

Enhancing the Drilling Process for Geothermal Resources by Combining Conventional Drilling and the Spallation Technology

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Keywords: spallation drilling, combination, hybrid drilling, costs

ABSTRACT

In order to enhance the integration of geothermal energy in the energy mix, the drilling costs have to be significantly reduced, as they account for up to 70% of the total investment for a geothermal power plant. A possible solution to intensify the conventional drilling process is to improve the energy transport from the surface to the drill head (currently performed by the drill string) by pumping combustible reactants to the front face of the bit. If these reactants are ignited, localized heat is transferred to the rock surface to spall or thermally weaken the rock structure. Spalling of rocks is based on the effect that certain crystalline rocks locally disintegrate into small disc-like fragments. Thermal rock weakening describes the significant reduction of the rock strength due to thermal crack formation. Besides the improved energy transport, thermally enhanced drilling decreases the wear-rate and increases of the rate of penetration in all rock formations, which significantly reduces the drilling costs for a geothermal project. In this report the working principles of such a combined hybrid-technology are reported, together with implementation possibilities, which aim to minimize the required adaptations of the currently used conventional drilling equipment. Additionally, the characteristic response of representative sandstones and granites to a thermal treatment was analyzed showing the feasibility of such a combined drilling process.

1. INTRODUCTION

The development of geothermal energy production from deep resources is hampered by the high costs of the drilling process. The currently used rotary technology based on the mechanical destruction of the rock performs well in soft and medium hard rocks, but faces difficulties in hard basement rocks as they are encountered in deep geothermal wells. Low penetration rates together with high wear rates of the drill bits are impeding the drilling process, leading to high costs [1-3]. Additionally, conventional rotary drilling is characterized by a poor energy transport, due to significant drag and torque losses along the drill string [4], leading to a low overall energy efficiency of the drilling process. Besides the different attempts to intensify the conventional drilling process, several emerging technologies are currently investigated by researchers around the world [5-8]. One pursued option is to pump combustible reactants (*e.g.* methane and air) to the front face of the drill bit to create a hot fluid jet which impinges on the rock surface. Thereby, the hot fluid jet can be used to spall the rock or to thermally weaken the structure, if the rock properties are unfavorable for spalling. The spallation process is based on steep temperature gradients induced by the impinging flame, creating high local thermal stresses in the upper layer of the rock surface (Figure 1 (a)). If the thermal stresses exceed a certain threshold, initial present cracks will extend at the surface (b) and later through the material (c). If sufficient thermal stresses can be induced, the cracks combine and a so called spall is formed (d1), which will be ejected from the surface (e1) and the process continues on the created surface [5, 9, 10]. If the rock cannot be spalled due to unfavorable rock properties, the flame jet can be used to further weaken the rock. This thermal treatment leads to a significant decrease of the rock strength, due to severe crack creation (d2) [11]. The cracked surface can then be excavated with conventional cutters (e2), whereas significantly less weight-on-bit and torque is required.

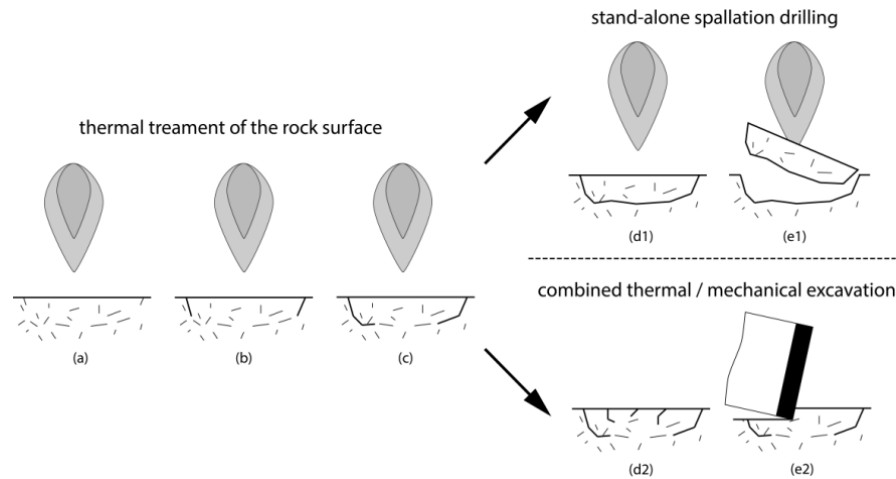


Figure 1: Illustration of thermal drilling. Common process: (a) initially present cracks, (b) crack initiation, (c) crack growth. Spallation: (d1) spall formation, (e1) spall ejection). Thermal weakening: (d2) further cracking of the surface, (e2) mechanical excavation of the cracked surface

2. HYBRID DRILLING – COMBINING CONVENTIONAL AND SPALLATION DRILLING

Generally, thermal spallation drilling has shown its applicability and efficiency in laboratory environments [12, 13] and in shallow drilling applications in hard rock formations with depths up to 311m [14]. High rates of penetration (ROP) of about 15 m/h in granitic rocks, crystalline sandstones and quartzites have been reported [15] and low wear-rates of the drill head could be achieved [16, 17]. Additionally, the drilling performance increases furthermore with increasing depth of the well. But the solid and compact rock encountered at this tests cannot be guaranteed in field-drilling applications over a long distance. Hard rock sections will be interrupted by non spallable sections as *e.g.* soft intrusions, loose agglomerates or highly fractured zones. In these sections only insufficient thermal stresses can be induced as the minerals can expand in the soft components of the intrusion or in the fracture aperture. Both will lead to an interruption of the spallation process and would require an excavation with conventional mechanical drilling tools. As an exchange of the spallation head to a conventional drill head vanishes most of the above discussed benefits of the technology, only a combination of spallation drilling and mechanical drilling seems to be appropriate for deep drilling operations. In spallable formations the head will excavate the rock in spallation mode, whereas in soft-formations or fractured zones the flame will significantly weaken the rock structure to allow a more efficient mechanical drilling process. Due to the thermal weakening, less weight on bit and torque is required, which could significantly reduce the wear-rate of the bit. This could also potentially enable the use of PDC cutters for hard rock drilling applications.

Figure 2 shows an illustration of a design suggestion for a hybrid drilling system combining thermal and mechanical drilling. The hot combustion gases are created in an internal combustion chamber. The flame jet is then directed to a flame slot on the front face of the drill head, where mechanical cutters are completing the drill bit face. The combustions chamber and the rest of the system is cooled with conventional drilling mud, keeping the temperature at an acceptable level. The flame assistance must be confined to a certain area to avoid thermal wear of the mechanical cutters. On the other hand an efficient heat transfer has to be provided and entrainment of cold drilling mud into the hot treatment zone [18] has to be limited to an acceptable level. Experiments showed that an air shield around the flame helps reducing water entrainment, provides a sufficiently large treatment zone and therewith enables an efficient use of the hybrid technology. Additionally, a mechanical load concept has to be integrated which transfers the load to the mechanical cutters and avoids load on the thermally stressed flame slot to optimize the life-time of the drill head. This concept also guarantees an safe use of the head by preventing severe damage to the flame slots which could lead to a blocking of combustion gases. The required fuel and oxidizer can be provided by transport of the fluids via dual or triple drill strings [19, 20] from the surface or storage in tanks integrated in the BHA. Both options should aim at minimizing the required adaptations from the conventional drilling technology reducing the investment costs required to use the spallation technology.

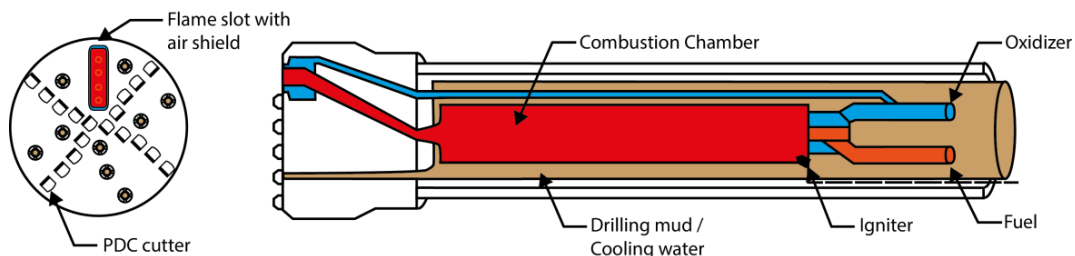


Figure 2: Illustration of a hybrid drilling system combining conventional rotary drilling and thermal spallation drilling.

3. FEASIBILITY STUDY OF HYBRID DRILLING

In order to investigate the effects of thermal rock weakening in rock materials, a preliminary study with flame and oven treated samples was performed. For the flame treatments, a methane-air burner with a flame temperature of about 1300°C was used to locally heat up the rock surface. Thereby, the rock samples were translated relative to the flame burner which is placed perpendicularly to the sample moving direction. During the treatments, the surface temperature of the samples was measured with an infrared pyrometer focused on the stagnation point of the flame. The samples were cooled down after the flame treatments under ambient conditions. The oven treatments were performed in an induction furnace system with a constant heating rate of 10 °C/min and temperatures up to 800°C. Once the maximum temperature was reached, it was hold for 30 minutes in order to allow heat conduction in the inner regions of the rock sample and to homogenize the overall sample temperature. After the treatment, the samples were removed from the oven and cooled under ambient conditions. Central Aare Granite and Rorschach Sandstone (both from Switzerland) were selected as the investigated rock samples. Central Aare Granite has shown excellent spalling behaviors, whereas Rorschach Sandstone appears to be not spallable. Before and after the experiments, the rock samples were tested with the scratch test method developed and performed by the company EPSLOG [21, 22]. This test uses a PDC-cutter to export material, creating a 10 mm-wide groove with different cutting depths, while measuring the applied forces on the tool. With the measured forces the strength and UCS of the material can be calculated. This techniques also allows a high resolution mapping of the actual material structure and the strength variation along the excavated groove. For the aim of the present work, this testing procedure was found to be the most appropriate. Since the effect of flame treatments on the material strength must be assessed at the rock surface, conventional strength testing techniques such as the UCS test would not be able to describe the occurring localized phenomena in detail. Further, this experimental methods shows a significant consistency with the investigated drilling technique. Therefore, the presented results could be potentially directly transferred to real drilling applications.

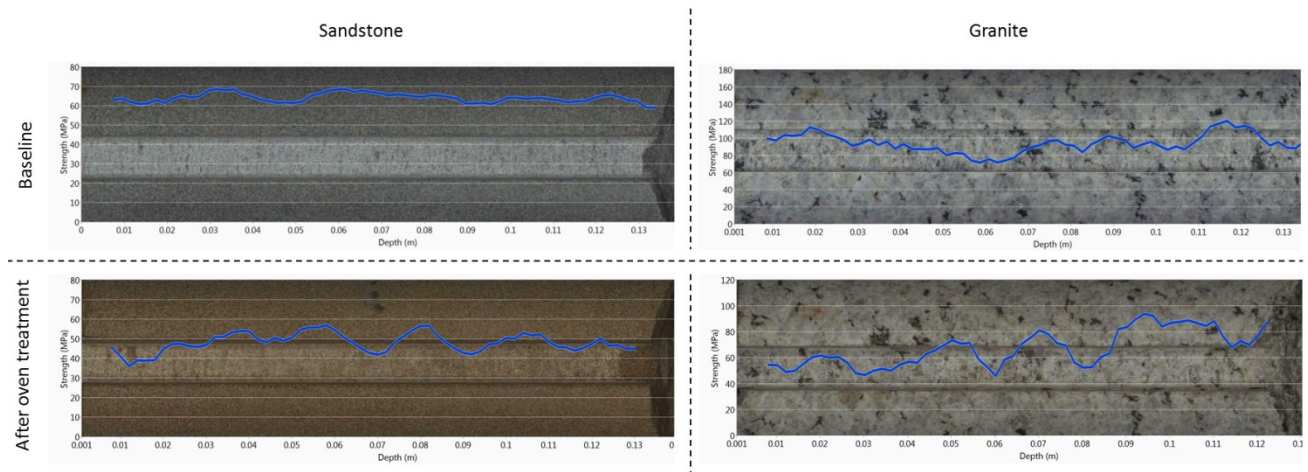


Figure 3: Variation of the strength along the length of the scratched samples. Left: Sandstone samples before and after the oven treatment. Right: Granite samples before and after the oven treatment. Note the differences in the strength profiles and the color changes of the rock materials after high temperature thermal treatments.

Figure 3 shows the variation of the strength along the groove before and after an oven treatment. Thereby the rock cores were scratched before the test (baseline), thermally treated and scratched again in the same groove (after the oven treatment). It can be seen that after the treatment the color of the material has significantly changed, due to alteration processes *e.g.* oxidation of the minerals. The strength after the treatment could be considerably reduced, showing the applicability of a combined system in a first feasibility study. Further treatments were performed with temperature ranging from 20°C up to 800 °C for sandstone and granite samples. The results of the preliminary experiments performed during this study are shown in Figure 4. Here, the strength reduction is plotted against the reached treatment temperature at the sample surface. The strength of the untreated material, obtained by the scratching procedure above-explained, was 105 MPa and 64 MPa for granite and sandstone samples, respectively. The reported strength values are the mean and the standard deviations of the window-based filtered data shown exemplary for the oven treatment in Figure 3.

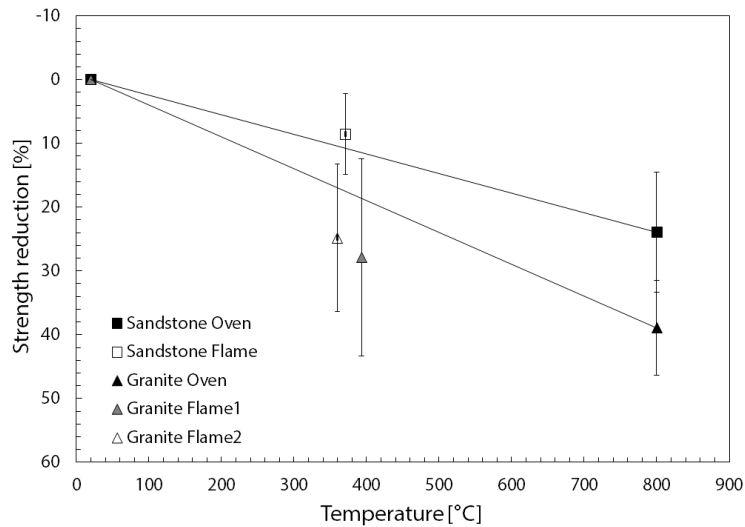


Figure 4: Summary of the investigated rock samples: strength reduction of the rocks due to a thermal treatment (analyzed by scratching the rock samples with a PDC cutter. Data presented in [23].

As it can be seen in Figure 4, both the oven and flame thermal treatments implied a certain strength reduction of the resulting rock material. For the high temperature range, around 800°C, the oven treated samples show a significant reduction of strength by about 25% for sandstone and 40% for granite. This is in agreement with the strength variation during high temperature oven treatments reported by Zhang et al. [24] and Tian et al. [25]. Flame treatments were performed at surface temperatures around 400°C. In this temperature range, sandstone and granite samples also showed a marked weakening after the treatment: the granite samples lost about 30% of their strength and the sandstone samples 10%. Even though large standard deviations were found, a clearly decreasing trend for the strength of the flame treated samples with temperature can be inferred also for temperatures up to 800°C. From the present experimental results, the strength reduction after flame treatments was found to be in agreement with data relative to oven treatments found in the literature, see Liu and Xiu [26].

4. CONCLUSIONS

In this work, a novel drilling technology was proposed combining mechanical and thermal spallation drilling. This hybrid technology could potentially combine the benefits of both drilling technologies and therewith contribute to the reduction of the drilling costs for geothermal projects. Technical design guidelines which are required for a successful application of this technology were presented. The applicability of this technology was shown in a first feasibility study, where a PDC cutter scratched the surface of untreated and thermally treated samples. This preliminary study showed the effectiveness of flame thermal treatments as a rock weakening assistance to conventional drilling. The experimental data allowed to conclude that the implementation of a flame jet as a thermal assistance in conventional drilling could reduce the forces on the drilling tools and in turns also the wearing of the drill bits during its operation. Ongoing research aims to solve the technical challenges of the above-introduced drilling technology.

5. REFERENCES

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