DRILLING OPTIMIZATION IN HARD AND ABRASIVE GEOTHERMAL VOLCANIC ROCK USING INNOVATIVE CONICAL DIAMOND ELEMENT BIT

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ABSTRACT

Generally, the formations found in the geothermal environment consist of volcanic and pyroclastic rocks, which are typically hard and sometimes abrasive. Roller cone tungsten carbide insert (TCI) bits are commonly thought to be the most suitable bits for volcanic rocks. Due to the nature of formation breakouts and swelling clays in the reservoir section, drilling this section as fast as possible in one bit run is necessary. However, this is not always possible since a roller cones bit's "life" is limited by its reliability (the maximum revolutions before the bearing seal fails).

The innovative conical diamond element (CDE) bit provides a solution for drilling in hard, abrasive rocks. The unique 3D geometry of the CDE in this PDC-based bit provides superior impact and wear resistance. The concentrated point-loading of the CDE enables it to fracture high-compressive-strength rock efficiently. There is no bearing seal life constraint because, being a PDC bit, the CDE bit has no moving/rotating parts.

In one of the well located in West Java geothermal field, the CDE bit was used to drill two sections: 12.25-in. and 9.875-in.. The results were excellent, with both sections drilled to total depth (TD) in one run (660 and 799 m intervals, respectively). Both bits showed the capability of reaching ROP greater than 50 m/h, but the ROP had to be limited to 20 to 30 m/h due to hole cleaning concerns. Despite this controlled drilling, a 20% higher ROP compared to offset wells drilled with TCI bits had been achieved. Faster drilling and bit trip saving brought an approximate of USD 398 K drilling cost reduction. The CDE bits were pulled out of hole in very good and re-runnable conditions (0-0 and 1-1 cutter dull grade), which potentially reduced cost of procuring new drill bits in the future.

1. INTRODUCTION

Geothermal as a sustainable energy is critical to Indonesia's energy need, especially considering that Indonesia has extensive geothermal resources. The master plan of the Indonesian government to increase the utilization of these resources has resulted in the current increase in exploration and exploitation of the geothermal fields. To reduce the cost involved, fast and efficient drilling is necessary during well construction operations.

The main distinction between hydrocarbon and geothermal drilling is the characteristics of the formations. In geothermal, the production zone to be drilled is not sedimentary rock, but hard volcanic and intrusive rocks. The formations present in the reservoir section of a geothermal well, have, in general, a very high compressive strength and can be abrasive.

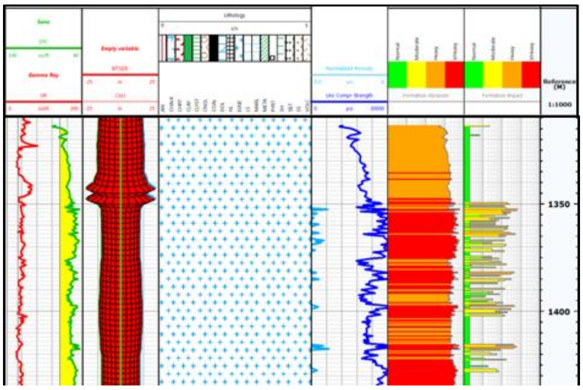


Figure 1 : Rock strength analysis result from the offset well

Figure 1 shows the rock strength analysis result from the offset well. The majority of the formations in the 12.25-in. and 9.875-in. sections are igneous rock and consist of tuff, breccia, and andesite. The compressive strength of the rock is approximately 24 to 32 ksi, indicating that this may not be PDC drillable. The formation may also be highly abrasive.

Drilling for geothermal resources is dominated by roller cone bits due to their effective cutting action in hard and fractured rocks. Compared to PDC bits' shearing action (Figure 2), there are two steps in removing the rock with a roller cone bit. The first step is indenting and fracturing the rock, and the second step is removing the rock from the crater that has been generated during the first step (Figure 3). Similar to using a hammer and chisel, the chipping and crushing action of a roller cone bit in hard formations encountered in volcanic environments is the most durable action for the cutting structure.

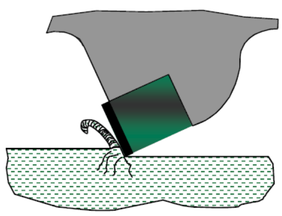


Figure 2 : PDC cutter shearing action

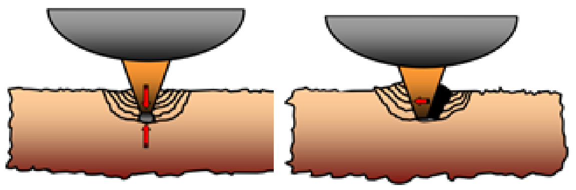


Figure 3 : Indentation and fracture and rock displacement process

However, the roller cone bit's main limitation is the total number of revolutions of the bit; there is an increase in the risk of failure of the cone, the bearings, and the seals with the increase of bit revolutions. This limitation can increase the drilling cost due to number of trips required to change the bit when the bit reaches the maximum revolution recommended. Figure 4 shows the 9.875-in. section performance of the nearby offset wells drilled by the same operator with minimum two TCI bits. The meterage of the runs was also low.

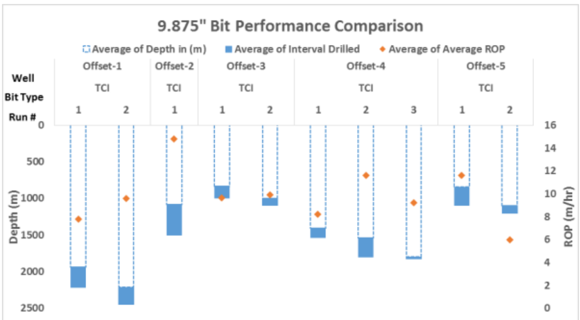


Figure 4 : TCI bit runs in nearby offset wells in the same field

Drilling the entire 12.25-in. and 9.875-in. hole sections through the hard tuff and andesite formations in one run was the main objective of the conical diamond element (CDE) bit introduction and application. Ideally, the drilling process should be as fast as possible to avoid long openhole exposure that could potentially lead to swelling clays and borehole breakouts, especially in the presence of total losses.

2. CONICAL DIAMOND ELEMENT (CDE) BIT

PDC bits with conventional cutters are not entirely suitable to drill hard formations due to the limitation of the durability of the cutter itself: the cutter fails the formation with shearing action, thus the abrasiveness of the formation can wear down the cutter very quickly. Geothermal formations require high impact levels that can break the cutter. However, the major benefit of a PDC bit is there are no moving parts that can limit the total revolution of the bit while drilling ahead.

A CDE bit was offered as a potential solution to drill the hole section in one bit run. CDE is a unique conical 3D cutter shape as shown in Figure 5.

Based on worldwide records, utilizing CDE bits has yielded very good results in field applications where impact damage and high compressive strength have limited conventional PDC bit's performance.

Figure 5 : Conical diamond element (CDE)

CDE has been developed in the laboratory for several years, and the diamond layer utilized is approximately double the thickness of a conventional PDC bit. Based on the laboratory result, this gives CDEs double impact strength and approximately 25 to 30% more wear resistance. The CDE inclusion in a PDC bit can improve the durability of the bit as shown in Figure 6.

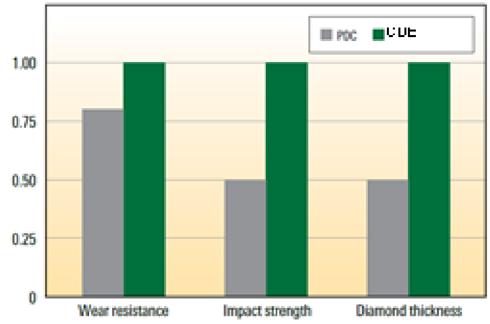


Figure 6 : Comparison between CDE and conventional PDC cutter

CDE fails the high-strength formation with "plowing action". Based on the finite element analysis (FEA) modeling as shown in Figure 7, the sharp conical geometry helps to concentrate the point loading and fails the rock more efficiently. The cutter-rock contact point experiences very high stress that increase the fracture generation rate, and this can be achieved by applying less force compared to normal PDC cutters.

In terms of directional capability and steerability, laboratory tests confirmed that CDE bits drill with an average 26% less torque than conventional PDC bits. This reduction in torque is equal to less-reactive torque fluctuation while drilling through high-impact formations or when changing drilling parameters. This less-reactive torque allows a better tool face control and a higher build rate capability than a normal PDC bits.

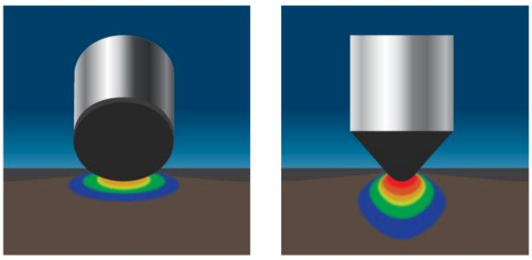


Figure 7 : Concentrated point loading by the CDE cutter

Field testing around the world, with more than 250 runs, shows that CDE bits increase the meterage drilled by an average 55% greater than with conventional PDC bits with 30% higher ROP. The durability of the bit also improves the dull condition. In addition, in many applications, CDE bits reduced bit trips and saved cost.

3. PREJOB PLANNING

This new technology required an extensive engineering work that included directional planning, bit design selection, FEA modeling and simulation, vibration analysis, bottomhole assembly (BHA) design, risk assessment, and economic analysis.

3.1 Well Operation Planning

The well profile is slant J-type profile with 28° inclination and the 2D azimuth shown in Figure 8.

The 12.25-in. BHA includes a motor, a measurement-while-drilling (MWD) tool, and only one stabilizer (a sleeve stabilizer on the motor) to reduce stuck pipe events due to packoff. However, the use of only one stabilizer can impact steerability, which required extensive engineering and simulations. Several iterations were done, resulting in an optimized BHA that fulfilled the directional requirement of each hole section. Based on the static BHA tendency simulations (Table 1 and Table 2), the dogleg severity (DLS) capability in the 12.25-in. and 9.875-in. sections is adequate to achieve the directional trajectory requirements (DLS capability range 2 to 7°/30 m).

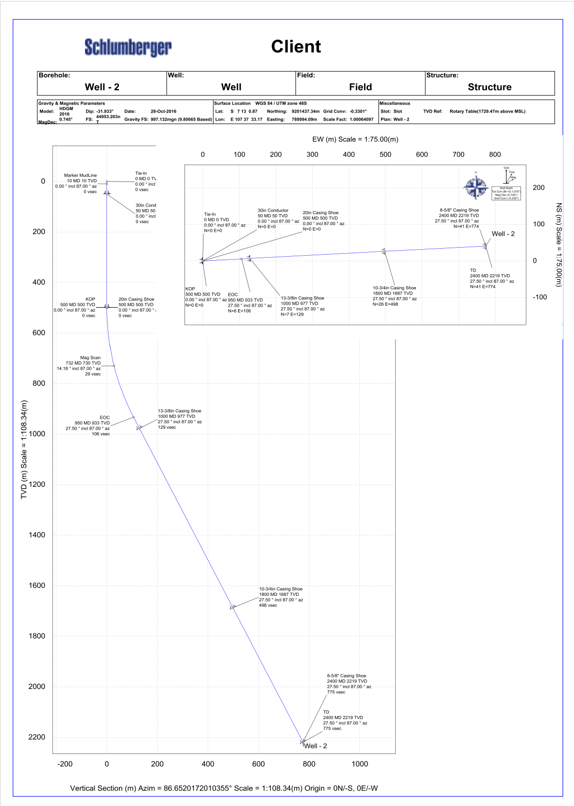


Figure 8 : Well Trajectory

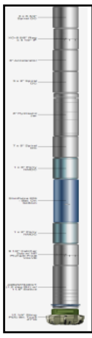
Table 1 : 12.25-in. BHA tendency simulation

BHA Tendency 12.25in Section						
DWOB	Rotary Build Rate	DLS in sliding	Effective Toolface in sliding	Build Rate at 100% setting	Turn Rate at 100% setting	Solution Converged
1000 lbf	deg/30m	deg/30m	deg	deg/30m	deg/30m	
0.00	-1.05	2.50	0.00	2.50	0.00	Yes
5.00	-0.90	2.50	0.00	2.50	0.00	Yes
10.00	-0.77	2.49	0.00	2.49	0.00	Yes
15.00	-0.67	2.48	0.00	2.48	0.00	Yes
20.00	-0.59	2.48	0.00	2.48	0.00	Yes
25.00	-0.50	2.47	0.00	2.47	0.00	Yes
30.00	-0.39	2.46	0.00	2.46	0.00	Yes

Table 2 : 9.875-in. BHA tendency simulation

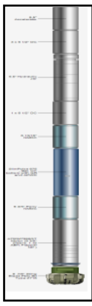
BHA Tendency 9.875in Section						
DWOB	Rotary Build Rate	DLS in sliding	Effective Toolface in sliding	Build Rate at 100% setting	Turn Rate at 100% setting	Solution Converged
1000 lbf	deg/30m	deg/30m	deg	deg/30m	deg/30m	
0.00	1.26	7.08	0.00	7.08	0.00	Yes
5.00	1.42	7.48	0.00	7.48	0.00	Yes
10.00	1.46	7.64	0.00	7.64	0.00	Yes
15.00	1.49	7.76	0.00	7.76	0.00	Yes
20.00	2.01	7.87	0.00	7.87	0.00	Yes
25.00	2.33	8.00	0.00	8.00	0.00	Yes
30.00	2.59	8.10	0.00	8.10	0.00	Yes

Figure 9 and Figure 10 show the BHA for each section. A motor BHA with 1.5° bent housing and 11.5-in. outside diameter (OD) motor sleeve stabilizer was the optimized BHA for the 12.25-in. section, and a motor BHA with a 1.15° bent housing and 9.375-in. OD motor sleeve stabilizer was used for the 9.875-in. hole section.



	Desc.	Manu.	Serial Number	OD (in)	ID (in)	Max OD (in)	Bot Type	Top Type	Bot Gender	Top Gender	FN OD (in)	FN Length (m)	Length (m)	Cum. Length (m)	Cum. Weight (1000 lbm)
1	12 1/4" Sting PDC Bit. Type Z716	Smith	JK8893	8.000	3.250	12.250		6-5/8 REG		Pin			0.29	0.29	0.2
2	A962M7848GT (1.5 deg BH) w/ 11.5" Sleeve	Schlumberger	N7072	9.625	7.850	11.500	REG	REG	Box	Box	9.625		9.28	9.57	6.4
3	9 1/2" Catcher Sub w/ NP Plunger Float VALVE	Schlumberger	KW 1135141-1	9.625	2.813	9.625	Regular	6-5/8 REG	Pin	Box	9.625	1.24	1.20	10.77	7.3
4	1 x 8" Pony NMDC	Schlumberger	SBD3626	7.625	2.875	7.625	6-5/8 REG	6-5/8 REG	Pin	Box	0.000	0.00	5.88	16.65	9.8
5	SlimPulse 825 - Bat. On bottom	Schlumberger	1867	8.250	5.000	8.410	6-5/8 REG	6-5/8 REG	Pin	Box	0.400	8.25	10.09	26.74	14.1
6	1 x 8" Pony NMDC	Schlumberger	JOP16BTS 029	7.875	2.875	8.000	6-5/8 REG	6-5/8 REG	Pin	Box	0.000	0.00	3.30	30.04	15.7
7	7 x 8" Spiral DC (7 joints)	Rig DATI	Rig DATI	8.000	3.000	8.000	6-5/8 REG	6-5/8 REG	Pin	Box	0.000	0.00	66.10	96.14	47.6
8	8" Hydraulic Jar	SMITH	35822J	8.000	3.000	8.000	6-5/8 REG	6-5/8 REG	Pin	Box	8.000	0.77	10.01	106.15	51.2
9	3 x 8" Spiral DC (3 joints)	Rig DATI	Rig DATI	8.000	3.000	8.000	6-5/8 REG	6-5/8 REG	Pin	Box	0.000	0.00	27.97	134.12	64.7
10	8" Accelarator	Smith	728320	7.750	3.000	8.000	6-5/8 REG	6-5/8 REG	Pin	Box	8.000	0.77	10.49	144.61	68.2
11	XO-6 5/8" Reg x 4 1/2" IF	Rig DATI	IT316	6.438	2.938	7.625	6-5/8 REG	NC50 (4 1/2 IF)	Pin	Box	6.438	0.50	1.24	145.85	68.5
12	3 x 6 3/4" Spiral DC (3 joints)	Rig DATI	Rig DATI	6.750	2.750	6.750	NC50 (4 1/2 IF)	NC50 (4 1/2 IF)	Pin	Box	6.750	0.45	27.19	173.04	76.7
13	6 x 5" HWDP (6 joints)	Rig DATI	Rig DATI	5.000	3.000	6.500	NC50 (4 1/2 IF)	NC50 (4 1/2 IF)	Pin	Box	6.500	0.50	55.51	228.55	85.6
14	5" 19.50 DPG, Premium To Surface	Rig DATI	Rig DATI	4.855	4.276	6.625	NC50 (4 1/2 IF)	NC50 (4 1/2 IF)	Pin	Box			10.00	238.55	86.4

Figure 9 : 12.25-in. section BHA details



	Desc.	Manu.	Serial Number	OD (in)	ID (in)	Max OD (in)	Bot Type	Top Type	Bot Gender	Top Gender	FN OD (in)	FN Length (m)	Length (m)	Cum. Length (m)	Cum. Weight (1000 lbm)
1	9 7/8" Sting Blade PDC Bit Type Z716	Smith	JM3397	7.500	3.250	9.875		4-1/2 REG		Pin			0.26	0.26	0.2
2	A700M7868GT Motor (9 3/8" Sleeve. 1.15 ABH, Flapper NP)	Schlumberger	06782	7.000	5.500	9.375	4-1/2 REG	4-1/2 IF	Box	Box	7.000	0.96	9.51	9.77	3.4
3	6 3/4" Pony NMDC	Schlumberger	5228-S2	6.438	2.750	6.750	4-1/2 IF	4-1/2 IF	Pin	Box	0.000	0.00	2.98	12.75	4.3
4	SlimPulse 675 - Bat. On bottom with GR and APWD	Schlumberger	1773	6.688	3.880	6.870	4-1/2 IF	4-1/2 IF	Pin	Box	6.750	0.63	10.47	23.22	7.6
5	6 13/16" NMDC	Schlumberger	79120 J	6.813	2.813	6.813	4-1/2 IF	4-1/2 IF	Pin	Box	0.000	0.00	9.08	32.30	10.6
6	1 x 6 1/2" DC	Rig DATI	Rig DATI	6.500	2.875	6.750	4-1/2 IF	4-1/2 IF	Pin	Box	6.625	0.42	9.35	41.65	13.4
7	6.5" Hydraulic Jar	Smith	26919J	6.375	2.250	6.500	4-1/2 IF	4-1/2 IF	Pin	Box	6.500	0.65	9.77	51.42	16.4
8	3 x 6 1/2" DC (3 joints)	Rig DATI	Rig DATI	6.500	2.875	6.750	4-1/2 IF	4-1/2 IF	Pin	Box	6.750	0.45	27.19	78.61	24.5
9	6.5" Accelerator	Smith	88772H	6.500	2.750	6.500	4-1/2 IF	4-1/2 IF	Pin	Box	6.500	0.77	10.07	88.68	26.9
10	12 x 5" HWDP (12 joints)	Rig DATI	Rig DATI	5.000	3.000	6.625	4-1/2 IF	4-1/2 IF	Pin	Box	6.625	0.52	111.13	199.81	44.9
11	5" 19.50 DPG, Premium To Surface	Rig DATI	Rig DATI	4.855	4.276	6.625	4-1/2 IF	4-1/2 IF	Pin	Box					

Figure 10 : 9.875-in. section BHA details

3.2 CDE Bit Design Selection

For this specific application, no PDC bit had been previously run in the field and only roller cone TCI bits had been used. Therefore, there was no reference to help in the selection of the most suitable PDC design.

However, there are some important factors to consider in selecting the best bit design:

- ROP: Have an "aggressive" profile to improve ROP without sacrificing durability.
- Torque: Produce as low torque as possible to improve stability and easiness to steer.

- Protection: Have a superior cutter protection from impact damage in the critical area (shoulder, nose).
- Technology: Use premium PDC cutter technology to tackle the hard and abrasive geothermal environment.

Based on these factors, a seven-bladed CDE bit equipped with 16-mm premium wear-resistant high-impact PDC cutters was proposed. The depth-of-cut limiter feature in the nose and the cone was included to improve its stability as well as its capability to steer (lower reactive torque in sliding mode). The CDE is placed in the backup position concentrated on the shoulder to provide the crushing action and protection to PDC cutters on the primary row. This design has no CDE on the leading position (primary row) to keep it aggressive for better ROP capability. Figure 11 shows the proposed designs for both the 12.25-in. and 9.875-in. bits.

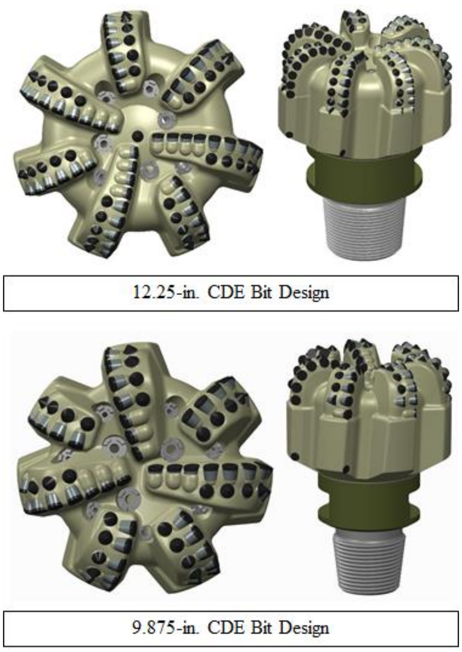


Figure 11 : Proposed CDE bit designs

In a geothermal drilling application in the Philippines, an 8.5-in. CDE bit could replace up to five TCI runs with an ROP three times faster and save the operators up to 10 days (Iskandar et al., 2016). A similar CDE bit design was utilized in this application.

3.3 FEA-Based Modeling and Simulation

The objective of this phase was to study the bit dynamics for a specific drilling system (BHA, well profile, drilling parameters, etc.). The main output of this simulation is the drilling parameters roadmap, which acts as a guideline for field personnel to operate the CDE bit in smooth and stable conditions. The FEA-based simulation was done in a Linux platform software that had the capability to model the drillstring components in detail from the bit up to surface. Figure 12 shows the CDE bit model in the software.

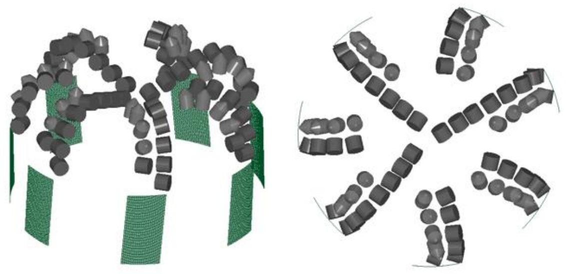


Figure 12 : Modelled CDE bit in the FEA simulation software

3.3.1 12.25-in Hole Section

Directional requirements in the 12.25-in. hole section dictated a BHA with 1.5° motor bend angle and 11.5-in. OD sleeve stabilizer. This BHA design would affect how the bit behaves when drilling the formation. Figures 13 and 14 show the vibration plot and drilling parameters roadmap generated from the FEA simulation.

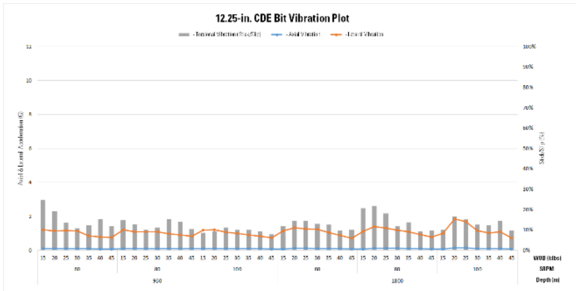
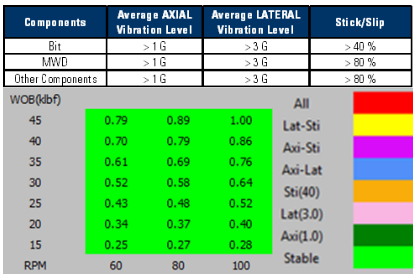


Figure 13 : Vibration plot for 12.25-in. CDE bit



Components	Average AXIAL Vibration Level	Average LATERAL Vibration Level	Stick/Slip
Bit	> 1 G	> 3 G	> 40 %
MWD	> 1 G	> 3 G	> 80 %
Other Components	> 1 G	> 3 G	> 80 %

WOB(klbf)			
45	0.79	0.89	1.00
40	0.70	0.79	0.86
35	0.61	0.69	0.76
30	0.52	0.58	0.64
25	0.43	0.48	0.52
20	0.34	0.37	0.40
15	0.25	0.27	0.28
RPM	60	80	100

Figure 14 : Drilling parameters roadmap for 12.25-in. section

3.3.2 9.875-in. Hole Section

For 9.875-in. hole section, the trajectory required a BHA with 1.15° bent housing and a 9.375-in. OD sleeve stabilizer. Figures 15 and 16 show the vibration plot and drilling parameters roadmap generated from the FEA simulation.

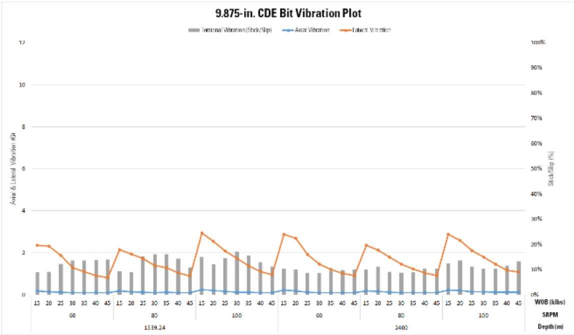


Figure 15 : Vibration plot for 9.875-in. CDE bit

Components	Average AXIAL Vibration Level	Average LATERAL Vibration Level	Stick/Slip
Bit	> 1 G	> 3 G	> 40 %
MWD	> 1 G	> 3 G	> 80 %
Other Components	> 1 G	> 3 G	> 80 %

WOB(klbf)				Legend
45	0.84	0.92	1.00	All
40	0.75	0.82	0.89	Lat-Sti
35	0.65	0.72	0.79	Axi-Sti
30	0.56	0.62	0.68	Axi-Lat
25	0.47	0.52	0.57	Sti(40)
20	0.38	0.42	0.46	Lat(3.0)
15	0.29	0.31	0.34	Axi(1.0)
RPM	60	80	100	Stable

Figure 16 : Drilling parameters roadmap for 9.875-in. section

4. CDE BIT OPERATIONAL EXECUTION

The bit prerun condition is shown in Figure 17. The CDE bit was made up to the directional BHA and run in hole until it reached the top of cement inside the casing.

Figure 17 : CDE bit pre-run condition

4.1 Drilling Out Cement, Plugs, and Float Equipment

As CDE bit is a fixed cutter bit, and it is paramount to ensure that all the equipment to be drilled out, such as plugs, float collars, and shoes, is PDC drillable, i.e., made of rubber, nylon, plastic, or cement. This was the case for the 12.25-in bit. The use of nonrotating plugs is recommended. With a relatively high motor bend angle, the drilling-out process was performed with extra caution to prevent a premature PDC cutter damage inside the casing.

For the 12.25-in. hole section, drilling was divided into two stages: 1) the tieback receptacle and 2) casing shoe. Drilling out cement in the tieback receptacle took about 6 hours, with an approximately 40-m interval of cement/float collar. The parameters used were 4 to 5 klbf WOB, 30 to 40 RPM, and 600 gpm, maintaining 2.5 to 2.8 kft.lbs surface torque.

Drilling out the cement and casing shoe took about 7 hours (an approximately 54-m cement/shoe track interval), using 5 klbf WOB, 30 to 40 RPM, and 600 to 700 gpm, maintaining 5 to 6 kft.lbf surface torque. No drilling issues were encountered during this phase.

4.2 Drilling Formation

4.2.1 12.25-in. Hole Section

The objective of this section was to penetrate the reservoir. Drilling started with 900 gpm + 1800 scfm aerated drilling 2000 psi, 10 to 25 klbf WOB, 30 to 40 RPM in the tangent section. A controlled ROP of maximum 30 m/hr was applied for hole cleaning. Total losses were faced several times while drilling the section. The drilling parameters are shown in Figure 18.

While drilling, several shocks were recorded by the MWD tool, and consequently drilling parameters were adjusted to avoid downhole tool failure. Drilling continued to hole section TD at 1600 m measured depth (MD). In this hole section, the CDE bit was capable of generating up to 18.3 m/hr ROP, with 19.8 m/hr rotating and 9.9 m/hr sliding ROPs. The torque and drag plot in Figure 19 shows that the actual friction factor was approximately 0.2 to 0.3 for both pickup and slackoff weights without any significant deviation from the initial model. Torque and drag were monitored closely to ensure good hole cleaning.

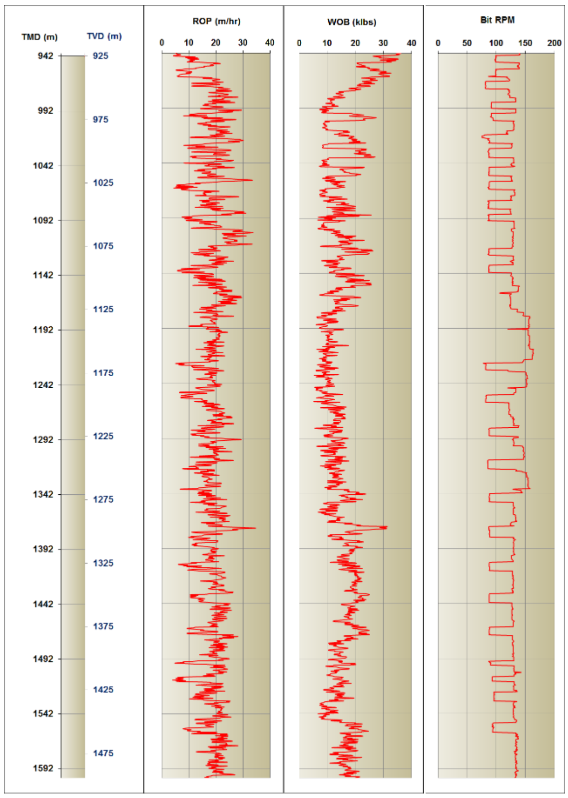


Figure 18 : Drilling parameters in 12.25-in. section

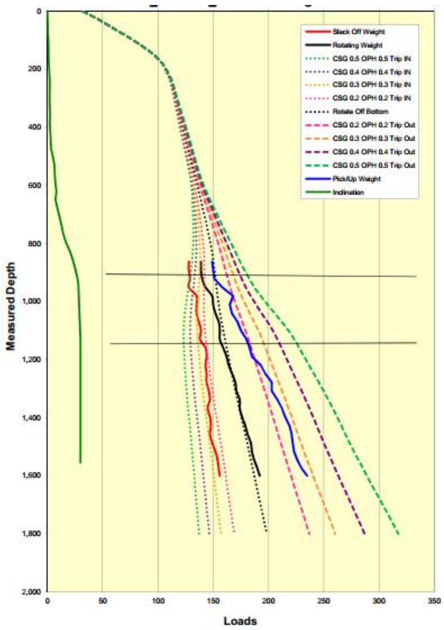


Figure 19 : Torque and drag plot

4.2.2 9.875-in. Hole Section

Total losses were experienced throughout the 9.875-in. section that was drilled with 40 to 60 RPM, 5 to 12 klbf WOB, and 470 to 565 gpm. Again, for hole cleaning, a controlled ROP of a maximum 30 m/hr was applied. However, the CDE bit showed the capability to reach ROPs in excess of 50 m/hr. The actual ROP in this section was 17.4 m/hr, with 9 m/hr sliding ROP and 19.6 m/hr rotating ROP. The overall condition of the hole was very good, and no drag was recorded while tripping. The drilling parameters are shown in Figure 20.

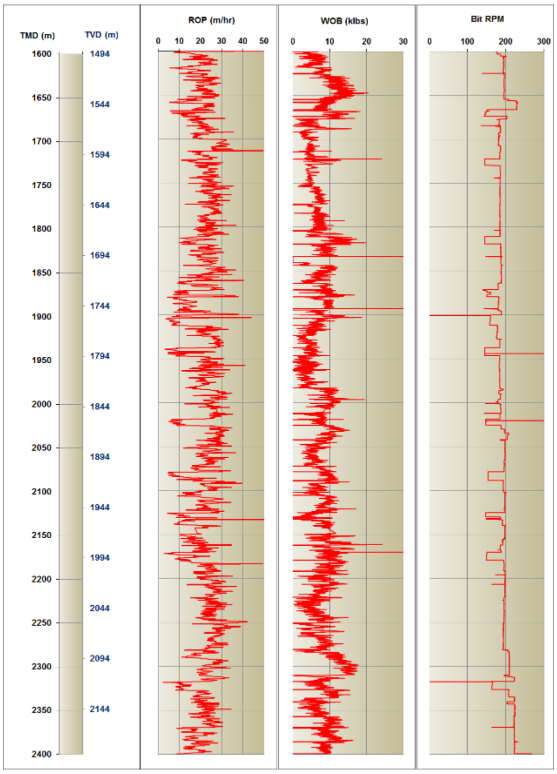


Figure 20 : Drilling parameters in 9.875-in section

In both the 12.25-in. and 9.875-in. sections, the motor steerability was effective, and no packoff events were experienced. The dogleg capability was consistent with 5°/30 m in slide mode, whereas in rotary mode, it built at 2°/30 m with a walking tendency to the left.

4.3 Bit Post-Run Condition

After successfully drilling the formation to section TD in one run for both hole sections, the CDE bits were pulled out of the hole in excellent and rerunnable conditions, as shown in Figures 21 and 22. The 12.25-in. CDE bit was dull graded 1-1-WT-A-E-I-NO-TD, and the 9.875-in. CDE bit was dull graded 0-0-NO-A-X-I-NO-TD.

Figure 21 : 12.25-in. CDE bit post run condition

Figure 22 : 9.875-in. CDE bit post run condition

The CDE successfully provided superior protection to the conventional PDC cutters on the primary row, and, at the same time, delivered a crushing action. This crushing action assisted the shearing action of the PDC cutters, thus improving ROP capability. The 'green' condition of the used bits have proven the premium quality of PDC cutters and the CDE to tackle the hard formation.

5. CONCLUSIONS

The first CDE bit implementation in a geothermal well in Indonesia was extremely successful in both the 12.25-in. and 9.875-in. hole sections that were drilled to section TD in a single run without any drilling/bit-related issue. Moreover, a remarkable increase in ROP was recorded. Figures 23 and 24 show the improvement made by the CDE bit over a roller cone TCI bit in the same field.

The average ROP (although "limited") was, in any case, in excess of 20% higher compared to offset wells drilled with TCI bits, bringing considerable savings to the operator. The directional control was equally excellent, maintaining the well inclination at 30° as per plan.

The CDE bits were pulled out of hole in very good and rerunnable conditions, thus completing a great success story.

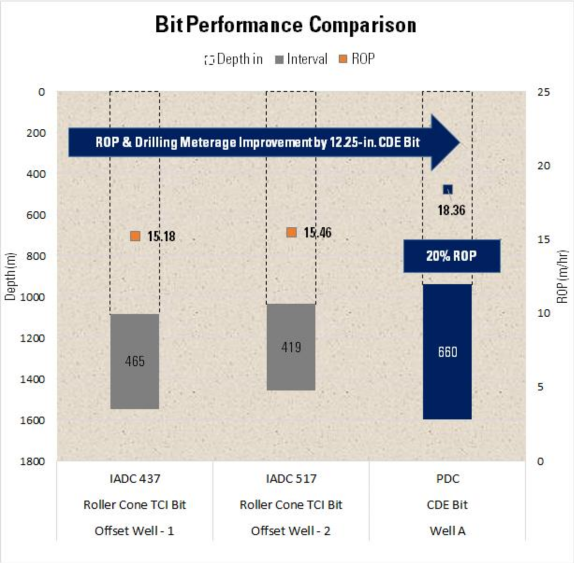


Figure 23 : 12.25-in. CDE bit performance comparison

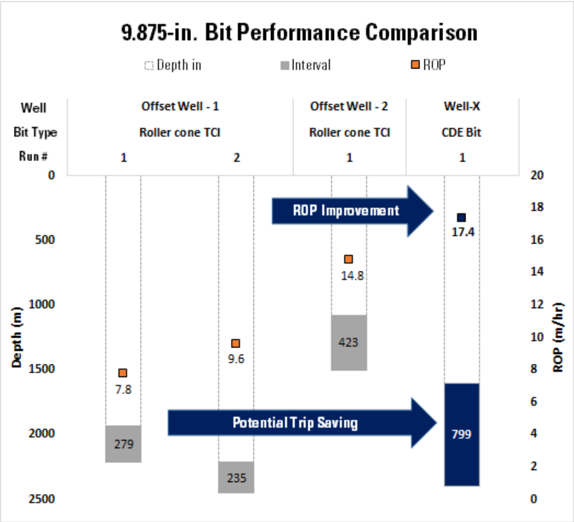


Figure 24 : 9.875-in. CDE bit performance comparison

The CDE bit technology has been proven to greatly improve drilling performance while lowering the overall drilling risks and allowing considerable cost savings. This first implementation of CDE bits sets a new benchmark in terms of drilling efficiency in the very challenging geothermal subsurface/drilling environment.

NOMENCLATURE

BHA	: Bottomhole Assembly
CDE	: Conical Diamond Element
FEA	: Finite Element Analysis
ID	: Inner Diameter
MD	: Measured Depth
OD	: Outer Diameter
PDC	: Polycrystalline Diamond Compact
POOH	: Pulled Out of Hole
ROP	: Rate of Penetration
RPM	: Revolutions per Minute
SRPM	: Surface Revolutions per Minute
TCI	: Tungsten Carbide Inserts
TD	: Total Depth
UCS	: Unconfined Compressive Strength

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