Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Well Testing and Modelling of Discharging Big Bore and 'Super' Big Bore Wells

Jaime Jose Quinao[1*], Mathew Singer[2], Mohsen Askari[1], Lutfhie Azwar[1], Matthew Hall[1], and Sunvi Ahsan[1]

[1]Mighty River Power, PO Box 245, Rotorua 3040, New Zealand; [2]Western Energy Services, Taupo, New Zealand

[*]jaime.quinao@mightyriver.co.nz

Keywords: well testing, wellbore modeling, large casing diameter, big bore

ABSTRACT

Big bore production wells have been drilled and are in full operation at the Ngatamariki and Kawerau geothermal fields. The recent Ngatamariki drilling campaign saw the drilling of a 'super' big bore production well with 18-5/8" cemented production casing, narrowing down to 13-5/8" cemented production casing and completed with 10-3/4" perforated liner in a 12-¼" hole and a 7" liner in an 8-½" hole. Big bore and super big bore production wells are drilled up to 3,000 meters and produce geothermal fluid up to 1,100 t/hr at 1250 kJ/kg discharge enthalpy. The successful drilling and operation of these wells have provided significant production contributions to the geothermal operations of Mighty River Power (MRP). The large mass flow and large casing sizes of the wells have presented unique challenges in full discharge downhole well test operations and well test results interpretation.

MRP and Western Energy Services (WES) have successfully logged and analyzed big bore and super big bore wells. The operational challenges required additional planning to ensure quality data and risk mitigation. The study presents the operational set-up that was required to safely run a wire line log at full discharge conditions. In addition, the study presents wellbore modeling results that highlight the challenges in understanding and modeling two phase flow behavior in high flow and large diameter conditions.

1. INTRODUCTION

Drilling wells to tap geothermal fluid from as deep as 3 km under the ground is a significant investment in any geothermal development. Economic and technical considerations in well drilling and completions have resulted in wells completed with larger capacities either through larger bores or multilateral completions (Stimac et al. 2000; Thorhallson, 2006; Sanyal, 2007). Bush and Siega (2010) reported on big bore drilling in MRP and the successful reduction of drilling costs and number of wells required in the field.

At present, MRP-operated geothermal fields in the Taupo Volcanic Zone (TVZ in Figure 1) have a fleet of big bore and super big bore wells producing anywhere from 35 to 40 MW or injecting up to 1000 t/hr of separated brine. While these are desirable production-injection conditions, logging the big bore wells on full discharge or full injection presents a challenge due to the large flow involved. For instance, the tool string should have enough weight to counteract the upward force of a discharging well.

Flowing pressure, temperature, and spinner (PTS) survey logs are primary data that provide information on a well's production characteristics. Flowing pressure profiles are used to quantify the overall productivity of the well and to generate pressure gradients that locate the steam-water interface (flashpoint) and two-phase gradients in the wellbore. Flowing temperature profiles are used to monitor reservoir fluid temperatures, providing a good calibration data set for geothermometer and discharge enthalpy values. Spinner logs are used to quantify fluid velocity, invaluable in determining feed zone contributions to total flow, monitoring feed zone changes and identifying flow diameter changes due to well damage. An integrated PTS analysis is used to generate a robust well conceptual model from which a wellbore model is built. A monitoring program that covers a majority of the wells in a field provides a better view of the overall reservoir health.

One survey provides the entire aforementioned well and reservoir surveillance information that, together with other downhole information, enables resource management teams to analyze changes to well and reservoir performance. Analyzing the big bore and super big bore flowing PTS data and building the wellbore model to match the well profile and well performance have presented some unique challenges.

This paper presents the MRP and WES experience in logging these high flow wells and the challenges in modeling and understanding their flow behaviors.

2. SLICKLINE OPERATION

2.1 Pre-job Planning

Pre-job planning was a crucial step to successfully log big bore and super big bore wells. Information such as flow rates, enthalpies, well head pressure and casing profiles were necessary to approximate the required tool string weight. The aim was to provide sufficient tool string weight to overcome the upward fluid velocity while at the same time ensuring no excess weight was added. The risk of adding too much weight could potentially result in extremely high upwards logging tension, especially on deep and deviated wells resulting in cable break or a stuck tool.

2.2 Safe Operations and Risk mitigation

A standard wireline setup was used to successfully log the big bore wells. This included a wireline truck, 25 tonne crane, 0.108'' slickline, and heavy duty winch. The big bore wells were logged using a memory PTS tool with multiple weight bars. Figure 1 shows a typical wire line setup.

Figure 1: Wire line unit with 0.108" slickline, 25 tonne crane and approximately 21 m of lubricator during a survey of a 750 t/hr well

A stinger (see Figure 2) is pre-installed on the wellhead prior to logging. A stinger mates to the flange just above the flow tee and has two primary functions. Firstly, it prevents the cable from being forced down the flow tee outlet pipe by extending vertically past the flow tee outlet; secondly it allows for the tools to be safely retrieved into the lubricator. Without a stinger, the well would need to be throttled back to allow safe passage of the tools around the flow tee. This would jeopardize the well stability and ultimately interfere with the well test data.

Figure 2: Typical Stinger Design

2.3 Tool string setup

Big bore wells require tool string weights in excess of 200 kg. Using multiple steel weight bars was impractical as the tool string length becomes excessively long. Alternatively, increasing the weight bar diameter would only increase the upwards force imposed on the tool. The solution was to invest in tungsten weight bars which are approximately 40% more dense than steel. Combined with the weight bars was a quick-connect system that allowed the weight bars to ‘snap’ together, making the vertical rig-up safer, more reliable, and faster.

Prior to running the PTS tool in the well, a drift run was first carried out. The drift run setup was similar to the PTS setup except the PTS tool was removed and replaced with a spang jar and bullnose such that if the bullnose became stuck, the spang jar could be used to free the tool. Alternatively, if the tool could not be freed, a secondary fishing string was on standby. The overall aim for the drift run was to ensure a safe passage for the PTS tool; run speeds were achievable and minimized risks of getting stuck.

2.4 Calculated vs. Actual logging tensions

One of the key factors for logging big bore and super big bore wells was the tool string weight. Excess tool string weight can result in cable damage, while lighter tool strings struggle to pass through the high velocity zone in the topmost section of the perforated liner. In this section there are normally two joints, 9 m each, of blank liner resulting in very high fluid velocity in a short section of the well. It is critical that the tool string has sufficient weight to overcome the upwards fluid force in this section. It is important that these forces are calculated to minimize risk and ensure safety.

The upward force from the wellbore was calculated using the following parameters: well head pressure, mass flow, internal casing diameter and enthalpy. The downwards force from the tools was calculated using an estimated tool weight, tool diameter and well inclination. Combining the upwards force from the flow and downwards force from the tool, a calculated net force was found. The resultant force needed to be in the downwards direction and not excessively large, somewhere in the region of 30 to 60kgf.

Using this method, five wells were analyzed for the calculated net force vs. actual tension data. Table 1 shows that the calculated result was generally higher than the actual tension data. This was likely because the calculated net force does not account for cable drag, tool drag, turbulent flow and tool buoyancy while moving downwards. In general, calculating the required tool weight proved to be extremely valuable by saving time and reducing risk.

Table 1: Comparison of Calculated to Actual forces

Calculated net force (kg)	Actual tension, moving downwards at 0.5 m/s (kg)
73.3	45
32.8	2
23.4	18
40.6	36
66	68

3. BIG BORE AND SUPER BIG BORE WELL TEST RESULTS

3.1 NM11

NM11 is a Ngatamariki super big bore, deviated well that was drilled and completed in January 2013 to a total depth of 3097 m MD (measured depth). The well was completed with 18-5/8" production casing from the surface down to 1005 m and a 13-5/8" production casing from 938 to 1417 m MD. The 10-¾ " perforated liner is from 1392 to 2995 m MD inside a 12-¼" hole and the bottom section is completed with a 7" perforated liner from 2961 to 3067 m MD inside an 8-½" hole.

NM11 is producing from a liquid-dominated reservoir at 280°C, producing 800 t/hr of fluid at a discharge enthalpy of 1200 kJ/kg. It feeds into the Ngatamariki power station and contributes around 35 MW of the 82MW Ngatamariki geothermal field.

3.1.1 Well Test Operation and Results

After a month in operation, a flowing PTS survey on NM11 was done in June 2013 to verify feed zone characteristics and monitor the well's recovery from the effects of cooling by drilling fluids. During the test, the well was producing 700 t/hr of fluid at 29.3 bar(g) wellhead pressure and an enthalpy of 1165 kJ/kg.

From the well test pre-job planning, the large diameter helps in reducing the required tool weight and required only four tungsten weight bars in addition to the PTS tool weight, totaling 150 kg at surface and 10 m tool length. Multiple passes at 0.8, 1.2 and 1.5m/s tool speeds were successfully carried out to profile the well, including stationary points between previously identified permeable zones to provide additional calibration.

The analyzed PTS and fluid velocity are shown in Figure 3. The flowing profiles were successfully simulated by a wellbore model. This model is now used to monitor well performance and diagnose changes to well behavior.

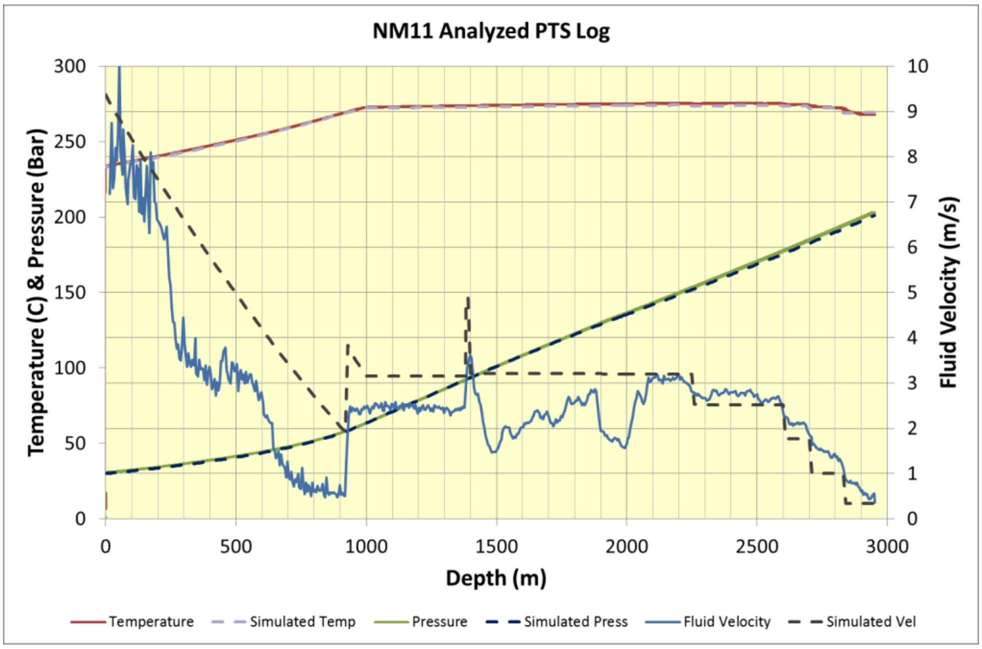

Figure 3: Analyzed PTS of NM11 flowing at 700 t/hr, 29.3 bar(g) wellhead pressure, and 1165 kJ/kg enthalpy

3.2 NM7

NM7 is a Ngatamariki big bore well drilled vertically and completed in July 2009 to a total depth of 2963 m MD. The well was completed with a 13-5/8" cemented production casing from the surface to 1451 m MD and a 10-¾ " perforated liner from 1309 m to the bottom inside a 12-¼" hole. As previously described, the highest velocity section is the first two blank joints at the topmost part of the production liner.

NM7 is producing from a liquid-dominated reservoir at 287°C and produces 1000 t/hr of fluid at a discharge enthalpy of 1230 kJ/kg. It feeds into the Ngatamariki power station and contributes around 42 MW of the 82MW Ngatamariki geothermal field.

3.2.1 Well Test Operation and Results

A PTS survey at full discharge was done to monitor the performance of the well. During the test, the well was producing 1000 t/hr at 23.2 bar(g) and an enthalpy of 1230 kJ/kg.

The initial tool weight required from the pre-job planning was 191 kg. During the early part of the operation, it was observed that the net resultant weight was not safe and would likely have an issue passing through the top of the liner. The tool was pulled out of hole and the set-up was modified by adding three more weight bars and two risers. The total tool weight used was 249 kg with a total tool length of 18.7 m. Stabilizing the extended lubricator was an identified risk, so a crane with the ability to support this set-up length was on stand-by. Multiple passes at 0.75 and 1.5m/s and additional stationary points between feed zones were successfully accomplished.

The analyzed PTS is shown in Figure 4 and was successfully simulated by a wellbore model. Note how the data from the stationary points were used to calibrate and correct the fluid velocity profile.

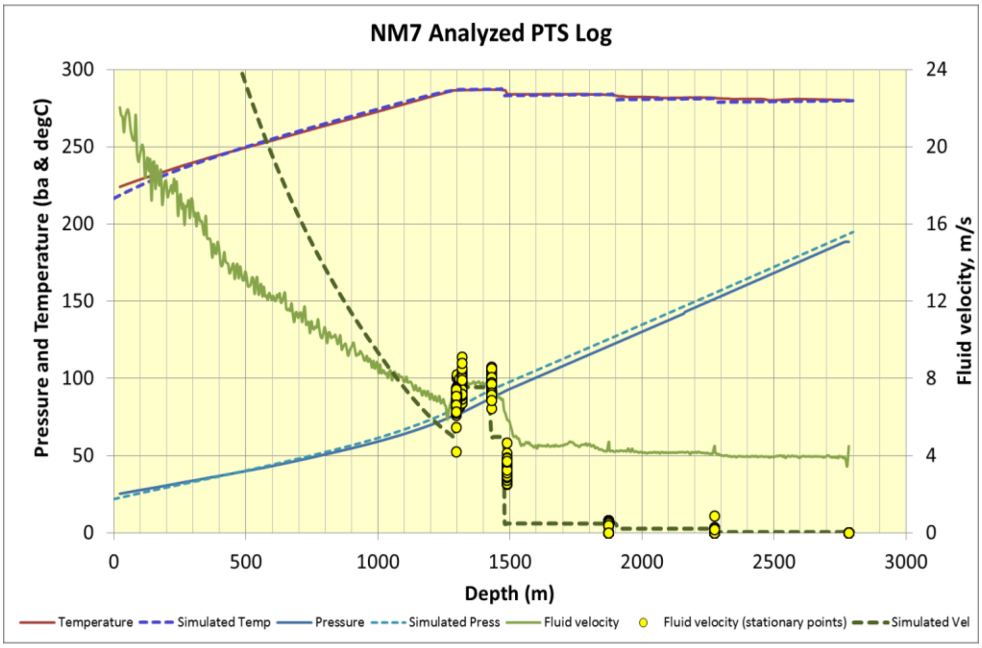

Figure 4: NM7 Analyzed PTS data simulated by a wellbore model

3.3 KA45

KA45 is a Kawerau Geothermal Ltd (KGL, owned by Mighty River Power) big bore producer. The well was drilled to a total depth of 2063 m MD in February 2008 and has been completed with 13-3/8” casing from surface down to 869 m MD and 10-¾” perforated liner from 845 m MD to the bottom of the well.

KA45 produces from a liquid dominated reservoir at around 280˚C and is capable of producing 700 t/h of mass at about 30 bar wellhead pressure and an enthalpy of 1220 kJ/kg. It contributes around 33MW of the 100MW generation from the KGL power plant.

3.3.1 Well Test Operation and Results

A flowing PTS was performed on KA45 in August 2013 to diagnose changes in flow performance. The test was done with a flow rate of around 350 t/h and a wellhead pressure of around 36 bar(g). A total tool weight of 100 kg with a tool length of around eight meters was required. Multiple passes at 0.6, 1.0, and 1.3 m/s log speeds were successfully performed.

The analyzed PTS data was successfully simulated by a wellbore model and is shown in Figure 5.

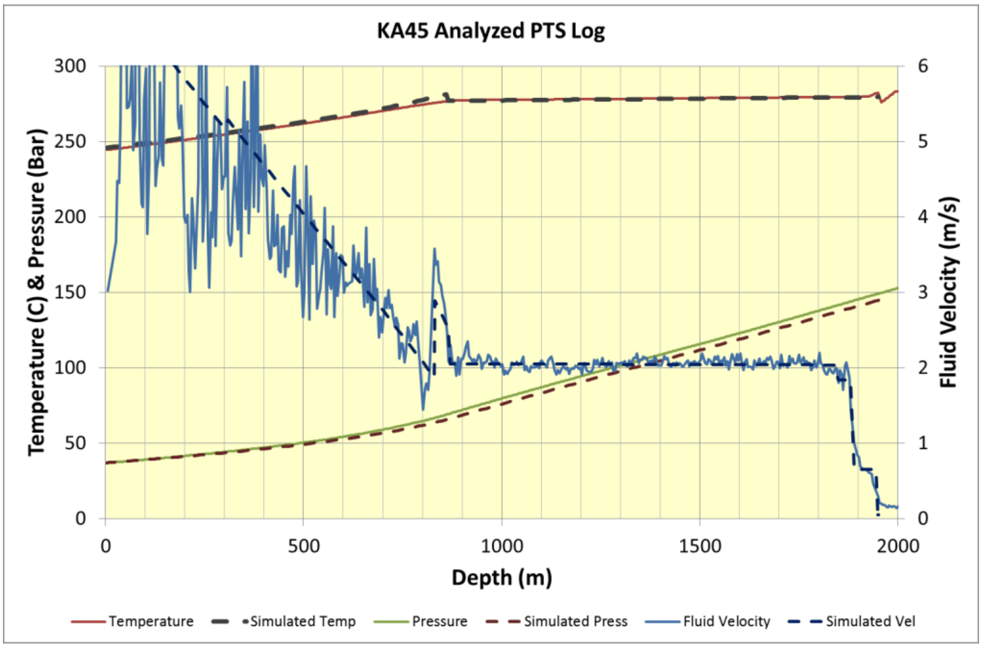

Figure 5: KA45 analyzed PTS data simulated by a wellbore model

4. DISCUSSION

Good coordination between MRP reservoir engineers and WES ensured the success and safety of logging big bore and super big bore wells. Pre-job planning and using a consistent approach in well test programs across fields have improved the understanding on the balance between what is technically and safely possible and what information is required from the test. Deviations from the program are discussed with safety and data quality in mind. The use of tungsten weight bars has enabled logging of large bore wells at fully open conditions. This ensured the stability of the well prior and during the test, providing a stable profile from which to build the wellbore models. To date, there has been no lost-in-hole PTS tool in the big bore and super big bore production wells.

The spinner data quality suffers during memory surveys due to the set log speeds against varying fluid velocities along the well (see Figure 6). For production surveys, if the up-log speed is at or near the upward fluid velocity, the spinner fails at low revolutions. At the moment, stationary points serve the purpose of additional calibration for spinner analysis. Continuous improvement on the standard logging program is to be implemented with a recommendation of moving to surface read-out (SRO) tools to maximize the spinner data reliability and amend the logging program in real time.

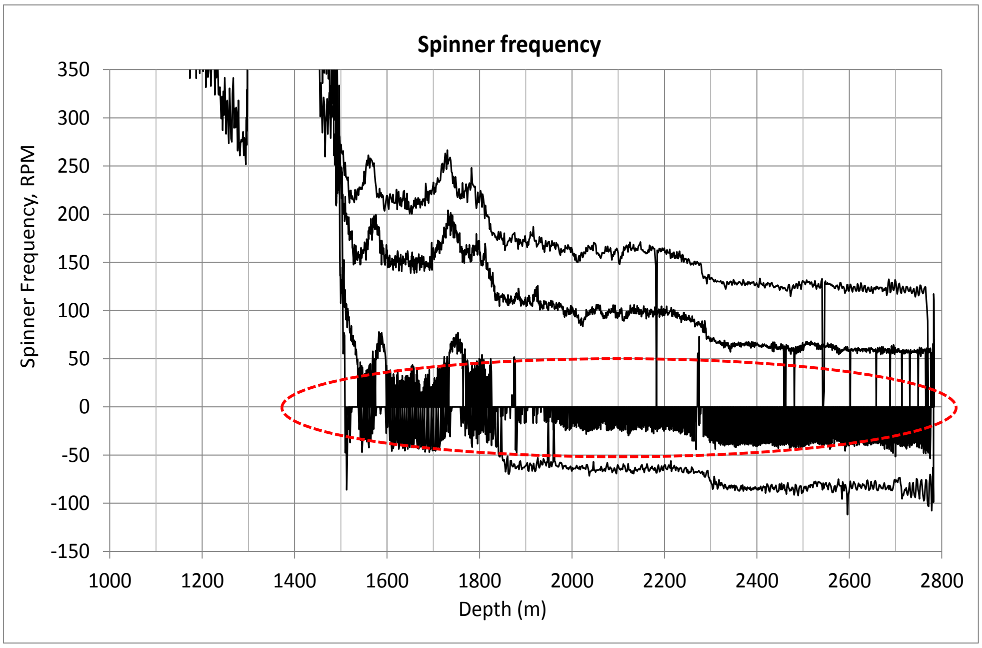

Figure 6: Spinner data issues when fluid velocity and log speed separation is not enough

Wellbore models successfully simulated the flowing pressure, temperature, and velocity profiles as shown in the previous figures. However, the deliverability curve based on the models of the analyzed big bore and super big bore wells overestimate the measured two-phase flow data (see Figure 7). To achieve a reasonable match to production data, additional pressure drop is required, currently implemented by increasing the friction factor in the model input. While this is not physically possible, this solution may indicate that there is a missing pressure drop term in the two-phase flow pressure drop correlations used. This additional pressure drop is not required in our models of standard-sized wells and is likely related to the large casing diameters of the big bore wells. Modifications to the model for this pressure drop are still being investigated and the current implementation via increased friction factor has the desired effect.

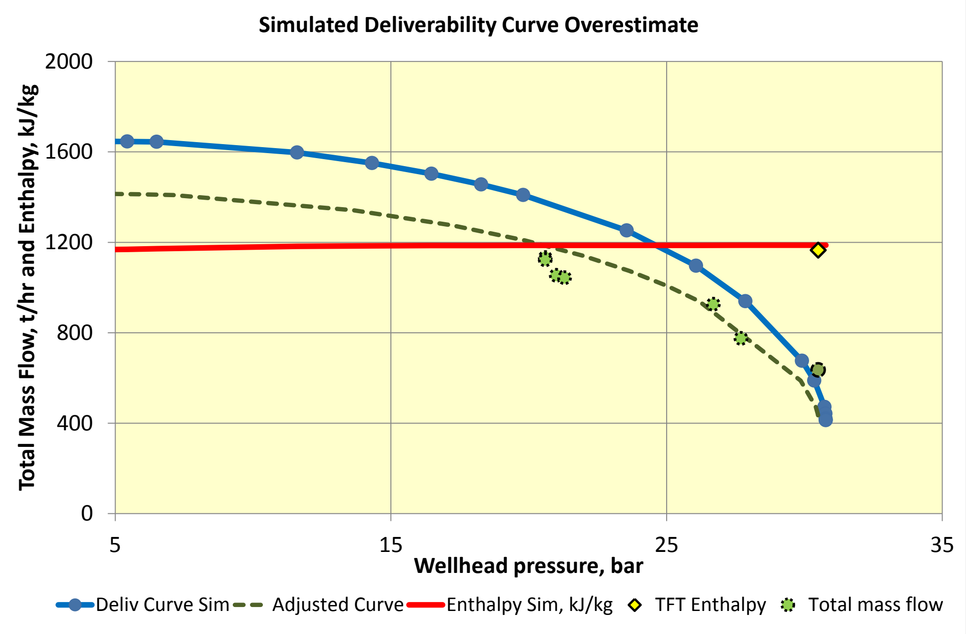

Figure 7: The deliverability curves from the calibrated wellbore models require an additional pressure drop to match total mass flow data at surface

5. CONCLUSIONS

Based on our experiences in logging big bore and super big bore wells, we therefore conclude that:

- pre-job planning and coordination is critical for safe and efficient operations;
- flowing surveys at big bore and super big bore wells requiring high tool string weights (up to 250 kg) can be safely done; and
- additional pressure drop affects flow in wells with large casing diameters.

6. ACKNOWLEDGEMENTS

The authors would like to thank Mighty River Power Ltd. for allowing the publication of these findings.

7. REFERNCES

Bush, J., and Siega, C.: Big bore well drilling in New Zealand – a case study, Proceedings, World Geothermal Congress, Bali, Indonesia, (2010).

Sanyal, S. K., Morrow, J. W., Henneberger, R. C., and Granados, E. E.: Well productivity enhancement by drilling multi-legged wells a quantitative assessment, Geothermal Resources Council Transactions, Vol. 31, pp 257-262 (2007).

Stimac, J., Baroek, M., Pazziuagan, D., and Vicedo, R.: Multi-lateral geothermal wells in volcanic-hosted reservoirs – objectives, challenges and results, Proceedings, World Geothermal Congress, Bali, Indonesia, (2010).

Thorhallson, S.: New developments in geothermal drilling. Presented at *Workshop for Decision Makers on Geothermal Projects in Central America,*UNU-GTP and LaGeo, San Salvador, El Salvador, (2006) accessed 15 April 2014, http://www.os.is/gogn/unu-gtp-sc/UNU-GTP-SC-02-27.pdf