Theistareykir Geothermal Power Plant – Successful Drilling Campaign

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ABSTRACT

The 90 MW $_{\rm e}$ Theistareykir is the latest geothermal powerplant in Iceland, commissioned in December 2017. The plant is powered by 14 production wells, currently yielding around 105 MW $_{\rm e}$ of steam. The geothermal resource is of high enthalpy and drilling in the most productive part of the field proved to be highly challenging due to overpressure in the uppermost 300 m and temperatures up to 380°C in the geothermal reservoir. In total 9 exploration wells were drilled from 2002-2012 before a decision was made to build the power plant in 2014.

Drilling works for 7-10 production wells in Theistareykir and Krafla geothermal areas was tendered in 2015. In total four international drilling contractors placed highly competitive bids and a contract was signed with the Iceland Drilling Company which provided the lowest bid. The drilling campaign started in May 2016 and was completed in August 2017. A total of eight wells were drilled to depth from 2.200 m to 2.700 m, all of them deviated. Number of challenges had to be met during the drilling and the first well had to be abandoned after a blowout. To avoid that from happening again, the design of the wells in over-pressured area was modified as well as the drilling mud program. The paper describes the challenges met during the drilling campaign and how they were met to ensure successful results.

1. INTRODUCTION

The geothermal area at Theistareykir is located in a mountain area in Northeast Iceland. The site is 300-350 m above sea level where average annual temperature is about 2°C with extremes ranging from -25°C to +25°C. It is usually very snowy during the winter. Húsavík is the nearest town to Theistareykir. A permanent all-year around road has been constructed, total 26 km, which connects those places. The town of Húsavík has a harbour and a domestic airport with daily flights to the capital Reykjavík. Driving distance between Reykjavík and Theistareykir is close to 500 km. It was a challenge to get international drilling contractors to bid for a drilling campaign in this remote area on a faraway island in the north Atlantic ocean - which Iceland is to most drilling companies.

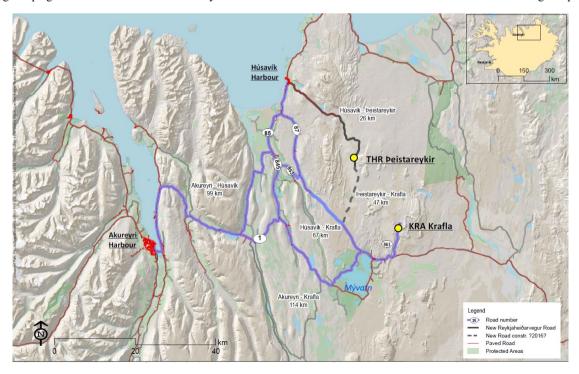


Figure 1: Map showing part of north-east Iceland and the location of Theistareykir area.

2. THEISTAREYKIR DRILLING CAMPAIGN

The municipalities around the Theistareykir geothermal area and landowners established the company, Theistareykir Ltd., in the year 1999 with the purpose of developing the geothermal resource to attract industry into the area. The first two exploration wells were drilled in 2002 and 2003. In 2005 Landsvirkjun bought one-third share in the company and funded further exploration drilling, in total four wells in the years 2006-2008. In 2010 Landsvirkjun bought all shares in the company and took full control over the project. In 2011 and 2012 three more wells were drilled. In 2014 a decision was made to build a 90 MW_e geothermal power plant at Theistareykir. At that time, total of nine exploration wells had been drilled in the area. Seven of them could provide steam to produce about 57 MW_e. The capacity of the geothermal field at Theistareykir was at the time estimated close to 200 MW_e. (Knútsson et al., 2018). Following the decision to develop the Theistareykir power project, a decision was made to tender out up to 10 geothermal wells, 7 firm and 3 optional.

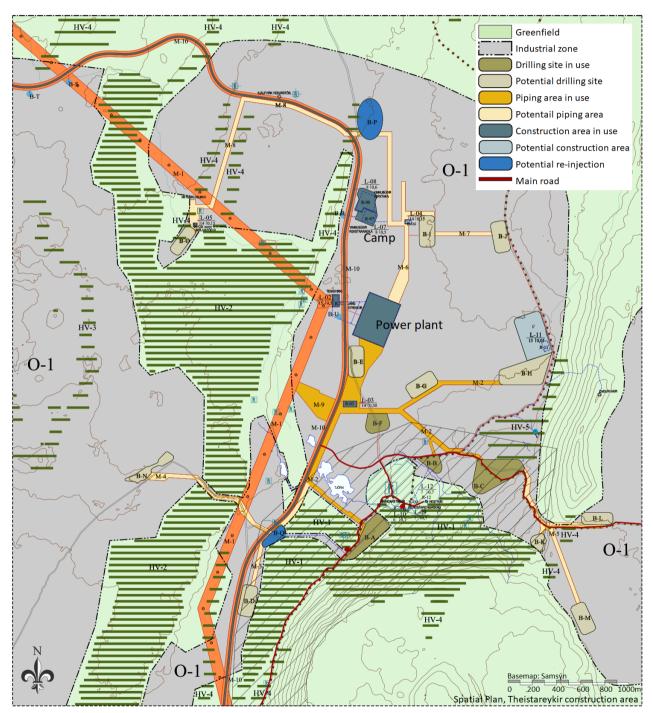


Figure 2: Theistareykir Local Plan.

2.1 Tender and preparation

Tendering documents were based on FIDIC - Red Book (Conditions of Contract for Constructions). The payment scheme can by referred to as "hybrid", i.e. prices were based on meterage, lumps sums, standby rates and unit prices. Performance security was set 10% and advance payment also. Underground risk to be shared 50/50 up to USD 1 Million, after that the risk was on Landsvirkjun. The contract was to be governed by the law of Iceland.

The tender was advertised internationally. Employees at Landsvirkjun with connections to international drilling contractors contacted them to draw their attention to the tender and offered them a site visit which couple of them accepted.

To make this tender attractive to international drilling contractors, a payment of USD 50.000 was offered for tenderers number 2 and 3 that fulfilled the requirements.

In general, the tender was for "integrated drilling works" with several exceptions in an attempt to make the tender more favorable for both Landsvirkjun and international drilling contractors. In most drilling campaigns in Iceland, all material has been provided by the drilling contractor. This is usually not the case on the international drilling market. Therefore, it was decided that Landsvirkjun would provide all steel for construction of the wells. This includes casings and liners, centralizers, float shoes and collars, wellhead flanges, expansion spools, valves etc. Landsvirkjun would also provide drilling pads, boarding and lodging services in a construction camp on site, water supply for the drilling work (up to 50-60 l/s) and wire line logging.

The contractor was to provide fully equipped drilling rig, trained and experienced crew, drilling equipment (drill string, drill collars, stabilizers, mud motors and drill bits), casing services, cement and cementing services, direction drilling services, mud and mud engineering.

The outcome of this was that Landsvirkjun received four valid bids from four international drilling contractors:

•	Jardboranir (Iceland Drilling Company)	(64%)
•	LNS Saga ehf and Leonard Nilsen and Sonner AS	(91%)
•	JV Entrepose Geodrilling and Borfélag Íslands ehf	(129%)
•	Dalrup & Söhne AG	(136%)

The numbers in brackets are percentage of cost estimate.

After couple of clarification meetings, a contract was signed with Jardboranir on February 5^{th} 2016. The companies in 2^{nd} and 3^{rd} place were paid USD 50.000 as promised. The management of Landsvirkjun decided to honor the company in the 4^{th} place also with the same amount.

At the same time, Landvirkjun tendered casings and liners. Twelve valid bids from twelve different companies were received, only one of them higher than the cost estimate, reflecting market conditions and relatively low oil prices. A contract was signed with the lowest bidder, ITECO. The contract amount was 52% of the cost estimate.

Mastervalves (10" Class 900 and Class 1500 expanding gate valves) were purchased from TIX-IKS after a tender and other material for the well construction was purchased after price enquiries to different suppliers.

Perforation of the liner was done by local workshop in Iceland for the same price as offered by a mill in China where the casings were manufactured. Manufacturing and testing of wellhead flanges and expansion spools were also carried out in Iceland.



Figure 3: Ship with casings being unloaded in Húsavík harbor. The casings stock was kept there.

2.2 The field, locations of wells, well design and drilling program

The environmental impact assessment was completed in the year 2010. All the impact caused by the estimated drilling operation was included. Previously, four sites had been permitted for the first 9 wells and 14 for the whole project. The drilling strategy for the campaign 2016-2017, was based on existing conceptual model. Each new well added valuable information and every well-siting and well-path were considered in detail according to the model. The general procedure was to hold a pre-spud meeting before drilling each well to inform everyone involved in the operation about conditions down under and expectations.

The design program was in general the same what concerns the casing depths, but different pressure classes (900 or 1500 psi) based on expected temperature and pressure in the reservoir. The most challenging part of the drilling operation was to get through the over-pressurized uppermost 300 m at the foothill of Mount Bæjarfjall.

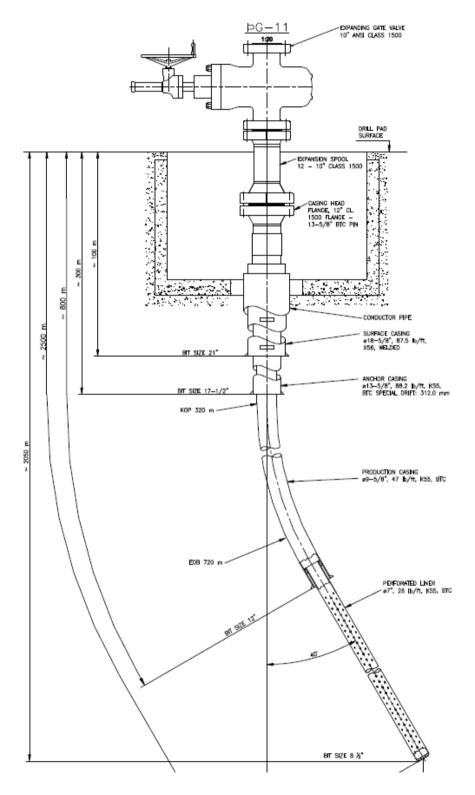


Figure 4: Casing and bit program for over-pressured well at Theistareykir.

2.3 Start of drilling campaign

According to contract, drilling was to start on June 1st 2016 with traditional mast and drawwork rig with 180 tons lifting capacity, Gardner Denver 700E, named "Jötunn". This rig had already drilled 4 wells at Theistareykir thus proving to be able to drill as requested. After signing the contract, the contractor suggested replacing the rig with a Drillmec HH-220FA, hydraulic rig with 220 tons top drive and automatic pipe handling system, named "Ódinn". This rig would first be available by end of June and in the meantime the contractor suggested to use a G-102 Soilmec hydraulic drilling rig, named "Sleipnir", with 100 tons capacity to drill the first sections of the wells. That rig was equipped with top drive and manual pipe handling system and had successfully completed similar tasks at Theistareykir on several occasions.

Landsvirkjun accepted these changes for various reasons including increased safety of the crew, less environmental impact like smaller drilling pads and less noise, faster rig mobilisation and many advantages of drilling with top drive.

Jardboranir started mobilisation of rig Sleipnir to the site by end of April. In spite of snow storms the rig was ready to spud the first well on May 11th 2016. In 36 days well THG-11 was drilled down to 802 m in three sections, with 40° inclination as planned, cased and cemented. Then, mobilisation to the next well started, THR-10. (Because of heavy snow in the area, well no. 11 was drilled before well no. 10).



Figure 5: Rig Sleipnir on the first well, THR-11, next to existing well (wellhead inside the igloo). May 2016.

2.3 Loss of well and change of drilling program

The drilling rig Sleipnir started drilling of well THG-10 on June 23rd. At 74 m depth, a blow-out occurred while drilling for the surface casing. Situation was soon under control and the zone was cemented off. After the blow-out, the rig and the surroundings were covered in drilling mud. Drilling continued after the well had been controlled and at 110 m the casing was installed and cemented.

Drilling for the anchor casing started on July 1st and went smoothly until temperature of the drilling mud increased suddenly at 184 m depth. The mud was replaced with water and the well was cooled down. Drilling was continued to 193 m and it was decided to cement the zone off. During installation of the cementing string, a blowout occurred damaging the rig and injuring one crew member.

To cut long story short, the following days where a struggle to gain control of the situation down hole. Temperature loggings inside the drill pipes showed flow between feed zones at 154 m and 184 m depths. On July 7th, hot steam and gas started to migrate to surface, outside of the surface casing and a decision was made to cement the well leaving the drill pipes and the bottom hole assembly in the well. Well THG-10 was then abandoned.

Both Landsvirkjun and Jardboranir made a root cause analysis on the incident, not leading to the same conclusion. Therefore, a group of drilling engineers from Landsvirkjun, Jardboranir and ÍSOR (Iceland Geosurvey) were asked to propose changes to the drilling program that would prevent something similar from happening again. Their main suggestion was to use heavy drilling mud (barite) instead of bentonite mud when drilling over-pressurized wells and to install an intermediate casing when drilling in similar conditions as were found in well THR-10.

Up until this point in time, 4 lost time incidents had happened which is not acceptable, neither for Landsvirkjun nor for Jardboranir. A comprehensive investigation of the situation lead up to a common agreement of increasing number of crew members by one person per shift, meaning less workload for the individuals.

The above was accepted by both parties and the drilling campaign continued.



Figure 6: Rig Sleipnir on well THR-10 after the first blowout, 4th of July 2016.

2.4 Drilling ahead

At this point in time, drilling rig Ódinn had arrived to the site and rig Sleipnir was transported to Krafla geothermal field to drill a makeup well for the powerplant. It was decided in the meantime to reject further use of the rig Sleipnir in the project. The reason was that the equipment did not meet technical requirements with regards to well control due to limited pumping capacity. Ódinn's first job was to continue drilling of well THG-11 which rig Sleipnir had drilled down to 802 m. That well was successfully drilled down to 2.217 m in 18 days, including end of well measurements and testing.

In the next 13 months, rig Ódinn drilled total of 7 new geothermal wells, all of them deviated. Total depth (actual length) of those wells were from 2.500 m to 2.700 m. On average it took 49,7 days to drill each of those wells including end of well testing and measurements. To move the rig between drill pads took on average 8,3 days. No lost time incident occurred in those 13 months.

The end of the Theistareykir drilling campaign was celebrated on Agust 29th 2017. It had lasted 476 days. Eight new geothermal wells were successfully completed.



Figure 7: Timeline for the drilling campaign.



Figure 8: Rig Ódinn on well THR-12 in September 2016. Steam pipes and powerhouse under construction in the background.

2.5 Outcome of the drilling campaign

After drilling of each well, they were kept closed for 3 to 7 months. In that period the wellhead was completed by installing discharge pipe lines and a steam separator/silencer. Then, the well was fully opened and power output measured. The capacity of the new wells was measured close to 48 MW_e. That is 6 MW_e on average from each well. Six of those new wells have been connected to the steam supply system for the Theistareykir powerplant which has two 45 MW_e units. Unit 1 started commercial operation by end of November 2017 and unit 2 in middle of April 2018 (Knútsson et al., 2018).

Apart from the rough start, the drilling campaign was successful. For instance, there was no fish left in any hole. In spite of change of drilling rigs, modified drilling program and updated well design the final cost of the drilling campaign was 88% of the contract value and only 65% of the original cost estimate.

The project was delivered on time, on budget and without serious injuries to people and no uncontrolled impact on the environment.



Figure 9: Rig Ódinn on well THR-14 in January 2017. Steam separators to the right of the rig.

3. CONCLUSIONS

The Theistareykir drilling campaign can be considered successful by several means. First, the number of wells and the steam required was delivered on time and under budget. Secondly, several international drilling contractors were keen to participate and offer competitive rates in a tender for a "hybrid" type drilling contract in a Northeast Iceland for couple of reasons. Market situation, both for drilling and material was favorable for buyers, helping to minimize the project cost.

In hindsight, a mistake was made by accepting last minute changes in drilling rigs. Despite careful planning and significant safety measures, a serious incident occurred, which not considered acceptable by Landsvirkjun. However, this event lead to significant modification in the design and working procedures when drilling in over-pressured formations. After that the project continued without serious incidents. However, the main learning is that a high temperature geothermal drilling project is never too well prepared and that drilling engineers have to be prepared for continuous improvements throughout the campaign.



Figure 10: Rig Ódinn on well THR-16 in May 2017 (to the left). Powerstation in front, Mount Bæjarfjall in the background.

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