Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Modular Solutions for Turn Key Geothermal Projects – Case Study Well Doublet Lansingerland, NL

Sebastian Homuth[1], Randy Loos[2]

[1]Deutsche ErdWärme GmbH & Co. KG, Stephanienstraße 55, 76133 Karlsruhe, Germany

[2]Züblin Spezialtiefbau Ges.m.b.H, Donau-City-Straße 9, 1220 Vienna, Austria

[1]sebastian.homuth@deutsche-erdwaerme.de, [2]randy.loos@zueblin.de

Keywords: project management, risk assessment, value engineering, turn key solution, case study, geothermal district heating

ABSTRACT

Despite favorable political and geological conditions geothermal projects for heat and/or electricity production face significant challenges in regards of structured project financing and execution. An experienced general contractor with the ability to provide project specific construction guarantees and a risk sharing approach can be the key element for the successful execution of geothermal projects. In order to provide turn key solutions a detailed technical and associated risk assessment needs to be performed. A long the way process optimization and technical updates can be implemented which will lead to faster project realization. This approach can be applied to the whole value chain of geothermal projects containing on a modular basis the project development and management, road, infrastructure and drilling location construction, conductor installation, well drilling including completion, heat and/or power plant construction as well as district heating network installation. The first successful implementation of this approach was done for the subsurface part of the geothermal doublet Lansingerland, NL.

The production well was designed as an exploration well to encounter all three potential reservoirs (Berkel, Delft and Alblasserdam) and was drilled with a maximum inclination of 54° to a final depth of 2709 m (2114 m TVD). The injection well was drilled with a maximum inclination of 61° to a depth of 2860 m (1859 m TVD). Both wells were successfully drilled with positive displacement mud motors instead of using cost intensive rotary steering systems despite the high inclination of the wells. The well test showed flow rates of up to 400 m³/h, associated temperatures of 60°C and a water/gas –ratio of approximately 1:1. Technical optimization of operational procedures and specific drilling services as well as project insurance solutions have been accomplished.

1. INTRODUCTION

Warmtebedrijf Berschenhoek B.V. intended to drill a geothermal doublet with the purpose to heat greenhouses situated in the Lansingerland region north of Rotterdam in The Netherlands. An appropriate concession is owned by the firm and local construction companies have been contracted to build the drill site and according infrastructure.

With regard to a turnkey system solution for geothermal heat and/or power plants, numerous aspects need to be taken into consideration in addition to the actual drilling work. As a general contractor, all of the professions that are relevant for a geothermal project can be offered and can include: Planning and construction of access routes and the drilling site, drilling and completion of conductor casing and geothermal well, planning and construction of heat and power plant, construction of district heating pipeline networks.

The drill pad is the solid foundation on which a geothermal well is drilled. The size of the well site depends on the foot print of the drill rig and production facilities needed. If all aspects are known to the general contractor time and planning optimization can be implemented easily. Casing strings are the main parts of well construction. The conductor casing isolates unconsolidated formations and groundwater and protects against shallow gas. Typical drilling depth of 20-70 m can be reached with much cheaper special foundation drill rigs. The surface casing is set to provide blowout protection, isolate water sands, and prevent lost circulation of drilling fluids. These deeper reaching surface casing can be installed with mobile truck-based drill rigs which have only a small foot print and are able to drill very efficiently the upper section to decrease cost on multiple well sites. The production casing or liner is used to isolate production zones and contain formation pressures to produce the geothermal fluid. The lower sections of the borehole can be drilled depending on the well design with compact and hydraulic driven modern semi-automated drill rigs. Geothermal heat or power stations utilize the heat from the geothermal reservoir to generate hot water for district heating and/or generate electricity via a turbine and generator. With the help of a qualified EPC contractor any size of geothermal plant installation can be planned and constructed efficiently up to the commissioning of the plant. District heating is a system for distributing heat generated in a centralized location for residential and commercial space and water heating via insulated pipelines. Incorporating specialized partners for such systems any length and size of network can be part of the general contractor scheme. In addition, specialized insurance solutions are sometimes the key for a successful bankability of a geothermal project. Therefore Lost-In-Hole (LIH) and Contractor-All-Risk (CAR) insurance packages need to be incorporated in the scope of a general contractor which also ensures that the overall interests of contractor and employer are aligned. All these aspects require of course a good contract and project management as well as suitable and powerful partners to successfully conduct such a geothermal project. In case of the Lansingerland project in Bergschenhoek (NL) this concept was successfully implemented for the first time for the subsurface part of the geothermal doublet.

Geological studies were done by Panterra Geoconsultants B.V. to investigate the geothermal potential for the concession. The Berkel/Rijswijk Sandstone and Delft Sandstone have been selected as the primary target formations which have the highest geothermal potential in the region. These formations are well known as a geothermal reservoir in the south-western part of the Netherlands. Based on the geological studies the most optimum subsurface locations for producer and injector have been selected and been used for the final well design.

2. RISK ASSESSMENT

In the region several wells have been drilled, either for production of oil in the past but more recently for geothermal purposes. Some of the closest geothermal offset wells are VDB-GT-01 and VDB-GT-02. All available public and additional offset well data has been analyzed to assess the drilling and completion risks.

Some of these risks are:

- Over the complete Tertiary swelling clays may occur, causing drill pipe to get stuck.
- In the Ommelanden and Texel chalk (total) mud losses may occur. One of the reasons of these mud losses are incised valleys in the Chalk (with permeable channel fill) or open faults.
- The Holland and Vlieland Clays can swell.
- The planned well trajectory cuts through a major fault. Mud losses should therefore be anticipated
- There are several faults in the study area. Minor faults could be present in the subsurface.
- There is a possibility that sub-seismic (i.e. not visible on seismic) faults are present in the area.

The following Figure 1 shows an overview of the identified potential drilling risks and associated stratigraphy.

Based on the identified risk appropriate contingency planning and mitigation measures have been implemented in the execution planning. Table 1 shows a few of these measures regarding the drilling process.

Table 1: Drilling risks and mitigation measures.

Formation	Drilling hazards	Mitigation measures
Upper North Sea Group	Unstable shallow sands Mudlosses in sandy topholes; Swelling clays; Washouts;	Install deep conductor Use low mud weights Start with low drilling parameters until firm formation has been reached. Inhibitive mud system, minimize open hole time Avoid reaming, limit flowrates.
Chalk Group	Cherts in Ommelanden fm.	Bit selection (have insert bit available at the drill site)
Holland	Mud losses in Holland Greensand	Use low mud weights Lost Circulation Material
Vlieland Sandstone	Swelling clays Cavings Sticky clays / bit balling Fault present in Vlieland Claystone (could cause losses) Mud losses	Inhibitive mud system, minimize open hole time, low fluid loss Maintain low fluid loss, optimize mud weight Inhibitive mud system, use bit with large junk slot area. Optimize mud weight Low mud weight, use LCM
Nieuwerkerk	Pyrite in Rodenrijs Claystone Mud losses in Delft sand	Use bit with back-up cutters Low mud weight

Stratigraphic Column Lansingerland				RESERVOIR	Major SEALS	Total hydrocarbon Gas shows 1% = 10.000ppm					Possible drilling hazards	
Group	Period	Formation	Member			VDB-01*	VDB-02	VDB-03	VDB-04	CAP-01		
Upper North Sea NU	Quaternary	"Diverse"				no record					Mudlosses and washouts in sandy topholes,sand cavings, slightly swelling clays.	Clayballs, overpulls, stuck pipe, swabbing.
		Maassluis NUMS										
	Tertiary	Oosterhout NUOT									Sand & silt cavings, trace pyrite.	
		Breda NUBA									Pyrite, swelling clays.	
Chalk CK		Ekofisk CKEK									Mostly in this Fm	Clayballs; overpulls; stuck pipe; swabbing
	Cretaceous	Ommelanden CKGR				< 0,5%					Layers of chert , pyrite. Possible mudlosses in base section 'KARST'.	
		Texel CKTX	Plenus Marl CKTXP			< 0,7%						
			Texel Marlstone CKTXM								Pyrite, trace chert, some mudlosses.	
Rijnland KN		Holland KNGL	Upper Holland Marl KNGLU			< 0,3% seldom up to 0.9%	< 0,5%			< 0,01	Swelling clays, cavings (mainly from the shales of the Lower Holland Marl), mudlosses in Middle Holland Claystone and Holland Greensand.	
			Middle Holland Claystone KNGLM			< 0,4% base 50m: 0%	< 1%			0		
			Holland Greensand KNGLG			< 1,5%	< 1,5%	< 0,2%	< 0,1%	0		
			Lower Holland Marl KNGLL			0,8 - 2%	< 2%	< 0,2%	< 0,1%	< 0,003%		
		Vlieland Sandstone KNNS	De Lier KNNSL			< 2%	< 0,6%	< 0,05%	0,05 - 0,2%	< 0,005%	Pyrite, mudlosses.	
			Vlieland Claystone KNNCM			< 2%	< 1%	< 0,2%	0,08 - 0,3%	0,01 - 0,25%	Very sticky clays, clay balls, bit balling, overpulls, swabbing.	
			Fault								Cavings. Mudlosses and/or influx of formation water or hydrocarbons?	
			Berkel Sandstone KNNSB			-	< 0,5%	< 0,2%	< 0,2%	< 0.15%	Mudlosses.	
			Berkel Sand/Claystone KNNSC			0 - 1%	< 1%	< 0,3%	< 0,2%	0,02 -0,2	Pyrite.	
			Rijswijk Sandstone KNNSR			0 - 2%	< 1%	< 0,6%	0,10%	< 0,22%	Mudlosses and/or influx of formation water. Pyrite.	
Schieland SL		Nieuwerkerk SLDN	Rodenrijs Claystone SLDNR			< 1,5%	< 2%	< 0,8%	0 - 0,1%	-	Pyrite, some cavings, Mudlosses in lower section.	
			Delft Sandstone SLDND					< 0,9%	0 - 0,02%	-	Mudlosses.	
			Alblasserdam SLDNA					< 1,1%	Top section 0,08 -2%	0,02- 0,43%	Mudlosses in sandy top layers, swelling clays.	

Figure 1: Stratigraphy related drilling risks and hydrocarbon gas show potential for the geothermal wells in the Lansingerland concession (Panterra report, 2016).

3. SUBSURFACE WORKS

Züblin Spezialtiefbau GmbH in Joint Venture with Huisman Equipment BV executed all subsurface works for the completion of the geothermal doublet in the Lansingerland concession. The production and injection well have been drilled with the rig LOC 400 (360 to hook load capacity) to 2709 m and 2860 m in order to produce thermal water from the Berkel/Rijswijk Sandstone and Delft Sandstone which have been selected as the primary target formations. The drilling works (conductor installation and deep drilling) including all drilling services (drilling fluid and solid control, directional drilling, casing running, cementing, mud logging, wireline logging) as well as the required energy and material supply (casings, float equipment, liner hanger, mud chemicals, wellheads) and the waste management have been part of the contract. In addition, major parts of both well tests including ESP string installation, surface pipework, data measurement and monitoring have been performed by the Joint Venture with a turnkey solution with lump sum contract.

Successful execution was based on the previously performed risk assessment and consequential cost structure as well as on technical optimization measures. The main technical adjustment in the execution phase was the utilization of positive displacement mud motors instead of a rotary steerable systems. This resulted in a severe decrease of exposed downhole risk and associated Lost in Hole insurance premiums.

All sections have been drilled with one bottom hole assembly mostly in one run to desired section depth.

3.1 Drilling and Testing LSL-GT-01

The 16" section of LSL-GT-01 (Fig. 2) was drilled with a 9-5/8" steerable motor assembly with 1.5° BH setting from 148 m to 1100 m and with one BHA. First nudge at 178m at 265 MTF to divert from the well LSL-GT-02 (planned) to avoid any collision issues. Kicked of at 600 m as per plan in a direction of 220° azimuth. The final survey was just shy of 50 deg inclination and 212 deg azimuth. This ideally set the well up for the next phase in the 12 1/4" tangent section. All the objectives were achieved in this section including reaming some tight spots. The average ROP was 8.1 m/hr.

The 12 1/4" section was also drilled with one BHA with a 8" steerable motor assembly with 1.15° BH setting from 1100 m to 2034 m. Drilled tangent maintaining inclination at 47° in a direction of 212° from 1100 m to section TD at 2034 m. The average ROP was 12.5 m/hr. Drilling to TD (2034 m) of the 12 ¼" section was done after 6 days, later it was decided to set the 9 5/8" shoe higher at 1987 m. To preserve the Berkel formation a weighted high visc pill was pumped and while POOH tight spots had to be reamed. A wash down trip followed by backreaming was also necessary which resulted in total of 4 extra days for this section. Completion with the 9 5/8" liner had to be carried out with extra precaution measures and was successfully washed down to planned shoe depth.

The 8 1/2" section was drilled again with one BHA with a 8" steerable motor assembly with 1.15° BH setting from 2034 m to 2709 m without problems. Because the targets were moved 48 m TVD shallower, oriented drilling was executed from 2044 m to 2152 m. From that point rotary drilling continued with a steady drop between 1 and 1.5°/30m. Well TD was called at 2709 m, 129 m deeper as planned and the Werkendam formation was still not reached. Final survey at bottom showed 35.18° inc, 219.08° azi. All targets, the originals and new, were hit. The average ROP was 12.2 m/hr. Actual drilling operation to reach TD lasted 4 days. For preparation of the wireline open hole logging an extra wiper/check trip was conducted. Open hole logging was followed by the cased hole logging campaign. The completion of this section with blanks and screens was then executed to a shoe depth of 2550 m. The lower part of this section to well TD remained open hole (see Figure 2 for well schematic).

The following well test was conducted directly after completion within 7 days including a successful fishing operation for the slickline and p/t gauges. The well testing showed maximum measured flow rates of 399 m^3/h and a maximum temperature of 60°C.

3.2 Drilling and Testing LSL-GT-02

The 16" section of LSL-GT-02 well (Fig. 3) was drilled with a 16" Tricone bit and a 9 5/8" steerable motor assembly with 1.5° BH setting and MWD-GR. It was drilled in rotary and sliding mode to 1136 m with one BHA. First nudge at 158 m at 90° MTF to divert from the well LSL-GT-01 to avoid any collision and magnetic interference issues. The start of the nudge was done from a scribe line as the MWD was still in the casing. Kicked off at 450 m as per plan in a direction of 156° azimuth. The final survey was 61.04° inclination and 156.48° azimuth. This ideally set the well up for the next phase in the 12 1/4" tangent section. All the objectives were achieved in this section. The average ROP was 13.49 m/hr. After hole cleaning the 13 3/8" surface casing was set with a casing shoe in 1130 m. The cement job was successfully completed, and complete pressure test and installation of wellhead and BOP was performed.

The 12 1/4" section was drilled with a steerable motor assembly with 1.15° BH setting from 1136 to 2214 m in one run. The BHA was building slightly in rotary for most of the section, only in the sandier formations it would show a minor dropping trend. The NOV Hemidrill motor performed very well, with ROP's up to 35 m/hr in softer parts of the section. Hole cleanig was good with 3500 lpm and 80-100 rpm. Last survey at 2195.7 m showed 59.95° inclination and 155.96° azimuth, 1.7 m below and 6 m left of the plan which was a good set up for the 8 1/2" section. The average ROP was 15,4 m/hr. Setting 9 5/8" Casing and cement Casing with Casing Shoe at 2209 m and pressure tested 13 3/8" casing and 9 5/8" liner with success.

The 8 1/2" section was drilled with one BHA with a 6 3/4" steerable motor assembly with 1.15° BH setting from 2214 m to 2860 m without problems. Oriented drilling was executed from 2227 m to 2460 m for the turn and drop to align to the targets. From that point rotary drilling continued with a steady drop of about 0.5°/30m. Well TD was called at 2860 m. Final survey at bottom showed 50.8° inc,144.51° azi. The average ROP was 11.9 m/hr. The installed 6 5/8" blanks and 7" wire wrapped screens completed this section with a casing shoe depth of 2858 m (see Figure 3 for well schematic).

A short well test with installation of an ESP string and build up phase have been performed within 4,5 days. The maximum measured flow rate was 370 m^3/h and the maximum temperature was 57°C.

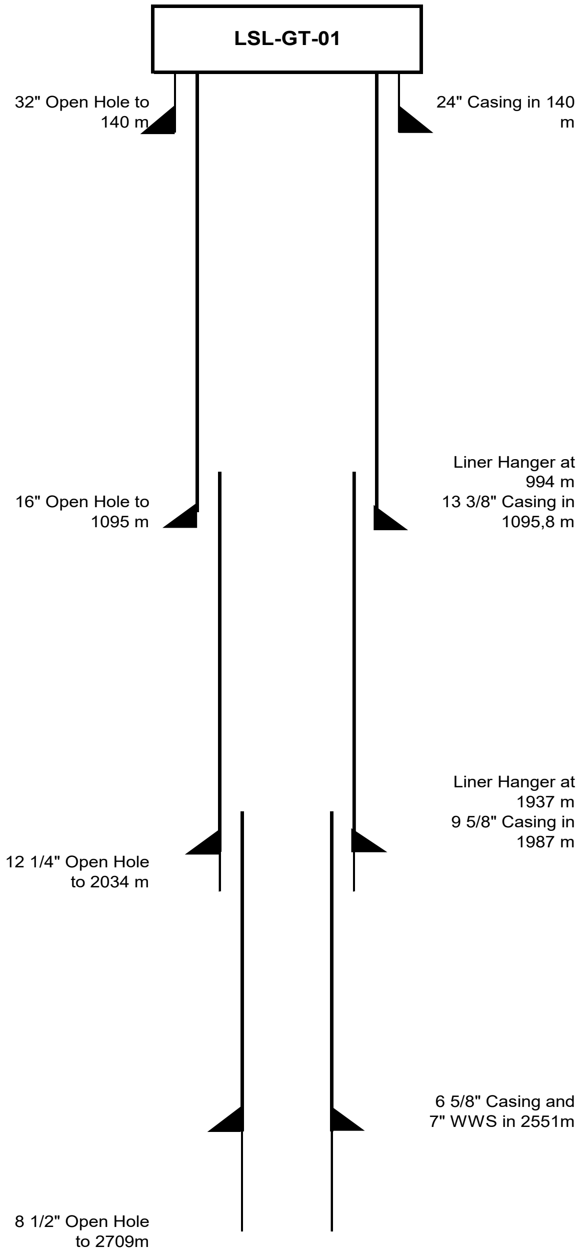

Figure 2: Well schematic of LSL-GT-01.

4. PROCESS OPTIMIZATION

Besides minor process optimization measures in the general plan of action the main adjustment which was incorporated has been the use of mud motors instead of rotary steerable systems for the directional drilling service. There have been basically two options to drill the 12¼" hole sections of the Lansingerland project; use a Positive Displacement Mud Motor (PDM) or a Rotary Steerable System (RSS). Both systems have advantages and disadvantages which of some are listed in Table 2.

In addition to the technical point of view the economical value of both operation modes has been assessed. If cost per 1000-meter drilling are considered the RSS cost per meter of ca. 85 Euro x 1000 m = 85,000 Euro compared to the PDM cost per meter of ca. 38 Euro x 1000 m = 38,000 Euro. Another important factor especially considering project insurance premiums are potential LIH / Replacement Values of these tools. The RSS averages at 1,200,000 Euro compared to the PDM which averages at 350,000 Euro.

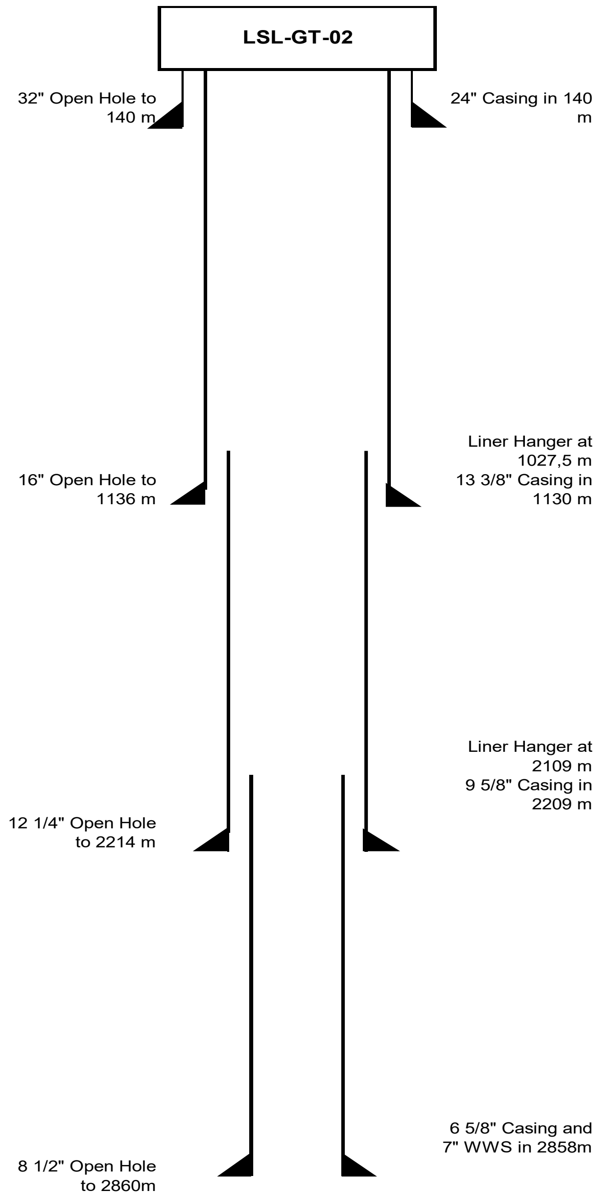

Figure 3: Well schematic of LSL-GT-02.

Taking into account these factors the PDM option was chosen for the Lansingerland project for the following reasons. RSS was developed for high complexity, accuracy and high-end formation evaluation, where a high rig day rate justifies the cost of a RSS. With the geothermal rig day rates and simple formation evaluation requirements (up to gamma ray) this is absolutely not the case. The well trajectories are not of such complexity that they require complex steering and can be done using a PDM. Most complexity of these wells are in the 16” hole where the kick off point is and another in the 8½” hole where the final turn is made starting from the 9-5/8” casing shoe. The formation target is wide and does not require an accuracy within 1 meter for which you would require a RSS (over-engineered vs. fit for purpose & cost effective technology of PDM). The running cost for a PDM compared to the RSS is about halve. Also, the repair and service cost as well as the LIH value of a PDM is less than 1/3 of a RSS. A PDM requires less power from the surface equipment than a RSS, the main power to the bit will come from the mud flow instead of having to run the top drive continuously at high loads (rpm – torque). Less chance of stick-slip with a PDM due to its rotary independence from the drill string resulting less potential downhole equipment damage and increased ROP in rotary drilling mode. Damage due to stick slip can lead to "Damage Beyond Repair" (DBR). Not all RSS are capable/reliable in drilling cement and float equipment with potential damage and high repair costs to the RSS and again can lead to DBR.

It's true that the higher RPM of a RSS could improve hole cleaning, but hole cleaning does not only depend on RPM. Hole cleaning more depends on other factors like mud properties and drilling practices: sufficient flow, reaming each connection drilled, control ROP, etc.. The 12¼” hole sections that has been drilled have be mainly holding inclination and making a turn in the last 75 meter meaning that most of the hole section we will be rotating the sting and although not over 120 RPM, 60 RPM also helps hole cleaning. With the motor you have bigger selection of bits. With a RSS the bit selection is way less and a unexpected change in formation or other parameters would make the RSS useless resulting in an extra bit trip and therefore cost. The next offset wells have as well been successfully drilled with mud motors.

Table 2: Comparison of PDM vs. RSS.

	PDM advantage	RSS advantage
Running Cost	X	
Lost In Hole (LIH) value	X	
Repair / Service Cost	X	
Ease of steering to target		X
Better hole Cleaning due to high RPM		X
Less chance of Stick Slip	X	
Drilling Float equipment / Cement	X	
Less Casing Wear	X	
Less Surface Torque	X	
RPM limitation		X
Less reaming required		X
General Higher ROP		X
Broader selection of bits	X	
Temperature Tolerance	X	
Less Failure	X	

Geothermal wells across the world are drilled with mud motors and the same counts for the majority of the O&G wells in the Southern North Sea. These O&G wells are way more complex then what most of the geothermal projects require. The success of the US Land O&G market has been mainly because of use of fit for purpose technology and cost-efficient solutions, not over-engineered technology. In the US on land 95% of the wells are drilled using mud motors in the steering section that build up to even 90 deg. Their standard practice is also to ream the hole every joint or stand drilled.

However, the following mitigation measures have been implemented to ensure a successful drilling operation with PDM technology:

- Ease of steering to target; proper selection of experienced Directional Drillers with the correct experience using PDM.
- Hole Cleaning due to high RPM. Hole cleaning does not just depend on RPM more important factors are to optimize mud flow, maintain proper mud properties, control ROP and ream every single drilled to clean the hole. If required and the hole dictates a wiper trip can be planned with a locked assemble to extra clean the hole prior running the 9-5/8” Casing. The 9-5/8” Casing should be rotatable and comprises a Reamer Shoe and can therefore be washed/reamed down to setting depth.
- RPM limitation; this is mainly effecting the assistance in hole cleaning and can be mitigated by the Hole Cleaning mitigation.
- Less reaming required; reaming a hole is not a bad thing and is only time consuming, the lower running cost of a PDM justifies the extra reaming time but would personally ream each joint drilled with an RSS as well
- General Higher ROP; depending on the formations an RSS can have higher ROP’s when it is run at optimal RPM to avoid stick slip. If stick slip occurs the ROP will drop to near zero with the risk of bit and RSS damage. The ROP increase is mainly seen in deeper layers which are more compact and homogeneous, the layers drilled in this project are not this and therefore not much difference in ROP was expected except for the required sliding and reaming sessions.

There was a change that an extra wiper trip of 1½ days was required prior running the 9-5/8” casing when drilling the well with a PDM but drilling these borehole sections with an RSS as the higher RPM only helps with hole cleaning, it does not guarantee a clean hole and other more important aspects contribute to hole cleaning. Besides this, the 12¼" hole section is mostly holding angle so most of the time the motor BHA was rotating as well. To mitigate most casing running issues the 9-5/8” casing was run with a rotatable liner hanger assembly and a reamer shoe. From surface to bottom the casing string can be rotated and washed down due to the use of the Casing Drive and once on drill pipe having the rotatable liner hanger.

With the expected loss zone in the 12-1/4” hole section the chances of losing a BHA are increased as well, obviously knowing this beforehand the chances of getting stuck can be reduced but an obviously increased risk remains. For the costs of losing or damaging an RSS two PDM’s and re-drilling the 12¼” hole section twice will still be cheaper.

5. CONCLUSIONS

Incorporating specialized partners for being part of a general contractor scheme provides execution and budget security. Depending on the individual project requirements and having a modular services structure all or only partial works of a geothermal project can be implemented in a general contractor scheme. In addition, specialized insurance solutions can be the key for a successful bankability of geothermal projects and therefore Lost-In-Hole (LIH) and Contractor-All-Risk (CAR) insurance packages should be incorporated in the scope of a general contractor. This also ensures that the overall interests of contractor and employer/project developer are aligned. This kind of project setup obviously requires an experienced contract and project management as well as suitable and powerful partners to successfully conduct such a geothermal project. In case of the Lansingerland project due to the detailed technical review of the general contractor and implemented technical optimization as well as risk mitigation and contingency planning of the project management of contractor and employer the doublet was executed in budget with reduced risk portfolio and consequential cost savings.

REFERENCES

PanTerra Geoconsultants: Proposed doublet in Lansingerland (G1135), 90 p, unpublished, (2016).