Lithostatic Pressure Effects on the Plasma-Pulse Geo-Drilling (PPGD)

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Abstract

Drilling cost is one of the main challenges facing the utilization of deep closed-loop geothermal systems, so-called Advanced Geothermal Systems (AGS). Plasma-Pulse Geo-Drilling (PPGD) is a novel drilling technology that uses high-voltage electric pulse to damage the rock without mechanical abrasion. PPGD may reduce the drilling costs significantly compared to mechanical rotary drilling, according to a comparative analysis that assumes ambient operating conditions. However, the level of performance of PPGD under deep wellbore conditions of higher pressures and temperatures is still ambiguous. Therefore, this contribution presents preliminary experiment results from the laboratory that investigate the effect of high lithostatic pressures of up to 150 MPa, equivalent to a depth of ∼5.7 km, on the performance of PPGD.

Introduction

Geothermal energy is in principle a renewable, limitless, and CO2-free energy resource. For continental crust, with a typical geothermal temperature gradient of 30 °C/km, one needs to drill deeper than 5 km to reach temperatures that are suitable for binary power cycles of 150 °C or greater [1, 2]. This may be accomplished with deep closed-loop geothermal systems, also referred to as Advanced Geothermal Systems (AGS). However, at 5 km depth, the drillbit encounters hard crystalline rock under extreme pressure and temperature conditions, where traditional mechanical rotary drilling is relatively ineffective, resulting in high drilling costs, making rotary-drilling-based AGS energy production uncompetitive [2, 3]. It is therefore necessary to employ a significantly cheaper alternative drilling method when constructing future AGS, such as Plasma-Pulse Geo-Drilling (PPGD) [4, 5, 2, 6, 7].

Like other "contactless" drilling methods, PPGD has the potential to reduce drilling and well completion costs significantly, as shown in comparative analyses [8, 9]. PPGD is a novel drilling technology that uses high-voltage pulses (i.e., voltage gradients of ∼140 kV/cm and electric pulse rise times of < 0.5 μs) to fracture the rock without mechanical abrasion. Instead, PPGD induces electric breakdown of the fluid in the rock pores. It is in fact the short pulse rise time that enables the electric breakdown (i.e., plasma arcing) to go through the rock and not through the drilling fluid. For a detailed discussion on PPGD, i.e., the concept, its pros and cons, we refer to [5, 10, and the references therein].

It has been shown [8, 9] that PPGD can increase the drilling performance, thereby lowering drilling costs, in granites under standard ambient (atmospheric) pressure and temperature conditions. Also, several modeling studies have studies PPGD under the ambient conditions [4, 5, 6, 7]. However, PPGD's main objective is to facilitate particularly deep drilling to depths of around 5 km and more, where the crystalline rock is under extremely high temperatures and pressures. The few experiments that have been conducted on PPGD or similar drilling technologies suggest a reduction in the PPGD performance when both hydrostatic pressure and temperature are increased [8, 11]. Our contribution here presents preliminary results of the effect of an increase in lithostatic pressure, by up to 150 MPa (i.e., corresponding to a depth of 5.7 km), on PPGD performance. It is worth noting that other experiments are ongoing, investigating the effect of increased temperatures and hydrostatic pressures on PPGD performance.

Method

Figure 1a shows the schematic of the experimental setup, which includes three systems: **(1) The loading frame system** that pressurizes the rock sample from 0.1 to 150 MPa simulates a lithostatic pressure at a depth ranging from 0 to 5.7 km. We place the load frame system in a tub filled with deionized water with an average electric conductivity, σ_w, of 30 μS/m (produced by an Ion exchanger MBK with 20 liter/min rate), which simulates the drilling fluid with a 0.1 MPa hydrostatic pressure. **(2) The pulse generator system**, which is a 12-stage Marx generator (PULSREX-20: manufactured by Kammermann Prozesstechnik GmbH and supplied by Swiss-GeoPower AG) generates a 200 kV high-voltage pulse with a pulse rise time of approximately 100 nanoseconds and an energy pulse of 210 J, at a pulse rate of 2 pulses/min, and a typical pulse profile is shown in Figure 1b. **(3) The electrical measurement system** that measures the voltage pulse profile (i.e., the peak voltage and the rise time). It consists of a co-axial capacitive voltage divider (a prototype manufactured by the HPE lab at ETH Zurich) of a division ratio of 1:1050 [12]. An oscilloscope from Keysight (DSOX1204G) of 2 GSample/second sampling rate and 70 MHz bandwidth is used to capture the signal from the voltage divider.

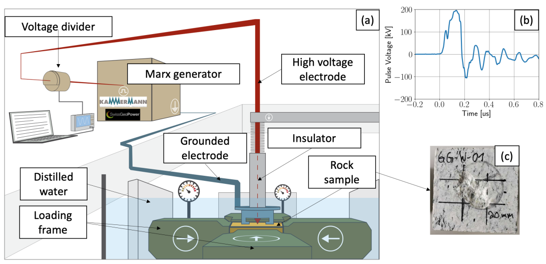

Figure 1: (a) Experiment setup, (b) typical pulse profile, and (c) typical damaged sample after the test.

To run one experiment, we follow the following steps: First, we place the sample in the loading frame and ensure that the deionized water level is above the rock surface. Next, ten pulses are sent from the Marx generator via the electrode systems to the surface of the rock sample. Then, we scan the surface of the damaged sample (see Figure 1c) using light microscopy to calculate the excavated volume of the rock. Finally, we calculate the PPGD performance, Q, which is defined as the excavated rock volume per pulse.

Results and discussion

Figure 2 shows the PPGD performance, Q, dependence on the lithostatic pressure confining the granite sample. In the low-pressure region of values less than 66 MPa, the PPGD performance tends to decrease when increasing the lithostatic pressure values until it reaches 56% of the baseline performance at the lithostatic pressure value of 66 MPa, i.e.,∼2.5 km depth. However, increasing the pressure beyond 66 MPa improves the PPGD performance again until it reaches 153% of the baseline performance at the lithostatic pressure value of 150 MPa, i.e.,∼5.7 km depth.

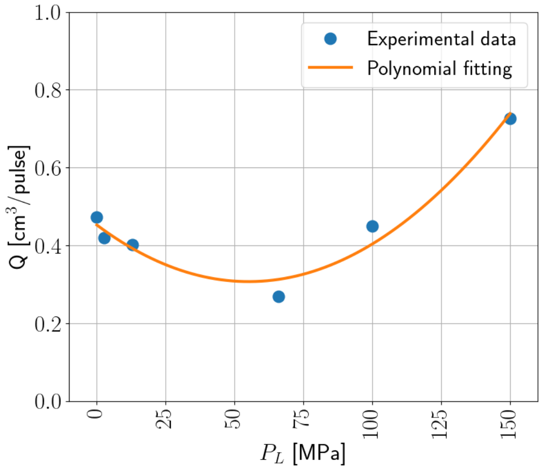

Figure 2: PPGD performance versus the lithostatic pressure.

Even though we meet the rise time pulse conditions, a few pulses still go through the deionised water, not the rock. Typically, increasing the confining lithostatic pressure on the granite decreases the electric conductivity of granite [13] and increases the pore fluid pressure, challenging the local plasma formation inside the rock pores [4]. Therefore, the probability of plasma arcing through the rock decreases with increasing pressure (i.e., depth), which decreases the PPGD performance. However, the higher confining pressure, greater than 66 MPa, tends to bend the free surface of the sample upwards, i.e., exerting upward tensile stress on the rock surface [14]. This tensile stress has the same direction of plasma pressure, which facilitates the plasma pressure buildup and thus inducing rock damage, improving the drilling performance. We are currently conducting additional experiments to fill in the curve with more data points and estimate error bars. Furthermore, experiments are ongoing to investigate the effect of temperature and hydrostatic pressure on PPGD performance, which is expected to provide further insights regarding PPGD performance as a function of wellbore depth.

Conclusion

This study presents preliminary results that show the effect of deep wellbore conditions, i.e., lithostatic pressure, on the Plasma-Pulse Geo-Drilling (PPGD) performance. During PPGD, increasing the lithostatic pressure decreases the PPGD performance (measured by rock breakout), Q, approximately linearly up to a lithostatic pressure of about 66 MPa (i.e., corresponding to a depth of $\sim$2.5 km). However, at lithostatic pressures greater than $\sim$66 MPa, the PPGD performance, Q, appears to increase again. Our current experiments show that an increasing in the lithostatic confining pressure to 150 MPa results in a Q value of 153% of that of baseline performance value of Q. Currently ongoing experiments, investigating the effect of increased temperature and hydrostatic pressure on PPGD drilling performance, Q, are expected to provide further insights regarding PPGD performance as a function of wellbore depth.

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