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Coiled Tubing Live Well Cleanout

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ABSTRACT

Contact Energy Limited (CEL) with their partners Western Energy Services (WES) in New Zealand have been pioneering live well cleanouts on production wells and reinjection wells. The most obvious advantage of live well cleanouts is very minimal production (or reinjection) down-time, and other advantages in production wells include avoiding thermal cycling of the casing and removing the wellbore scale fragments to the surface which prevents blocking the reservoir. In 2018 CEL successfully cleaned out 1 reinjection and 6 production wells, and gained back 34.3MW$_e$ of generation at only a fraction of the cost of a traditional rig workover. Since inception CEL and WES have cleaned out a total of 30 wells (3 reinjection wells and 27 production) at several geothermal fields. CEL and WES are continuously developing the method and pushing the boundaries on what can be achieved.

Initial concepts for using coiled tubing in geothermal wells were developed from oil and gas technology which was then adapted to suit the harsh geothermal environment. In this environment, the highly destructive high-temperature geothermal fluid proved to be the biggest hurdle for job design and tool suitability. Our team first selected a variable vane style mud motor to power a milling bit to mechanically remove the scale from the wellbore. Although successful in multiple wells with apparent soft scale, the limited motor life resulted in poor performance for harder scale and extended milling section operations. Despite an initial success rate of less than fifty percent over the first five attempts, both CEL and WES retained a clear appetite for innovation, fuelling a path to broader thinking and design alterations that has led to recent successes. Trials on multiple candidate wells have demonstrated the suitability of coiled tubing for this purpose. Through pushing of traditional boundaries this technology continues to evolve as a trusted and reliable method to remove scale in geothermal wells. The technology has been utilized to clean out production and reinjection wells to a diameter of 14.5” ID (16” casing) and depths of up to 3000m.

1. INTRODUCTION

Figure 1: Cooling channel lined with fragments of calcite scale removed from a production well with live well cleanout technology.

Scaling is the number one reason for loss of production or reinjection capacity in geothermal wells (Wilson and Gilliland, 2015). In 2013 CEL and WES started to trial different tools and methods for removing wellbore scale (predominantly calcite and silica) using a Coiled Tubing (CT) unit on live wells. Initial success was mixed and Wilson et al. (2015a) reported that CT was not suitable for all cleaning workovers. A combination of factors including available motor torque, mill design and BHA (Bottom Hole Assembly) reliability contributed to the lack of success. In one failed attempt on WK-269 - a large-diameter production well in Wairakei - 8 motors were expended in 10 separate BHA runs down hole, with only a 3.7” diameter able to get through the scale to total depth (TD). This was enough to increase production by 130t/h (about 20% recovery), but nothing close to full production, and having to run 10 BHAs was never going to be sustainable. The live well cleanout method had been proven in concept (Wilson et al., 2015) and then CEL and WES continued to innovate, pushing the envelope of available well treatments, and improving the economic sustainability. The current suite of tools for live well cleanouts includes the Coiled Tubing Hammer (CTH) and high temperature motor. Figure 1 shows a cooling channel lined with fragments of calcite removed from a production well with current CT live well cleanout technology. The cooling channel is after the atmospheric separator and carries the separated geothermal water and cuttings to the soakage or holding pond.

Working in a live flowing geothermal well can be a difficult proposition as the materials and processes need to withstand sustained high temperatures and high total mass flows, which can push tools around down hole and induce detrimental vibrations. Also, any fluids/chemicals need to be environmentally friendly and robust enough to withstand the extremely harsh conditions.

2. RIG CLEANOUTS

Historically, geothermal wells have been cleaned out using a small workover drilling rig. The economics of working over wells is related directly to the costs of employing the workover rig and the associated lost production time whilst the well is out of service. A rig cleanout can cause a well to be out of service for 6 weeks or more at a potential loss of thousands of megawatt hours unless there is available steam behind the wellhead to make up for the production loss.

Contact has some of the oldest geothermal wells in the world with the Wairakei Power Station being commissioned in 1958 and serviced over the years by over 100 wells for production and reinjection. Contact currently operates five power stations across three distinct geothermal fields: Wairakei, Ohaaki and Tauhara. A lot of the wells drilled before the 1980s were completed with short and long round thread casings. These have a very low strength in compression or tension and are prone to pop free under the high loads frequently found in a geothermal environment, especially due to thermal expansion or contraction of the casing when it heats up or cools down. Traditional cleanout technology required cooling (quenching of the well with cold water) which increased this loading cycle on vulnerable well casings. A quenched cleanout also deposits all the fragments of scale removed from the wellbore back into the reservoir, which can mean a volume greater than $5m^3$ of scale blocking the near-wellbore reservoir (positive skin). In this scenario the recovery rate when bringing the well back into service is often not 100%, due to the blocked feed zones. Some of the recent rig cleanouts performed by CEL up till 2013 required acidizing to remove the scale blocking the feed zones, with acid delivered either via CT or by pumping from the surface. CEL has been aware of these issues and hence are continually improving the options to develop more efficient cleanouts.

3. COILED TUBING LIVE WELL CLEANOUT DEVELOPMENT

In the early 1990s CEL trialled jet washing CT cleanout technology that had been pioneered in the Salton Sea (McClatchie and Verity, 2000) however these trials had mixed results and at the time rig cleanouts were still reasonably cost effective, so the method lost traction. After a long hiatus, in 2013 CEL started a new wave of investigations into new and improved methods for well cleanouts.

The first technology investigated was broaching, which is a slick-line technique where a special cutting tool and a set of spang jars is run in hole and attempts to chisel a hole through the scale (Wilson et al., 2015b). In practice, broaching proved unable to obtain a full drift cleanout in any casing bigger than 7”. In addition, the scale that grew back in place tended to be harder than that which was originally removed, and so repeatability was often not achievable. Broaching and other wireline methods are still being considered but have been superseded by the effectiveness of CT live well cleanouts.

CT live well cleanouts allow large benefits by reducing the time the well is out of service, not allowing casing to undergo thermal cycling and therefore having no detrimental effect on the properties of the casing or cement bond with the steel (Pereira, 2014). In the latest iteration of CT cleanouts, a variable vane type motor called the MacDrill was initially identified as the only tool available that could handle the >260°C temperatures often found in a geothermal environment. Initial successes were had with this tool: in total 6 wells were worked over (one well twice) with the MacDrill, and there was complete success in 2, partial success in 3, and 1 was a complete failure. The longest run time in hole was 7.5 hours with this tool. Table 1 shows the wells where the MacDrill was utilised. Product inconsistency, low available torque and limited expected life eventually put this method to the sword. Consequently, CEL and WES began searching for alternatives to the MacDrill and found an additional international CT tool supplier of high temperature capable motors, as well as in-house capability to develop bespoke tools, including the coiled tubing hammer (CTH).

Table 1: MacDrill performance

Well	Casing size	Hole Size	Interval cleaned (m)	Time to clean (hr)	Ave ROP (m/hr)	Notes
BR48	7"	5.9"	10	2	5	First success seemed awesome,100% recovery
WK269	10-3/4"	3.7"	200	5 days	1	Used 8 motors in 10 runs, partial improvement, (20%)
WK245	10-3/4"	3.7"	150	3 days	1	4 motors used, partial recovery
BR15a	7"	5.9"	200	1 day	10	Good job, 100% recovery
BR53	7"	0"	0	4 days	0	No success
BR53 again	7"	3.7"	180	5 days	11	Small improvement

3.1 New tool development

Figure 2: Over 5m^3 scale removed from WK267 with the CTH, deposited in the weir box beyond the silencer.

Initial trials for the CTH and high-temperature motor were conducted on production well WK123a with outstanding results. Both methods proved to be successful in removing scale with the CTH showing the greater rate of penetration (ROP) and better potential. The CTH was selected for development, utilising completely local contractors and tools due to the potential long-term cost savings. The CTH centred on using a down-the-hole (DTH) air hammer connected to a specially designed BHA. After a couple of initial successes, the real challenges were met. With a seemingly endless amount of design and reliability issues to face, motor development was prioritised over the initial desire to use only live well cleanout options. Losing the live well momentum was hard on the team but production-critical operations forced a regression to quenched cleanouts to de-risk the operations and increase the probability of success. However, success is never guaranteed and one big-bore Wairakei production well proved too difficult for a quenched motor option, resulting in two broken motors and a subsequent fishing operation.

With persistent pressure on suppliers to continue to develop a motor suitable for the flowing geothermal conditions, a powerful and reliable option was given. With the motor option providing consistent successes with slower ROP it took the pressure off the CTH technology as the only tool available. Using the CTH and motor options in combination exposed several key learnings and allowed time to resolve the issues without having to walk away from an unsuccessful operation. For a lot of the wells in Wairakei, the calcite scale is typically quite hard with compressive strengths around 60-80 MPA. However, the crystalline nature of the calcite makes the scale brittle, and its tensile strength is ~10 times lower (Internal GNS report). Clay inclusions are prevalent in the Ohaaki scale which reduces the strength, and it seems to be easier to remove with the motor method due to the shearing effect produced by the mills. In Ohaaki however the CTH still has far greater ROP.

These mills are specially made to optimise this shearing effect required to remove scale from the wellbore, with the motor exclusively, an under-reamer has also been used which has enabled the clean out of larger-diameter wells where the production tee pipe work on top of the wellhead is smaller than the casing internal diameter or situations where casing damage precludes getting mills and bits through. The under-reamer and high temp motor are outstanding tools and have really opened the scope for available well scale treatments, allowing greater diameter cleans than previously experienced.

In contrast, the CTH utilises percussion to break scale by smashing it and overloading the tensile strength, while keeping the crystal lattice together. The CTH has by far the greater rate-of-penetration (ROP) potential, however the motor is suited for difficult wells where obstructions can be present, which will affect the success rate. Currently there is capability to use both methods (CTH and motor) to clean out to 14.5” diameter and to depths of 3000m. With the surface handling facilities at CEL the effectiveness of live well cleanouts is easily apparent. Full weir boxes as shown in Figure 2 are a common occurrence.

4. CHALLENGES

The challenges in the development of a reliable repeatable geothermal live well cleanout system have been numerous and significant. Often during development, the engineers are not aware of the problems and must test all the relevant parameters. While preplanning and development are important, such tasks can focus on specific items that either don’t matter or force the development team to concentrate on some issues at the expense of others.

Figure 3: Severe internal erosion

This was certainly the case for the live well cleanout system development. The major concern prior to inserting CTH tools past the master valve was whether they were going to stay on the end of the coil. After two runs down hole this was a problem solved, but with one problem solved another two were uncovered. The issues of seals, corrosion and understanding flowing well dynamics began to rear their heads and cause problems. Each time down-hole something new was learned, simulations and test jigs can only tell you so much, putting the tools on the end of coil and running in-hole is the real test of performance.

After two successful well cleanouts (one Wairakei production well WK123a and another Ohaaki reinjection well BR40 which was cleaned out in less than half a day), we thought we were set and ready to take on the world. The next well brought us crashing back to earth. Ohaaki production well BR48 was the site where nothing would work. At BR48 severe internal corrosion in the string was encountered, which induced severe erosion on the inside of the tools. It took over a month to remove rust and fully treat and prevent more problems from occurring in the coil. This was a lesson in effective coil management and erosion- corrosion mitigation, and humility. Figure 3 shows severe erosion on internal tools.

During the development of these new techniques, what was truly required was a full research and development budget and ability to make this happen. However, a downturn in the power market meant that all the R&D work had to fall within existing operational budgets and constraints. Solving the corrosion issues required a step back from the well head to conduct system tests utilising the Bell Block Laboratories and Te Awamutu Tooling Facilities, the local partners in CTH development. In this instance the test jig, lab tests and simulations could not be avoided and provided confidence to go back down hole again.

Through the earlier work with the Macdrill, suitable seals capable of surviving the downhole conditions were identified. However, these proved to be incompatible with the new tools, and the resulting BHA leaks were a considerable hold up in development. During the development of the high temp motor technology more advanced seals were identified and proved acceptable with both downhole assemblies.

The consistent drive to clean bigger and hotter wells proved a challenge for both systems but gaining real down hole experience proved vital in understanding the complex dynamics occurring in a live well cleanout operation. There was initially great success with the CTH on shallow Wairakei production wells less than 1000m deep, and these were being cleaned out in less than a day, however it was not possible to achieve anything below this depth. With a combination of effective BHA seals, refined operating parameters and new bit design, CEL and WES have significantly expanded the envelope for CTH suitability to clean out to 13-3/8" casing, to depths of 2200m, and up to temperatures of up to 300°C. With the motor and under reamer there has been successful clean out of 16" casing to 14.5" ID, depths of 3000m and temperatures of 320°C. CTH average ROP is about 1.5m/min whereas the motor sits around 0.2-0.3m/min. However max ROP for the CTH has been 5m/min and motor 3.3m/min.

5. RESULTS

CEL and WES have cleaned out 30 wells including 3 reinjection wells since 2014 using the live well cleanout methodology. This includes 5 wells for other operators. In the 2019 financial year to date of writing Contact and WES have cleaned out 1 reinjection well and 8 production wells for an additional 41.3MWe gain. This has been achieved orders of magnitude faster and more cost effective than equivalent rig workovers. The average economic payback for these wells is less than 2 months.

Table 2: Wells cleaned out for CEL

Well	Date	Job Type	Well Type	Metres of scale	Liner Size	Scale Type	Recovery
WK123	1 July 2016	MIlling	Production	50	7"	Calcite	55%
WK123A	4 - 14 July 2016	Hammer	Production	78	7"	Calcite	100%
BR40	14 - 16 July 2016	Hammer	Reinjection	70	7 5/8"	Silica	100%
BR60	2 - 3 Aug 2016	Hammer	Production	NA	7"	Calcite	0
BR48	Aug - Oct 2016	Hammer	Production	NA	7"	Calcite	0
WK 245	11 October 2016	Milling	Production	0	10-3/4"	unknown	0%
WK 269	15 October 2016	Milling	Production	0	10 3/4"	Calcite	0%
BR41	13 - 15 July 2017	Hammer	Reinjection	257.4	6-5/8"	Silica	100%
BR36	2 - 3 Aug 2017	Hammer	Production	50	6 5/8"	Calcite	50%
WK116	22 - 23 Aug 2017	Hammer	Production	120	6 5/8"	Calcite	100%
BR 60	1 November 2017	Milling	Production	55	7"	Calcite	69%
WK271	4 - 12 Dec 2017	Hammer	Production	NA	7"	Calcite	0
WK 271	1 December 2017	Milling	Production	10	7"	Calcite	85%
WK269	1-Feb-18	Hammer	Production	NA	10 3/4"	Calcite	0
WK269	1-May-18	Hammer	Production	49	10 3/4"	Calcite	100%
BR16	1-Jun-18	Hammer	Reinjection	825	6-5/8"	Silica	100%
WK67	1-Jul-18	Hammer	Production	50	6 5/8"	Calcite	100%
WK74	25-Jul-18	Hammer	Production	21	6 5/8"	Calcite	100%
WK123A	21-Aug-18	Hammer	Production	99	7"	Calcite	100%
BR36	13-Oct-18	Hammer	Production	88	6 5/8"	Calcite	100%
BR61	29-Nov-18	Hammer	Production	33	7"	Calcite	100%
WK267	27-May-19	Hammer	Production	222	10 3/4"	Calcite	100%
BR48	13-Jun-19	Hammer	Production	264	7"	Calcite	100%
WK258	2-3 July 19	hammer	Production	112	9-5/8"	Calcite	100%
WK261	8-9 July 19	hammer	Production	152	9-5/8"	calcite	100%

Production well recovery has also improved significantly during the development period. Rig cleanouts and quenched motor cleanouts do not carry the scale to surface but instead send it into the bottom of the well, the annulus and the reservoir itself, damaging permeability and in extreme cases blocking entire feed zones. Following the well quench a formation heat-up period and well compression are normally standard procedure. Once the well is back in a flowing state, an on-site separator must be used to recover the cuttings from the well, this can take several days and increases the time the well is out of service. Even through this process, getting full recovery is not always achievable. In the most recent example at Wairakei, WK269 was cleaned out using a quenched method on coil in 2016. This well came back in at 60% of expected production. In 2018 a live flowing cleanout was completed on WK269 and achieved 100% recovery. All the recent live well cleanouts using the CTH since 2018 have resulted in 100% recovery. The meaning of "recovery" is a return to the expected production capacity of a fully clean wellbore with the expected enthalpy.

Reducing costs has recently been a significant driver for CEL. Since the end of the Wairakei improvement program in 2013, which saw the commissioning of Te Mihi and upgrade of the Wairakei steamfield, the focus has switched from development to innovation. A good example of this and a chance to showcase the continuous improvement drive within CEL and WES is the recent history of Ohaaki Production well BR48:

- In 2011 a rig cleanout was conducted on BR48. This job had the well head pipework removed and the well out-of-service for 6 weeks. The rig took 6 days to mobilise on site and 2 days to complete the job. Recovery was 85% of expected production capacity.
- In 2014 there was the first live well cleanout on coil utilising the MacDrill (Wilson et al., 2015a); this job took 2 days to complete and total time in hole was 12 hours. Cost was 30% of the expected Rig AFE (Authorisation for expenditure, Budget). Well was out of service for 3 days. Recovery was 100%.
- In 2016 a CTH run was attempted and severe internal erosion was suffered. A motor had to be brought in for a quenched cleanout on coil. This job took 3 days, milling 2 m of hard scale in 40 minutes. Production recovery was 90% at a cost of 25% of the rig AFE. While the well was out-of-service for 2 weeks, this mostly comprised time for re-heating the well.

- In June 2019 a CTH run was completed which cleaned out 230m of calcite scale in 48 minutes. Total time in hole was 7 hours and the well was back on production as the crew were rigging down. This job cost 15% of an expected rig AFE and provided 100% production recovery.

CONCLUSION

With the ever-growing competitive nature of the renewable energy sector, innovations and improvements to geothermal power systems must be made. In the case of well scaling, the easy solution is to drill new wells, but the economics and environmental constraints are getting tighter by the day. By using an advancement on existing technology more commonly used for oil and gas or construction drilling applications, Contact Energy was able to remove the need for new well drilling entirely for nearly five years with significant cost savings. This saving was the driver for the extensive investment into new ideas and pushing the limits of traditional CT applications. With great risk comes great reward and both Contact and WES have enjoyed the collaborative success that has been achieved and solidifying Coiled Tubing's place as an effective solution to the global geothermal market.

The two options available have their benefits and drawbacks. The motor option is slower ROP in hard scale but can be utilised with an under reamer to open up diameters where surface equipment or downhole casing obstructions are constraints. The CTH air hammer has been developed to get greater ROP and faster turnaround to achieve single day cleanouts as well as the ability to clean out reinjection wells by lifting the fluid and cuttings out of the well.

REFERENCES

McClatchie. D.W. and Verity. R.; The removal of hard scales from geothermal wells: a case history, *SPE/ICOTA Coiled Tubing Round Table* (2000).

Viveiros Pereira. V; Calcium Carbonate Scaling Control in Geothermal Well PV8 in Sao Miguel, Azores, Combining Chemical Inhibition and Mechanical Reaming; United Nations University Geothermal Training Program, Iceland, Reports (2014), Number 33.

Wilson, D., Aranas, M., Bixley, P., Anderson, J. and Patterson, D.: Application of Coiled Tubing for Live Well Workovers, *Proceedings*, 37th New Zealand Geothermal Workshop (2015a).

Wilson. D., Gilliland, J. and Austin, A.: Broaching: An Effective Method of Well Intervention for Calcite Scale Removal, *Proceedings*, World Geothermal Congress, Melbourne, Australia, April (2015b).

GNS science (internal report to Contact): Results of a geochemical, mineralogical and physical properties assessment of calcite scale from wells WK269 and WK245, Wairakei Geothermal System, with some comparison with scale from BR45 scale, Ohaaki Geothermal System. (2017)