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Recent Geothermal Well Work-Over Experiences at the Kawerau Geothermal Field, New Zealand

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ABSTRACT

Ngati Tūwharetoa Geothermal Assets Ltd. (NTGA) ensures uninterrupted supply of geothermal energy to the Kawerau Industrial Complex in New Zealand through effective operations and maintenance of its steamfield assets. This paper describes the challenges encountered and the solutions developed from two recent well work-overs carried out by NTGA. The first well work-over had access issues requiring wellhead changes and the use of a smaller drilling rig to fit the small well pad. The second well work-over was required to improve wellbore access for well integrity and reservoir monitoring. The challenges identified in both work-overs required creative solutions in collaboration with the geothermal and the wider energy industry. The successful work-overs ensured the long-term reliability of the two production wells. The solutions developed and their potential applications in future work-overs are discussed.

1. INTRODUCTION

1.1 NTGA Steamfield Operations

Ngati Tūwharetoa Geothermal Assets Ltd. (NTGA) is an iwi-based geothermal energy supplier in Kawerau, New Zealand, supplying geothermal energy to the Kawerau Industrial Complex for industrial direct heat use and to the TOPP1 binary cycle power plant for power generation.

The Kawerau Industrial Complex is the world's largest geothermal direct heat user for industrial process heat. NTGA currently supplies the complex with around 6 PJ of geothermal energy used in the various pulp and paper, wood products processing, and timber drying operations in the area. The TOPP1 binary cycle power plant generates 21 MWnet of electricity from NTGA's steam and the separated geothermal water by-product from its industrial direct use steam supply.

Figure 1: The Kawerau Industrial Complex in 2018 (three binary cycle power plants not in photo)

NTGA's steamfield assets comprise of production and reinjection wells, two-phase separators, and clean steam plants (Moore, 2011). Ongoing capital investment in new assets and regular maintenance of older assets ensure NTGA's safe operations and uninterrupted supply of geothermal energy to its downstream customers. Well condition monitoring activities are carried out to regularly verify the reliability of the wells and identify issues ahead of time.

1.2 Well Condition Monitoring

A well condition monitoring program was developed by updating the uneven, multi-year interval monitoring frequency to a regular yearly frequency. Well condition monitoring is carried out downhole using either a high-temperature casing condition (HTCC) tool and/or a pressure, temperature and spinner (PTS) tool running on wireline.

The HTCC tool is used to estimate the casing thickness and evaluate potential metal loss especially those caused by external casing corrosion. The PTS tool is mainly used to verify the production and injection characteristics of a well. However, its spinner and temperature measurements have been useful in detecting possible casing issues otherwise missed by the HTCC.

Implementation of the well condition monitoring program resulted in the early detection of possible well casing damage in production wells. Full implementation of the well monitoring program to all production wells is complicated by the presence of anti-scalant systems installed in the wells.

Anti-scalant systems are downhole tubes that inject anti-scalant chemicals deep into the production wells to mitigate calcite deposition. The new production wells drilled by NTGA have been fitted with an updated anti-scalant design that utilises a 1/4-inch ID tube, lubricators and risers which allow for regular tube pull-outs for anti-scalant maintenance and reliability testing, and for downhole well condition monitoring and reservoir data measurements. However, a number of the older production wells still have the first-generation anti-scalant design (armoured ¼-inch tubes) installed (see Figure 2).

This first-generation anti-scalant tubes are effective in mitigating calcite deposition but are challenging to maintain because tube pull out requires wells to be quenched and the wellhead master valve to be closed. Pulling out the first-generation designs is an inefficient and costly process if the wells are to be regularly monitored. Also, a previously uneven maintenance schedule has left some tubes inside the wells for a long time, resulting in additional risks during tubing pull-out. These additional risks include fraying of the tubing armour when it fails during pull-out, creating a “bird’s nest” inside the wells that causes stuck tubes during maintenance checks. Another risk of undisturbed old anti-scalant tubes involves cementing of the tube into the casing wall through the deposition of residual calcite and/or other minerals. The cemented tube could fail during pull-out, leaving the dispersion head or parts of the tubing as “fish” inside the well. These first generation designs are in the process of being replaced by the retrievable anti-scalant tubing design.

Figure 2: Production well with first-generation anti-scalant tube installed.

1.3 Well Work-Overs

Well work-overs or well repairs are carried out to ensure the long-term reliability of geothermal wells. In the case studies presented in this paper, two well work-overs are discussed: (1) re-sleeving KA47 to repair a leak in the production casing and (2) scale drill-out in KA27 to remove well blockage and re-establish flow. Both work-overs had unique challenges that required some innovative solutions to be successful. These case studies are discussed in the next section.

2. CASE STUDY 1 – KA47 RE-SLEEVING

KA47 is a 20-MWe production well capable of producing around 600 tonnes of geothermal fluid per hour (167 kg/s) under normal operating conditions. The well was drilled and completed as a large bore well (13 3/8-inch ID production casing) in January 2008 and currently supplies geothermal fluid to NTGA’s clean steam plant and high pressure steam to Carter Holt Harvey Woodproducts.

During production, hot fluids were observed on the well pad outside of the well cellar and in between the 30 and 40-inch ID casing annulus at the ground surface. Chemical analysis of the sampled fluid indicated that it comes from the shallow geothermal aquifer mixed with groundwater. In 2010, annular cement sealing was attempted but was unsuccessful. Casing annulus gland sealing caps fitted with valves for fluid sampling were installed in the wellhead to closely monitor the fluid chemistry as a proxy for changes in the well condition. Additional downhole casing integrity testing was deferred due to the shut-required anti-scalant design and lack of field capacity to take the well out of service.

2.1 Well Integrity Testing and Results

In 2016, NTGA successfully drilled and completed a new production well that provided enough capacity to cover for KA47's shut-in. NTGA and Western Energy Services (WES) developed a program to verify the well's integrity and to upgrade the anti-scalant system to the current retrievable design.

Due to the suspected casing issue, the well was slowly quenched from the bottom using the anti-scalant tubing system. An HTCC survey was completed and results indicated no significant metal losses along the casing. However, the PTS survey carried out with the well under a 50 t/hr quench water injection indicated a hot fluid inflow to the well from a possible leak in the production casing. A multi-finger caliper and a downhole camera run were carried out to verify the possible leak. While the camera run was unsuccessful, the multi-finger caliper results confirmed a poor casing liner lap joint at the same depth as the hot inflow observed in the PTS.

With a confirmed casing issue and the risk of the well fluid exiting through the leak during high production pressures, a work-over plan to repair the casing was developed.

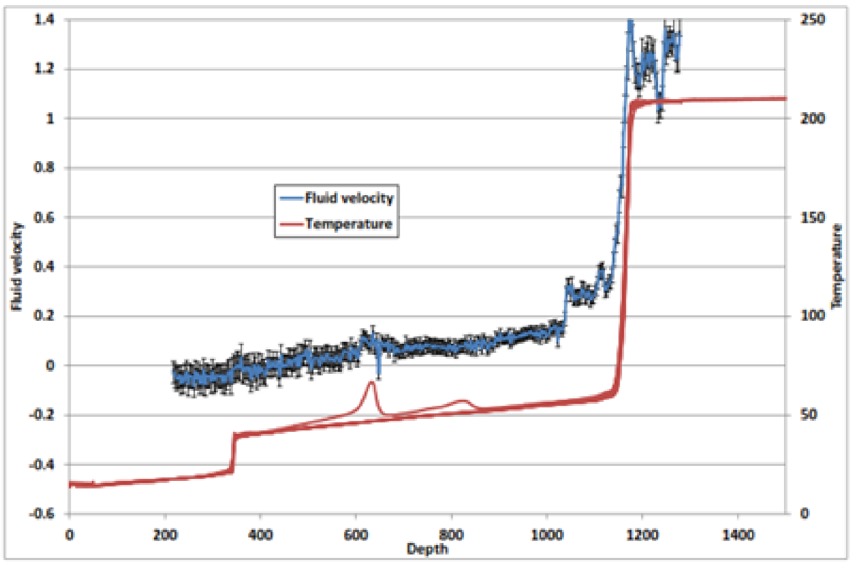

Figure 3: Fluid velocity and well temperature profile under injection indicating an inflow at ~355 m depth (Grant, 2016).

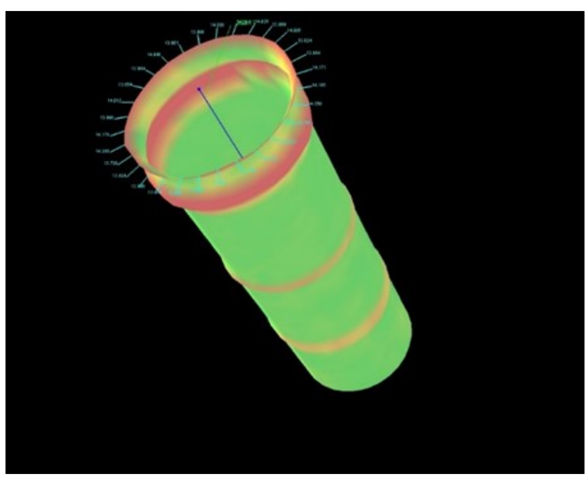

Figure 4: Three-dimensional (3D) image of the multi-finger caliper survey result confirming the casing anomaly at the inflow depth.

2.2 Work-Over Plan

The main work-over plan was to run a 10 3/4-inch diameter scab liner to the full length of the 13 3/8-inch diameter casing then cement the liner in place, back to the surface using high density cement slurry. The planned work-over will repair the casing leak but will likely reduce the capacity of the well due to the reduced wellbore diameter.

2.3 Work-Over Challenges and Solutions

The work-over plan also posed some key challenges that needed to be addressed to ensure a successful repair.

One of the key challenges of the plan is the elevation of the well's master valve. KA47's master valve was fitted at 2 m above ground level based on the original drilling rig used to complete the well. This rig is no longer available and at this elevation, no available work-over rigs would fit over the well.

The well's casing head flange (CHF) was successfully lowered to just above the ground level and the master valve was refitted. This was carried out by MB Century using a geothermal wellhead equipment repair tool (GWERT), one of the first use of this rigless temporary packer technology in New Zealand to isolate the well during the wellhead lowering and master valve refit.

Figure 5: Before and after photos of KA47 wellhead lowering and master valve refit.

Another key challenge encountered was the small area in the KA47 well pad. The well pad had a small available area and would not be able to accommodate larger work-over rigs. MB Century's geothermal rig 16 would fit the area but the rig has already been decommissioned by this time. NTGA engaged Webster Drilling and Exploration Ltd., an oil and gas drilling company, to complete the well repair. Webster's Nova-1 rig on the KA47 well pad is shown in Figure 5.

Figure 6: KA47 work-over using the Nova-1 rig.

Another challenge was how to successfully cement the new 10 ¾-inch diameter liner/sleeve inside the 13 3/8-inch diameter production casing, all the way back to the surface. The flow of the dense cement slurry in the annular space between the existing casing and the new liner/sleeve was improved by machining the 10 ¾- inch liner collars to provide extra annular clearance for the cement.

2.4 Work-over and Results

With the key challenges resolved, a successful work-over was carried out on KA47 by installing a new 10 ¾-inch scab liner/sleeve to repair the casing liner lap joint leak. A new casing head flange and a new master valve were installed on the well to match the new 10 ¾-inch production casing. A new retrievable anti-scalant system was also installed.

Well performance evaluation after the repair showed minimal flow reduction due to the smaller diameter liner. An injecting PTS downhole survey carried towards the completion of the work-over also confirmed that the casing leak has been successfully cased off. The well was successfully returned to service by top-heating it from nearby wells. KA47 is back as a reliable production well for NTGA and is now accessible for regular downhole surveys and well integrity monitoring. The repaired well with the retrievable anti-scalant is shown in Figure 6.

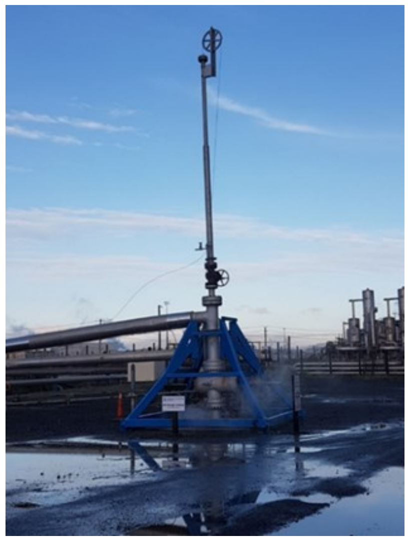

Figure 7: KA47 after well repair and anti-scalant system upgrade.

3. CASE STUDY 2 - KA27 ANTI-SCALANT UPGRADE, ACID FLUSH, AND SCALE DRILL-OUT

KA27 is a 7-MWe production well with a capacity to produce around 240 tonnes of geothermal fluid per hour (67 kg/s) under normal operating conditions. The well was drilled and completed with an 8 5/8-inch diameter casing in 1979 and supplies geothermal steam mainly to the Norske Skog pulp and paper mill.

The well has a long history of calcite scale build-up managed through regular well work-overs. These work-overs used to require pulling out the well’s perforated liner and mechanically cleaning it at the surface before being reinstalled.

In 2001, an anti-scalant feasibility study for KA27 was completed following successful trials in other production wells. An anti-scalant system using an armoured tube was installed. The anti-scalant system successfully mitigated calcite scaling in the well and eliminated the requirement for regular work-overs.

The anti-scalant system’s success and the shut-required tubing maintenance meant that the tubing installed in KA27 was not frequently pulled out. Following the successful work-over and recovery of production well KA47, KA27 was taken out of service to remove the old anti-scalant tubing, complete a casing condition survey (HTCC), carry out a flowing PTS survey and install a new and retrievable anti-scalant system.

3.1 Tubing Pull-Out, Well Integrity Testing and Results

KA27 was quenched and prepared for anti-scalant tubing pull-out. One of the key risks in quenching KA27 and and pulling out its anti-scalant system is the system’s age and the risk of residual scale (assumed to be mostly calcite) sloughing off from the production casing, or scale adhering to the tube and/or cementing the tube to the production casing well. A contingency acid flush plan was developed to mitigate this risk.

The acid flush plan aims to dissolve enough volume of the scale to allow the retrieval of a stuck anti-scalant tubing while mitigating the risk of corrosion in the well casing. The acid flush would not aim to stimulate the feed zones, i.e., any stimulation effect is a secondary positive result.

During the quench program, there was an observed intermittent blockage and then clearance at increased quench injection pressure in the wellbore. This was likely caused by scale sloughing off the side of the production casing as the casing contracts with cooling, blocking the flow of quench water, and then clearing out with injection at higher pressure.

During the tubing pull-out, residual scale was coating the anti-scalant tubing (Figure 8) for about 790 m before the tubing was held up at 576 m depth. At this point, the well also stopped accepting quench water indicating a blockage in the well. High pressure pumps were used to cycle the quench pressure up to 100 bars to dislodge the blockage. The blockage was dislodged, the quench flow was re-established, and the acid flush plan was implemented to ensure maximum tubing recovery.

Figure 8: Scale around the KA27 anti-scalant tubing.

3.2 Acid Flush Results

Mercury NZ, another geothermal field operator in Kawerau, was engaged to review the acid flush concept and provide technical recommendations on a range of acid mixture options. Western Energy Services and Utrex carried out the acid flush program in the well.

Around 7,400 litres of acid mixture (hydrochloric acid and formic acid) and acid corrosion inhibitor was injected into the well to dislodge the stuck tubing. The stuck tubing was successfully pulled out except for 11 m length of tubing and the 4-meter dispersion head attached at the bottom of the anti-scalant tubing. The well quench was maintained.

3.3 Preparing for Well Integrity Testing

Gauge rings (scale probes) of various diameters were run in the wellbore to verify the well clearance for the well integrity surveys (HTCC and PTS) to be carried out. The gauge rings encountered obstructions at various depths in the well that would block the HTCC tool but would allow the PTS tool to be run.

A 7-inch diameter broach was run on wireline to mechanically dislodge the scales and improve the well clearance. However, the dislodged scales appeared to block the well. After initial success in removing the blockage through cycling the quench pressure, the well was blocked again at around 610 m depth and would not clear with pressure cycling. A 2.5-inch diameter chisel was also run on wireline but could not break through the blockage. At this point, the well needed a mechanical intervention with more power than the wireline broach and chisel. The surface equipment was demobilized, the well was put on bleed, and the site was made safe while the team planned for a mechanical intervention.

3.4 Mechanical Clean-out

Western Energy Services were engaged to carry out a live mechanical clean-out, i.e., no quench required, while ThermaRock engineering designed a two-phase muffler/silencer to fit the requirements of the live clean out program and of the site lay-out.

The live mechanical clean out used a coiled-tubing unit (CTU) to convey the mill downhole and clear out the blockage at 610 m depth and all remaining obstruction down to the bottom of the well.

Figure 9: KA27 mechanical clean out using a coiled tubing unit.

Successful clearance of the main blockage was confirmed when the well started to flow while the mill was drilling through the obstruction. The rest of the mechanical clean out operation was carried out while the well was flowing through the muffler/silencer. This ensured that the well could be returned to service quickly, if required.

3.5 Well Integrity Testing Results and New Anti-Scalant

Once the well was cleared of obstructions, downhole HTCC and PTS surveys were carried out to check the condition of the casing and the feed zones of the well. The HTCC and PTS survey results showed that the 39-year old well has excellent casing condition. A new retrievable anti-scalant system was installed in KA27 (Figure 10) and the well was easily brought back online.

Figure 10: KA27 with new anti-scalant system installed.

4. CONCLUSIONS AND RECOMMENDATIONS

NTGA's recent work-over experiences highlight the need for a collaborative and solutions-based approach to well asset management and well work-over programs. Multiple service contractors were involved in various parts of the program and technical experts from other geothermal operating companies provided technical support as required. The relevant information and expert advice provided by the different collaborators helped NTGA resolve the unique challenges encountered.

4.1 Potential Future Applications of the Work-over Solutions

The solutions developed to overcome the work-over challenges would be considered in future work-over and anti-scalant upgrade programs in Kawerau. Specifically, the following recommendations should be considered at the planning stages:

- Oil and gas work-over rigs provide an additional option dependent on the specific well and well site lay out requirements;
- Hydraulic removable packers could be used in future wellhead upgrades and master valve changes;
- Machining the collars of the scab liner/sleeve could mitigate the risk of poor cementing when re-sleeving a well;
- Considering the quench program based on the inferred well casing condition, e.g., carrying out a slower quench program for wells with suspected casing issues and using existing tubings in the well for quenching, if possible;
- An acid flush plan should be available for all upcoming anti-scalant system upgrade where the system has been undisturbed for a long time due to the likelihood of residual scale deposition;
- Live mechanical clean outs could reduce well downtime during well work-overs and should be considered if practicable;
- A hold-point should be clearly defined for when a regular well integrity monitoring activity becomes too complicated and requires a proper well work-over plan.

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