reinjection well. Trials have also assessed the effectiveness of various meters, data retrieval methods and the duration of flow testing to optimise data retrieval.

1. INTRODUCTION

1.1 Geothermal setting

Rotorua City straddles the Rotorua Geothermal Field (Figure 1), which is a shallow high temperature system that is predominantly tapped for individuals direct and commercial use (spa resorts, hotels and hospital) rather than for large scale energy generation.

The wells are small, typically 100mm or 150mm in diameter, and shallow less than 150m depth (with most about 80 – 120m deep). The use is typically small scale (50 to 200 tonnes/day), with temperatures ranging across the field from 90°C to 200°C.

Significant geothermal surface features occur at Whakarewarewa (southern upwelling zone) and Ohinemutu – Ngatuna (northern upwelling zones).

To sustain these features a no-take zone 1.5km radius centred on Pohutu Geyser (Figure 1) is in place. Also a TOUGH2 model was developed in 1994 that informed policy to require all abstraction to be reinjected back to source, except for unique circumstances; where a net loss has been allowed for.

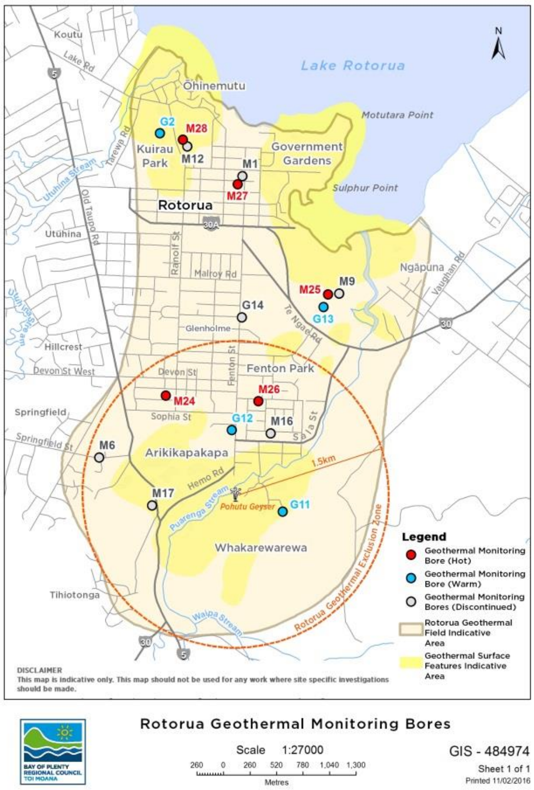

Figure 1: Rotorua City straddles the Rotorua Geothermal Field.

1.2 Regulatory setting

The geothermal resource and surface features are managed by policy set under the Rotorua Geothermal Regional Plan and by Resource Consents under the Resource Management Act 1991. To support the regulatory functions (that include a plan change) and provide data for a review of the 1994 model to support a plan change, a pilot study has been initiated to determine how best to obtain crucial datasets of actual flow, temperature and pressure at abstraction sites, with resource consents, across the field.

1.3 Pilot Study

The aim of the pilot study is primarily to find a method of measuring the flow, often 2-phase, from these small wells that are typically located in highly built-up and restricted space areas. Resource consents authorise landowners with wells to abstract and discharge the geothermal resource. However there is limited field data to quantify the actual use from the well in relation to volumes authorised under consent.

This pilot study is to determine a safe, easy and cost effective way to allow the volumetric assessment via flow measurement of this resource use. Once a preferred flow measurement option is determined then the pilot study will continue with the testing of fifteen wells across the field. The hope is that the results of this study will provide a methodology for a continued roll-out of a measurement method across the field to all consented geothermal takes.

2. METHOD DEVELOPMENT

For existing large industrial geothermal takes, methods are established for the measurement of mass flow, temperature and pressure. Most operators have comprehensive continuous monitoring systems and have the resources and the technology to ensure accurate data measurement using a variety of methods. However these methods are not easily replicated for multiple small takes, such as the direct use occurring in the Rotorua field. A particular issue is affordability for small single residential users, as measurement of flow and collection of data is a requirement of resource consent.

2.1 Key issues with monitoring geothermal flow

There are a number of matters regarding Rotorua geothermal flow from wells that need to be considered when finding an appropriate measurement method:

- Two phase fluid (i.e. fluid and steam+gas)
- Flow patterns vary from sluggish, to pulsating, to consistent (flow variance)
- Scaling or pitting (erosion) from chemical reactions within the pipe (variance of internal pipe diameter)
- Fluid/gas properties (presence of non-condensable gases (NCGs) alters meter accuracy and device life)

Also several design criteria had to be met:

- The flow measurement apparatus had to be small enough to cause no obstruction or disruption to the business/ householder
- The urban setting of most of the wells in Rotorua mean access, space, noise limits, health and safety concerns; particularly the ability to safely dispose of excess test fluid can hinder flow measurement
- The apparatus has to be constructed to remove the gas but not cause any back pressure in the system as some wells will stop flowing
- The physical state and configuration of most the production wellheads means the best location is on the reinjection pipework. This may change in the future
- Testing on the reinjection well meant that only water and gas had to be dealt with, not steam as well
- Ease of access and ability to undertake downhole measurements was a crucial factor in deciding the 15 trial wells

Therefore BOPRC have had to find methods that can address (or minimise) as many of these issues as possible, whilst providing sufficient and reliable information. Advice was sought from MB Century, Dobbie Engineering and Kiwi Geothermal to help scope and initiate the design for this trial program.

It was found that inappropriate valves and lack of maintenance at many production wellheads hindered flow measurement due to safety concerns. Improving well safety and design is currently being addressed through a separate work stream by BOPRC and Rotorua Lakes Council.

Four methods of flow measurement were considered for this study; ultrasonic meter; total flow calorimeter; downhole flowing Pressure Temperature Spinner (PTS); and inline flow meter with flow loop. It was considered that these methods are easily sourced and could accommodate the space restricted areas of an individual's direct source use.

2.2 Trial set-up

Rotorua Lakes Council has supported the flow testing trials by providing use of an appropriate well for testing. The Council nursery wells, located in Rotorua; Government Gardens, have been used to assess the flow measurement methods for this trial. The site provides ease of access and a safe working environment with correct headworks at the production and reinjection wells.

Production well (RR1042) is cased to 76.5m and open hole to 120m into fractured Rhyolite. The well has a flowing well head pressure (WHP) of 4.2b, which gives a feed temperature of 153°C.well

In Rotorua there are concerns with safety in regard to disturbing production wellheads, where maintenance can be poor and safety measures are limited. The temperatures on the production line are two phase, but the temperatures are not above flash point; they are at flash point.

An option to consider as a future trial method would be to fit a separator at the production wellhead, separate the steam and water flow and then do individual measurement using an orifice plate (Mubarok & Zarrouk). However the current situation limits this approach with consideration of well safety and access on production wells.

When testing at the production well the gas fraction can be virtually ignored because it is only ½ of 1% of total mass flow. The steam fraction is far greater and occupies far more total volume than the gas.

When testing at the reinjection well, at atmospheric pressure (or for some wells vacuum) then the gas fraction, while being only 0.5% of the mass, occupies 80% of the volume. This creates serious errors for flow measurements and can be a concern when using an ultrasonic or paddle meter. The calorimeter is the exception because the gas 'flashes off' to atmosphere.

It was decided to move the trial to the reinjection line. Setup near the reinjection wellhead should theoretically ensure single phase flow. This would be the safest option for any ongoing monitoring of wells across the field.

Reinjection well (RR137) is cased to 61m and open hole to 65.3m, with a reinjection temperature of 90°C. All geothermal take is reinjected. The distance between production and reinjection well is 57m. Typically in Rotorua the production and reinjection wells are in close proximity and near the same depth. Therefore the reinjection well can act as a proxy for the production well.

This is why the reinjection well is used for downhole measurements. There is access, but no tube installed. The well requires a measurement/ master valve to be fitted on top to allow instrument access.

Due to the natural behaviour of the geothermal fluid being sluggish and of inconsistent flow, preliminary testing of meters in the reinjection line pipework (ultra-sonic, in-line paddle and in-line mechanical) was unsuccessful. The meter readings did not calibrate with the calorimeter results and reliable flow results could not be attained.

It was decided to insert a flow loop in the reinjection line, and incorporate the meter within the flow loop. This mobile construct would allow a known diameter section of scale free pipe to be used for flow testing, and aid in gaining a laminar and more consistent flow through the meter. However this alone did not address inconsistency in flow measurements. To overcome potential issues with non-condensable gases and two phase fluid it was decided to construct and insert an appropriately sized separator as part of the flow loop construct (Figure 2). It is noted that when using a flow separator gases including H_2S and CO_2 will be vented. This allows for accurate measurements because the entrained gas is not affecting the meter readings. During the trial when the separator was too small (only 3 litres), the collapsing gas bubble could even cause the meter to run backwards.

The construct of a flow loop, which incorporated an appropriately sized separator and vent, prior to the meter, gave flow readings consistent with that obtained at the calorimeter. It was decided to progress with testing of different meters with this flow loop construct (Figure 2).

This flow loop would consist of two parts;

the flange-pipe-valve bypass assembly; this bypasses normal flow through the separator without taking the well out of service. The bypass assembly is permanently connected in the reinjection line (Figure 3); and

the portable flow loop + separator + meter, which is inserted when measurement taking is required (Figure 4).

The flange-pipe insert allows for the installation and removal of any type of meter without having to shut in and restart the wells. The flow loop can be configured for whatever meter is chosen. The flow loop is taken away at the end of the test, but can be left installed if preferred.

The separator needs to be vented, to dispose of the separated non-condensable gases to the atmosphere. Venting to the atmosphere requires adherence to the Rotorua Lake Council bylaws that require gas to be vented 6m above ground level.

The existing reinjection wells have a 6m well mast installed. To avoid having to vent into this mast, or having to erect a separate 6m high vent, the flow loop was re-configured (Figure 4). This provided pipework from the top of the separator and a little ½ inch pipe, running up the side of the separator is to get rid of entrained gas. This gas is vented back into the flow loop pipe work, after the meter and flow measurements have been taken (Figure 4). This allows the gas, along with the water, to be discharged to the reinjection bore.

Once single phase (gas free) fluid is obtained, different flow meters could be inserted and tested. This method is potentially relatively cheap and repeatable.

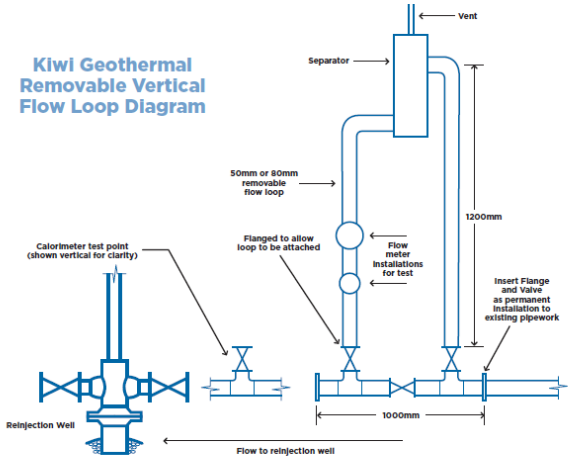

Figure 2: Design of flow loop for trial in reinjection line.

Figure 3: Flange-pipe permanent set-up at reinjection well.

Considerations for the inline flow meter are:

- Ability to use on a variety of pipe diameters for small domestic and commercial geothermal takes
- Ability to accurately read fluids up to 130˚C and flows up to 1000 litres/min (reinjection line temperatures are typically <100 ˚C)
- Ability to measure temperature and flow reliably
- Whether the meter has data logging capabilities and able to run on mains or battery for extended periods of time
- Susceptibility to scaling or corrosion
- Portability and transferability to other sites
- Tamper proof (for public areas)
- Cost

Figure 4: Flow loop + separator + inline meter; rig design for roll-out of trial implementation.

3. SUMMARY OF TRIALS

A calorimeter test was performed simultaneously with the flow loop/meter, to calibrate flow results (compare flow measurements at calorimeter and meter). At times two or three meters were trailed together for comparison of flow results. The flow loop can be used for any meter or flow rig arrangement as desired.

The mechanical aspects of the trial were successful, with the flow loop installation being reasonably straightforward.

3.1 Total flow calorimeter

Calorimeters measure both flow and enthalpy (heat content) of the geothermal fluid. The calorimeter can be used at the production or reinjection wellhead, however for Rotorua it is usually at the reinjection line for safety (i.e. lower temperature and pressure). Use of calorimeters on production wells are typically for short term test (minutes), not for continuous flow testing. Used fluid is then discharged to sewer.

Total use of heat (kW) is measured by taking the production wellhead pressure (from which we can also calculate the temperature), and the temperature at the reinjection wellhead and multiplying this difference by the flow (i.e. the kW used is the flow (kg/sec) x the heat difference kJ/kg). Basically this is the method applied in Burnell & Young 1994. However most Rotorua wells do not have a working pressure gauge on the production well and no temperature gauge on the reinjection well.

Using the calorimeter measurement method (Figure 5 & 6) accommodates two phase flow, but has limited use in Rotorua, due to the requirements for adequate space and access for the calorimeter (transported on large trailer). Also fluid flow is measured over a relatively short period of time so as it only provides a snapshot of actual usage, rather than the behaviour of use over an annual period.

Calorimeter testing is also quite costly, due to the requirement to hire the unit, plus staff to run the testing, and would be cumbersome for roll out across a large number of sites in Rotorua. Therefore an alternative reliable meter was sought.

Figure 5: Connector to calorimeter near reinjection well.

Figure 6: Calorimeter in operation during trial.

3.2 Downhole flowing Pressure Temperature Spinner (PTS)

Downhole tools can be used to measure flow, temperature and pressure from production wells. This method can also give very useful downhole information relating to reservoir conditions. The well needs to be in good condition and flowing. The accuracy of the flow, calculated from the spinner readings, depends on calculations that require known casing diameters. New or recently cleaned wells are likely to give the best results. This method takes flow at the production well, so total use would be calculated by comparing it to flow data collected at the reinjection well using other methodology.

This method was not trailed at Rotorua because:

- most production wellheads cannot be isolated (i.e. absence of or poorly maintained master valve)
- the current valves/casing are too small to allow tool access
- the condition of most well casings is unknown or unreliable
- the diameter of the well can be compromised by scaling and or corrosion
- only new or recently cleaned wells are likely to give good results, the condition of most production wells in Rotorua ruled this approach out
- requires removal of tubing and reconfiguration of the production well
- built-up sites can also inhibit access to the large trucks needed to run the tool.

3.3 Ultra-sonic meter

Ultra-sonic meters are external meters that are attached to existing pipework. This method potentially has the advantage of allowing continuous monitoring without any disruption to the user, and low associated costs (i.e. no work required on wellhead to fit infrastructure for the meter). However ultrasonic flowmeters are designed for use on single phase fluid flow (uncommon in the Rotorua geothermal field).

Initial tests using an ultra-sonic meter directly on the reinjection line, were not able to provide consistently accurate flow results. This could be due to in-pipe scaling issues, and two phase fluid (water and steam) flow.

The meter was installed onto the flow loop and tested again (calibrated against a calorimeter). The average flow, as measured through the calorimeter was 25.5 l/min and the ultra-sonic measured an average of 26 l/min (1.56 t/h or 37.4 t/day).

This time it provided reasonable results in line with the flow measured at the calorimeter. It appears that the flow loop has reduced issues with using the ultra-sonic meter and as such the test was successful.

It was concluded that when configured to a vertical flow loop the ultrasonic meter gives readings as accurate as a calorimeter. This is due to the pipe being completely filled with liquid. However concerns around potential for error when fitting the ultra-sonic meter and risk of tampering resulted in this method not being preferred for wider use. Also the paddle meter and ultrasonic meter require a longer run of pipe than the current flow loop trial setup; this becomes a matter of practicality.

3.4 Inline flow meter

Using the paddle (Figure 7) and turbine meters (Figure 8) within the flow loop without the separator gave skewed results. This was particularly pronounced for the paddle meter. The inline impellor read approximately 25% higher than the calorimeter. In the calorimeter the steam cools to water and any gas is flashed off.

The paddle meter is much more affected by the entrained steam and gas as it has a low inertia paddle that is very sensitive to differing flows – such as slugging wells and mixture of steam/gas and water which flow at different velocities. However this was remedied with the installation of a separator into the flow loop, prior to the meters. This had a dramatic effect on the flow readings, in that the inline meters now read a flow close to the calorimeter reading. The inline separator enables the flashing steam and any gas to be removed prior to going through the flow meter.

A series of five output tests were carried out using the flow loop - separator method, with the inline flow meter and the calorimeter, for calibration. The tests were a success. The tests also showed that the capacity of the separator played a crucial role. Figure 9 shows one of the trail pipe arrangements of the test equipment. This concept worked, but not well and has been improved to the final concept, stream-lined for the final trail roll-out (Figure 2 and 4).

While the gas was able to be separated, it is noted that to measure total geothermal mass it will be necessary to measure the gas, and therefore the total proportion of gas and fluid. As such a meter could be installed to measure any gas separated using the loop. For the purpose of this trial the gas component of the mass flow is minimal and was not measured. If necessary the flow loop construct does provide for gas collection to be incorporated in future.

The safe dispersal of gas will be achieved by connection to the existing vent installed, as a requirement of the Rotorua Lake Council Geothermal Bylaw, at the reinjection well (Figure 4).

Figure 7: Paddle meter used for trial

Figure 8: Turbine hot water meter

3.5 Implementation of method

The trial has been undertaken as a proof of concept. The current design will be used on fifteen selected in-service reinjection wells across the field, over a period of 3 months, with flow meters being run for a minimum of one week for each well. The meter will be connected to a logger (solar power) set-up for data collection.

Criteria for well selection included:

- Safety (e.g. wells that have been and deemed safe and in accordance with WorkSafe's Well Maintenance Guidelines for Shallow Wells)
- Range of well sizes (with focus on medium and high flow wells)
- Established working relationships with well owners
- Ease of access for testing
- State of well head (degree of modification required to carry out testing, or urgency to upgrade)
- General state of well (e.g. wells that have recently been cleaned)
- Area where we have no or limited data (e.g. where geothermal model would benefit from additional data)
- Production well head works allow thermocouple or PTS (Pressure, Temperature & Flow) runs to be undertaken.

Matters that have been considered to identify a preferred measurement option include:

- Required accuracy of data for use in current geothermal model and to assess compliance with conditions of resource consent (take/discharge)
- Cost of rig construction from set up to monitoring
- Services and skills required to install and carry out testing
- Ease of installation and access
- Ability to use a custom made flow rig at multiple sites (repeatability)
- Health and Safety
- Tamper proof (particular for testing undertaken in public areas)

Figure 9: Trail construct - flow loop with separator prior to inline flow meter.

It has been decided to proceed with the implementation roll-out using the separator loop with the turbine hot water meter (or similar), due to ease of use and being relatively tamper-proof.

3.6 Record of measurement

As the intent of the flow monitoring is for measurement of continuous flow, data logging/telemetry is an important consideration. This will allow real time monitoring of sites. This has positive implications for both the safe and efficient measurement of the resource.

5. CONCLUSION

BOPRC has sought a method(s) to measure the flow, temperature and pressure of geothermal fluid from wells consented to take/discharge as direct use from the Rotorua Field.

The information collated from this trial has provided methods of data measurement that are suitable for compliance of geothermal takes/discharges with conditions of resource consents; and use of the flow, pressure and temperature data to help determine enthalpy from calculations and steam tables. It is hoped that these data sets will form part of other survey data to be incorporated into the re-run of the TOUGH2 model so providing management options for the field.

The pilot study has provided a proof of concept that will now continue with the roll-out of the flow loop rig to 15 sites. Once the implementation trial has been completed and the data assessed, it will then be decided if this program is suitable to be rolled-out over the entire field for all consented geothermal takes/discharges.

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