

Custom PDC Bits Significantly Increase Drilling Performance in Tauhara Geothermal Drilling Project

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ABSTRACT

The use of polycrystalline diamond compact (PDC) bits in geothermal applications has always presented challenges in terms of bit durability, directional response, and economic viability of such bits in these applications.

This paper focuses on two sets of challenges associated with designing PDC bits in 20¾ in. and 12¼ in. sizes to drill through hard volcanic and sedimentary formations in the Tauhara geothermal field of New Zealand.

This paper discusses PDC drill bit design, cutter selection, root cause analysis of drilling dysfunctions, and other limitations affecting overall drilling efficiency. It will also demonstrate drilling parameter sensitivity analysis, drilling practices used to reduce bit damage while improving overall drilling performance, and the economics for both sections.

For the above project, two bespoke bits were designed, built, and tested. This paper presents the results of these bit runs, the learnings made, and future iterations. It will show that the tailored bits outperformed all previous bit runs in the Tauhara field and saved the Operator significant drilling time.

1.0 PDC HISTORY INTRODUCTION

1.1 Use in Geothermal Applications

Fixed cutter bits, also called polycrystalline diamond compact (PDC) bits, have been experimented with by Geothermal Operators in the past. Many fixed cutter options were trialed in the smaller diameter sections but quickly built up a reputation of being unreliable, costly, and not robust enough to handle harsh igneous rock and geothermal drilling conditions. Many past trials resulted in poor performance due to premature failure of the cutting structure, leading to early trips out of hole.

In addition to this, the use of large diameter fixed cutter bits was considered uneconomical, risky, and unnecessary in these applications by many geothermal operators. Roller cone bits were typically sought out due to their robustness, lower cost, and proven reliability in New Zealand. The formations that are typically drilled throughout the surface and production sections consist of interbedded sedimentary and volcanic deposits. While fixed cutter technology will drill sedimentary rocks efficiently, these bits falter when drilling volcanic strata common in geothermal applications.

This paper details the advancement in PDC cutter technology and bit design that allowed them to excel at drilling performance in most lithologies and saved rig time across the campaign.

1.2 PDC Cutter History

PDC technology has advanced immensely over the years. Initially, PDC cutters used monomodal grit¹, planar interfaces², and unleached cutters. Over time, improvements have been made in depth and direction of leaching, non-planar interfaces between the tungsten carbide and diamond face have increased in geometric complexity, and the multi-modal composition of the diamond has become ever more complex. Additionally, the pressure and temperature at which PDC cutters are sintered have also increased. This combination enables PDC cutters to have higher resistance to thermal, abrasion, and impact damage. These performance increases first made PDC bits feasible in extended reach, deep water, and harsh applications, which enabled them to shine. These advancements have resulted in cost savings for many applications by avoiding tripping for bit related failures such as a dull bit.

¹ Consistent diamond grain size in the diamond table.

² Interface plan between the stable diamond and tungsten carbide substrate.

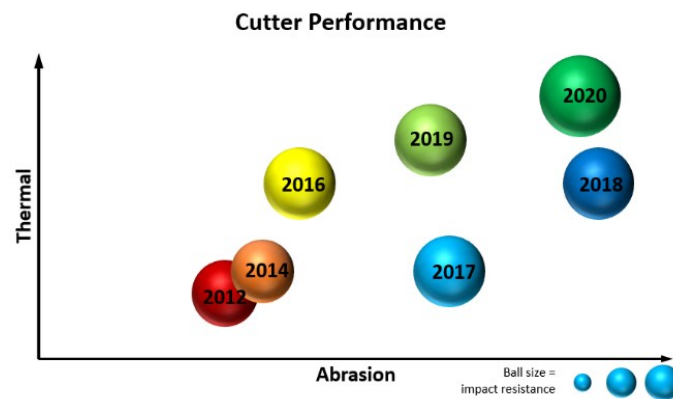


Figure 1: Development of PDC cutters over time. Performance in all metrics; thermal, abrasion, and impact resistance has drastically increased. Scale is proprietary.

1.2.1 Shaped Cutters

There are two types of PDC cutters with non-planar cutting faces in this paper: the 3D and 4DX cutters as shown in Figure 2. The 3D cutter has been well proven to increase rate of penetration (ROP) since its introduction in 2015. The resilience of this cutter is also superior to the traditional round cutter as shown in SPE-199598 (Rahmani et al. 2020). The 4DX cutter is a newer development that has been shown as a further improvement over the 3D cutter in terms of drilling efficiency.

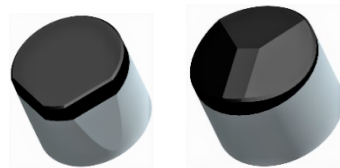


Figure 2: Non-planar cutters referenced in this paper: 3D cutter (left) and 4DX cutter (right). The cutting edge in both cases is on the bottom of the black area.

1.2.2 IADC Grading System

The International Association of Drilling Contractors (IADC) developed a revised grading system in 1992 for fixed cutter drill bits. The system is comprised of eight parts and was developed to provide an industry-wide standard for recording the physical condition of the worn bit for future reference (Brandon, et al., 1992).

The IADC grading system is comprised of inner cutter wear, outer cutter wear, major dull, major dull location, bearing life, gauge measurement, other dull characteristics, and reasons pulled. Some past performance reasons pulled were penetration rate (PR), bottom hole assembly change (BHA), torque issues (TQ), and bit hours (HR) which relates to bearing life.

For further information regarding the dull grading system refer to the SPE-23939 (Brandon, et al., 1992) paper referenced.

2.0 APPLICATIONS

2.1 20¾ in. Application

The unique 20¾ in. bit size was engineered by the operator to be small enough to pass through a 21¼ in. annular blowout preventer (BOP) stack and large enough to allow for 18¾ in. casing with special clearance couplings to be set to depth. Due to the unique bit size, only one drill bit manufacturer was able to reliably supply roller cone bits and thus became the baseline performer in the Tauhara and Wairakei fields in the early 2000s. At the start of the 2020 drilling campaign, there was an opening to trial new technologies and as a result, a custom 20¾ in. PDC bit was designed specifically to combat geothermal drilling challenges economically.

The 20¾ in. application drills through the Huka Falls Formation (sandstone, siltstone, and mudstone) and the Racetrack Rhyolite which is characterized by unstable breccia zones at the top followed by brittle but hard igneous rhyolite beds. The Waiora Formation follows and is primarily a tuff lithology and can be used to set deep casing in injection wells. The primary focus of this paper is on production wells with a casing set depth in the Rhyolite lithology which typically drills from 165m – 650 m true vertical depth (TVD).

2.2 12¾ in. Application

The 12¾ in. wide diameter production section drills through a variety of sedimentary and igneous lithology's including Ignimbrite, Andesite, Rhyolite, and Greywacke basement. In large diameter geothermal wells, the interval runs between 1050m and 2000m for production wells, and 1400m and 2400m for injection wells. Historically, this section was drilled with 8½ in. diameter drill bits, requiring multiple bits, both roller cone and fixed cutter, to achieve total depth.

3.0 DRILLING DYSFUNCTIONS, FAILURE MECHANISMS, AND BENCHMARKS

3.1 Surface Section

Four past Tauhara Wells, TH13, TH14, TH20, and TH21, used a 20¾ in. mill tooth roller cone bit to drill the primary surface section and set 18⅝ in. casing. The bits used were rerun/used bits from other fields, with an initial dull grade of 1-1-WT. Average interval drilled was 180m with an average ROP of 5.5m/hr. The section was drilled with a packed rotary BHA, commonly drilled with 50-60 RPM and 10-15klbs weight on bit (WOB). This is considered inefficient drilling parameters for large diameter roller cones to effectively crush rock and achieve good performance. As a result, the primary root cause for poor performance was identified as sub-optimal drilling parameters, worn teeth, and bit hours. For the purpose of this paper, the baseline roller cone performance measure is taken from a recent well, TH024, where optimum drilling parameters were used to determine baseline ROP. The data will be compared against a 20¾ in. fixed cutter design to show increased performance in surface formations. The results of those tests will be shown in section 5.1.

Previous considerations that warranted drilling with reduced parameters was the risk of hole collapse and lost circulation leading to stuck pipe. These issues were typically seen throughout other fields in the Taupō Volcanic Zone and ROP was limited to mitigate risks. In the Tauhara field, the risk associated with these issues was reassessed and given less likelihood of occurring due to more competent formations. This enabled a higher instantaneous ROP limit of 50 m/hr to be set.

3.2 Production Section

Past Tauhara wells were designed with a standard 8½ in. diameter bore production section. This interval was limited by bit durability, with common reasons pulled being low penetration rate, bit hours, or torque. Some wells also had designated core points (CP) midway through the production section; however, multiple bits were still used due to worn bit condition, leading to increased bit and well costs.

The former types of reasons pulled can be mitigated with improved bit selection, parameter optimization, and advancement in cutter technology. Common failure mechanisms of both tungsten carbide inserts and polycrystalline diamond cutters were: worn teeth (which is considered normal wear for PDC drill bits); cored out, where the inside portion of the drill bit has no remaining cutting structure; chipped teeth; and broken cutters. The latter dull grades are all considered abnormal wear.

Of the 8½ in. production section, offset wells TH09, TH10, and TH12 were analysed for benchmark performance and results can be seen in section 5.2.

It is also noted the fixed cutter bits used were not optimal for geothermal applications, where 5 blades and 19mm cutter bits (519) were used in harsh rock applications. Advancements in fixed cutter design and software have shown that these configurations can be too aggressive for hard rock drilling, leading to premature failure of the cutting structure. Of the few roller cone bits run in the production section, these generally lacked performance in sedimentary lithologies but provided stable drilling and low torque through hard igneous rocks. The primary disadvantage of roller cone bits in the production section is being limited by bearing life and cutter durability.

4.0 PDC CUSTOM DESIGN

Figure 3 defines some of the key features and design aspects of a fixed cutter bit. These terms will be used across this section.

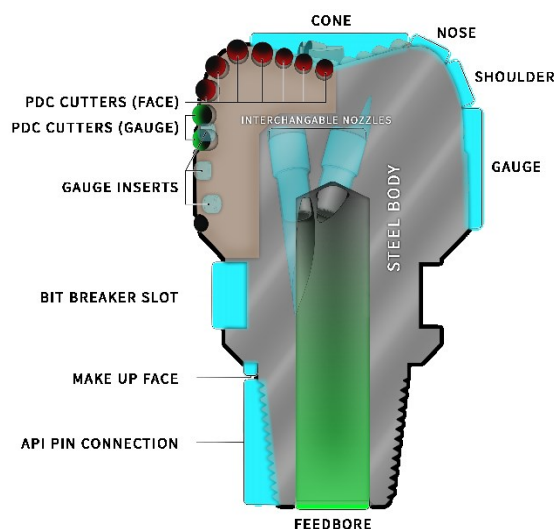


Figure 3: Common construction and elements of Fixed Cutter drill bit.

4.1 20¾ in. PDC Design

The key consideration was to design a bit able to drill 10 wells without the need for repair or replacement. The area of highest concern was that either vibration or a nodule of hard formation would cause a broken tooth (BT) or chipped tooth (CT) dull condition. Whilst

thermal wear was not considered to be as significant a risk due to the observed wear on the previously used roller cone bits, there must always be some degree of thermal wear consideration to shoulder cutters performing 4000m of drilling.

Key Design Concepts:

The tip profile for this bit is based on a 4-curve tip profile. The tip profile refers to the line connecting the tip of all the cutters on a single plane. This is the first step in designing a new bit because it lays the foundation for the aggressivity, durability, stability, and steerability on the drill bit. The cone region on this design is deep enough to provide stability. The nose of this bit is flat enough that there are multiple cutters engaging any new formation to prevent overload. The shoulder of the bit is slightly longer than the most common shoulder to allow more cutters to be fitted into this region and therefore distribute the thermal load over more cutters. There are two gauge cutters on every blade to ensure that in the event of failure of a single gauge cutter due to vibration, the bit could continue to be run in further wells with no detriment to performance.

Rather than have a smaller number of blades with backup cutters on each blade, a better solution was proposed that increased the blade count to 8 with no secondary cutters. This meant that every cutter has dedicated cooling and cutting evacuation. In the event of BT on a cutter, this layout has improved overall durability.

Through risk analysis, a broken cutter in the cone was of greatest consequence; in a standard bit with 3 blades to centre, loss of one cutter in this spiral can often lead to core-out. To counteract this, 4 blades of cutters can be designed to meet at the centre of the bit. While the use of 4 blades to centre can result in a reduced ROP, this configuration provides the greatest insurance in the event of a broken cutter as the remaining cutters are not overloaded. However, the innermost cutters are generally congested due to limited space on the blade and therefore cuttings can build up in this area of the bit. The bespoke 20 3/4" design uses an innovative method to allow the blades to be joined above the hard-faced area while still allowing fluid flow to the bit centre and relief for cutting evacuation.

Large 19mm cutters with a 3D shape were chosen since the section was relatively easy drilling. The chisel shape of the 3D cutter, combined with the 19mm cutter size, increases the point loading on the formation. The resultant increase in ROP ensures that minimal bit revolutions are required to complete the section and therefore cutters can travel the least linear distance.

A choice was made in the design of this bit that placing a larger chamfer on the cutters would be preferable to using a higher cutter back rake to better resist impact damage. The analysis behind this decision is shown in Figure 4.

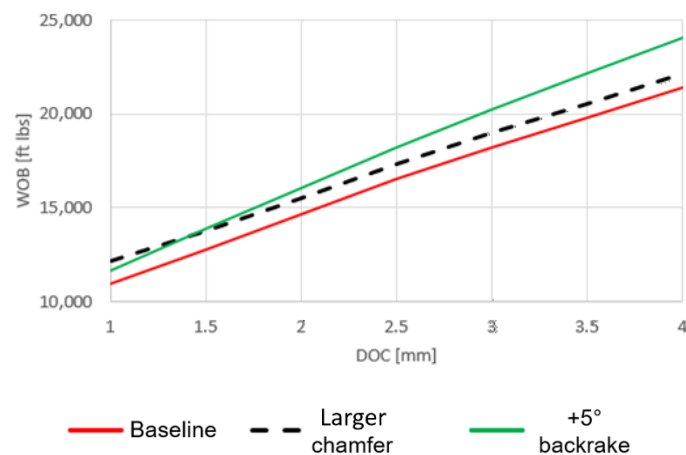


Figure 4: It can be seen that for a depth of cut greater than 1.2mm/revolution (13m/hr @ 180RPM), it is preferable to use a larger cutter chamfer over a 5° back-rake increase.

The final component considerations when designing this bit were the secondary components. The effectiveness of the torque control components in achieving the desired ROP without torsional vibration is dependent on engaging at a specific component height. Wear on these parts would restrict their effectiveness. For this reason, the most wear-resistant material was chosen—PDC. The components located next to the gauge pad are placed for lateral stability. These components don't engage the formation unless there is vibration. As such, they must be made from an impact-resistant material, which resulted in these being constructed from tungsten carbide. Finally, the shoulder components designed to resist impact damage were expected to be subjected to a mix of impact and abrasive wear, and therefore a component that combined a tungsten carbide matrix with interspersed diamond grit throughout was used here.

Hydraulics were then optimised in computational fluid dynamic (CFD)³ software to ensure that cuttings were effectively cleared away from the cutters and evacuated through the junk slot. Blade front protrusions were also included to further optimise the passage of flow.

The final bit referenced throughout this paper as the 20 3/4 in. TKC89 is an 819-configuration bit designed with the expected durability to drill 4000m while ensuring a high ROP.

³ Ansys Fluent owned.

4.2 12¼ in. PDC Design

The key consideration for the bit selection and iteration process for the 12¼ in. section was to ensure a design durable enough to last over 1000m of hard volcanic rock drilling while maintaining good ROP. Designing bits for harsh rock applications have to address several failure issues to ensure the bit is durable enough to withstand thermal loads, abrasive wear, and impact damage. Using experience within another geothermal field in Sumatra, Indonesia, the base 12¼ in. fixed cutter design was used and modified to suit the drilling challenges associated with the production interval in the Tauhara field in New Zealand.

Key Design Concepts:

The first iteration of the 12¼ in. fixed cutter bit (noted as A1 from this point forward) used in the Tauhara field is the same design that drilled successfully in the geothermal application in Sumatra, Indonesia. The bit design has 4 primary blades to centre to improve durability in the cone and nose region. This is important as the nose area of the bit is the most prone to impact and thermal damages, so increasing cutter density allows for redundancy in the event of impact failure.

The A1 was equipped with premium impact and abrasive resistance cutters. This bit utilized 3D cutter shape technology in the primary cutting structure to provide a point loading effect to fracture the hard volcanic rock. This feature gives the bit additional aggressivity and better overall drilling efficiency.

In the secondary cutter position, which is directly behind the primary 3D cutters, high density impreg (HDI) cutters were used. HDI cutters are made of a mix of diamond particles and carbide powder, impregnated with an alloy binder under high temperature and pressure. Unlike PDC cutters that shear the rock, HDI cutters grind the formation. While drilling, HDIs are worn down to conform to the shape of the primary cutters. As HDI cutter material is softer than a PDC cutter, it cushions the impact forces on the primary cutting structure when encountering hard formation. Another key benefit of HDIs are their ability to manage torque fluctuations by controlling the depth of cut on the drill bit. This leads to a reduced likelihood of cutters over engaging in hard formation and breaking.

The A1 was used in the first two wells in the Tauhara campaign (TH24 and TH25) and was extremely successful. Both bits completed the 12¼ in. section to total depth (TD), exceeding ROP expectations and interval drilled. The results of these wells can be seen in section 5.2. From the dull grade and images of the bit wear seen in Figure 5, it was decided to iterate and improve the durability on the shoulder and gauge areas. The primary root cause of cutter failure was identified as lateral vibration and impact damage – see Figure 5.



Figure 5: 12¼ in. A1 design drilled 1351m through hard volcanic rocks at 19m/hr. Considerable impact damage can be seen on the shoulder and gauge region.

The second iteration had to be delivered within a tight timeframe, therefore a simple change was suggested for A2 design.

These changes targeted the broken cutters encountered on TH24 and TH25, most likely from vibration. New premium impact resistance cutters were strategically placed to manage this challenge. Hairline fractures were identified on the 3D cutters therefore a 4DX cutter shape was suggested to provide better support and impact resistance to the diamond table in this area. In addition to this, the 4DX shape provides additional PDC coverage for abrasive resistance. This change was able to occur quickly and provided a new design to be trialled in TH28 well.

The results will talk about the following bit designs:

1. 12¼ in. FTKC76 – A1
2. 12¼ in. FTKC76 – A2

5.0 RESULTS

The following data represents records from the new drilling campaign, which was made up of four appraisal wells: Tauhara TH024, TH025, TH026, and TH028. Both roller cone bits and custom-designed PDC bits were trialled in like for like applications. The below figures represent the ROP achieved over the interval drilled for different formations.

5.1 20¼ in. Performance

As of July 2020, the 20¼ in. TKC89 drill bit has drilled over 1000m and is in good, sharp condition. The dull grade of the bit was 0-0-CT-A-X-I-ER-TD, which indicates the bit is still in very good rerunnable condition. One single cutter on the gauge of the bit exhibits some chipping (CT) and erosion (ER) can be seen on the steel hardfacing. See Figure 6 for bit condition.

The 20¾ in. bit performance will be compared against the 20¾ in. roller cone bit in the following formations: Huka Falls, Racetrack Rhyolite, Waiora Formations, and Tauhara/Volcanic Sediments.



Figure 6: 20¾ in. TKC89 drill bit showing good condition with minor chipping on the gauge. The below performance charts and results were compared on packed rotary assemblies and drill off tests were performed to optimise performance depending on hole conditions.

The following figures; 7, 8, 9 and 10, display interval drilled in meters, starting at depth in and finishing at depth out. ROP is displayed by the green dot and values on the secondary axis. The runs are split by well name, bit name and formation.

Through the Huka Falls Formation, the performance doubled when directly compared to a roller cone bit.

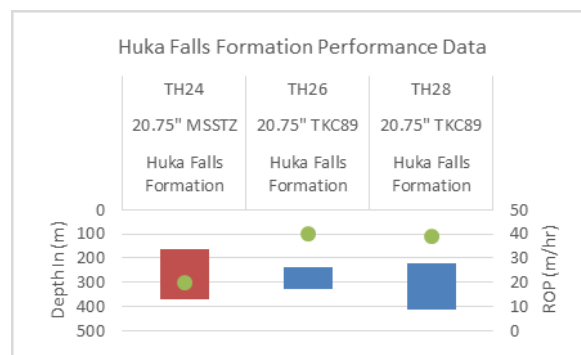


Figure 7: 100% increase in performance through the Huka Falls Formation on packed rotary assemblies.

The Racetrack Rhyolite is an igneous volcanic rock with common vein fragments of quartz, calcite, and zeolites. The rock is typically hard and can be tough to drill through. Both roller cone and fixed cutter bits were trialed in this particular rhyolite lava without much improvement noticed. ROP of 5m/hr appeared to be the flounder point in both bit types.

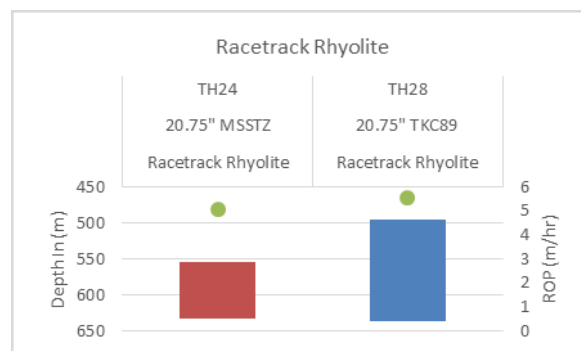


Figure 8: Comparable performance through Racetrack Rhyolite on RC and PDC bits.

The last formation the 20¾ in. bit was assessed in is the Waiora Formation. This formation is primarily comprised of interbedded tuffs and siltstones, which typically respond well to fixed cutter drilling. Figure 9 details another performance gain through this formation by switching to fixed cutter technology.

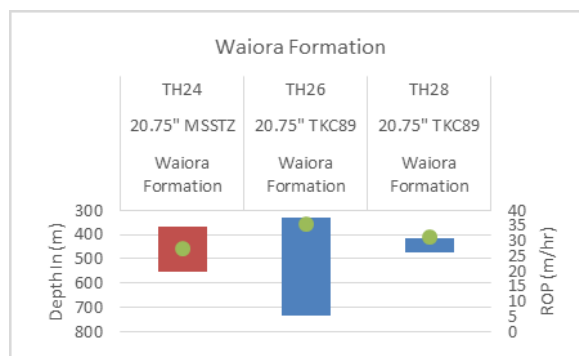


Figure 9: 20% average increase in performance through the Waiora Formation.

5.2 12¼ in. Performance

Performance in the production section is compared directly in Ignimbrite and Andesite/Dacite formations.

The offset wells are TH09 (drilled in 2007), TH10, and TH12 (close offset drilled in 2006).

In TH09, TH10, and TH12, core samples were taken to help identify production section lithology as lost circulation is common while drilling geothermal wells and cuttings are unable to be retrieved through returns.

Across the 2020 Tauhara campaign, two 12¼ in. bit designs were used in the production section as described in section 4.2. These two designs were run on rotary assemblies in both vertical (TH024, TH025) and tangent or hold applications (TH028). The performance of these runs is shown below.

Ignimbrite Lithology

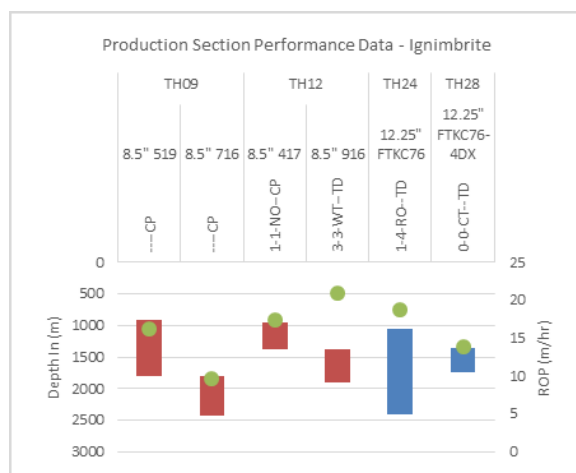


Figure 10: Performance of 12¼ in. and 8½ in. drill bits through Ignimbrite lithology. TH24 used A1 design while TH28 used A2.

Figure 10 shows the drill bit performance from TH09 and TH12 compared to new wells TH24 and TH28 drilling through Ignimbrite. The bits used from left to right on the chart are a 5 bladed 19mm fixed cutter bit, a 7 bladed 16mm fixed cutter bit, an insert roller cone IADC 417 bit, and a 9 bladed 16mm fixed cutter bit. The only difference between the two 12¼ in. designs that were run was cutter shape. TH24 used 3D cutters and TH28 used 4DX cutters (see section 1.2.1 for details). The primary driver for this change was to address the impact damage on the shoulder and gauge of the bit, which was evident after pulling out of hole on TH24. Comparing the two runs on TH09 through Ignimbrite (separated by a core run), two very different fixed cutter types were used to drill the sections. The 519 bit achieved a ROP of 16m/hr while the 716 drilled at 10m/hr. It is noted the dull grade of these bits was not recorded. The reduction in ROP on the second run is likely due to three factors – increased blade count, reduced cutter size, and increase in formation hardness with depth. Combining the interval and performance of these runs, total interval drilled is 1523m at an ROP of 12.6m/hr.

Performance on TH024 achieved a single run length of 1351m and average ROP of 19m/hr, which is a 50% increase in performance from TH09 results. Moreover, looking at the force applied in these two identical applications the following observations were made:

- 8½ in. 716 required 4klbs/inch to drill at 10m/hr though Ignimbrite (33klbs, 150RPM)
- 12¼ in. FTKC76-A1 required 1.7klbs/inch to drill at 19m/hr through Ignimbrite (20klbs, 90RPM)

This shows the 12¼ in. design required 50% less force while still drilling faster in the same formation. This observation can also be related to the efficiency of 3D cutter designs requiring less WOB to produce the same ROP when compared to cylindrical cutters.

Roller cone vs. fixed cutter performance was also observed from TH12. These runs were separated by a core sample that indicated Ignimbrite formation. The roller cone drilled 20% slower followed by a 9 bladed 16mm cutter bit run, indicating PDC bits cut more efficiently through Ignimbrite lithology.

Another aspect to consider is the dull grade. As a bit wears the overall average ROP drops due to the diamond cutting structure becoming worn and less able to fail rock at the same rate. This is why increased WOB is usually required to maintain ROP at depth; however, this can sometimes not be achieved through increased parameters alone.

On TH24, the bit came out in worn condition with a dull grade of 1-4-RO-S-X-I-BT-TD, which indicates there was a ring out on the shoulder and several broken teeth. This can be seen in Figure 11.



Figure 11: 12¼ in. FTKC76 A1 drilled on TH24 was pulled with a ring out on the shoulder after drilling 1351m through Ignimbrite.

A design iteration was made to move towards a combination of 4DX and 3D cutters as described in section 4.2 to help combat the impact and lateral vibration damage seen on this run.

The results of this change can be seen from the run on TH28. This bit drilled through 366m at 14m/hr of Ignimbrite Formation and was pulled with no significant wear to the cutting structure. The reduction in performance seen in this well was due to holding tangent while drilling with aerated mud, which required an ROP limit of 20 m/hr to be set to reduce risks.



Figure 12: 12¼ in. A2 run on TH28 was pulled with no cutter wear after drilling 366m through Ignimbrite.

With this in mind, the 12¼ in. A2 design was still able to gain an average of 20% ROP increase through Ignimbrite when compared to 8½ in. fixed cutter bits.

Dacite Lithology

Dacite lava has a composition between Andesite and Rhyolite. Performance and dull grade of a run on TH10 and TH25 are compared below.

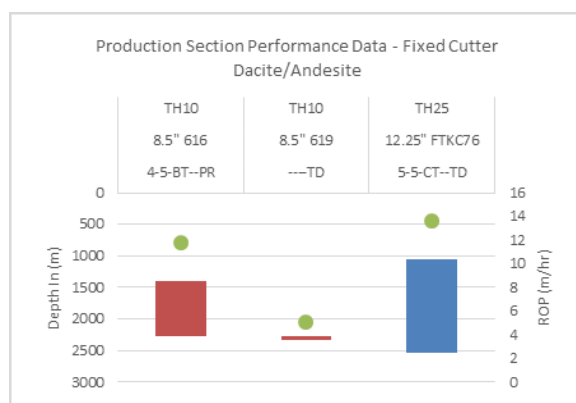


Figure 13: Production performance data through Dacite and Andesite lithologies with the 12¼ in. FTKC76-A1 design.

From Figure 13, two bits were used to reach TD on TH10 due to bit wear. The first bit was 4-5-BT, which indicates over 50% of the cutting structure was damaged or the remaining cutters were at blade height level. This means the bit would have been unable to make any significant progress no matter how much weight was added. A subsequent 6 bladed 19 mm cutter bit was run in hole to finish off the 70m interval to TD, which is considered a very expensive interval for this well.

In comparison the 12¼ in. FTKC76 with 3D cutters was run on TH25 through Andesite lithology and achieved the whole interval before being pulled for TD. In this well it is noted the bit was pushed until failure to extend TD past its original target which was 2400m. The design enabled extra meterage without the sacrifice of performance to explore deeper. This shows the importance of premium fixed cutter technology and custom designed drill bits in geothermal applications.

Overall, this design was able to achieve 70% increase in interval drilled while increasing performance with a large diameter bore through harsh volcanic lithology. This was also achieved without any impact to hole condition and a perforated liner was installed successfully on these wells.

6.0 ECONOMICS

An important aspect of switching to premium large diameter fixed cutter technology is the economic viability of using bespoke bits. This section will detail the comparable value between roller cone and fixed cutter bits for the 20¾ in. section and the reduced risk of pulling out of hole in the production section for 12¼ in. bits. Both overall leading to a lower cost per meter for the section over a campaign.

6.1 20¾ in. Economics

Large diameter economics are required to ensure that switching to custom design PDC bits are appropriate for these applications. As most anchor casing intervals are relatively shallow, the effect of bit trips does not have as significant an impact on the overall cost per meter of the section, therefore making ROP crucial for these economics.

Cost per meter is described by the following formula:

$$CPM = \frac{\text{Bit Cost} + \text{Rig Rate (per hr)} * (\text{OB Drill Hours} + \text{Trip Hours})}{\text{Interval Drilled}} \quad (1)$$

The performance results of the 20¾ in. TKC89 were extrapolated to provide an estimate cost benefit over a 10-well campaign. Average ROP used for the remaining wells was 17m/hr, which is less than the average that the bit actually achieved across the three drilled wells. This study found the 20¾ in. TKC89 fixed cutter bit had a reduction in cost of 25% when compared to running new roller cone bits in the same application.

To match the cost per meter over a single well, the fixed cutter bit would need to achieve an increase in penetration rate of 116% to maintain the economic value due to increased bit price. This is not impracticable in some formations as seen in section 5.1; however, re-runability (reusability) of these bits provides the ultimate value in switching over to large diameter fixed cutter technology.

Another primary advantage of fixed cutter technology is the added reliability of bit life with the elimination of roller bearings and temperature limits.

6.2 12¼ in. Economics

When it comes to deep, hot, long production intervals in harsh applications, new fixed cutter bits are easy to justify. In the past, metal faced seal roller cone bits were used due to their robustness as diamond cutters generally prematurely failed due to impact and abrasive damage in geothermal rocks.

With advancements in PDC cutter technology and shaped cutters being introduced, this risk is reduced significantly to bring a reliable product to market for geothermal applications.

In many of the historical applications, multiple bits were run making the tripping time and subsequent rig time more significant factors affecting cost per meter. Switching to reliable fixed cutter technology that was custom designed resulted in up to a 70% reduction in cost per meter over a single well (TH10). The ability to quickly modify fixed cutter PDC designs also allows further improvement across multi well campaigns to address additional cutter failure modes and dulls. It also creates an environment for test cutters to be trialled in harsh applications and allows for deeper exploration at reduced cost per meter when cutters are staying sharper for longer.

7.0 DESIGN ITERATIONS

7.1 20¾ in. Potential Design Improvements

Only one gauge cutter was chipped after three runs totalling 1,090m. This will have no detriment to performance due to the number of cutters across the blade profile and the level of redundancy in the cutting structure. The only notable wear is some minor erosion to the hardfacing material in a few locations.

At such a time that the next bit is manufactured, alternative hardfacing protection can be considered to help reduce the extent of the erosion seen. Changes in the geometry of the blades can be evaluated to help reduce the occurrence of erosion in the next iteration

It should be noted that, as the intention is to drill a total of 4000m, this bit has only partially achieved its goal. Once the dull condition of the bit is greater than an overall 1-2-WT grade, the bit will not be run again without repair/replacement. A decision between repair and replacement will be made at that time. Although the initial runs have been successful, it is not possible to determine the full success of this bit until it is retired, and full economics can be calculated. At this time, further design enhancements may be suggested.

7.2 12¼ in. Design Improvements

Though a small change in the cutter grade and cutter shapes has improved the dull of the 12¼ in. FTKC76 A2, a third design iteration on the drill bit was necessary to further improve the stability and durability. These design changes included a tip profile modification and some back rake changes.

The new design targets improvement to stability and durability on the shoulder region. In this design change, the position of the nose from the bit axis is made larger, while maintaining the same cone angle. An increase in cone volume was aimed at helping bit stability. This was confirmed by cutting structure analysis software, where the A3 bit is compared against its predecessor. The tip profile was optimised for better impact resistance and the nose is made rounder to allow more PDC cutters to be placed along the blade and spread WOB evenly across the cutters.

The cutter's back rake angle plays a major role in how the bit interacts with the formation. It can have an effect on the depth of cut, reactive torque, and impact resistance on the drill bit. As the objective is to improve impact resistance on the shoulder region, the cutter back rake on the new design was increased by at least 20%. Although a higher back rake can affect the bit's aggressivity, the cut shapes in the shoulder are smaller and will not cause a significant impact on the bit performance.

With the ongoing development in cutter shape technology, Contact Energy also plan to trial 5D shaped cutters in this application. These 5D cutters are intended for use on the shoulder area in positions most prone to impact related damage. The impact resistance of the 5D cutter has been tested in the lab through progressive drop test and the results are very promising when compared with a planar cutter of the same grade.

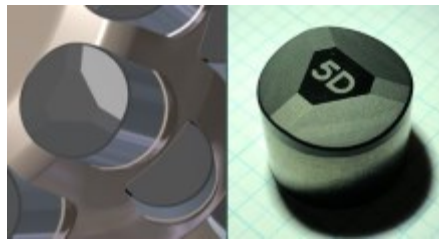


Figure 14: 5D cutter shape to be trialed in geothermal applications.

The benefits of point loading cutters have already been seen in the hard and abrasive formation of the Tauhara field. This can be reinforced with secondary components shaped with a ridge and placed at an angle – see **Error! Reference source not found.**. The additional point loading effect makes it easier to fracture the rock and could further improve performance in this application.



Figure 15: Ridged secondary components for potential trial in Geothermal Applications.

8.0 CONCLUSION

The use of fixed cutter PDC bits in geothermal applications is no longer considered unreasonable with current technology. Using custom designed drill bits that are tailored to the application resulted in cost savings across the multi well campaign. In the 20¼ in. section, the fixed cutter design proved economical after only three wells, which totalled 1090m drilled. Compared to purchasing roller cone bits for this section, a 25% cost saving is estimated over a 10-well campaign. The 12¼ in. fixed cutter design resulted in 20-50% performance increase depending on lithology as well as up to a 70% reduction in cost per meter when compared to historic wells.

The combined improvements in fixed cutter bit design and PDC cutter technology provides huge potential for significant drilling improvement in other geothermal applications, which could also benefit from cost savings in both surface sections and production sections. It also provides added reliability compared to roller cone bits with the elimination of temperature limitations and moving parts.

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