Exploration, Suspension, Perforation, Extraction. The WK265 Success Story

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ABSTRACT

Since 2005, Contact has drilled 30 new production wells in the north-western part of the Wairakei resource (Te Mihi) to support additional generation. Drilling conditions in this area can be difficult with under-pressured and unstable formations, together with very high permeability. These conditions resulted in abandonment of two of the early wells and several more were sidetracked to reach their planned targets. While the best permeability and temperatures for production are usually found at 800-1500m, the field development strategy has been to spread the production risk and target permeability over a range of depths. WK265 was originally designed to target production from below 2000 metres. Cementing the production casing for WK265 was unsuccessful due to a strong interzonal flow in the casing annulus. Attempts to employ backfill cementing over a two week period also proved unsuccessful - with more than 900 tonnes of additional cement pumped during the 12 backfill attempts. A decision was made to suspend WK265, while the subsurface conditions could be fully evaluated, and the rig subsequently proceeded successfully to complete additional wells on the same pad. Following the suspension of WK265, downhole surveys showed that temperatures suitable for production were present in the zone of uncemented casing. Two years after the original drilling, the production casing was perforated close to the permeable zones. Subsequent testing showed the recompleted well to have a capacity to produce more than 10MWe.

1. INTRODUCTION

1.1 Te Mihi Steamfield Development

The Te Mihi area of the Wairakei geothermal field was originally explored in the 1960's when 8 wells, drilled to depths of around 1000m were completed. These wells confirmed both high temperature and high permeability in the western part of the Wairakei resource. However, no further development beyond the original Wairakei 192MW station did not proceed at that time as reservoir pressures in the new Te Mihi wells was rapidly declining in line with those being measured in the Western Borefield.

In the 1980's three of the existing exploration wells from the Te Mihi area were connected to the production system and over the next few years 10 new wells from this area were added to make up the steam supply to the Wairakei station as the older production wells in the Eastern and Western Borefields declined.

In 2005 a new drilling campaign to provide sufficient steam to fully load both the Wairakei and Poihipi stations commenced. For this campaign a larger rig than had been previously used at Wairakei, with capacity to reach more than 3,000 m depth in good drilling conditions, was employed. On completion of this development drilling program at the end of 2013, 30 new production wells had been drilled, with a maximum depth of 2760m (The rig had also be used to drill reinjection wells at Wairakei and at Tauhara and Ohaaki over this period). To improve later reservoir management options, a range of production well designs was used, with production casing depths varying between 500 to 1500m. While the best permeability has been found between 800-1500m, high permeability feedzones have been encountered down to 2300m.

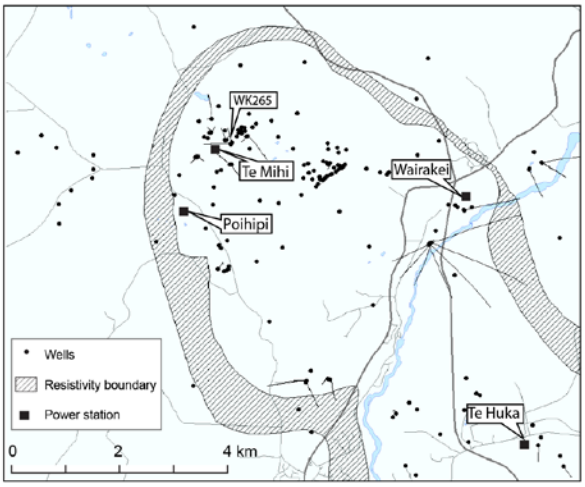

Figure 1 Wairakei geothermal field showing location of the power stations and WK265.

Setting and cementing deep production casing in the Te Mihi area can be difficult due to the combination of zones of very high permeability, the under-pressured liquid reservoir, and in some cases unbalanced pressures within the liquid reservoir (Winmill, 2014).

1.2 WK265 Design and Drilling

WK265 was the last well to be drilled on a three-well pad and the casing was designed with a 9-5/8" production liner to cope with the expected subsurface conditions that had been encountered in the previous two wells.

After setting the 13-3/8" casing to 508m, drilling continued using an air-water system, toward the target depth for the production liner of 1450m. Even using the air-water system, total circulation loss was encountered at 756m. Drilling continued with intermittent returns to 830m, then below 830m the 12-1/4" hole was drilled using an air-water system without returns down to the casing depth at 1445m. The 9-5/8" production liner was run to 1442m, with the top at 439m, providing a 69 m overlap with the 13-3/8" casing.

The primary cementing job for the production liner failed, due to what later became apparent as flash-setting caused by unexpected high temperatures in the casing annulus. Over the next 11 days 12 separate cementing jobs were performed. More than 900 tonnes of cement were pumped through the liner overlap with no indication of sealing the casing overlap.

2. DOWNHOLE TESTING

At this stage it was decided to remove any remaining cement from inside the casing and carry out downhole logging to assist in understanding the well and casing conditions. The 9-5/8” casing was cleaned out to just above the casing shoe at 1440m.

2.1 Cement Bond Log

A radial bond log was run to check the cement behind the 9-5/8” casing. This indicated that below 1380 m there was poorly cemented casing and above 1380 m there was no sign of cement.

2.2 Stage Completion Test – PT Logging

A series of PT profiles were then performed both during water injection and with the well shut-in, with the objective of determining the overall injectivity index of the well in the current condition (with flow through the production liner overlap) and to identify the depths of permeability outside to casing. The results of these logs are plotted on **Figure 2**. The temperature profiles clearly show that during injection there is an inflow of hot fluids into the casing annulus at 550-600m, with this fluid exiting to the formation at the deepest permeability at 830m, with no significant permeability below this depth. The pressure change measured at the depth of the production liner hanger (439m) while the injection flow varied from 0 to 130 t/h changed by less than 1 bar, indicating very high permeability in the casing annulus.

At this stage it was decided to suspend any further drilling operations and move the rig while the test results and options to remedy the situation were assessed.

2.3 Assessment

A review of local reservoir conditions and results from nearby wells and reservoir temperatures indicated that the main permeable zone at 830m encountered in WK265 was near the upper contact of a buried rhyolite where very high permeability and temperatures in the range 230-240°C are expected. While the shallower feedzones at 500-600m depth had temperatures of around 220°C, the 830m zone was close to 242°C.

3. CASING PERFORATION

3.1 Planning

To be able to effectively access the production potential behind steel the only real option was to perforate. This is a standard procedure for the oil and gas industry where well completions are particularly different to geothermal operations, however the geothermal experience with explosives is typically limited to severing operations to retrieve stuck pipe. This has not been on a regular occurrence in Contact’s operations and consequently there was lack of expertise with planning and performing explosive operations. In order to come up to speed with the HAZNO and the Explosive Regulations an explosives handling course run by one of the local contractors was carried out for Contact staff. This clarified the requirements for bringing explosives on site and the associated handling and storage requirements.

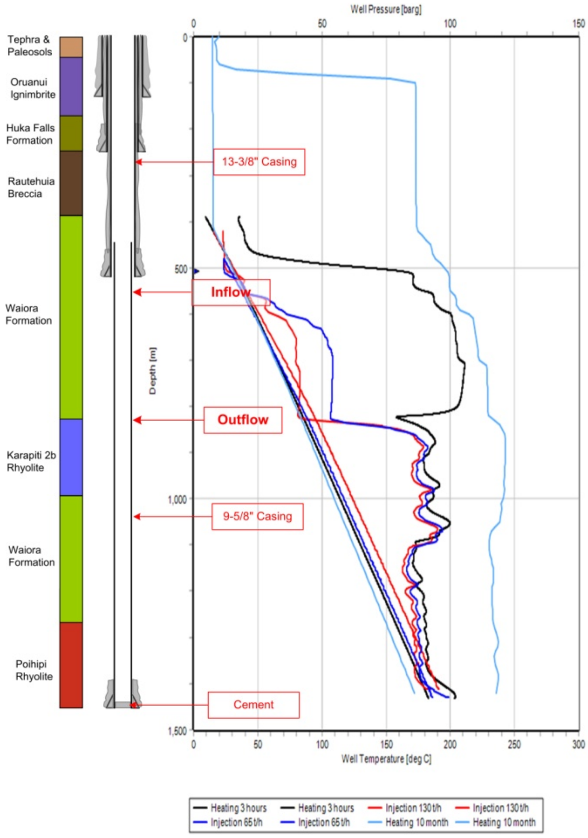

Figure 2 WK265 casing and PT surveys before perforation

3.2 Design work

Shot selection and placement is critical to obtain the best effect of perforations and consequently considerable work was undertaken by the Contact reservoir and drilling engineering team to identify the required perforation size, density and penetration. To determine shot density it was important to look at critical buckling and any increase in thermal stress that could be induced on the 9-5/8” L80 casing (bearing in mind that the casing was anchored at the top by the liner hanger and at the bottom by cement). A five shot per foot density with 0.57” (14 mm) hole diameter holes was chosen for WK265.

Due to the interzonal flow behind casing there was some concern that it would not be possible to achieve adequate cooling for the explosives. To reduce this possibility, HMX explosives were chosen which have a Temperature rating of 204°C for 1 hr. In addition temperature profiles while injecting cold water were measured in the casing prior to the perforating operation. In this case the deepest charges could be located at 830m, just above the sharp temperature increase seen during cold water injection (**Figure 2**). This depth also corresponds with the target permeable zone identified from the geology and PT logging.

3.3 Production Simulation

Experience with other high permeability wells which had similar feedzone temperatures to those at WK265 indicated that an output up to 10MWe equivalent would be expected from a "normal" well design completed to this depth.

To ensure that the production flowrate would not be limited by the perforations, differential pressure calculations were performed for single and two-phase fluid through the casing. From these calculations it was determined that 450 x 0.57" holes would be required to ensure that the pressure loss due to the wellbore configuration would be greater than that due to the perforations. At a density of 5 SPF (Shot per Foot), this equated to 3 joints of casing to be perforated at 150 holes per joint.

3.3 Perforation and Analysis

In preparation for the perforation job the well was placed on quench and a baseline injectivity test was performed. This test confirmed the results from the previous tests run while the rig was onsite (**Figure 2**). The perforating charges were run in a carrier constructed from 4-1/2" steel pipe (ERHSC Expendable Retrievable Hollow Steel Carrier). This has the advantage that the explosives are all pre-assembled off-site and the debris associated with the shaped charges is recovered after firing.

Figure 3: Perforation gun laid out ready to be run

Following the perforation job, downhole video camera and multi-finger caliper surveys were performed on the well to assess the effectiveness of the job. These surveys confirmed the successful detonation of all charges and perforation of the production casing. However they did show some of the holes on the high side of the well did not achieve full penetration. The 60-finger caliper data can be used to generate a 3D image of the internal surface of the casing.. **Figure 4** below shows a scaled image of a section of perforated casing with the coupling clearly located in between two joints of perforated casing (right image), next to a blown up image of the casing perforations clearly visible with definite penetration through the steel shown.

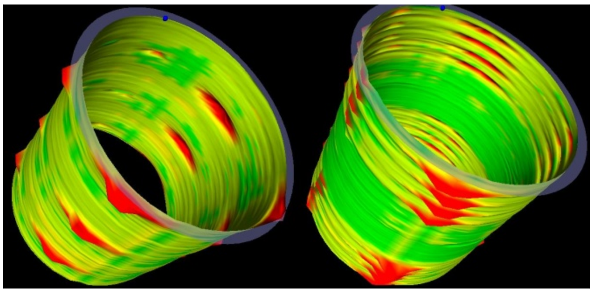

Figure 4 Image derived from the 60-finger caliper log of a perforated section

Figure 5 below shows a good image of 2 perforation holes. The hole in the centre of the image has scale lodged in it, this is likely to be internal scale blown off during the explosion then carried out with the quench fluid. The image is on the low side so the hole spacings are slightly closer together due to the gun being closer to the casing wall on the low side. No centralisers are used when running in perforation charges.

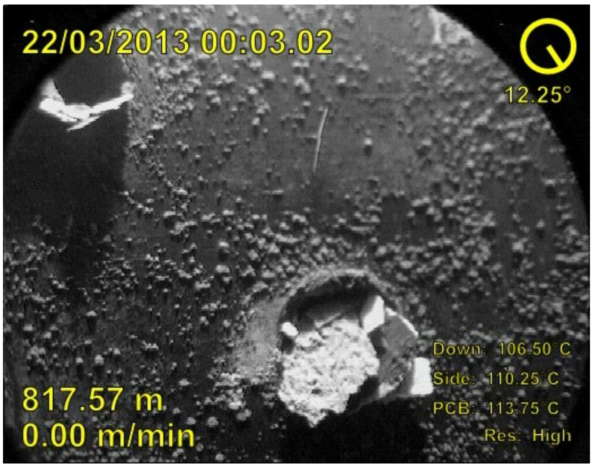

Figure 5: Two perforated holes.

3.4 Post-Perforation Injectivity

Following the casing perforation an injectivity test was conducted over a range of flows up to 150 t/h. The pressure change measured at the perforations was less than 0.1 bar over the flow range, indicating extremely high permeability.

4. PRODUCTION TESTING

WK265 was perforated near the end of the steamfield development project and at the time did not have a connection to a testing silencer or production line. A vertical discharge was proposed to confirm the production potential before connecting to the steam gathering system. As the well was located in the middle of a steamfield still under construction and adjacent to the Te Mihi station construction site, good planning and communication was required to enable the vertical discharge test to be performed with minimal disruption to the construction activities.

4.1 Discharge

The vertical discharge was conducted on a morning where construction levels were low and the steamfield construction team had temporarily moved out of their offices (located on the same wellpad, **Figure 6**). Short term vertical discharges can be unreliable in predicting long term output, and this test indicated a stable flowrate of about 290t/h at 11.5 bg WHP. Using an assumed enthalpy of 1050kj/kg to match the downhole temperature at the production zone, a production potential of more than 6 MWe was expected.

Figure 6: Vertical discharge being conducted in the middle of the construction site.

WK265 was connected into the Wairakei steamfield in January 2014 and a full output test confirmed the high production rates seen in the vertical discharge with an electrical potential of over 10MW. This is greater production potential than the two other "regular" wells completed on the same pad.

5. CONCLUSION

In any drilling campaign there is a very high ongoing cost, irrespective of actual progress in terms of drilling ahead. When progress is effectively stopped due to issues such as casing cementing problems there is pressure on the engineers to make the "right" decision quickly: In this case choosing between continuing backfill cementing operations and deferring further drilling operations. The option to suspend operations and move on to the next project while the problems can be further assessed, should always be considered. As long as the well can be made safe and the rig can be moved safely there is always an option to return once unforeseen problems have been assessed and if necessary specialist equipment brought to site. WK265 is an example of good decision making and good outcomes. This requires a working environment where thinking outside the box is encouraged and put to use. WK265 could have ended up as a "P&A" but after applying some innovative thinking and decision making it is now one of the larger production wells from the Wairakei field.

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REFERENCES

Winmill R.: Contact Energy Drilling Campaign 2005-2013 – Results, Learnings and Events. Proc. New Zealand Geothermal Workshop, Auckland, New Zealand. (2014).