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Kymera™ Hybrid Bit Technology Reduces Drilling Cost

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ABSTRACT

Drilling cost reduction is a major concern for geothermal operators and crucial to long-term geothermal development. Reducing drilling days and lowering per-foot costs are primary means to achieving this goal. Baker Hughes, Inc. (BHI) developed the Kymera hybrid bit with these goals in mind. The advantage of the Kymera bit technology versus standard tungsten carbide insert (TCI) bits is in the Kymera's combination of roller-cone design and polycrystalline diamond compact (PDC) bit design. In trials at EnergySource's Hudson Ranch II project, performance data from 12.25- in (311 mm) and 9.875- in (250.8 mm) Kymera bit runs are compared to TCI bit runs in offset wells. Performance is measured using a systematic approach comparing revolutions per minute (RPM) and rate of penetration (ROP) in both slide and rotating modes. Formation and depth are also factored into the performance data. The Kymera hybrid bit increased rates of penetration and total footage drilled per bit run, resulting in a significant reduction in cost per foot (CPF) versus standard roller-cone bits for a substantial cost savings.

INTRODUCTION

Hughes Christensen Kymera™ hybrid drill bits combine PDC and roller-cone technologies. The Baker Hughes design team used the combined roller-cone crushing action on the bottom of the hole prior to the PDC shearing and sweeping action simultaneously. The results yielded higher rates of penetration using the PDC bits' combined action with the steerability of a TCI bit. The combination is extremely effective in complex formations. Results have shown that many of the dynamic dysfunctions typical to each type of bit, such as stick-slip and re-crushing cut rock in TCI's or back-whirl in PDC's, can be minimized with the hybrid design.

First Run in Monterey Shale

In 2009, the first 12.25- in (311 mm) Kymera hybrid model was employed in the Monterey shale. The initial run proved successful, and additional bits ordered and are being run extensively in Kern County, California, USA.

First Run in Geothermal Well

The first geothermal Kymera hybrid bit run occurred in basalt, at the Theistareykir field, in Iceland in 2011. Based on a long history of drilling the geothermal wells in Iceland with roller cone bits and several attempts to make PDC bits work it was concluded that the hybrid bit technology might have a good potential in this application. With additional supporting data from laboratory tests in igneous rock, Baker Hughes, Inc. and the Iceland Drilling Company agreed to a well plan and tested a 17.5-in (444.5 mm) and a 12.25-in (311 mm) Kymera hybrid bit solution in one of the Theistareykir geothermal wells. The objective was to benchmark rate of penetration (ROP) and durability compared to conventional roller cone bits.

The 17.5- in (444.5 mm) Kymera hybrid drill bit drilled 567.6 feet (173 m) to the total depth (TD) at 885.6 feet (270 m) with a conventional rotary assembly. The average ROP was 35 feet per hour (10.8 meters per hour) which is approximately three times faster than conventional roller cone bit runs in offset wells.

The 12.25- in (311mm) Kymera hybrid bit was used on a steerable motor drilling at controlled ROP and reduced weight on bit (WOB) to meet the directional requirements. The 12.25-in (311m) section was drilled to total depth achieving directional objectives and building inclination from 0 to 35 degrees. The Kymera drill bit drilled 1597.8 feet (487 m) at an average ROP of 69.01 feet per hour (21.3 m per hour) which is 18 feet per hour (5.48 m per hour) faster than the best TCI in the field.

CASE STUDY: HUDSON RANCH TRIALS

Multiple Kymera hybrid bits have been employed at EnergySource's Hudson Ranch II project and met the expectations of higher ROP and more footage as compared to the roller-cone bits previously used in offsets. No PDC bit runs in the field have reached the depth intervals that the Kymera hybrid has drilled. PDC bits are generally not successful in geothermal applications. The formations are very inconsistent, abrasive and much more highly fractured than drillers encounter in typical oil and gas environments, where PDC bits are generally successful. All previous attempts to use PDC bits in the formations were met with very limited success while roller-cone bits significantly outperformed the PDC bits on a dollar ($USD) per foot basis, as a past norm.

In 2012, Geothermal Resource Group (GRG) tested the Kymera hybrid bits in production drilling. The results have proven the hybrid's-ROP is RPM sensitive and the relatively high RPM yields some of the best ROPs encountered in the interval sections. The high revolutions per minute (RPM) somewhat limited the life of the bits because of bearing /seal wear in the roller cones, however when balanced, the Kymera hybrid bit outperformed all previous roller-cone bits.

Some steering and micro-tortuosity problems were encountered, leading to excessive hole drag. This problem should be eliminated as more directional experience is gained during additional Kymera hybrid runs.

APPLICATION

Geology at Hudson Ranch Trials in Salton Sea

The Salton Sea comprises the Salton Trough, which lies at the northern end of the East Pacific Rise, which is part of an extensional basin formed by the boundary between the Pacific and North American plates. The area is seismically active because it evolves the transform plate boundary of the San Andreas Fault system.

The Salton Trough comprises Colorado River sediments. The near-surface geology encompasses two late-Cenozoic sedimentary units, Shavers Well, dominated by clays, arkosic sandstones and conglomerates and the Borrego, comprising primarily siltstones and mudstones, with an interbedded Pleistocene Bishop Ash deposit. These sedimentary units overlay the Tertiary basement of meta-sediments and intrusive mafics.

Initial drilling occurs in unconsolidated sand and clay where the primary focus of the drilling crew is preventing borehole enlargement. The formation becomes harder and more consolidated with depth, and ROP decreases accordingly. Maintaining an acceptable ROP includes varying the compressive strengths of the individual units as they are drilled and frequent variance of the weight-on-bit and RPM. RPM-dependent drill rates are more common, indicating that low compressive strength formations predominate.

The rocks from the surface are unconsolidated because of poorly consolidated sandstones and siltstones. By roughly 1500 feet (457.2 m), the rock becomes consolidated enough to be self-supporting. By around 9000 feet (2743.2 m), the rocks become a mixture of gabbroic and meta-sedimentary rocks.

DESIGN SOLUTION

The goal is reducing drilling costs for both geothermal production and injection wells. All of the wells were step-out wells, therefore, they were designed with recompletion as long-term production or injection wells in mind. The casing set is significantly larger than the hole drilled so a high alloy production or injection liner can be run from the top of the open hole section back to surface for a later date. The Kymera hybrid bits were used in the production / injection zone with directional drilling tools comprising of steerable/MWD drilling systems and one TruTrak™ system.

The results are measured by examining the past and present bit runs of the 12.25-in (311 mm) and 9.875-in (250.8 mm) TCI roller-cone bits and comparing them to the Kymera hybrid bit runs in similar intervals for production and injection wells. These results are then applied to a Cost-Per-Foot (CPF) formula for comparison.

ANALYSIS

Cost Per Foot

Equation 1 shows the cost per foot calculation and includes a rig rate set at USD $60,000 per day and trip time of 1000 feet/hour (304.8 meters per hour) based on "depth out" of focused bits in analyses.

Equation 1: $CPF = \frac{Operating\ cost * (Drilling\ time + Trip\ time)}{Footage}$

- **Operating Cost** ($USD) = bit cost plus rig cost assuming rig rate for all calculations to be $60,000 (USD) per day
- **Drilling Time** (hours) = drilling hours for bit in that section of well

- **Trip Time** (hours) = assumed for all calculations to be 1000 feet / hour (304.8 m/hour) based on depth out of bit
- **Bit Cost** ($USD) = approximate cost of bit
- **Footage** (feet) = total footage drilled by bit in that section of well

CASE STUDY 1

Two 12.25-in (311mm) HP533X Kymera Hybrid Bits in Production Wells

The first 12.25-in (311mm) Kymera hybrid bit was employed on well HRP-19-2 with a steerable/MWD directional system. The 16-in (406.4 mm) liner was hung and cemented to 3962 feet (1207.6 m) and the shoe track cleaned with a 14.75-in (374.6 mm) bit to 3982 feet (1214 m). The first 12.25-in (311mm) Kymera hybrid bit was employed in this zone on an 8-in (203.2 mm) steerable motor with MWD and drilled from 3982 feet (1214 m) to 6334 feet (1931m). This first Kymera drilled 2352 feet (717.0 m) in 82 drilling hours. This first run was completed in less than four days and eight hours (including trip time) with two short trips and included drilling a directional hole with an inclination ranging from 4 to 10-degrees. It was obvious the bit could have run a lot longer and made a lot more hole. Refer to **Image 1a** for Kymera dull photograph.

The second 12.25-in (311 mm) Kymera hybrid run on well HRP-19-1 also utilized a steerable/MWD directional system. Conditions were similar to Well HRP-19-2 run which started at the bottom of the 14.75-in (374.6 mm) hole with the same drilling assembly. In the directional hole, weight on bit and the pump rates were increased to maximize the ROP. The bit was run more hours and would have run additional time but encountered problems holding direction. The Kymera hybrid bit drilled from 3083 feet (939.7 m) to 7075 feet (2156.5 m) in 87 drilling hours, just under five days (including trip time) with three short trips; all while drilling the directional hole with an inclination from 5 to 15-degrees. The charts and run distance, hours, and ROP in the paper reflect performance to the start of time drilling (which was used in an attempt to hold direction). Refer to **Image 1b** for Kymera dull photograph.

The second 12.25-in (311 mm) Kymera hybrid run on well HRP-19-1 also utilized a steerable/MWD directional system. Conditions were similar to Well HRP-19-2 run which started at the bottom of the 14.75-in (374.6 mm) hole with the same drilling assembly. In the directional hole, weight on bit and the pump rates were increased to maximize the ROP. The bit was run more hours and would have run additional time but encountered problems holding direction. The Kymera hybrid bit drilled from 3083 feet (939.7 m) to 7075 feet (2156.5 m) in 87 drilling hours, just under five days (including trip time) with three short trips; all while drilling the directional hole with an inclination from 5 to 15-degrees. The charts and run distance, hours, and ROP in the paper reflect performance to the start of time drilling (which was used in an attempt to hold direction). Refer to **Image 1b** for Kymera dull photograph.

Results from the first to second Kymera hybrid run include increased footage drilled by 731 feet (222.8 m) and increased ROP from 28.9 feet per hour (8.8 m per hour) to 35.4 feet per hour (10.8 m per hour). The dull grade of 2-2-WT/CT which proved the bit's good condition (reference **Image 1a** and **Image 1b**) and the bearings/seals were effective, indicating the bit still had significant useful life remaining.

12.25-in (311.15mm) HP533X, S/N 7027244
HRP-19-2 Run 7, 2352 feet (716.9 m)

Image 1a

12.25-in (311.15mm) HP533FX, S/N 7028374
HRP-19-1 Run 7, 3083 feet (939.7 m)

Image 1b

The 12.25-in (311mm) Kymera hybrid bits ran in the production wells were compared to TCI roller cone offsets at the same depth ranges with the results illustrated in **Figure 1a** and **Figure 1b** and detailed in **Chart 1a**. The cost per foot summary is shown in **Chart 1b** and concludes a 40% to 50% improvement over TCI offset averages.

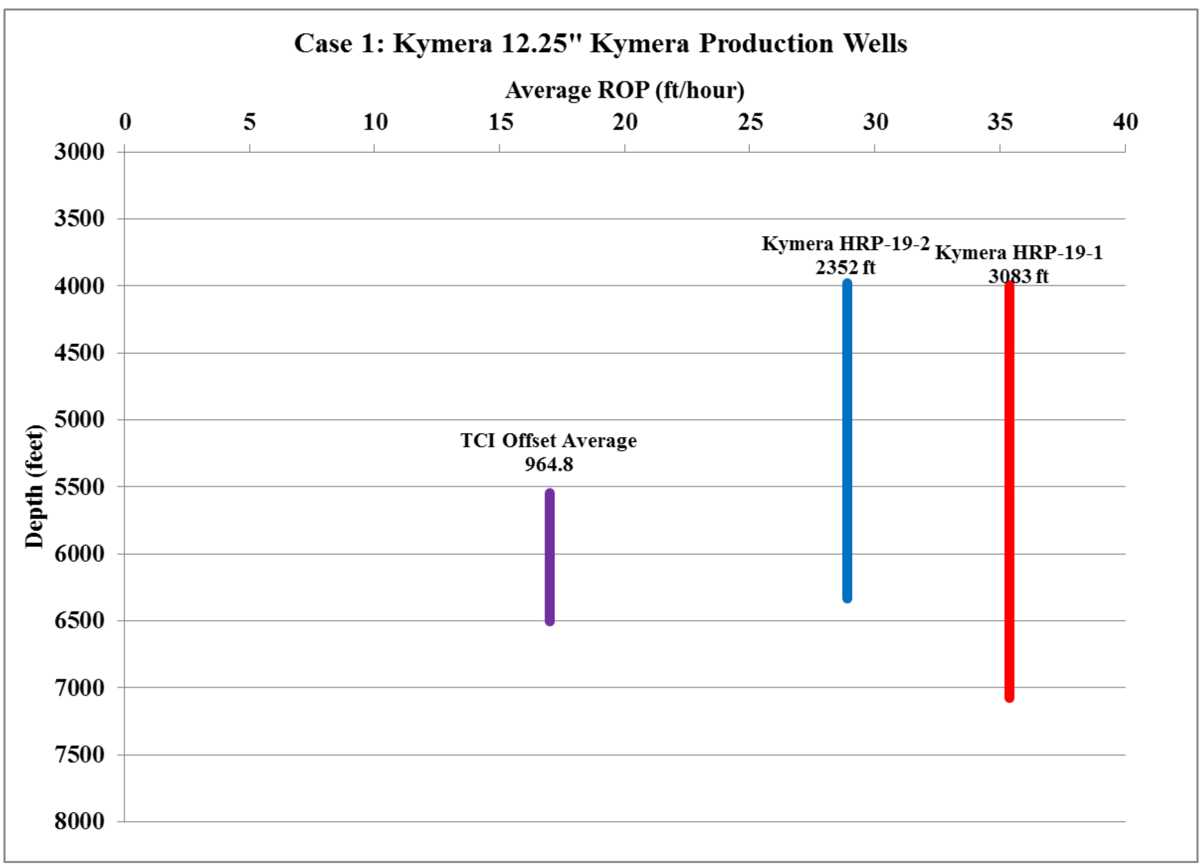

Figure 1a

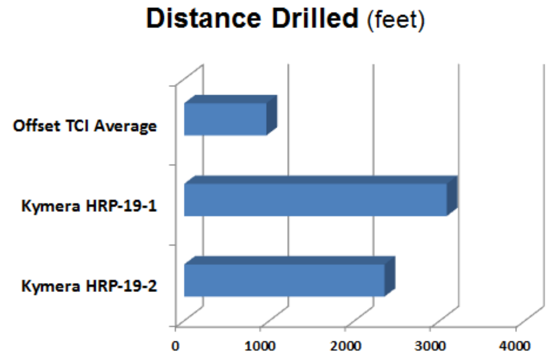

Figure 1b

Well	DEPTH IN (ft)	DEPTH OUT (ft)	DRILLED (ft)	ROP (ft/hr)
Kymera HRP-19-2	**3982**	**6334**	**2352**	**28.9**
Kymera HRP-19-1	**3992**	**7075**	**3083**	**35.4**
Offset TCI Average	**5543**	**6508**	**964.8**	**17**
Offset TCI 1	3235	4101	866	15.2
Offset TCI 2	4101	5677	1576	27.2
Offset TCI 3	5677	5996	319	17.2
Offset TCI 4	5996	6870	874	20.8
Offset TCI 5	6870	7500	630	14.8
Offset TCI 6	5909	6784	875	10.9
Offset TCI 7	6784	7586	802	11.6
Offset TCI 8	7586	8256	670	11.8
Offset TCI 9	3859	5410	1551	20
Offset TCI 10	5410	6895	1485	17.3

Chart 1a

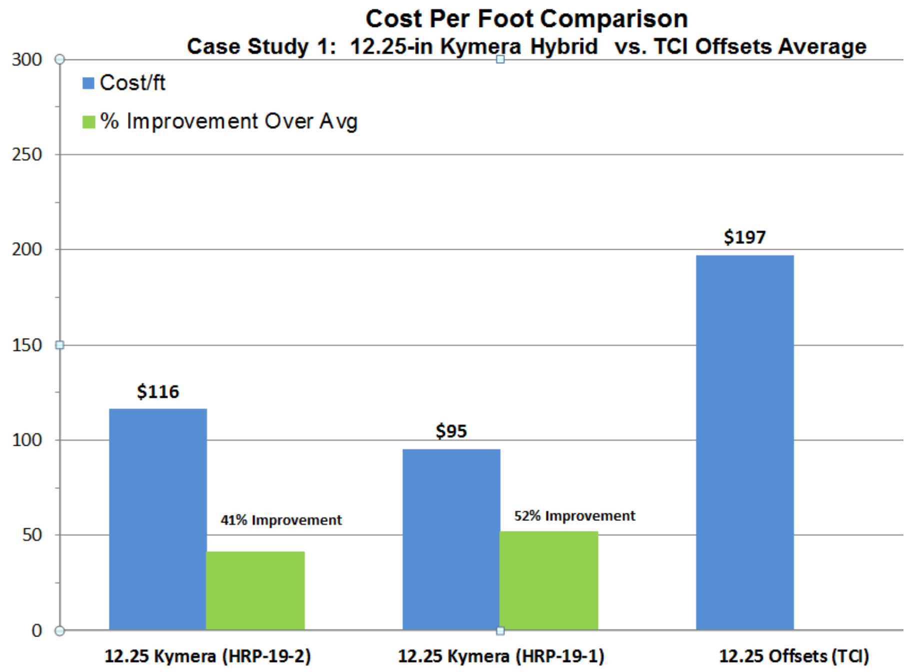

Chart 1b

CASE STUDY 2:

Three 12.25-in (311mm) HP533X Kymera Hybrid Bits in Re-entry Deepening Well

The Hudson Ranch 19-1ST1 well is a side-track, reentry well for deepening. There are three 12.25-in (311 m) Kymera hybrid bit runs on this injection well. The well was plugged and re-drilled using tri-cone TCI bits to a depth of 6164 feet (1878.8 m) to minimize the well bore micro-tortuosity.

The first Kymera hybrid bit in the deepening operation was run on a TruTrak™ drilling system which uses pads to push the bit in the desired direction on a constant basis and is not rotated while drilling employing a low-speed motor. The ROP was 26.7 feet per hour (8.13 m per hour) and bit drilled 358 feet (109.1 m) in 14 hours, in 2.5 days, including trip time, building angle from 14 to 19 degrees with a 30 degree change in azimuth; all while working on pumps in order to effectively activate the TruTrak™ . The ROP of 26.7 feet per hour (8.13 m per hour) is attributed to the significantly lower RPM at the bit; therefore, the bit was pulled out to change drilling systems and improve the ROP. This bit remained in excellent condition and was used for the next BHA run.

The second Kymera hybrid bit run was a re-run of the first Kymera on a steerable motor MWD drilling system. The repeat Kymera completed 1055 feet (321.5 m) in 47 drilling hours over four days and 10 hours, including trips, with one trip to the shoe for one half day of repairs and one full day spent on repairs to the rig circulating system to eliminate noise that hampered tool communications. The ROP was lower than the first run on the TruTrak™ at 22.2 feet per hour (6.7 m per hour) because of the RPM at the bit was still too low. The hole angle dropped from 19 to 15 degrees and the azimuth changed by an additional 40 degrees. The bit remained in very good condition, but not in full gauge (less than 1/16-in out) and was pulled to resume drilling with the TruTrak™ system.

The third Kymera hybrid bit was new and run on a higher motor speed TruTrak™ system. The bit drilled 1974 feet (609.2 m) in 45.5 hours in three days and eight hours of drilling, which included reaming tight hole from 6928 feet (211.6 m) to bottom before starting the drilling process. The drift angle was built to 20 degrees and dropped back to 14 degrees while changing azimuth 35 degrees. Significant problems were encountered communicating with the TruTrak™ drilling system. The bit was pulled because of a significant drop in ROP and was the first Kymera that showed significant wear. The overall ROP was 35.6 feet per hour (10.8 m per hour), the bit was 4/16-in (6.35 mm) out of gauge with broken TCI teeth on cone gauge row and PDC cutter wear on gauge area. See Image 2 for dull photograph. The deepening was completed with conventional TCI bits. The increased ROP confirms that a higher speed motor is necessary to increase ROP.

12.25-in (311.15mm) KM533X S/N 7036079
HRP-19-1ST1 Run 5, 1974 feet (601.7m)

Image 2

The TCI roller cone offsets at the same depth ranges showed the following results illustrated in **Figure 2a** and **Figure 2b** and detailed in **Chart 2a**. The cost per foot summary is shown in **Chart 2b** and concludes a 65% improvement over TCI offsets.

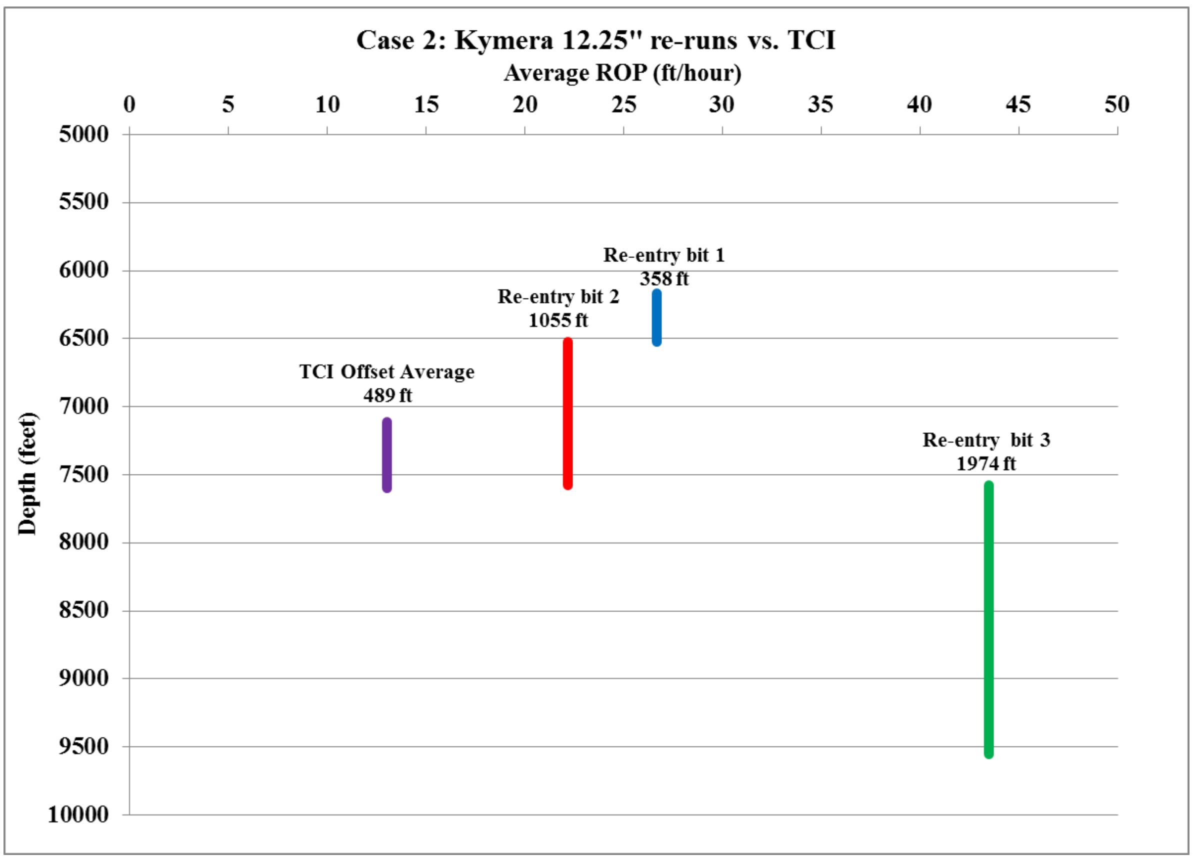

Figure 2a

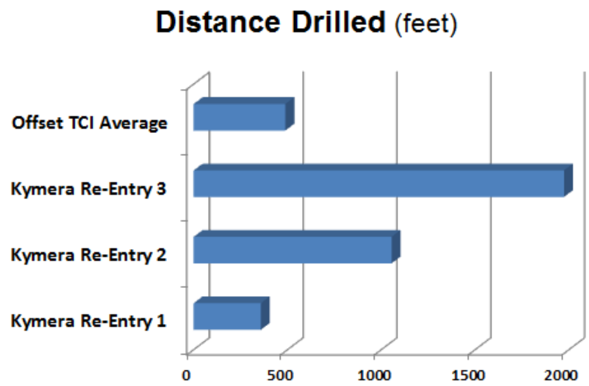

Figure 2b

Well	DEPTH IN (ft)	DEPTH OUT (ft)	DRILLED (ft)	ROP (ft/hr)
Kymera Re-Entry 1	**6164**	**6522**	**358**	**26.7**
Kymera Re-Entry 2	**6522**	**7577**	**1055**	**22.2**
Kymera Re-Entry 3	**7577**	**9551**	**1974**	**43.5**
Offset TCI Average	**7111**	**7599**	**489**	**13**
Offset TCI 1	8256	8600	344	8.2
Offset TCI 2	5996	6870	874	20.8
Offset TCI 3	6870	7500	630	14.8
Offset TCI 4	7586	8256	670	11.8
Offset TCI 5	7075	8442	47.5	30
Offset TCI 6	8442	8900	16.5	30
Offset TCI 7	7853	8575	32.5	38
Offset TCI 8	5909	6784	875	10.9
Offset TCI 9	6784	7586	802	11.6
Offset TCI 10	6334	7853	65.5	35

Chart 2a

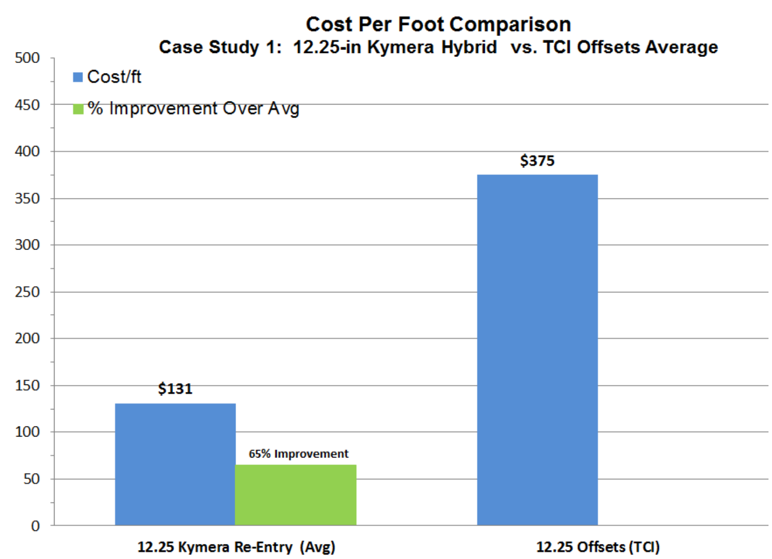

Chart 2b

CASE STUDY 3:

Three 9.875-in (250.8 mm) Kymera Hybrid Bit Runs in Injection Well

The HRP-IW-8 injection well employed a 9.875-in (250.8 mm) Kymera hybrid bit with steerable directional system. The 13.375-in (339.7 mm) casing was set at 4102 feet (1250 m). The shoe was drilled out with a 9.875-in (250.8 mm) bit and a 12.25-in (311 mm) under-reamer to 4120 feet (1255.8 m) leaving 6 feet (1.8 m) of 9.875-in (250.8 mm) hole from 4114 feet (1253.9 m). The Kymera hybrid was run on a 6.75-in (171.5 mm) steerable motor/MDW system. This motor speed was 168-215 RPM in slide and rotary mode. The bit drilled 1893 feet (576.9 m) in 71.5 rotating hours over 3.75 days (including trip time and two short trips). This is the first 9.875-in (250.8 mm) Kymera hybrid run employed in this application, therefore the Krev's were watched and pulled on hours. The bit showed to be in excellent condition.

Image 3a

The second 9.875-in (250.8 mm) Kymera hybrid run; followed the first in the same hole. The WOB was increased in addition to flow rate. Results showed an increased distance drilled by 505 feet (153.9 m) in harder formations and 4.2 feet per hour (1.22 m per hour) ROP increase. The hybrid bit drilled 2398 feet (730.9 m) in 78 hours over four days (including trip time and two short trips). The bit was pulled on hours, although not in as good as condition as the last bit, but still displayed a very good dull grade as depicted below in **Image 3b**.

Image 3b

The third 9.875-in (250.8 mm) Kymera hybrid run was also successful. The bit made 963 feet (293.5 m) in 49.5 hours in three days and seven hours, (including trip time with no short trips). The bit was pulled because of down-hole tool failure, WOB and RPM (calculated) were backed off and the formation was harder. Despite the bit having had a very good dull grade (reference **Image 3c**) the well was completed with a TCI bit.

Image 3c

The TCI roller cone offsets at the same depth ranges showed the following results illustrated in **Figure 3a** and **Figure 3b** with additional details in **Chart 3a**. The cost per foot summary is shown in **Chart 3b** and concludes a 17% improvement over TCI offsets. The Kymera was also used at a greater depth than any TCI had been run to at that time and the offset average is in slightly shallower and therefore somewhat more drillable formation.

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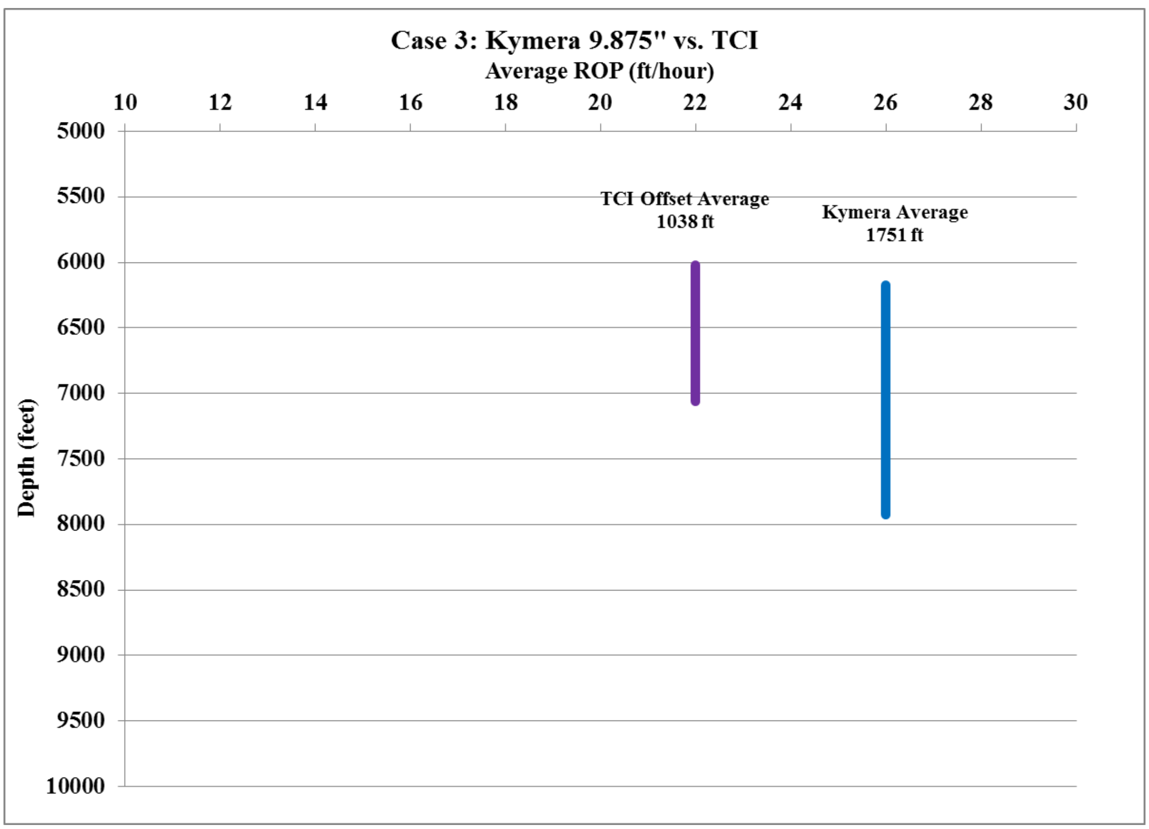

Figure 3a

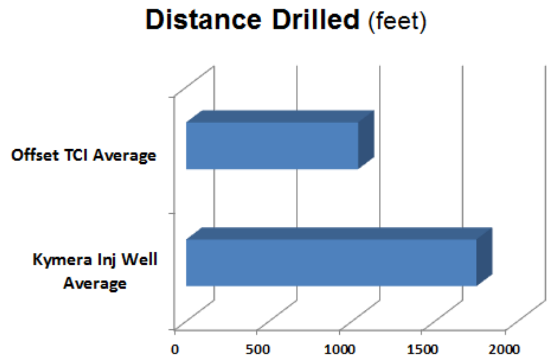

Figure 3b

Well	DEPTH IN (ft)	DEPTH OUT (ft)	DRILLED (ft)	ROP (ft/hr)
Kymera Inj Well Average	**6173**	**7925**	**1751**	**26**
Offset TCI Average	**6021**	**7059**	**1038**	**22**
Offset TCI 1	4400	5745	1313	22.4
Offset TCI 2	4480	5869	1389	26.2
Offset TCI 3	5869	6500	631	19.1
Offset TCI 4	6500	7716	1216	23.6
Offset TCI 5	7716	8325	609	21.4
Offset TCI 6	4286	5774	1488	28.1
Offset TCI 7	5774	7109	1335	18.8
Offset TCI 8	7109	7534	425	19.8
Offset TCI 9	7534	8668	1134	21.4
Offset TCI 10	5745	6822	1077	17.5
Offset TCI 11	6822	7589	767	22.2

Chart 3a

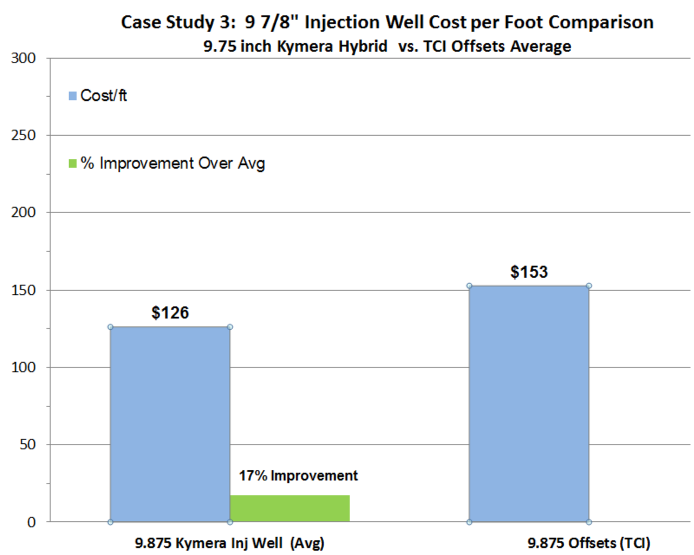

Chart 3b

CONCLUSION

The Kymera bit technology for the Salton Sea formations shows improvement in lowering the CPF versus conventional TCI bit drilling. Rig capabilities and directional drilling system parameters are critical for both Kymera and TCI bit performance. The CPF summary charts portray the end results of cost per foot savings, guiding future decisions for bit selection in geothermal environments. The final statistics reveal the true value of the Kymera hybrid bit at the Hudson Ranch II project.

Analyzing the 12.25-in (311.15 mm) bit run data from Wells 19-1, 19-2, and 19-1 deepening, the Kymera hybrid bits averaged a 26.1 feet per hour (7.9 m per hour) rate of penetration, with an average of 1783.3 feet (543.7 m) of footage per bit. TCI bits averaged a 16.2 feet per hour (4.9 m per hour) rate of penetration for an average bit run of 542.1 feet (165.27 m) drilled. Five runs transpired using Kymera hybrid bits versus 10 runs with TCI bits, with an average of 3.26 TCI bit runs required to equal each Kymera bit run.

Results for 9.875-in (250.8 mm) bit run data from Hudson Ranch I injection wells: IW-1, IW-2, and IW-3, while keeping the same trip time and operating cost assumptions, proved that TCI bit costs on the Hudson Ranch I wells can be based on an average footage of 547 feet (166.7 m) per 9.875-in (250.8 mm) TCI bit run and an ROP of 21.2 feet per hour (6.46 m per hour). In Hudson Ranch II well IW-8, TCI bits were used to "finish the hole". The first TCI run, subsequent to a Kymera run from 8403 feet (2561.2 m) through 9366 feet (2854.7 m), was expected to complete drilling operations but was pulled due to down hole tool failure. Its successor was pulled at the final depth. Two of the three 9.875-in (250.8 mm) Kymera hybrid bits run were given dull bit grades indicating that they were capable of finishing the well, with the final 9.875-in (250.8 mm) Kymera run on well IW-8 pulled due to down-hole tool failure. This makes direct comparisons difficult, but given two similar TCI runs over comparable depth intervals, a Kymera hybrid run in the hole at 6005 feet (1830.3 m) and pulled at 8403 feet (2561.2 m) due to steering issues made a 78 hour run at 30.7 feet per hour (9.36 m per hour), versus a TCI average of 64 hours per run at 19.1 feet per hour (5.82 m per hour). This translates to a 21.8% improvement in the total run hours for the Kymera and a resulting 60.1% improvement in the ROP. Steering issues remained an issue throughout drilling with both 9.875-in (250.8 mm) and 12.25-in (311.1 mm) Kymera hybrid bits, with the conclusion being that the low strength formations in the Salton Sea are more easily penetrated using high speed motors.

One of the most important considerations when using project or field data is that no geothermal developer is in the position to perform specific or controlled testing. Whether or not to run the Kymera hybrid drill bits had to be based on both existing information about the potential of the bit to perform as expected. The results, except where listed, are obviously peculiar to the Hudson Ranch field. Broader rulers regarding the performance of the Kymera hybrid bit require testing in more fields where the variety of geological substrate offers the possibility of the development of a greater data set. At present, the drilling team from the Hudson Ranch II project regards the current data set as justification for the Kymera bit runs in the Salton Sea.

Geothermal Resource Group looks forward to additional evidence from other fields utilizing Kymera hybrid technologies with operational improvements and plans to continue utilizing the hybrid bits in future geothermal wells. GRG's subsequent goal comprises extending the run time and ROP to achieve a one-bit-per-hole size.

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REFERENCES

Alles, D. (2011). Geology of the Salton trough. Informally published manuscript, Dept. of Biology, Western Washington University, Bellingham, WA, Retrieved from http://fire.biol.wwu.edu/trent/alles/GeologySaltonTrough.pdf

Baker Hughes, Kymera hybrid drill bit technology. (2014, January 27). Retrieved from http://www.bakerhughes.com/products-and-services/drilling/drill-bit-systems/kymera-hybrid-drill-bit-technology

OilOnline Staff (2013, July 30). Kymera bit produces rop gain. Oilonline.com, Retrieved from http://oilonline.com/industry-news/upstream/kymera-bit-produces-rop-gain/