EVOLUTION OF GEOTHERMAL DIRECTIONAL DRILLING IN INDOENSIA THROUGH FIT-FOR-PURPOSE ENGINEERING WORKFLOWS AND TECHNOLOGY MAPPING

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Keywords: *geothermal, directional drilling, sliding, torque and drag, hole cleaning, well trajectory.*

ABSTRACT

Environmentally sustainable growth is strengthening the momentum of the global energy transformation. Renewable energy costs decline, production efficiency improvement and technology advancement are driving the future energy shift within reach. Located in the "Ring of Fire," Indonesia is home to 147 volcanoes, with 120 of them classified as active. Drilling geothermal wells in this area possesses unique operational challenges from surface to reservoir section. One of the significant challenges faced is the total mud loss circulation, which results in several operational complexities, including insufficient hole cleaning, high torque and drag, and hole instability, leading to a high risk of stuck pipe. Directional drilling companies have become technological partners for geothermal operators in search of solutions to address these problems. Over the past five years, geothermal drilling in Indonesia has seen an exponential learning curve through fit-for-purpose BHA design and technology mapping workflows. Electro-magnetic MWD technology, and high-performance mud motors in aerated drilling, have enabled significant enhancements in operational efficiency. The application of finite element analysis simulators has been instrumental in predicting the directional tendency response of dumb iron BHAs, which, combined with 24/7 operational surveillance through the real-time decision centre has enabled operators to prevent unexpected bit trips and reduce operational risks.

Located 40 km south of Bandung in West Java, Wayang Windu Power Generation is operated by Star Energy Geothermal (SEG) Limited a wholly-owned subsidiary of Star Energy. SEG has drilled more than 45 wells in the Wayang Windu field to supply steam to the two generating unit, namely Unit 1 and Unit 2. In 2019, SEG started a drilling campaign to provide steam as a make-up capacity. The wells were planned to be drilled from the existing pads to aim at subsurface targets that were not vertically beneath the pad. The directional well path had to be designed to penetrate the subsurface targets, and hence steam could be produced as per the subsurface department's objectives. The well path had to be drillable safely, and casings could be run to each section depth.

1. DIRECTIONAL DRILLING PLANNING

1.1 Simplified Well Trajectory

The drilling campaign was intended to produce more steam from the existing pads, targeting multiple natural faults. Hence the well trajectories need to be designed directionally as practically as possible to avoid the adjacent wells, to be drillable and to penetrate the subsurface targets. The well trajectory was being simplified to reduce directional work, especially in TLC and TS zone areas. It requires to slide when steering with a mud motor. The pipe will be steady (no rotation) for a period. There is a risk that drilled cuttings being accumulated around the BHA can potentially cause the pipe to get stuck. The risk is increased when sliding in a total loss zone since the drilled cuttings will not be able to be circulated out to the surface. The well trajectory was designed so that the steering work ended prior to entering the reservoir zone. It would then be avoiding to steer the well in the total loss zone. Wells was kicked off in either 26" or 17-1/2" and finished the steering prior to entering the reservoir formation. There were several subsurface targets to be penetrated at different depths. Figure 1 shows the well trajectory and targets assigned for one of the wells. The profile was purely 2D without turn. This involved extensive discussion with subsurface team and the Drilling team to simplify the target and fault intersections.

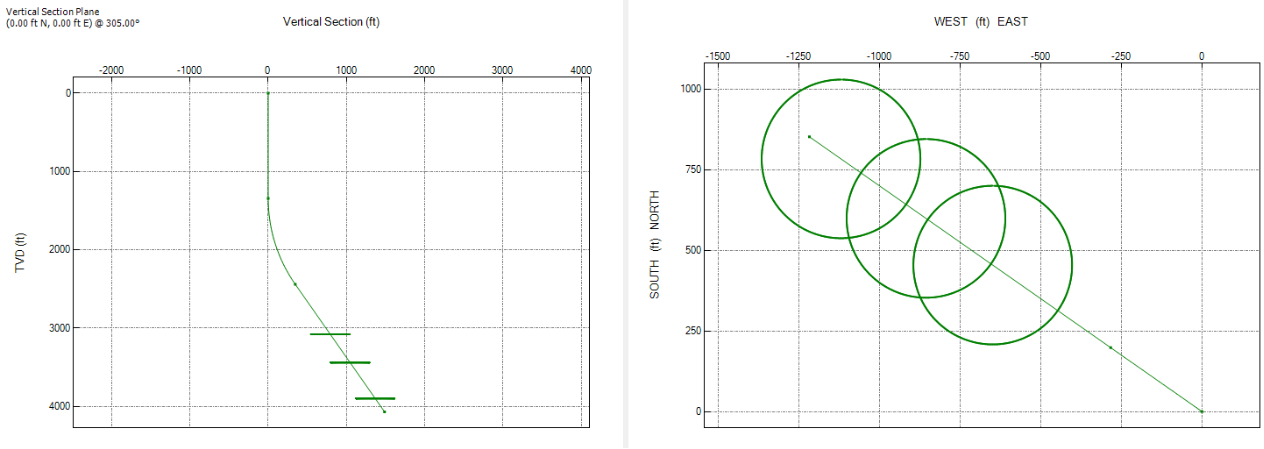

Figure 1: Trajectory profile

The dog leg was maintained a maximum ~ 2.5 - 3 deg/100 ft, as was shown in table 1 on the next page. The length of the steered interval would be reduced, and side force was low. The surface casings then could be run to shoe depth without significant problem.

High inclination will make it more difficult to clean the hole, especially when encountering partial/ total losses. Whenever possible, it is preferable to have a lower inclination (below 40 deg). Directional work also as much as possible be done early in the section where loss circulation is not anticipated. Certainly, by having a simpler profile and shallower depth, it will contribute in avoiding high T&D issues with deeper depths. This well profile simplification is essentially useful to reduce accumulative fatigue while drilling.

Comments	MD (ft)	Incl (°)	Azim Grid (°)	TVD (ft)	Elev (ft)	DLS (°/100ft)
Tie-In	0.00	0.00	0.00	0.00	6193.73	N/A
Marker MudLine	32.32	0.00	170.00	32.32	6161.42	0.00
30in Conductor	*229.00*	*0.00*	*170.00*	*229.00*	*5964.73*	*0.00*
20in Casing Shoe	*1256.00*	*0.00*	*170.00*	*1256.00*	*4937.73*	*0.00*
KOP	1356.00	0.00	170.00	1356.00	4837.73	0.00
Inc 10 Deg	*1750.00*	*9.85*	*170.00*	*1748.06*	*4445.67*	*2.50*
EOC	1876.00	13.00	170.00	1871.55	4322.18	2.50
13 3/8in Casing Shoe	*2746.00*	*13.00*	*170.00*	*2719.25*	*3474.48*	*0.00*
MBE-7 Steam 1 Target 040121	*3113.10*	*13.00*	*170.00*	*3076.94*	*3116.79*	*0.00*
MBE-7 Steam 2 Target 040121	*3483.48*	*13.00*	*170.00*	*3437.83*	*2755.90*	*0.00*
MBE-7 Steam 3 Target 040121	*4123.24*	*13.00*	*170.00*	*4061.19*	*2132.54*	*0.00*
10 3/4in Casing Shoe	*4430.00*	*13.00*	*170.00*	*4360.09*	*1833.64*	*0.00*
MBE-7 Brine 1 Target 040121	*4796.67*	*13.00*	*170.00*	*4717.36*	*1476.37*	*0.00*
MBE-7 Brine 2 Target 040121	*5638.45*	*13.00*	*170.00*	*5537.57*	*656.16*	*0.00*
8-5/8in Casing Shoe	*6000.00*	*13.00*	*170.00*	*5889.85*	*303.88*	*0.00*
MBE-7 Brine 3 Target 040121	*6857.35*	*13.00*	*170.00*	*6725.23*	*-531.50*	*0.00*
MBE-7 Brine 4 Target 040121	*7377.58*	*13.00*	*170.00*	*7232.12*	*-1038.39*	*0.00*
7in Casing Shoe Well TD	7500.00	13.00	170.00	7351.41	-1157.67	0.00

Figure 2: DLS Severity

1.2 Avoiding Well to Well Collision

It is not uncommon that there are more than six slots in one well pad at Wayang Windu field. The centre-to-centre distance between slots is usually ~20-30 ft. The well trajectory must be designed to avoid collision with other wells.

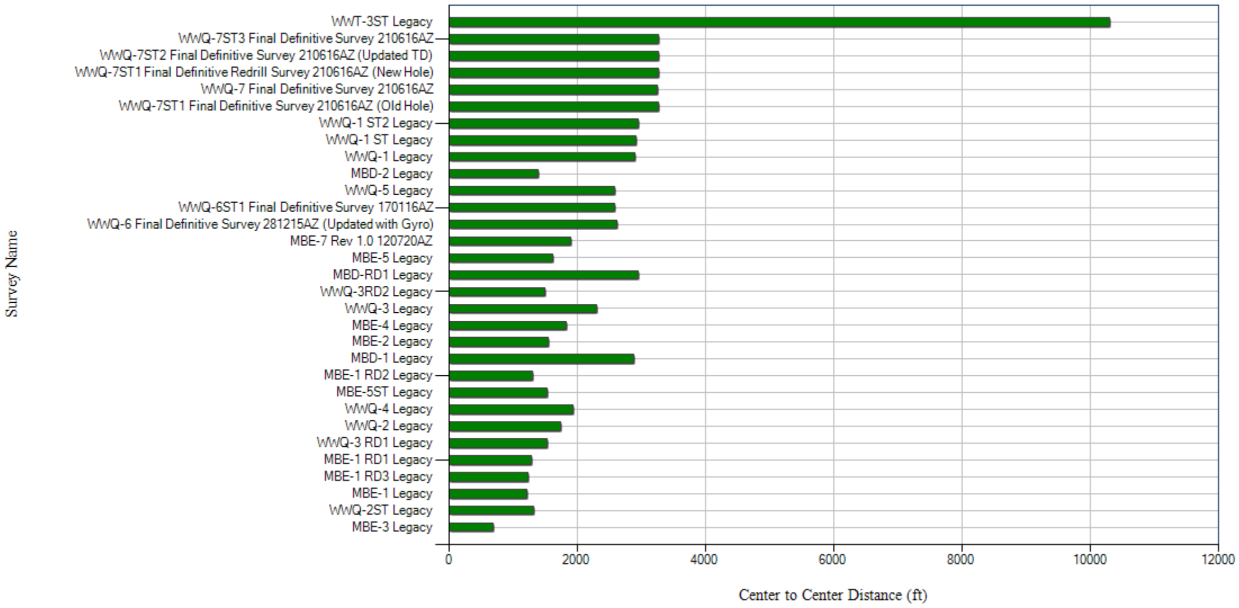

Figure 3: Oriented Separation Factor

Schlumberger Drilling Office (DOX) software were used to simulate the anti-collision. It considers the error of uncertainty (EOU) of the survey tools. The oriented separation factor (OSF) between planned well and offset wells were then calculated. Due to ferro-magnetic property of volcanic formation, the azimuthal magnetic surveys measurement was affected, and this resulted in a bigger EOU. Since the EOU was bigger, the OSF will be lower and less than 1.5 which is the minimum required by Schlumberger standard. Figure 3 shows that the OSF were lower than 1.5 at the surface for most of the offset wells. It gave a warning that potentially the planned well could hit one of the offset wells.

A prevention plan was developed to avoid collision with other wells. That included making sure center-to-center distance between planned wells and offset well were as far apart as possible, and using the travelling cylinder (TC) plot as guidance for the directional driller when steering the well. The black, yellow, and green line in the middle of TC plot in figure 4 show the tolerance line. Directional drillers (DDs) would steer the well so that the actual trajectory would not cross the line from the surface to the end of steering depth. The tolerance lines were given in color coding to have easier look, each color determine at which depth the DD need to be in regards to bottom hole positioning. As it is shown, the tolerance radius was small. Hence the DDs had to be aware all the time and steered the well within the boundary. The hole surveys in 26” and 17-1/2” sections were taken using MWD tool. Meanwhile, the reservoir zone (12-1/4” below) will be acquired using a gyro survey.

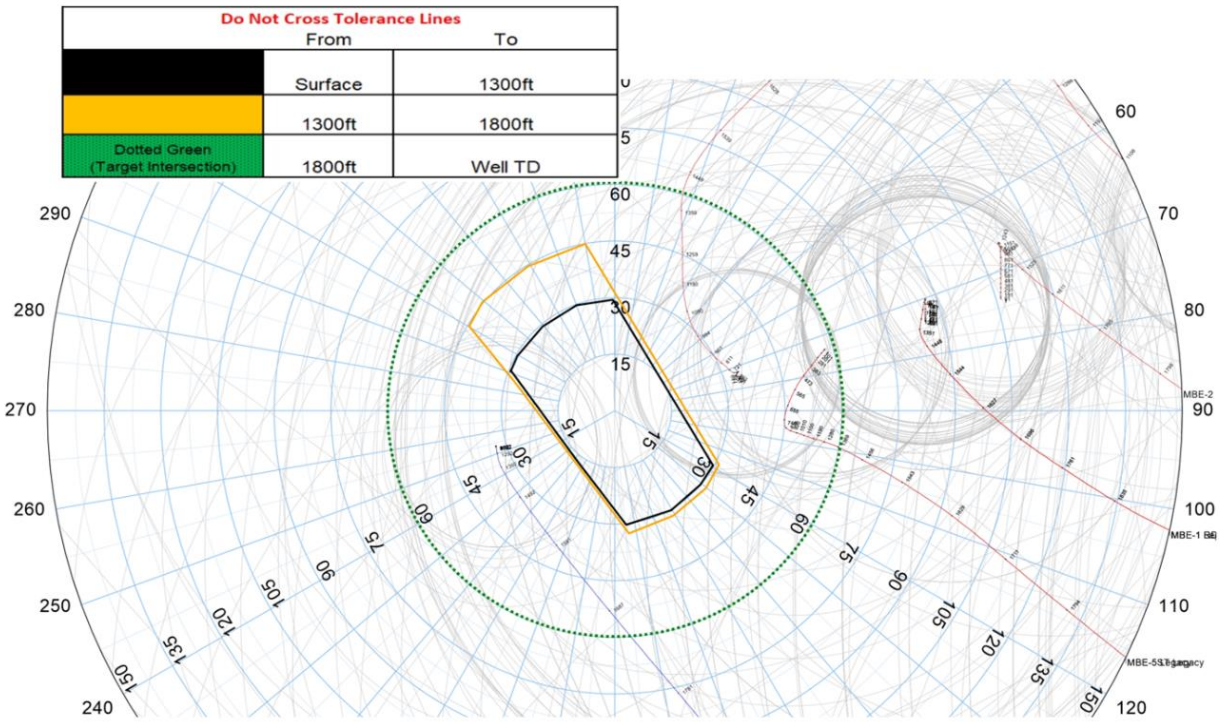

Figure 4: Travelling Cylinder Plot

1.3 BHA Design and Steering Requirement

Several considerations were taken when designing the directional BHA in this geothermal drilling campaign. Each of BHA component had to be selected to meet the steering and dog leg capability, to reduce the risk cuttings accumulated around the BHA, to enable pumping high flow rate for hole cleaning, to minimize drill string magnetic interference and to have jar with enough impact in case pipe stuck in the hole.

For 26” section, a 9” mud motor was chosen with high torque capability. This resulted in longer life of the motor to drill to section target depth (TD section). The bent housing 1.15 deg was selected. A sleeve stabilizer with 25-3/4” outside diameter (slightly under gauge) and string stabilizer 25” outside diameter (OD) were chosen to generate the dog leg capability. DOX was used to estimate the dog leg capability of this motor and stabilizer configuration. The calculation in figure 5 shows that it has 4 -7 deg/100 ft dog leg capability when sliding 100% (will depend on formation). The setting would enable the planned dog leg (~3 deg/100 ft) to be achieved with ~60% sliding interval and ~40% rotating interval.

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/100ft	deg/100ft	deg	deg/100ft	deg/100ft	
0.00	-0.63	7.45	170.23	-7.34	14.50	Yes
5.00	-0.72	7.46	170.24	-7.35	14.51	Yes
10.00	-0.93	7.47	170.25	-7.36	14.52	Yes
15.00	-1.17	7.48	170.26	-7.37	14.51	Yes
20.00	-0.93	7.49	170.29	-7.38	14.49	Yes
25.00	-1.06	7.50	170.32	-7.40	14.47	Yes
30.00	-1.03	7.48	170.37	-7.38	14.36	Yes
35.00	-0.81	7.12	170.38	-7.02	13.65	Yes
40.00	-0.80	6.98	170.52	-6.89	13.19	Yes
45.00	-0.89	7.29	170.57	-7.19	13.70	Yes

Table 1: Mud Motor Dog Leg Capability

When drilling hard andesite formation, a normal stabilizer blade can be easily worn out and hence reduced the OD. It will then reduce the dog leg capability of this mud motor-stabilizer configuration. Stabilizers that were used in this geothermal drilling campaign had apply hardfacing process. The stabilizer blade hardfacing was HF 6000. This process applies tough molten carbide particles of varying sizes held in a nickel chrome matrix which provides excellent bonding properties and greater surface wear characteristics are achieved. However, even with all of that prevention, if the formation is really abrasive, it will wear out the stabilizer gradually over time, therefore real time actual monitoring on DLS is crucial to ensure the BHA is not dropping significantly, apart from that, a robust game plan needs to be created accordingly. There are two sources of magnetic interference, i.e. the ferromagnetic volcanic formation and the drill string. An effort to minimize drill string interference was to add non-magnetic drill collars directly around the magnetic surveying tool. An MWD tool was used to take the survey. The DOX program calculated drill string magnetic interference and resulted in azimuthal error based on the BHA configuration. Below is the example for 26" Directional BHA that is being utilized in this campaign.

Type	Desc.	Manu.	Length (ft)	Cum. Length (ft)
Bit	26" Bit	TBA	2.43	2.43
Motor	A962M7848GT (25-3/4" Sleeve, 1.15 ABH)	Schlumberger	30.45	32.87
Misc. Sub	9-1/2" Catcher Sub w/ NP Plunger Float Sub	Schlumberger	4	36.88
Stabilizer	25" IBS Stabilizer	Schlumberger	8.1	44.98
Collar	1 x 9-1/2" Collar	Rig DATI	31.04	76.01
Shock Sub	Shock Sub 9-1/2"	Smith	12.83	88.84
Misc. Sub	Crossover (7-5/8" Reg Pin x 6 -5/8" Reg Box)	Rig DATI	3.77	92.61
Collar	8-1/4" NMDC	Schlumberger	30.94	123.55
MWD	XEM 800	Schlumberger (...	33.4	156.95
Misc. Sub	Gap Sub	Schlumberger (...	3.67	160.63
Misc. Sub	UBHO sub	Schlumberger	5	165.63
Collar	8-1/4" NMDC	Schlumberger	30.94	196.56
Collar	4 x 8" Collar	Rig DATI	120.11	316.68
Jar	8" Hydraulic Jar	Smith	33.17	349.85
Collar	2 x 8" Collar	Rig DATI	60.01	409.85
Misc. Sub	Crossover (6-5/8" Reg Pin x 4 -1/2" IF Box)	Rig DATI	3.77	413.62
Collar	1 x 6-3/4" Collar	Rig DATI	29.86	443.48
HWDP	13 x 5" HWDP	Rig DATI	401.23	844.71
Drill Pipe	**5" 19.50 DPS, Premium**	**Rig DATI**	**221.38**	**1066.09**

Figure 5: BHA Configuration

Furthermore, Schlumberger Headquarter (HQ) team is implementing a new limit for Optimum Operating Window (OOW) with Blue Schlumberger BHA, and this has helped significantly in gaining more flexibility on the operating window, to be specific in terms of RPM for the mud motor in top section (can go up to 100 RPM in tangent part – as shown in table 2). As we know that string rotation is one of the key factors in geothermal drilling. Another initiative is to utilize one time "temporary BHA" in the 26" Section. With continuous learning curve and fruitful discussion with client, manage to optimize 30in conductor depth around 180-190 ft MD. By having this deeper conductor depth, it can accommodate Bit to(?) MWD (length around 185 ft) as the main part of the BHA. Eventually, this had enabled the rig to use one time only temporary BHA prior picking up the full directional BHA and saved around 36 hours of time.

Maximum Downhole rpm									
Motor Size	Borehole Section	Housing	Bend Angle, °						
			Straight—0.00	0.39	0.78	1.15	1.50	1.83	2.12
4¾–5 in	Curve	Articulated bend housing (ABH)/fixed	90	90	80	50	40	40	40
	Tangent/straight	ABH	120	100	100	100	100	100	100
	Tangent/straight	Fixed	160	160	160	140	120	120	100
6¾–7 in	Curve	ABH/fixed	80	80	70	70	60	40	30
	Tangent/straight	ABH	120	100	100	100	100	80	50
	Tangent/straight	Fixed	160	160	150	140	130	80	60
7¾–8½ in	Curve	ABH/fixed	80	80	50	40	40	30	
	Tangent/straight	ABH	120	100	100	100	100	50	
	Tangent/straight	Fixed	150	150	130	120	120	60	
9⅝ in	Curve	ABH/fixed	90	90	50	40	40	30	
	Tangent/straight	ABH	120	100	100	100	100	50	
	Tangent/straight	Fixed	140	140	140	130	120	60	
11¼ in	Curve	ABH/fixed	90	90	60	50	30		
	Tangent/straight	ABH	120	100	100	100	50		
	Tangent/straight	Fixed	140	140	130	120	60		

Table 2: Mud Motor RPM Limit

For 17-1/2" directional BHA, we are using Slight build BHA in order to optimize rotation after getting around 30 deg inclination – rely on slight build BHA tendency. The DD needs to prepare a sliding strategy to reduce drilling time with optimizing rotation. Minimize sliding when necessary in hard formation (e.g. Andesite, and Dacite formation). We have managed to drill with great ROP and no Motor failure / MWD failure YTD. Drilling with normal mud and aerated with low to high SCFM and with known high corrosion rate of Geothermal system, whereby the corrosion rate is significantly high (up to 486 MPY). One of the key mitigations in this campaign to reduce corrosion rate are: implementing high pH in the mud system (pH 9-10), utilizing corrosion inhibitor, and utilizing internally coated drill string

For Top section drilling (26" and 17-1/2" Section), apart from normal full return drilling, the BHA needs to have the ability also in totall loss - aerated drilling condition (multiphase flow). Therefore, a robust roadmap aerated simulation needs to be performed and also being tracked in real time and then compare it with the nearby offset well. This real time comparison will help us to determine the optimum concentration on aerated composition.. This includes to accurately determine the mixture of flow (Q-mix) of water and air (drilling fluid), the motor pressure drop after flow mixture, and the impact of the mixture with respect to motor and MWD tool specifications.

Figure 6 depicts the optimum AFR mixture to meet the criteria and to design/monitor the mixed flow (Q Mix – air and water) across the motor. This allows staying within the motor's specification range (600-1200 GPM). These parameters are monitored daily during execution and act as a reference for the aerated drilling design.

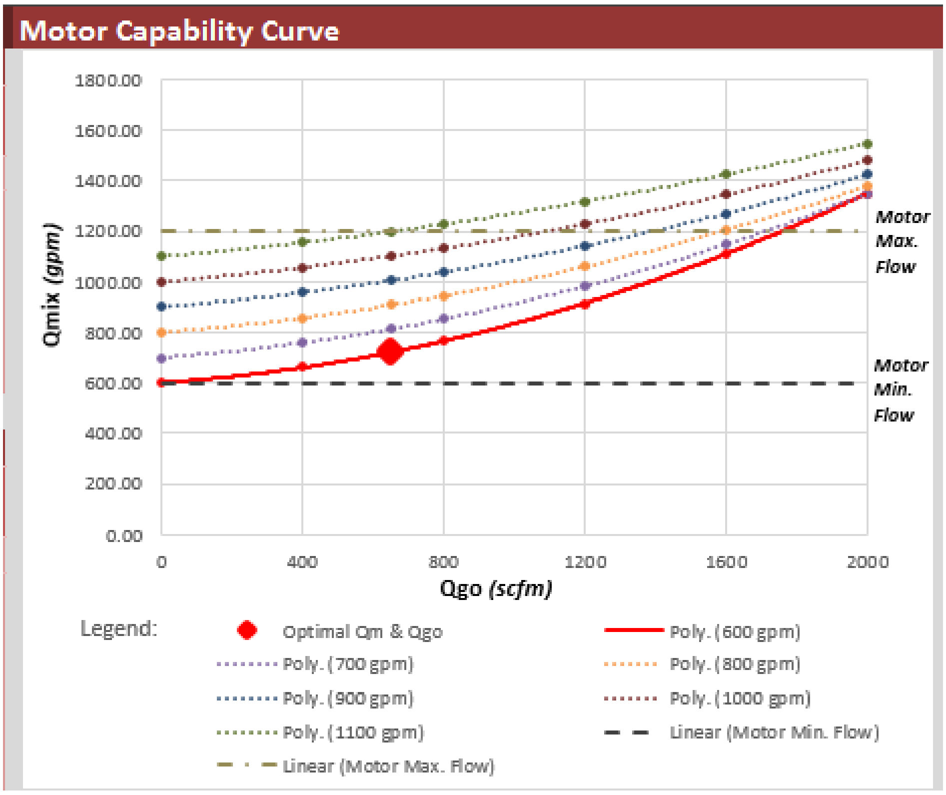

Figure 6: Aerated Drilling Flow Rate Sensitivity

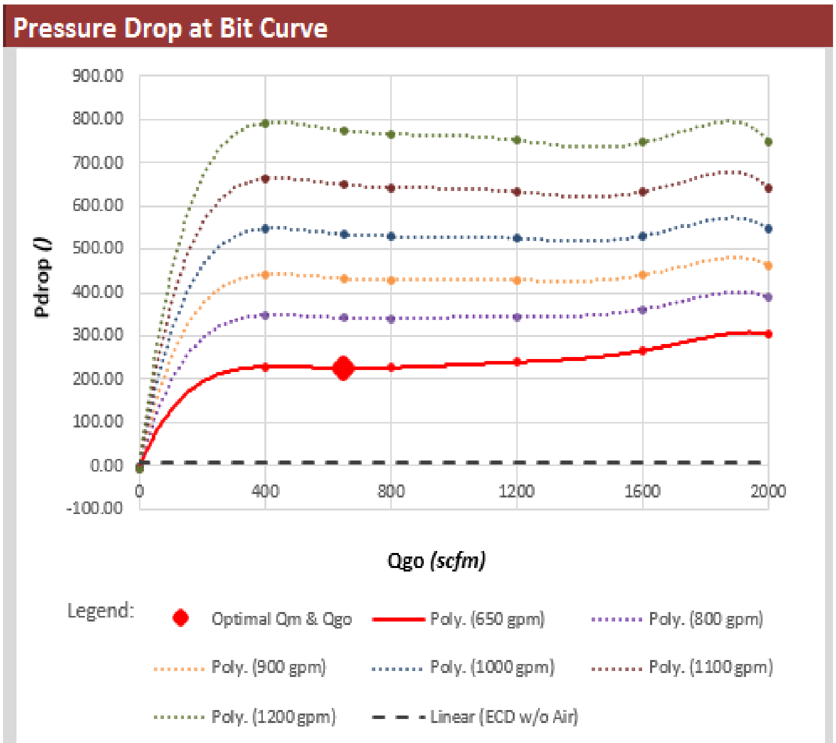

Figure 7: Motor Pressure Drop Sensitivity

Figure 7 shows the pressure drop sensitivity when pumping air and water (a mud-lubricated motor bearing was used, which requires a minimum of 250 psi pressure drop at the bit.

The steering strategy in top section was designed to reduce the sliding interval as much as practical, which requires the drill string to remain not rotate, limiting hole cleaning to rely on flow rate and not drill string rotation. In addition, sliding interval were reduced when drilling into loss zones to reduce the risk of stuck pipe. Regular monitoring of tripping loads and torque was practised at all times to identify any abnormal trends that may indicate poor hole cleaning.

Meanwhile for Reservoir section BHA (12-1/4" Section and 9-7/8" Section) we are using a rotary BHA with single stabilizer. By having the trajectory locked already in the main curve profile in 17-1/2" section, we will then have the flexibility on rotary BHA to have slight build / slight drop BHA as required. This rotary BHA also had helped in terms of wider window for parameter for hole cleaning, pumping LCM, maximum aerated concentration and certainly minimizing number of stabilizers to reduce chances of stuck pipe due to hole pack off. Another initiative is to reduce number of big OD (Outside Diameter of DC (Drill Collar) to be re-adjust with smaller OD (Outside Diemater) of HWDP (Heavy Weight Drill Pipe), this will reduce the time to make up BHA, reduce chances of stuck pipe and reduce overall surface torque at well TD.

2. CONNECTION PRACTICES

Based to the offset data study that had been carried out in 2015, on the Stuck Pipe incident Commonalities – one of the highest stuck pipe incidents is when circulation being stopped and even more complicated when already have total losses situation. This condition is the case when taking an MWD directional survey or when making a Drill Pipe connection. By having this study, together with all stakeholders, a strategic approach was being made as per below.

In terms of taking the directional survey, we are using MWD Electromagnetic Survey (MWD XEM) in the BHA, whereby there is no additional time needed for taking the survey. Essentially the survey is achieved when the connection is being made.

In terms of connection practices, the strategic approach was being made by using aerated fluid and reaming with high velocity. We need to ensure that ESD is not too low that can cause wellbore stability issues, especially below the shoe. With the help of aerated drilling, cuttings were lifted as high as possible further away from the BHA to prevent pack offs. The concept is to drill with Hydrostatic pressure as close as possible with pore pressure to have a higher fluid level in the wellbore. With the high fluid level, certainly, cuttings will be able to be distributed evenly and higher than BHA. In addition, sweeping Hivis (High Viscosity fluid) to help mud rheology is also a key factor in a successful connection. After reaching stand down / kelly down in one stand of drillingback reaming up with velocity around 1500 fph and reaming down with velocity around 2000-3000 fph, with aerated. Then, checking Torque and Drag Pick Up / Slack Off measurement, if the trend is increasing, then perform the reaming once more, otherwise straight away perform the connection. The idea is by reaming up faster and helped with aeration, will able to move the cutting further away from the BHA and then the connection can be made safely. Therefore, both reaming velocity and aerated composition are critical in this regard.

By implementing above approach, manage to drill safely with full return or TLC condition to well TD with faster well delivery time.

3. TORQUE AND DRAG DESIGN

The torque and drag (T&D) model is an important simulation to monitor hole cleaning and to prevent stuck pipe events, and define optimum rig sizing selection.

Figure 8 shows the T&D model vs actual data for a hole section in one of the wells drilled in Wayang Windu. During the planning stage, a 0.35 friction factor was used as a general guideline for the T&D design; however, and as part of the design, this figure was adjusted based on actual conditions in Wayang Windu (aerated drilling and total loss circulation).

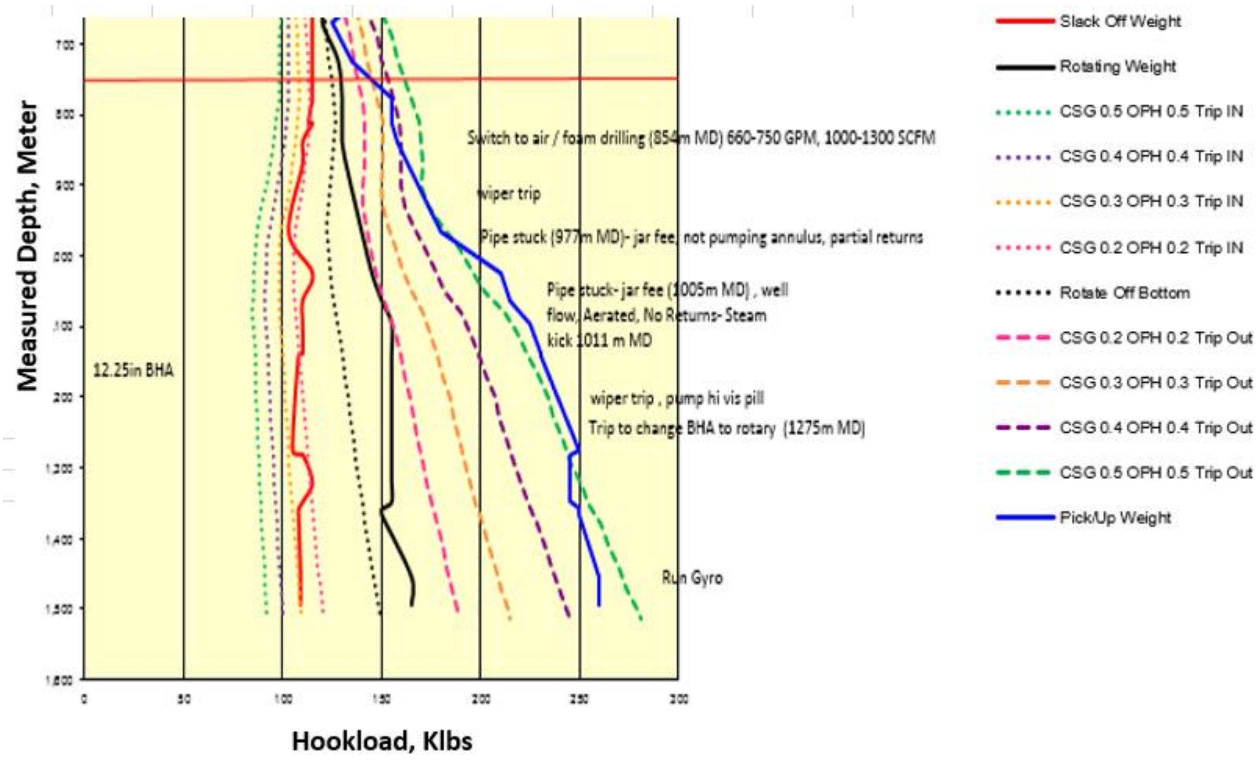

Figure 8: T&D Characteristic in geothermal well

For the T&D design in geothermal drilling, the following has to be taken into account:

- Total loss environment (low fluid level in the well)
- Low hydrodynamic pressure / ECD (air + mud mixture) reducing the buoyancy of the drill string.

The Schlumberger drilling team has been working closely with Star Energy to identify and deploy new technology and to modify the well trajectories, reduce drilling torque and successfully drill to the target depths. Some of the aspects considered are using lighter BHA, simplify well trajectory and increase top drive capacity.

RIG CAPACITY	1000 HP	1500 HP	2000 HP
Pulling Capacity, Klbs	**600**	**700**	**1000**
Drill Pipe Tensile (II), Klbs: • 5", 19.5#, G-105, S135 → Z140 • 5.5", 21.9-24.7#, TSS105 → S135 • 5.875", 23.4-28.7#, S135 → V150 • 5.5", 25.2-34.02#, S135 → VM165	 **436 - 582** 483 – 704 691 – 895 760 – 1062	 436 - 582 **483 – 704** 691 – 895 760 – 1062	 436 - 582 483 – 704 **691 – 895** 760 – 1062
• **T&D Max Surface Torque** • DP Connection: NC50 • Hi Torque DP Connection: XT-50, 55	• **6500 ft-MD → 26000 – 27000 ft-lbs** **30700 ft-lbs** • 46000 – 52800 ft-lbs		
Rotary Table Size	27.5"	37.5"	37.5"
• TDS-350 Ton, 1000 HP • TDS-500 Ton, 800 HP	• **700 Klbs, 37000 ft-lbs** • 1000 Klbs, 37500 ft-lbs		

Figure 9: T&D Basis of Design for geothermal well

ISSN 2703-4275

As mentioned earlier, robust T&D simulation is an important aspect of rig sizing. In the early design phase, T&D was calibrated with a specific geothermal field with all unique downhole complications that helped the client to define rig sizing. The basis of design is shown in figure 9 above. The downhole complications that lead to higher friction factors are: under gauge Bit, drilling massive boulder rocks with larger rock cuttings, multiple losses and drilling through faults. We started off by pulling the data on T&D and calibrated it with Offset well. Then, perform a comparison between calibrated values vs Rig Pulling Capacity on 1000 – 1500 - 2000 HP rig option. Horsepower selection of the rig will determine its load – and certainly, this will be related to cost and safety, with the challenging mountainous area, potential landslide road, challenging road condition, and remote location.

Geothermal by its nature has the highest likelihood of stuck pipe (from a study conducted in 2015 – geothermal wells in Star Energy West java had an average 2 stuck pipes per well), thus need to ensure that rig sizing is sufficient to release from a stuck pipe stuck pipe situation, i.e. pull capacity, top drive rotation, and tubular Margin Overpull. Tool/ equipment rig failures also had contributors for this stuck pipe incident. This Stuck pipe category due to rig equipment includes two different types of failure; a) causing the mud pumps to shut off (pop-off valve), thus preventing circulation in the borehole or b) due to lack of circulation/movement as a consequence of rig equipment breakdown (TDS, etc) that directly involved and led to a stuck pipe incident.

The next phase was checking the Drill Pipe – as we know in geothermal, this is considered as sour service environment, thus Drill Pipe grade G-105 is the most recommended one. With the given G-105 Tensile Yield of 436 Klbs, thus the first limiter will be Dill Pipe itself. By doing this, we know that if we were to use higher HP rig above 1500 HP (with higher pulling capacity), it will not add any values because already being limited by DP G-105.

In addition, the next phase was checking Top Drive specifications. For Top Drive we can use TDS 350 Ton, whereby TDS 800-1000 HP is enough (TDS 350 Ton with Pulling capacity 700 klbs - align with rig capacity and having greater torque 37 kftlb as per T&D simulation).

Furthermore, thorough checks were being performed on the Rotary table size opening. The weakness for 1000 HP Rig is with small Rotary table opening of 27.5in opening, thus will not have the ability to drill 36in hole to set 30in the conductor. By this analysis, rig sizing was narrowed down to 1300 or 1500 HP Rig option. This is the case when the client need to add cellar +/- 7 cellar or even more in one pad (most cases in geothermal).

Summing up all of those pieces of information together, we were helping the client to select the most optimum rig for this campaign, i.e not necessarily going with the highest Horse Power Rig, by using 1500 HP rig. The concept is we want to have less loads, lighter equipment, lower number of soil bearings, that eventually will have safer and lower cost in the challenging mountain with limited roads. This has saved overall of 8% less on loads for rig moving, 20% less in fuel, and 7 % less in soil bearing requirement.

4. CONCLUSION

- Simplifying well trajectory plays a significant effect on well success. It minimized directional work in the reservoir zone.

- Directional steering strategy with a proper motor's sliding-rotation ratio was effective in reducing over steering and high DLS. Directional tendency and DLS capability modelled by Drilling Office was proven in the execution.

- Multiphase flow in geothermal drilling was studied to come up in a safe operating window in terms of flow rate and pressure drop for motor and MWD operation.

- Connection practices strategic approach by implementing aerated and reaming with high velocity.

- Torque and drag characteristic of geothermal wells were analyzed and calibrated for hole cleaning monitoring and aiding rig sizing selection.

- With all above approaches, successfully drilled the wells in the field and lowering Cost/ Megawatts.

NOMENCLATURE

BHA : Bottom Hole Assembly

MWD : Measurement While Drilling

TLC : Total Loss Circulation

TS : Tuffaceous Siltstone

DLS : Dogleg Severity

MWD : Measurement While Drilling

OD : Outer Diameter

ROP : Rate of Penetration

RPM : Revolutions Per Minute

SRPM : Surface RPM

Dumb Iron: Purely tubular tool (no mechanical/electronic inside it)

2D :Two Diemntional well profile (no turn rate applied)

DOX :Drilling Office X Software

EOU : Ellipse of Uncertainty

OSF :Oriented Separation Factor

ACKNOWLEDGEMENTS

The authors would like to thank both Star Energy and Schlumberger for permission to publish the data and information contained in this paper.

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