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Deepest Geothermal Well in Indonesia: A Success Story

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ABSTRACT

In geothermal, there are a lot of researches suspecting that there is another layer of reservoir deeper than the usual layer which has higher temperature and pressure. Particularly in Chevron Geothermal Indonesia, the layer of reservoir deeper than the present commercial layer in -5,500 ft.sl has not been reached yet. It would be a "moon landing" if the technology and specific drilling practices are founded to reach the reservoir. In 2012-2013 Drilling Campaign, Chevron Geothermal Indonesia (CGS), AWI Deepest Well was drilled to depth 10,402 ftMD/ 10,007 ft TVD (elevation -6,701ft.sl). The successful of AWI Deepest Well drilled deeper has proven that southwest area of the Salak field has deep commercial layer and It is also one of the deepest geothermal well in Indonesia to date.

Several best practices that team have captured to deliver of successful of drill deeper in the next project are BHA design optimization and higher temp BHA design. Beside of that, aerated drilling, defensive drilling, close monitoring of torque and drag and two mud coolers in drilling fluid system are other key success factor that need to be considered for next project campaign.

The successful of AWI Deepest Well drilled deeper has proven that some concerns about technical limit and design limit to drill deeper into hot zone can be answered. By having lesson learned, best practice and the information from AWI Deepest Well can improve the success of drill the deep well in Salak field. For Geothermal industry, in the future the success of AWI Deepest Well drilled deep can be a milestone for geothermal wells and reservoir development.

1. INTRODUCTION

Salak Geothermal field is one of two geothermal fields operated by Chevron Geothermal Indonesia, located in west java and has been produced since 1994 with total operating capacity is 377 megawatts. In order to maintain steam supply to support full generation, one of the strategies is well development program thru drilling campaign. The latest drilling campaign in Salak field was 2012-2013 drilling campaign which has been completed 11 new drilling wells.

AWI Deepest Well is one of the well was drilled in 2012-2013 drilling campaign, the objectives were combination of steam supply generation and value of information of Salak reservoir deep section. AWI Deepest Well was planned to drill in southwest of the field, based on offset wells were drilled, will be drilled to proven zone which projected reservoir temperature higher than 600 deg F. AWI Deepest Well map location depict in figure1.

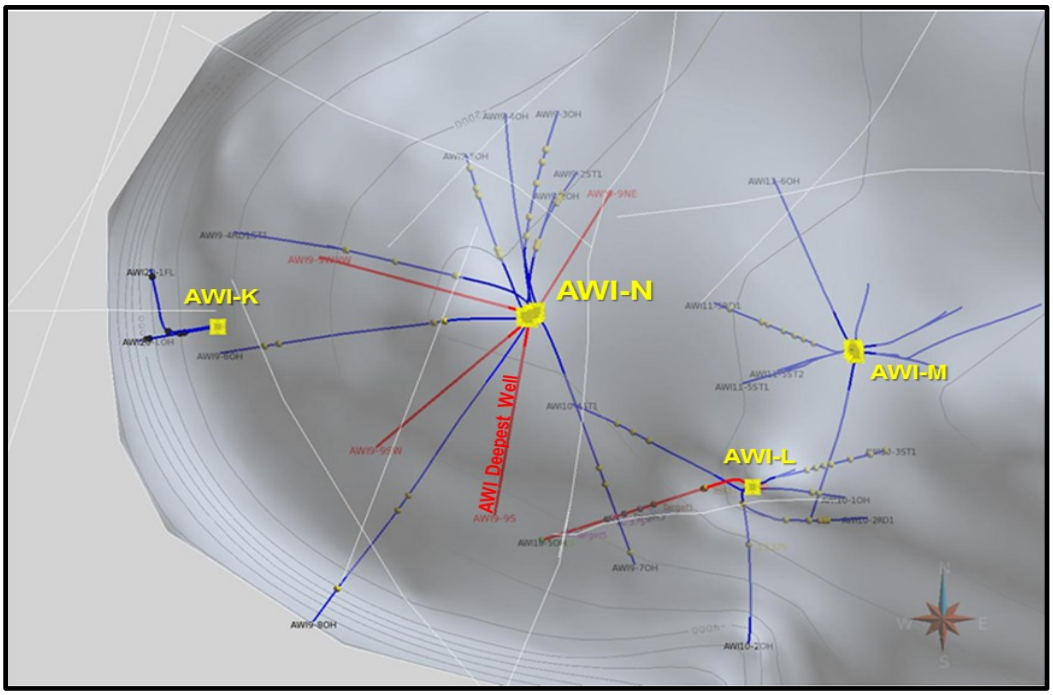


Figure 1: AWI Deepest Well Map Location

AWI Deepest Well also was planned to be extended drilling to the deeper zone of Salak reservoir, particularly in Chevron Geothermal Indonesia, the layer of reservoir deeper than the present commercial layer in -5,500 ft.sl has not been reached yet.

2. AWI DEEPEST WELL KEY CHALLENGES

During planning phase, CGI drilling team observed that the key challenges to drill deep geothermal well are high temperature and total losses, which results high risk of stuck pipe. Furthermore, CGI drilling team also found out that the key success factor to drill deep geothermal well is not only reducing the risk of having stuck pipe, also extending the hole section when drill in reservoir in order to have contingency hole section to drill to planned target depth. For AWI Deepest Well, 12-/14" hole section was planned to be extended, this section was planned to be drilled for 5800 ft length, will be drilled to permeable zone, which will have potential risks of stuck pipe and total losses. AWI Deepest Well drilling hazards depict in figure 2.

Stuck pipe will have serious consequence that lead to lose of drilling time and money, for AWI Deepest Well, stuck pipe event can be lost of opportunity to drill to deep section. In order to reduce the risk of stuck pipe, dealing with both high total losses and temperature is required, expected wellbore temperature is higher than 600 deg F.

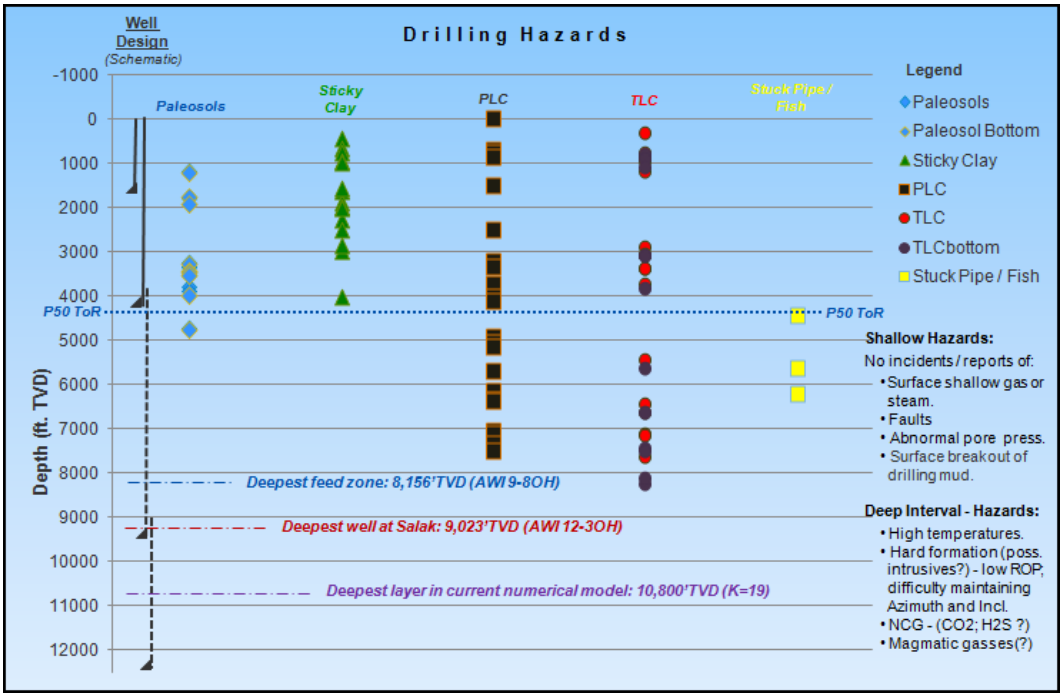


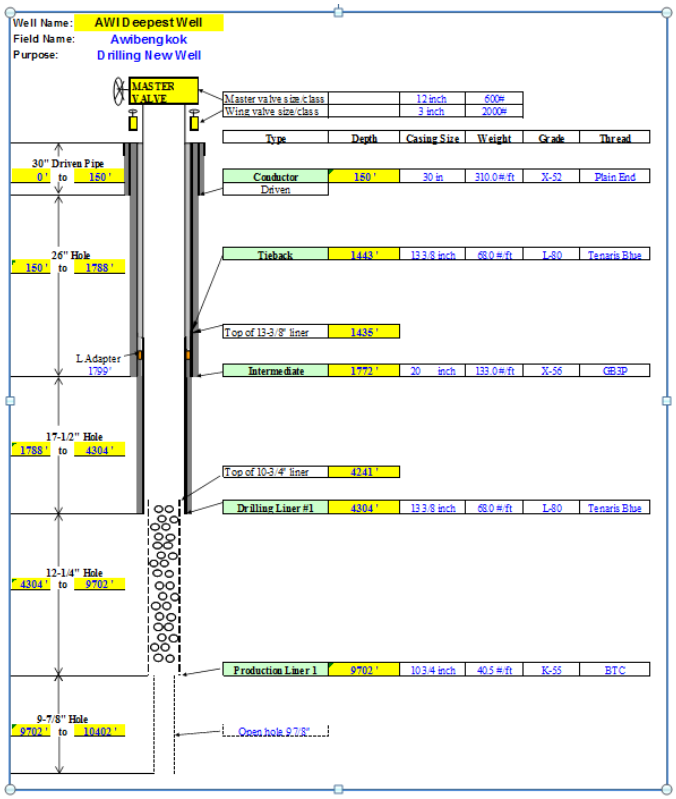
Figure 2: AWI Deepest Well Drilling Hazard

3. AWI DEEPEST WELL DRILLING STORY

AWI Deepest Well was planned to be drilled to 13,000 ft.MD /12,481 ft.TVD (elevation -9,175 ft.sl) and to be completed with 4 different diameter holes (26", 17-1/2", 12-1/4" and 9-7/8") and 1 contingency hole (7-7/8"). AWI Deepest Well was expected to drill to the losses zones, partial losses projection was starting from depth ~2000 ft in 17-1/2" hole section and total losses projection was starting from depth ~4200 where the top of reservoir zone.

AWI Deepest Well was spudded on 27 June 2014, the drilling was started with 26" hole section to depth of 1798 ft and then followed with 17-1/2" hole section to the Top of reservoir depth at 4314 ft, those section was completed by 1 bit ran. Reservoir section was drilled with 12-1/4" hole section to the depth of 9702 ft and then followed by landed the 10-3/4" perforated casing to the bottom. This section was completed with 2 bit ran safely with no stuck pipe event and also during drilling those section were successfully managed the return to the surface.

After drilled out 10-3/4" casing shoe, while continuing drilling about 300 ft of 9-7/8" hole section, there were experienced big total losses that lead to hydrostatic column dropped significantly in the wellbore and then followed by increasing the wellbore temperature and pressure that lead to well control issue. Due to the high risk of wellbore phenomena uncertainty then the team decided to suspend continuing drilling in order to be able to do study to improve the understanding of wellbore phenomena. AWI Deepest Well actual schematic and overall performance depict in figure 3.



Description	AFE (Days)	Actual (Days)	Variance f/ AFE	Remarks
Rig Move and Rig Up	8.35	10.45	2.09	Wait on Regulator Permitting
Drilling 26" Hole Section	2.54	3.33	0.80	Land Slide Near Misses
Run & Cement Casing 20" casing	1.45	1.11	(0.34)	Succesfully Set 20" Casing on Bottom
Drilling 17 1/2" hole section	3.16	3.29	0.13	Succesfully Drilled With 1 Bit Run
Run & Cement Liner 13 3/8" casing	1.71	2.72	1.01	Multiple Cement Squeeze Job
Run & Cement Tie Back Casing 13-3/8" casing	1.21	1.09	(0.12)	Succesfully Set 13-3/8" Casing Tie Back Safely and Timely
Drill 12-1/4" Hole Section	5.74	7.85	2.12	Succesfully Drilled 5390 ft of 12-1/4" Hole Section Safely Without Any Stuck Pipe Event
Run 10-3/4" Liner	1.02	1.43	0.41	Succesfully Set 10-3/4" Liner on Bottom
Drill 9-7/8" Hole Section	7.01	1.40	(5.61)	Experienced With Major TLC Event, That Leaded to Hydrostatic Colomn Drop. Wellbore Pressure and Temperature Increase Significantly
Logging Job on 9-7/8" hole	1.36	0.00	-	Suspended
Run 8-5/8" Liner	1.89	0.00	-	Suspended
Total Days	35.44	32.68	(2.76)	

Figure 3: AWI Deepest Well Actual Schematic and Overall Performance

4. AWI DEEPEST WELL KEY SUCCESS

Even though AWI Deepest Well not able to complete drilling to planned target depth at 13,000 ft.MD /12,481 ft.TVD (elevation -9,175 ft.sl), however, AWI Deepest Well has been successfully drilled to deep layer of Salak reservoir at -6,701 ft.sl, deeper than -5,500 ft.sl, where the deepest Salak wells ever drilled before.

The successful of AWI Deepest Well drilled deeper has proven that southwest area of the Salak field has deep commercial layer and it is also one of the deepest geothermal well in Indonesia to date.

Another key successful of AWI Deepest Well is drilled 5390 ft of 12-1/4" hole section safely without any stuck pipe event and wellbore problem, this is the longest 12-1/4" hole section that ever drilled in CGI. During drilling this section, the team also able to manage total loses and high temperature risks.

The successful of drill the longest of 12-/4" hole section can improve the chance of success drill the deep well in the future and also can be a milestone for geothermal wells and reservoir development.

5. AWI DEEPEST WELL BEST PRACTICE

During AWI Deepest Well drilling, several best practice and lesson learn has been identified that contribute to the success of drill to deep layer reservoir and some of it also can answer several concerns about technical limit and design limit.

5.1 Trajectory Design

During AWI Deepest Well planning phase, several well targeting and placement alternatives were assessed by the team, the preferred alternative was chosen to drill well as a standard J type directional well with azimuth of 196 deg and a maximum inclination of 17.7 deg, AWI Deepest Well directional plan depict in figure 4. In order to answer the challenge of total losses and stuck pipe, the team observed several best practices that can be adapted to AWI Deepest Well trajectory plan. AWI Deepest Well end of drilling build curve was planned before reached top of reservoir zone due to this zone high potential of loses, reservoir zone will be drilled in tangent section so it will minimize BHA steering work and keep it in fully rotate. AWI Deepest Well trajectory also designed to have maximum build angel rate of 3 deg/100 ft, it will reduce wellbore tortuosity and prevent high torque and drag. However, the consequence is required the kick off point in shallow section and build of directional curve will be completed with two hole section which are 26" hole section and 17-1/2" hole section.

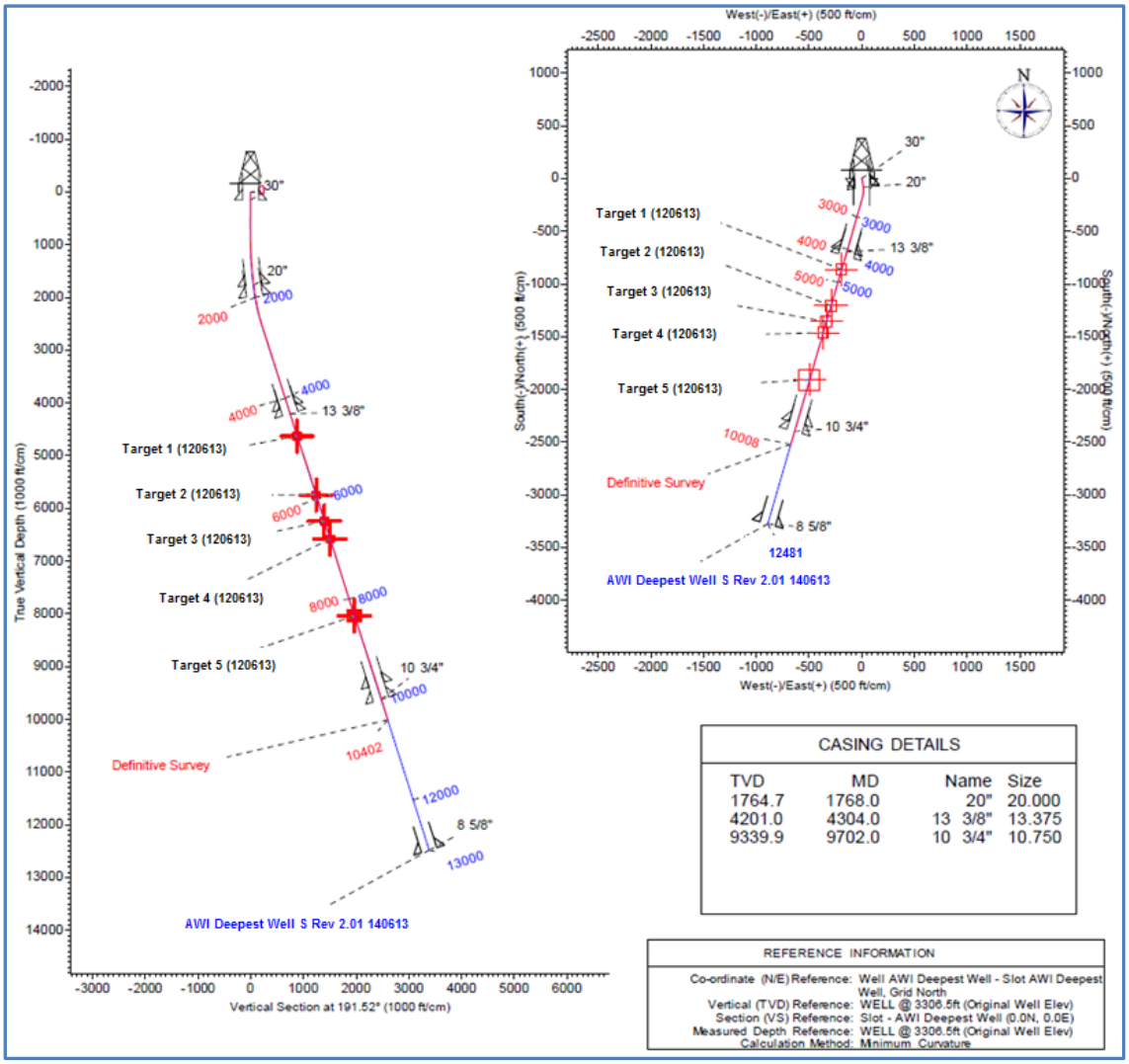


Figure 4: AWI Deepest Well Trajectory Plan

5.2 BHA Design

The challenges of AWI Deepest Well BHA design were durability in high temperature environment and in volcanic sediment rock and BHA stability to drill in long section. In order to prevent high temperature, high temperature of mud motor, drilling bits, Measure While Drilling (MWD), Pressure Monitoring While Drilling (PWD) and others high temperature down hole tool were prepared. BHA temperature limit depict in table.1

Table 1: BHA Temperature Limit

Item	Drilling Tools / Material	Temp. Limitation
1	BOPE (rubber butyl elements)	180°F / 82°C 210°F / 99°C (for max. 1 hr.)
2	Down-hole Mud Motors (stator rubbers)	320°F
3	MWD ('Measurements-While-Drilling') tools	302°F
4	High temperature Tri-cone bits	550°F
5	Mud polymer	400°F
6	Cement slurry / blend (Primary 13-3/8" cement job).	550°F (Depend on additives and density)
7	Explosives (for back-off)	500°F
8	Wireline electrical wire	450°F (Good for 8 hrs)
9	Wire-line logging tools (FMI; MSIP; CBL-USIT)	325°F / 163°C
10	Mechanical Sidewall Coring Tool (MSCT) – flasked.	370°F / 188°C
11	'Kuster' PT memory tool	697°F / 369°C

In order to enhance BHA durability in volcanic rock, team were observed lesson learn of using big drill collar size which is 9-1/2" drill collar to minimize MWD body contacted with formation, mud motor stabilizer with HF 600 hard facing to prevent attrition of hard and abrasive formation, extra protection of Tri-cone bits with 100% diamond protection to prevent bearing and seal failures, to be adopted in AWI Deepest Well.

AWI Deepest Well was planned to drill with mud motor and Tri-cone bits start from surface to planned target depth in order to have BHA stability during drilling, those were proven in previous wells that can reducing the torque and drag and also improve hole geometry.

5.3 Drilling Fluid Circulation System

Managing wellbore temperature within down hole tools temperature limit and ability to pump huge amount of fluid uninterruptedly always an issue for geothermal wells, in total loses condition drilling fluid to be pumped is required more. In AWI Deepest Well, two mud cool coolers was planned to utilize in order to manage mud return temperature. During rig preparation of 2012-2013 Drilling Campaign, rig mud system has been upgraded, high capacity mixing tank of 400 bbl per minute, in order to manage drilling fluid properties especially during loses condition.

During drilling of AWI Deepest Well, mud cooler system was proven able to reduce the return temperature about 30 deg f. AWI Deepest Well Mud Return temperature and pumping in temperature in 12-1/4" hole section depict in figure 5.

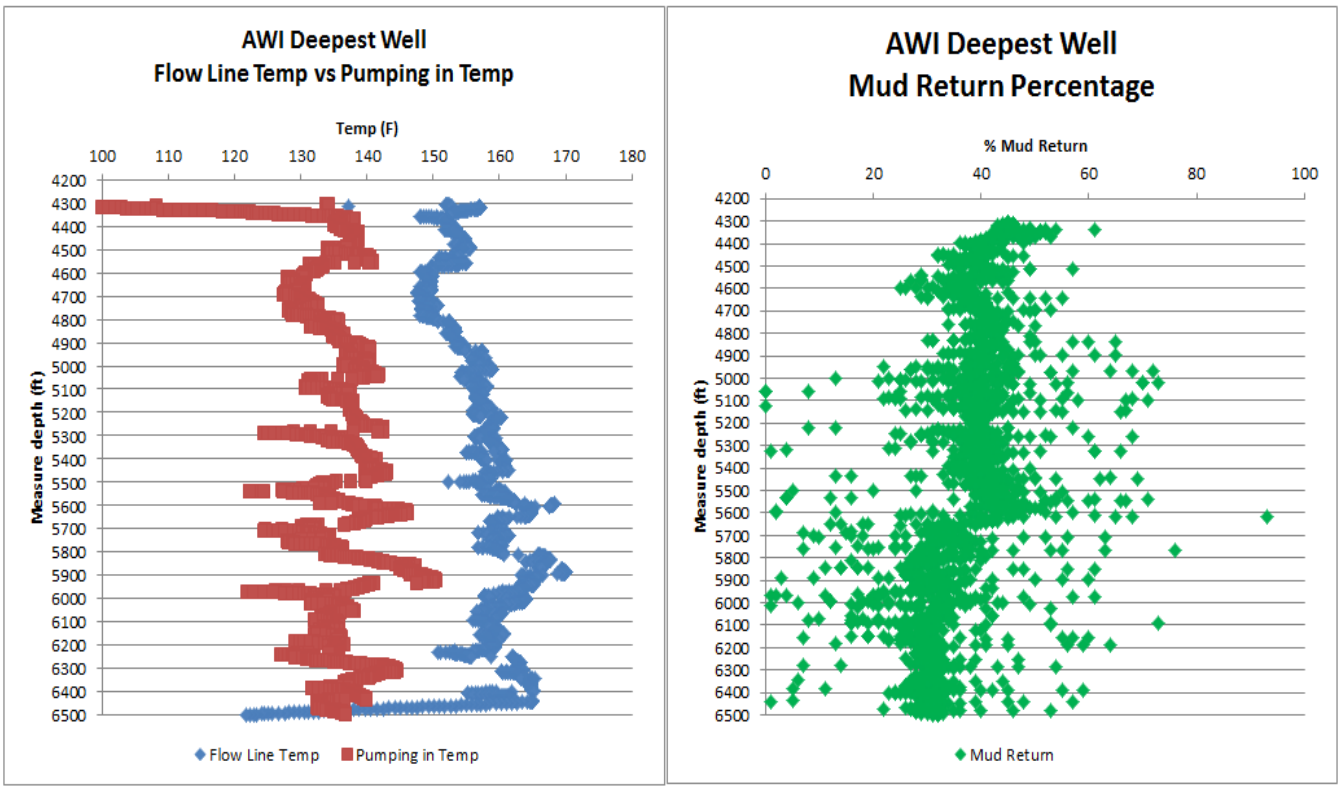


Figure 5: AWI Deepest Well Mud Return Temperature and Pumping In Temperature

At 6504 ftMD of 12-1/4" hole section, there were total losses event, gaining the return has been attempted but it was not successful, in order to secure the wellbore, drilling was continued with combination of mud pumping from inside of 800-900 gpm and backside of 5-10 bpm, installed high capacity mixing tank was successful managed mud volume and properties as per plan.

5.4 Down Hole Parameter Real Time Monitor

Stuck pipe prevention is needed to take look on detail during the planning phase of drilling geothermal well in order to eliminate stuck pipe event, ability to monitor down hole real time parameter will prevent stuck pipe event. AWI Deepest Well was planned to use EMT and PWD in order to have warning sign for abnormal condition that leads to stuck pipe event. Except directional survey, EMT also provided real time wellbore temperature, the temperature data was used to prevent down hole tools expose by high temperature that exceeded of the tools limit, it also used to update fluid circulation model, aerated model and well control prevention during drilling.

In 12-1/4" hole section, EMT was successful ran to planned TD section at 9702 ftMD, it was the longest of EMT tool ever ran in Salak Geothermal Field, based on EMT technical manual, working depth without repeater sub is up to 8000 ft. Best practice of the successful of ran EMT in long section were used of low frequency setting which improved of signal strength and placement of surface antenna that improved of signal communication between down hole and the receiver in the surface.

EMT and PWD were successfully ran up to TD of AWI Deepest Well at 1008 ftMD with no equipment failures, it was successfully provided down hole real time data which gave ability to monitor down hole condition, warning sign for abnormal condition and inputted data to update the models during drilling that resulted AWI Deepest Well have free stuck pipe event.

5.5 Down Hole Parameter Real Time Monitor

A reliable Well design is key success of drilling a well, it will be more critical for advance well such as AWI Deepest Well which will be drilled deeper, a good well design can be identified all potential risks and also have the mitigation for all identified risks so all of well objectives can be achieved. Chevron drilling team had developed an approach of collaboration between engineering and operations and software to design the wells and monitor the progress, this approach called "defensive drilling" which will be adopted in AWI Deepest Well. During well designing process, drilling team have done well design software simulations in order identified all possible risks and the mitigation and also to be able projected the drilling process.

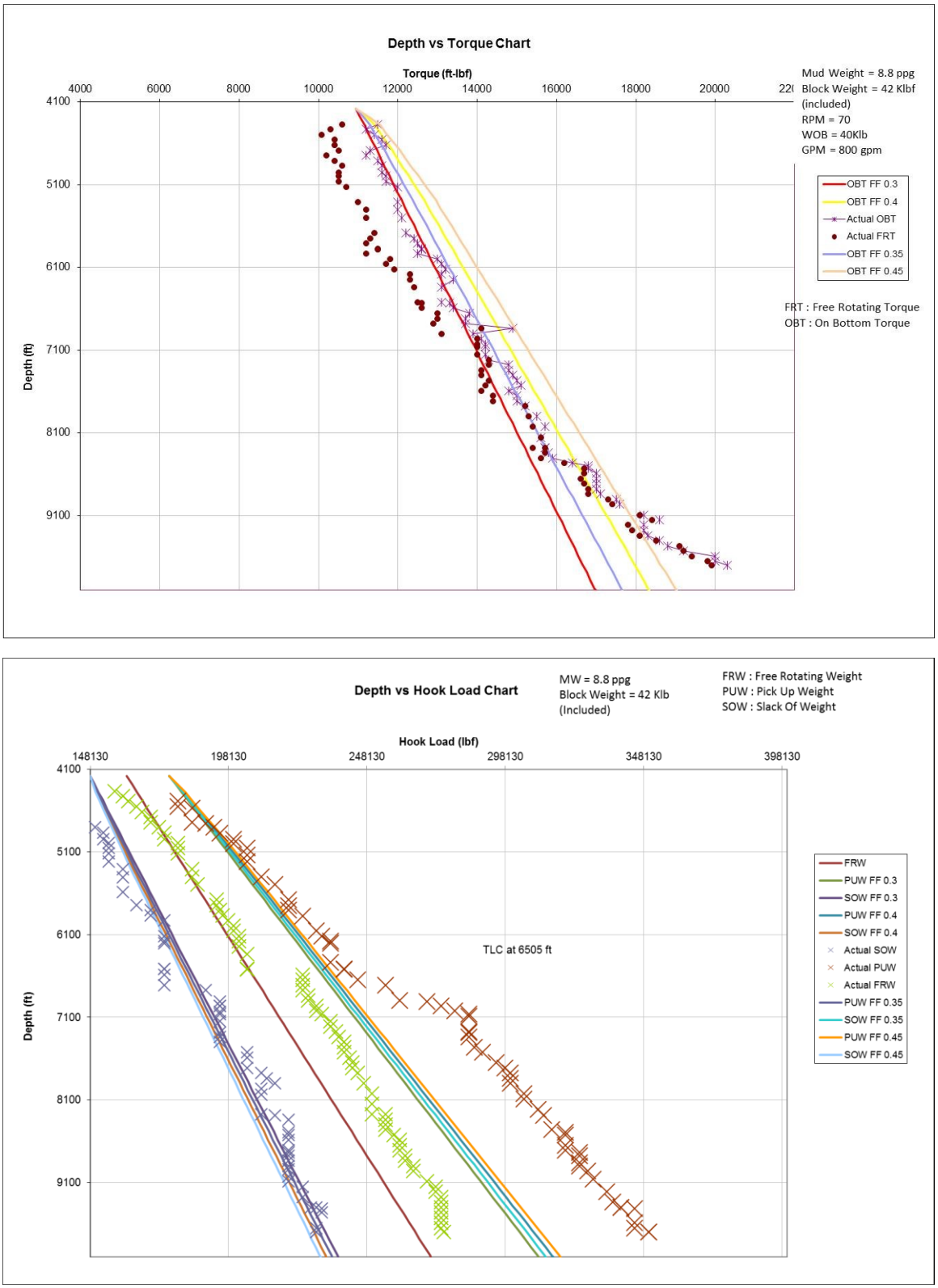


Figure 6: AWI Deepest Well 12-1/4" hole section actual parameter. (a) Torq and drag plot and (b) hook load plot

As mentioned before for the key challenges of AWI Deepest Well, drilling team observed the torque and drag were parameters will be a challenge especially in loses condition that can result hole cleaning problem and stuck pipe event, and also the loads will be

another challenge due to drilling long section and deeper. Defensive drilling was applied to answer the challenge, during well designing phase engineering has been done software simulation, Landmark's Engineers Desktop™ (EDT) as Chevron Global standard was used, the model result of software simulation converted by engineer to easy-to-use plots as anticipated parameter trends, field operation updated the plots with actual parameters and used is as parameter trends observation which allowed to observe anomaly condition and took correction action immediately. Figure 6 is AWI Deepest Well 12-1/4" hole section torq and drag plot and hook load plot.

The integrated approach of defensive drilling implementation has proven to mitigate the risk of stuck pipe incident, for AWI Deepest Well, the challenge of extended the 12-1/4" hole section can be answered and it became the longest 12-/14" hole section ever drilled in Chevron geothermal Indonesia.

5.5 Aerated Drilling

One of the biggest challenges in drilling a geothermal well is loss circulation, the team realized that AWI Deepest Well will more risk of loss circulation due to it was planned drill to proven reservoir and to deep section. Lesson learned from previous well, Aerated drilling has been successful gained the circulation that leads to better hole cleaning for drilling, adequate formation evaluation for earth scientist, and better geothermal production for reservoir are those key benefits.

In AWI Deepest Well, Aerated drilling modeling became one of key activities during well designing phase. During the drilling, the model was updated with wellbore pressure from PWD to be able monitor hydrostatic balance at down hole. Aerated model of AWI Deepest Well depict in figure 7, it shows from depth 6400' down, ECD has dropped significantly as shown by PWD data. This strongly indicated that the mud column in the wellbore has dropped to some certain depth. Difference of ECD before and after circulation can give general figure of where the depth of current water column in the wellbore is. By knowing it, the team can plan the corrective action accordingly.

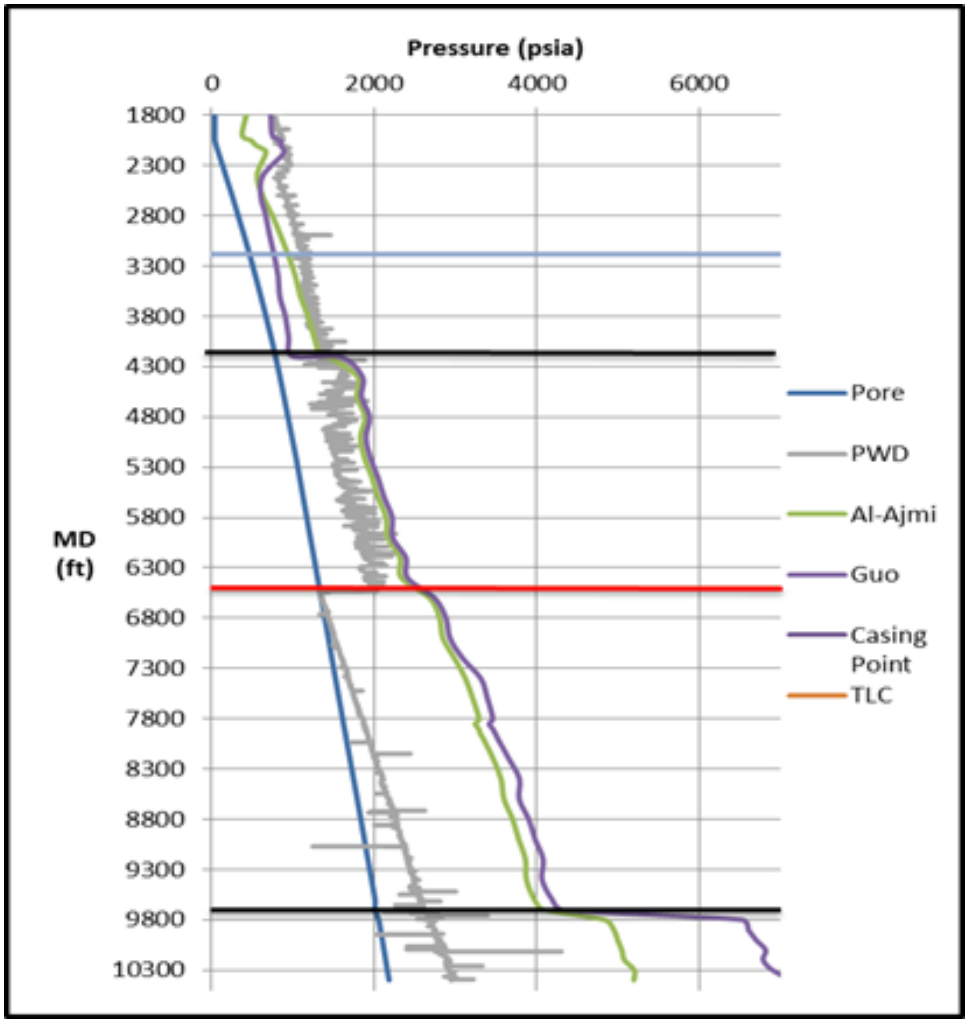


Figure 7: AWI Deepest Well Aerated Model

CONCLUSION

The successful of AWI Deepest Well drilled deeper has proven that some concerns about technical limit and design limit to drill deeper into hot zone can be answered. By having lesson learned, best practice and the information from AWI Deepest Well can improve the success of drill the deep well in Salak field. For Geothermal industry, in the future the success of AWI Deepest Well drilled deep can be a milestone for geothermal wells and reservoir development

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