Novel concepts to construct cost-effective geothermal wells with Electro Pulsed Power Technology

Report on technical requirements and definition of load assumption

D2.2

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Executive summary

The DEEPLIGHT project aims to create a contactless drilling method using Electro Pulsed Power (EPP) technology, as to be a game changer, being superior compared to conventional drilling methods. Work package 2 of the project will develop an EPP-tool by testing a current drilling tool for EPP drilling from TU Dresden, and designing and building a new tool for EPP drilling by IHC, which will also be tested. These tests, or experiments, are done in collaboration with TNO at the Rijswijk Centre for Sustainable Geo-energy (RCSG) in The Netherlands.

This report addresses Task 2.2, which deals with general requirements for the EPP drilling tools. This report explains specifications, such as load assumptions, working conditions and Key and Qualitative Performance Indicators of the EPP-tool. It is a technical document that will guide the technical development of the EPP tools in this project and will help to compare the EPP technology that is developed with the existing EPP technology and other methods for drilling geothermal wells. The most important design parameters and operational limitations are mentioned, as well as basic parameters for the experiments that will take place in TNO's RCSG. The document also provides input for the other work packages of the project to ensure that all activities match the identified requirements for EPP drilling tools.

A comparison between the EPP-tools of IHC and TU Dresden will be done in the final stages of this project. During the project and development of critical components and subsystems, the KPI's will be revised and added, and the specifications may change with new insights.

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Abbreviations

BHA	Bottom Hole Assembly
EMSE	Electrical Mean Specific Energy
EPP	Electro Pulse Power
HMSE	Hydromechanical Mean Specific Energy
HV	High Voltage
KPI	Key Performance Indicator
QPI	Qualitative Performance Indicator
RCSG	Rijswijk Centre for Sustainable Geo-energy
ROP	Rate of penetration
WP	Work Package

1. Introduction

This first chapter introduces background, scope and aims of this report.

1.1. Background

One of the main objectives of the DEEPLIGHT project is to develop non-mechanical drilling with Electro Pulsed Power (EPP) technology as to be a game changer being superior to conventional drilling methods. To achieve this objective the development of an EPP-tool, as part of Work Package 2, starts with the full-scale testing of an existing TU-Dresden set-up for EPP drilling. In parallel the design and construction of a set-up for EPP drilling by IHC takes place, which is subsequently also subject of full-scale testing. These full-scale testing activities, i.e. experiments, take place in collaboration with TNO at the Rijswijk Centre for Sustainable Geo-energy (RCSG) in The Netherlands making use of a drilling rig, positioned above a 350 m deep well that can be adapted to obtain a relevant testing environment. This drilling rig will need to be prepared for integration with the specific EPP-tool to perform the first set of experiments with the existing EPP set-up of TU Dresden. The results of these tests will serve as a reference point to compare with the characteristics and performance of the EPP-tool of IHC, which will performed by a set of full-scale experiments in the final year of the project. In the experiments, and also in parallel activities of the DEEPLIGHT project, each EPP sub-system will be separately investigated in order to obtain a complete and fully functional EPP-tool. The full-scale experiments that will be performed with the drilling rig at the RCSG have the objective to acquire engineering parameters for next steps, such as prototype development, and to determine the efficiency and feasibility of the EPP drilling technology. This will be done by drilling a number of meters of cement in the already existing well under the RCSG rig and which is completed with a 20” cemented casing. A working depth of around 60 m is anticipated at the moment to allow simulation of subsurface drilling in a controlled environment.

1.2. Scope

This deliverable report is generated for the project’s WP2 and specifically for Task 2.2, which focuses on general requirements for the EPP drilling tool. The report describes specifications such as load assumptions, working conditions and Key Performance Indicators. It is a technical document that will be used as a basis to further develop the EPP-tool in this project and will be used to objectively benchmark the developed EPP technology against existing EPP technology and more conventional methods for drilling of geothermal wells.

This document will describe in chapter 2 the design parameters, including load assumptions and working conditions of the EPP-tool, which are based on data from the system design studies in WP1 (Well Engineering Partners and Iceland Drilling Company). In Chapter 3 the design goals for experiments at RCSG will be given. Next, Key and Qualitative Performance Indicators (KPIs and QPIs respectively) for the EPP-tool will be described in chapter 4.

The specifications and KPIs as found in this document form a basis for further technical development steps for the tooling in WP2, such as the design of the High Voltage (HV) pulse generator, the electrodes and the High Voltage Power Supply. During these steps KPIs and specifications will be further updated.

The activities of WP2 should lead to a 12.25 inch bit size diameter EPP-tool to be tested in year 3 of the project at the drilling rig at RCSG and to drill a 12.5 inch hole. The tool is expected to have a maximum length of 9 meters. This EPP-tool will consist of a HV pulse generator and electrode system, discharging between 400 and 800 KV with the following interconnections:

- HV cable connecting to a surface located High-Voltage power supply.
- Integrated mud circulation system.
- Integrated air circulation system for HV switch operation (0.8 MPa)
- Second air circulation system for refreshing of high pressure air (1.0 MPa).
- Data and control lines from surface to EPP-tool. At this moment one current probe will be installed near the top of the HV Generator.

2. Operating Conditions

2.1. Experimental Bottom Hole Assembly

In conventional drilling terminology a bottom hole assembly (BHA) comprises the entire section, from the drill it to the lower end of the drill pipe. The drill pipe has the function to carry the weight of the BHA, to control the orientation and rotation of the BHA and to conduct the drilling fluid (or mud). The *conventional* BHA consists (from bottom to top) of the drill bit, mud motor (optional) or other steering device (optional), measuring & telemetry tool (optional) and drill collars and/or heavy wall drill pipe. The latter is to provide vertical downward force on the drill bit while preventing the BHA to buckle.

The *EPP*-BHA is different from a conventional BHA. The drill bit is replaced by electrodes, which are directly connected to the pulse generator; with a power supply and convertor being mounted on the surface. This section is expected to be 7.5 meters long and forms the heart of the EPP-system and is therefore the heart of the entire DEEPLIGHT project. An earlier EPP- BHA has been developed by TU Dresden and will also be tested at the RCSG; more information about the technical details of this system can be found in [DEEPLIGHT-Deliverable-D2.3_v1.0.pdf] on the project website.

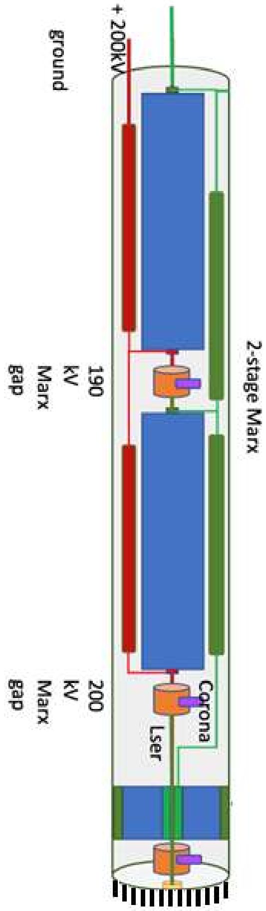

Figure 2-1 - Schematic drawing of the BHA

Since little rotation is needed, a mud motor will not be required, nevertheless some limited clockwise and counterclockwise rotation will be applied. Currently, an idea is being worked out to rotate the rotary table and keep the BHA with cable stationary, as an alternative of the reciprocal rotation of the drill string. A heavy wall drill pipe will not be required since no significant vertical downward force is needed. So, the BHA will have a significant lighter weight.

A schematic drawing showing downhole EPP-Tool in the TNO test rig can be seen in Figure 2-2, with a more detailed Schematic drawing of the BHA (including generator and schematical electrodes) in Figure 2-1. Note that connections with the HV-cable, the data line, and pressurized air tube will have to pass downhole as well, using a protected umbilical. Drilling fluid flow will be similar to conventional drilling. Nozzle pressure drop, amount and -shape is to be determined yet.

The yellow casing (13 3/8") will be suspended in the rotary table using a special 'landing joint' that allows locking in the rotary table and mud to be dumped below the rig floor. The mud will be collected below the floor and with trash pumps pumped to shakers. A 16" casing will be attached to the bottom of the 13 3/8" casing which will be used to carry the sample (In this case concrete) and to provide a bigger distance between electrodes and casing.

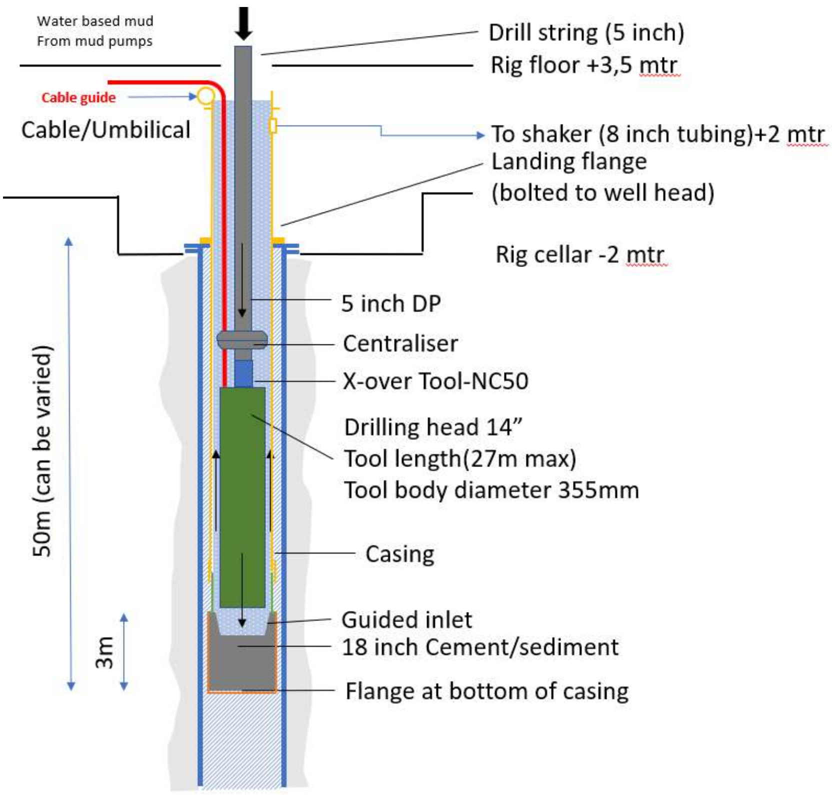

Figure 2-2 - Schematic drawing showing downhole EPP-Tool in the TNO test rig

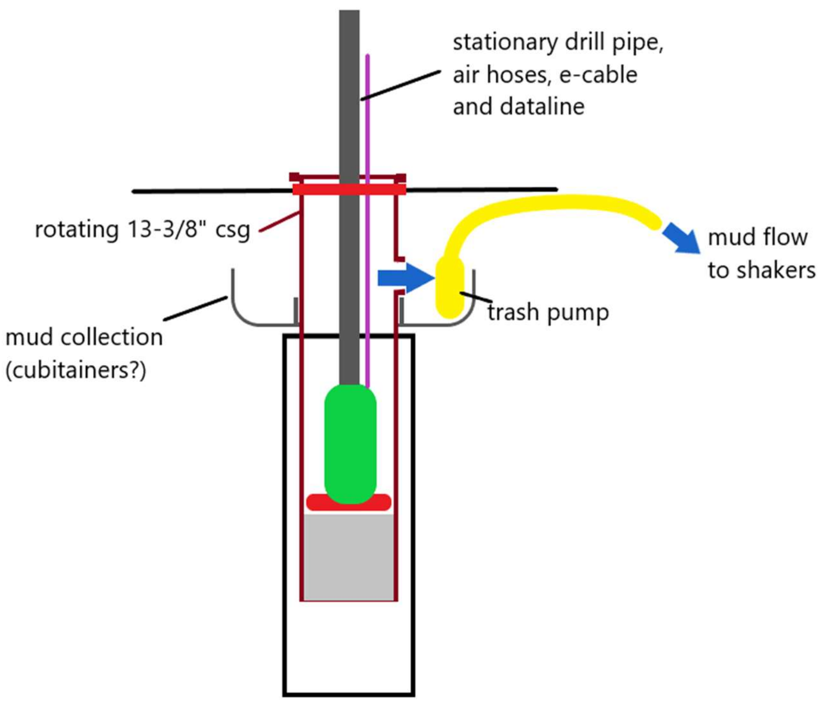

Figure 2-3 - Suggested setup with continuously rotating 16" casing

In general, most electronic packages in drilling tools are placed concentric and in the center of the tool to have the smallest impact caused by rotational variations or bending while drilling that may cause shocks and vibrations. It is also easier to design and maintain because it requires less space. Drilling fluid flows down inside the tool to the nozzles, providing cooling to the internal electronic packages. Different tool layout configurations are shown in Figure 4. Design 1 will be used because of large diameter of capacitor used.

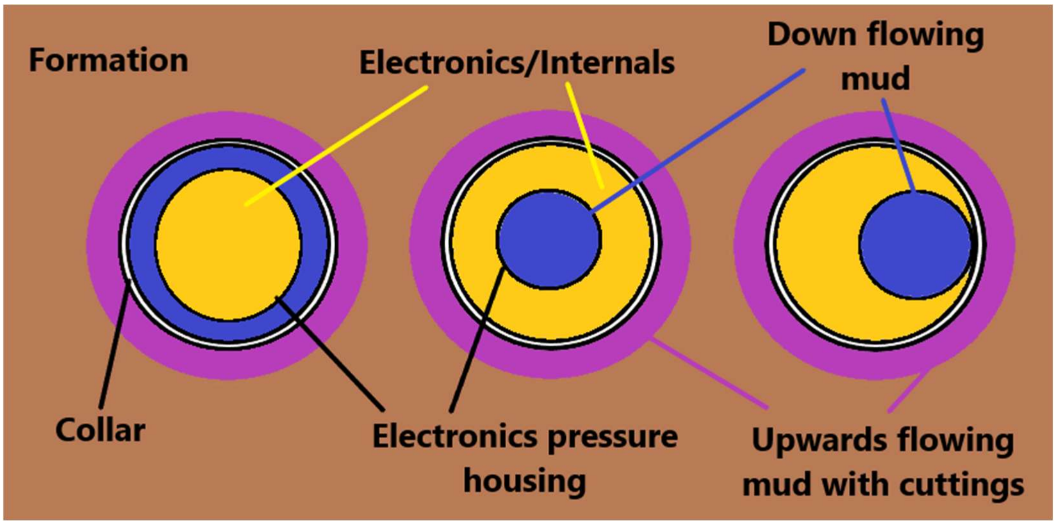

Figure 2-4 - Cross sections of possible tool configurations

The EPP-tool consists of

- An integrated 400 kV autonomous working high voltage pulse generator with electrodes, which will be supplied by a 100 kV 12 kW surface located power supply. This power supply can connect to a standard 400 V 3 Phase 25 A 50-60 Hz grid connection, or by a stand-alone portable generator with at least the same ratings.
- An integrated drilling fluid system which needs to be connected to the circulation system of the RCSG rig facilities. No alteration of the RCSG system is to be expected.
- An integrated air circulation system for high voltage switch operation. A surface located compressor system of 12 bar with a volume of 400 liters/min intake capacity need to be connected to the EPP-tool. Compressed air need be low moisture, at least non-condensing at all points.
- Data and control line from surface to EPP-tool. At least one current probe will be used to investigate pulse waveforms during operation.

2.2. Working and Drilling conditions for experiments at RCSG

The parameters as shown in Table 2-1 will be used to develop the IHC EPP-tool. These parameters have been determined in collaboration with Well Engineering Partners, e.g. via project deliverable document D1.2 [1]. As has been briefly mentioned in the introduction, these parameters will form the baseline of the technical development and will be updated once more information comes from tests done with the TUD EPP-tool at TNO's RCSG, from fundamental experiments conducted at TU Eindhoven, or from discussions with any of the industry partners.

The rotation will be provided by hanging the (13+3/8) casing in the rotary table and turn the rotary table with constant angular velocity. The BHA and drillpipe can be made up using the false rotary table; which is a support of sorts placed over the original table. This means that electrodes, tool, drillpipe and cable all stay stationary during operation.

Table 2-1: Drilling and mud flow conditions for TNO RCSG.

Environmental conditions		**Units**
Minimum downhole temperature	0	[°C]
Nominal downhole temperature	10	[°C]
Nominal operational mud flow	1500	[l/min]
Maximum operational mud flow	3000	[l/min]
Maximum part of diverted mud flow at Sub	80	[%]
Operational annular mud velocity	t.b.d	[m/s]
Nominal nozzle pressure	5 to 15	[bar]
Number of nozzles	7	[-]
WOB (should be practically zero), max.:	50	[kN]
RPM (rotating casing+cement)	0 to 10	[RPM]
High Voltage Power Supply (comes with remote control)	400	[V]
	30	[kW]

Nominal downhole temperature will likely not deviate more than 2 °C from the suspected 10 °C, since the drilling experiment will not exceed 60 m, whereas the temperature increases with 3 °C per 100 m in the Dutch subsurface. The heat from friction (pressure) in the fluids system need to be added to the temperature, estimated to be 4 °C at max.

Specific mud flow rates will be determined during the rest of the project. IHC Mining expects to produce cuttings of maximum 4 mm with first experiments in HV lab environment at TU Eindhoven. In accordance with Figure 4, this should result in a minimum mud velocity of 0.3 m/s in the annular space, using water based mud [2]. This is in line with a simplified hole cleaning model as function of grain size, developed by TNO and WEP for the activities in DEEPLIGHT's WP4, as can be seen in Figure 5. More precise calculations should be made once cuttings size has been confirmed, which can be done after the pulse generator and electrodes have been tested. Collaboration with TNO and WEP shall be made to further determine minimum slip velocity.

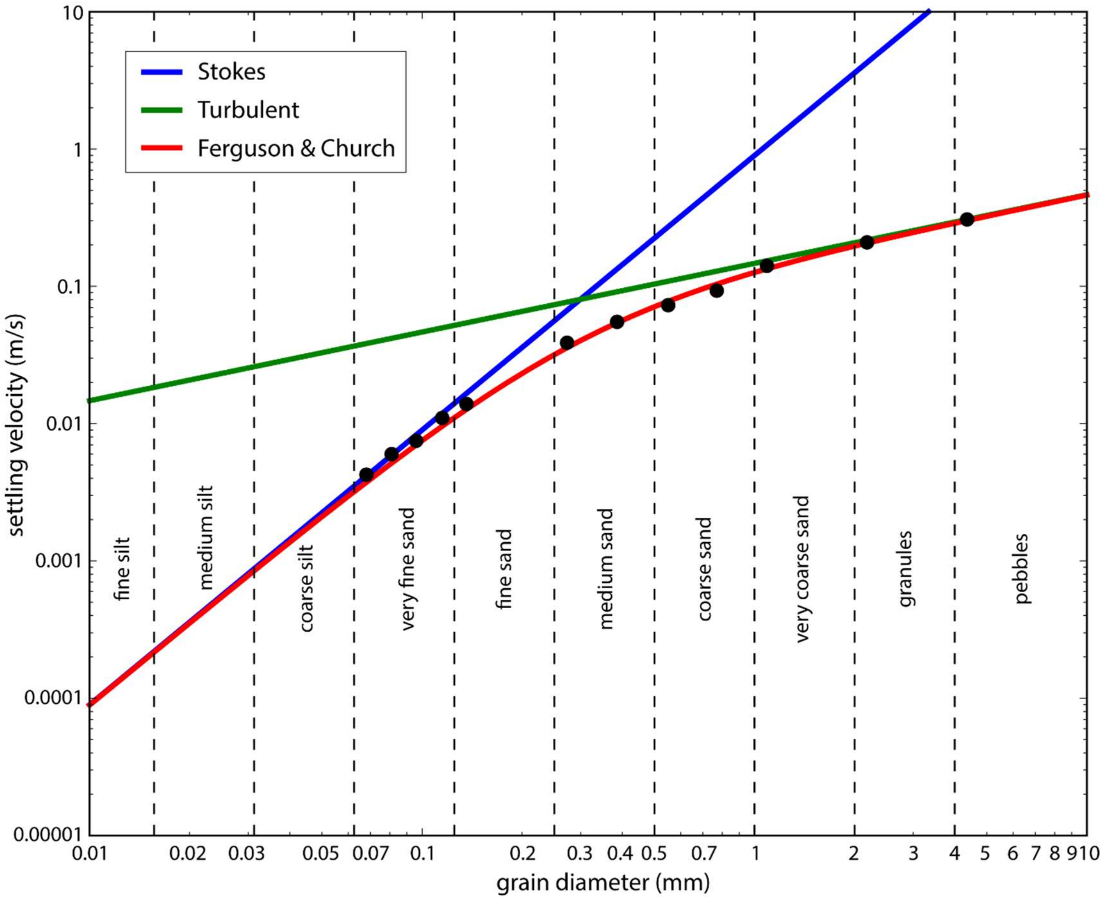

Figure 2-5 - Graph showing settling velocity against grain diameter. Expected maximum grain size for the IHC-tool is 4 mm, resulting in a minimum annular mud velocity of 0.3 m/s. [3]

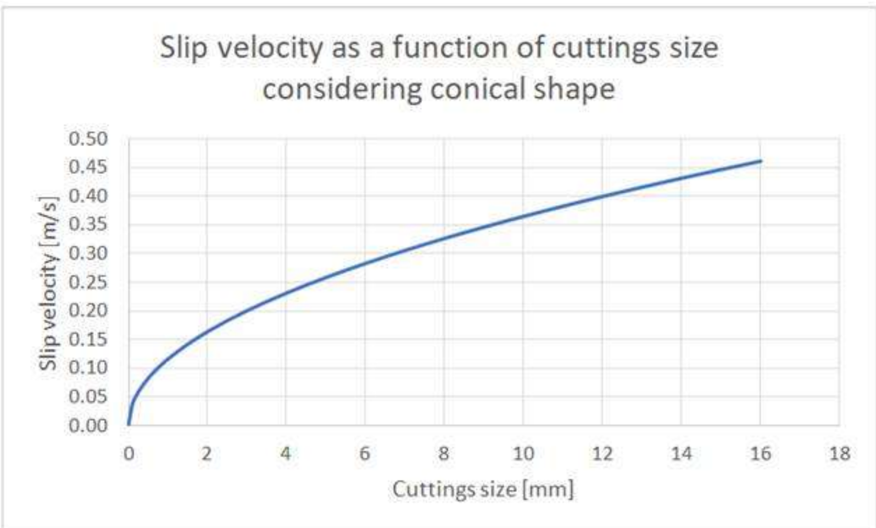

Figure 2-6 - Graph of a simplified model by TNO to calculate slip velocity

2.3. Load assumptions

One of the main parts that should be assessed for development of the EPP-tool are mechanical load assumptions. These parameters (found in table 2-2 below) are collected from DEEPLIGHT project deliverable D1.2 [1] and from discussion with TNO. Experiments in the TUE lab and from TUD's tool at RCSG will give more specific assumptions at a later stage, which can be used to design a more rigid tool. The specifications will impact some of the following design parameters:
- Maximum downhole pressure will impact the minimum thickness of the BHA outer wall.
- The weights and torques on bit will change the design and minimum thickness of the electrodes.

Table 2-2: Load assumptions to be considered in design of the tool.

Maximum downhole pressure	10	[bar]
Maximum allowable pressure	50	[bar]
Maximum weight BHA	3000	[kg]
Nominal weight on bit	0-3	[t]
Maximum weight on bit	5	[t]
Maximum torque on bit (torque limiter may be needed)	500	[N*m]

3. EPP design and operational considerations and KPIs

The design goals as mentioned in this chapter are a set of constrictions that all parties will need to be informed of, as to ensure the system integration will go smoothly. These will be the basis of which both the BHA and the drilling rig should be capable of interacting with. When all parties agree to these design settings, a next step in the design for the EPP-tool can be made, since IHC can use these settings in the development of the housing and interconnections of the EPP-tool. In case of length this means that the tool cannot exceed a certain total length, and that the cranes at the rig should be able to move the tool components around. The prepared hole should fit the electrode diameter of 12.25 inches, and the drill should be able to move reciprocal with a certain angular velocity.

3.1. Design goals for RCSG Experiments

An overview of the envisaged design goals are provided in Table 3-1 below.

Table 3-1: Dimensions, interfaces and design restrictions of EPP-Tool in RCSG test

Dimensions & interfaces		**Units**
Max length total	18	[m]
Max length per section	9	[m]
Max. bit diameter	12.25	[inch]
Bit connection	n.a.	
Connection to drill pipe	5” drill pipe: NC-50	
Downhole temperature	5 tot 15	[°C]
Housing and liner material	SS-304	
Nominal Housing outer diameter	220	[mm]
Minimum casing diameter (API casing)	16	[inch]
Bore hole diameter	12.25	[inch]

4. Performance Indicators for RCSG tests

4.1. Introduction to KPIs for Prototype Assessment

The use of Key Performance Indicators (KPIs) is an essential tool for objectively assessing and comparing the performance of prototypes during testing, providing insights to track progress, and make informed decisions for optimization.

KPIs are measurable metrics that provide insights into prototype performance. They offer a standardized framework to evaluate attributes aligned with the prototype's goals.

KPIs eliminate bias and ensure a fair evaluation process. They quantify a prototype's capabilities and the comparison of multiple prototypes using a common metric set. This allows stakeholders to identify promising design iterations.

The next paragraph lists the selected KPI’s which will be used in an objective assessment and comparison of prototypes. The KPI’s will also be used as an input the parameters to be measured and/or determined during the RCSG tests.

There are also indicators which cannot be directly measured, but which are still important in making the comparison between the prototypes and technology. These indicators are Qualitative Performance Indicators (QPIs) and will be introduced in paragraph 4.3 and listed in paragraph 4.4 .

4.2. List of KPI’s

The KPI’s will be listed below, with a short explanation of what the KPI entails and how it will impact the EPP-tool if this KPI would be improved, along with how it can be expressed or measured.

Rate of penetration (ROP) on bottom is a measurement of the drilling velocity and will be expressed in [m/hr]. A higher ROP means a quicker and less expensive drilling operation. Ideally the ROP will be higher than conventional drilling methods. For the experiments at RCSG on IHC’s EPP-tool the ROP of the EPP-tool of TUD will be used as the benchmark.

Minimum Flow Rate should be maintained to prevent settling of cuttings. Minimum annular flow velocity is 6 m/s according to RCSG.

Maximum bit pressure is 50 bar.

Hydromechanical Mean Specific Energy (HMSE) shows the average amount of mechanical energy needed to drill into a certain volume of rock. Being able to optimize upon a lower HMSE increases efficiency of the drilling technique [kW/m].

Electrical Mean Specific Energy (EMSE) shows the average amount of electrical energy needed to drill into a certain volume of rock. Both this and HMSE will give us a total MSE which can be compared to TUDr MSE [kW/m].

Total length of EPP-tool: While a longer tool is easier to design and manufacture, transport and rig setup will give limits to maximum length. The maximum length proposed is 18 m, but the aim for the design is to keep it as short as possible. Therefore, the length has been set as a KPI [m].

Lifetime of pulse generator: The pulse generator, like any tool, will have wear and tear over its lifetime. Being able to have a high Mean-Time Between Failure increases cost effectiveness. Ideally the Pulse Generator would not need to be serviced during the drilling of any one well, meaning this can be expressed as total depth of the well.

Lifetime of electrode: The electrode will also experience fatigue during its lifetime. The goal of this project is to find an electrode setup which would outlast any other conventional drill bit. Ideally a cheap electrode could be developed which would last one or more wells, without having to replace it during drilling, meaning this KPI can be expressed as total depth of the well [m].

Drilled Distance Between Failures is a measure of how long a drill rig usually functions before it encounters an issue. It is a method to measure the reliability of the equipment or system [m].

Uptime as a percentage of the total drilling time

4.3. Introduction to QPIs for Prototype Assessment

In the world of drilling operations, performance is more than just numbers. It is also about understanding the intangible factors that shape effective performance. This paragraph introduces a pivotal aspect of drilling assessment - Qualitative Performance Indicators (QPIs). Unlike traditional measurements, QPIs shed light on the impossible or hard to measure parameters that contribute to successful drilling outcomes. By also exploring these unmeasurable aspects, we gain a complete perspective that enhances our grasp of drilling performance evaluation and its significance for the industry.

4.4. List of QPI's

Health, Safety, Environment, Quality. No incidents should be the norm. Proper steps have already been taking by TNO and partners in DEEPLIGHT project Deliverable 2.1 [4].

System integration: Assembling all EPP components without (major) technical issues and successful integration in the rig environment

Tool control: Full automatic working of machine, testing operational control and responsiveness of EPP-tool

Cutting removal capability: Cutting removal refers to the effectiveness of equipment and processes in clearing rock fragments generated during drilling. Proper removal prevents obstructions and blockage, and ensures efficient EPP drilling. Depending on well geometry, proper cutting removal can be calculated. By analyzing cuttings, one could determine if the drilling process is running smoothly.

Compatibility with different sorts of formations: As of this moment it is unsure if EPP technology will be suitable for every type of rock formation. Being able to measure an EMSE and ROP for a certain formation gives information about effectiveness and efficiency.

Compatibility with different mud types: Oil based mud has drastically different electrical properties, for example higher breakdown strength and lower dielectric constant. This will make it harder for proper breakdown through the rock. Water Based Muds have many additives that may interact with the EPP tool.

5. Conclusions

The DEEPLIGHT project aims to revolutionize geothermal energy production through the development of an innovative drilling and well construction system based on Electro Pulsed Power (EPP) technology. This report describes the specifications, load assumptions, working conditions and key performance indicators for the EPP drilling tool, as well as the operational conditions and performance indicators for the EPP-CwD concept. It provides the first outlines for the design and operational restrictions, as well as the base parameters for experiments to be conducted at TNO's Rijswijk Centre for Sustainable Geo-energy (RCSG) and TU Dresden's test facilities. It will guide the project developments including the one on a High Voltage pulse generator, electrodes, and power supply components.

The global configuration of the EPP drilling tool that the DEEPLIGHT project is aiming for involves various interconnected systems, including a HV cable, drilling mud pump system, air circulation system, silicon oil pumping system, and data/control lines. The main challenges and risks for the EPP drilling tool are related to the compatibility with different mud types, the effects of pressure and temperature on the electrical properties of the materials, the reliability and durability of the electrodes and the HV cable, the synchronization and control of the EPP pulses, and the safety and environmental aspects. In year 3 of the project, this EPP drilling tool will be tested at TNO's rig in large-scale experiments aiming to demonstrate its capabilities by drilling several meters in cement or in other relevant formations. TNO might use short casing strings filled with cement or different formation types (as proposed for TU Dresden tests) which would reduce the testing costs, and drilling performance can already be estimated based on several meters of drilled cement.

The project also aims to develop and evaluate the EPP-CwD concept, which combines the EPP technology with a Casing while Drilling (CwD) system. This concept has the potential to further increase the drilling efficiency and reduce the costs and environmental impact of geothermal drilling operations, by eliminating the need for tripping and cementing operations. The EPP-CwD concept will be evaluated in terms of its technical feasibility, economic benefits, and environmental impact, using numerical simulations, laboratory experiments, and life cycle assessment methods.

This deliverable, and near-future updates, serve as a critical reference for all the DEEPLIGHT work packages ensuring that the development activities align with identified possibilities and requirements for EPP drilling tooling and EPP-CwD concept.

6. References

[1] "Exploring grain settling with Python," Hindered Settling, 9 August 2013. [Online]. Available: https://hinderedsettling.com/2013/08/09/grain-settling-python/. [Accessed 2023].

[2] E. Sosa-Massaro, "Specification for the development of the EPP – CwD concept and evaluation of economic benefits," DEEPLIGHT project deliverable D1.2, 2022.

[3] Z. Sylvester, "Exploring grain settling with Python," 9 08 2013. [Online]. Available: https://hinderedsettling.com/2013/08/09/grain-settling-python/. [Accessed 2023].

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