PROCEEDINGS, 45th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2020
SGP-TR-216

Feasibility Study and Application of IoT Based Hybrid LASER Drilling System in Geothermal Fields

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Keywords: LASER drilling, IoT, Well completion

ABSTRACT

Geothermal energy extraction, from secondary sector of business, can be profitable when reservoir is exploited to its maximum capacity, with proper parity with an effective model. The model should be economically feasible as well. A long-term solution in the generation energy from subsurface by mitigating problems involved in conventional drilling methods can be achieved by LASER Drilling techniques. LASERs device is the novel technique for geothermal energy exploitation program, which deals with emission of a focused beam of light. Also, application of IoT is expanding with the augmentation of digitalized era in all the industries and can be well sourced for efficient data collection and transmission. The fundamental aim is to contemplate the most efficient and achievable hybrid model of LASER drilling along with application of IoT to enhance drilling activities and mitigate production problems. Mechanical and thermal properties of rock that affects the drilling operations are reviewed for LASER-Assisted Drilling (LAD) prerequisite. The application of this hybrid model LASER in well drilling, completion and efficient data transmission while infield operations are congregated. Problems associated with conventional drilling and completion methods such as skin effect, borehole tortuosity and several other wellbore frailties are scrutinized. The probable solution for these problems with standard references are anatomized and concluded in this review.

1. INTRODUCTION

In the 100-year history of conventional drilling operation, LASER drilling technology is the first major breakthrough to change the fundamental rotary drilling concept. LASER drilling mainly focuses on three principles of absorption, reflection and scattering of heat energy between LASER and rock. Few rock properties are most suitable for this process, assists in drilling, making operation easier.

Though the lab tests have proven the feasibility of LASER, there are many unsolved challenges like lowering of LASER in a downhole assembly, reduction of rock permeability, weakening of formation in deeper wells, and direct destruction through ablation. As suggested by Graves (1998), numerous techniques are available for drilling completion like spallation or fusing/vaporizing. Out of these methods, spallation consumes lesser energy and breaks the rock into smaller cutting which is more suitable for deeper well drilling operation.

Thermal drilling technology uses the heat energy to apply stress on the rock formation to drill through it. The formation rock utilizes the given heat energy, and it vaporizes, spall or melt. There is no direct contact between the tool and the rock, and hence it reduced the tool wear and tripping time, and therefore cost. Usually, rocks have low thermal conductivity. Therefore when applying heat local temperature of rock increases which induces thermal stress. This stress created microcracks and fractures, which reduces rock strength. Factors on which strength of rock depends are porosity, pre-existing fracture, mineral composition, matrix composition and structural characteristics. And at higher temperature physical and chemical properties of the rock changes. By the mean of dehydration, rock decarbonization, and polymorphic transformation of rock's mineral leads to rock softening.

The LASER can reach make temperature to reach up to the melting temperature of the formation rock, and when the cooling of this melt takes place, it acts as a liner. Therefore the cost of the casing and liner during drilling can be reduced. Rate of drilling in case of conventional drilling depends on WOB, Mud circulation, rotary speed, hydraulic horsepower, bit design and wellbore size to drill. But in the case of LASER drilling, the rate of drilling depends on wellbore size and delivered power. Also no out-of-balance or out-of-axis turning is expected, as LASER head does not have any contact with the formation rock.

LASER converts electric, chemical and heat energy into the photons (electromagnetic radiation). These photons created through stimulated radiation forms a monochromatic coherent beam of energy. This intense energy beam is used for spallation, melting or vaporization of the rock depending on the power transmitted and parameters associated with pulsing the LASER. The energy beam can change its angle using lenses. This phenomenon is useful to focus the beam in any direction for drilling and also for perforation. Perforation can be extended deeply by directing the fiber optic into the perforated area. In many cases, the effective permeability of rock around the tunnel can be increased relative to the virgin zone. Some LASER which has potential to be useful in drilling sectors are Deuterium Fluoride (DF) and Hydrogen Fluoride (HF), Chemical Oxygen-Iodine Laser (COIL), Carbon dioxide laser (CO2), Carbon monoxide laser (CO), Free-Electron Laser (FEL), Neodymium: Yttrium Aluminum Garnet laser (Nd:YAG), Krypton Fluoride excimer laser (KrF), and Diode Laser (Ketata et al. 2005).

IoT is an amalgamation of data collection, storage and inspection. By hybridizing IoT with LASER drilling system, vast data analysis for efficient drilling and monitoring is possible. At specific pulse rate and operating parameters, LASER can melt one formation while vaporizing other formation, generating data, which can be inspected through IoT network and can modify LASER operating parameter as per requirement.

2. LASER-ENHANCED DRILLING AND LASER ASSISTED FRACTURING FOR SUBSURFACE EGS APPLICATIONS

Conduction-dominated EGS targets represent a more abundant source of energy is at the depth greater than 6 km, where temperature can range from 200-300°C (figure 1) (MIT, 2006). Here vast geothermal reservoir remains unexploited due to the technical and economic challenges faced by the conventional drilling methods (Foro Energy, 2016). The cost of drilling at this depth is more than 10 million dollars a well.

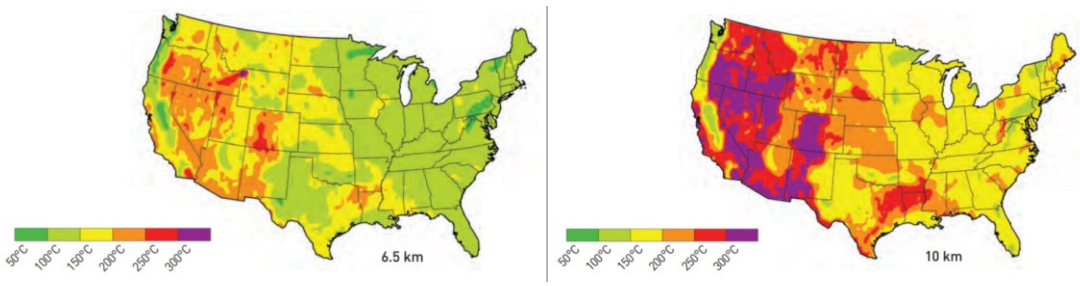

Figure 1: Temperature at the depth of 6.6 and 10 km (MIT, 2006)

Usually, the hard rocks like granite have no porosity. Therefore by applying heat energy, thermal expansion of granite can takes place. This expansion causes the rock to create micro-fissures as there is no space available for occupying the expanded volume. This property of the hard rocks can also be utilized by the LASER drilling for the economic drilling of the hard formation.

Applying pulsed LASER using fiber optics, in EGS applications can induce thermal expansion of rock along with many fissures and micro-fissures network. Study of Ezzedine et al. 2015 shows, experimentally and theoretically, that application of LASER drilling increases the rate of penetration by the factor three at 700°C from the thermal softening effects of the LASER only. Due to this, the cost of drilling can be reduced compared to conventional drilling.

Rate of penetration issue can increase well cost as much as 15% to 20% more than in easily drilled formation (MIT, 2006). Although cost reduction is not formally analyzed, LASER drilling clearly shows a reduction in cost by reducing rig rental time, lighter and lower rig cost by allowing a high rate of penetration. This also makes low-grade EGS resource accessible economically.

3. MECHANICAL AND THERMAL PROPERTIES OF ROCK MATERIALS IN THERMAL ASSISTED DRILLING

The reflective property of the rock depends on the rock composition, while scattering depends on wavelength λ of the LASER beam. Planar surface, like a mirror, reflects much of the LASER energy, while rough surface mainly scatters the incident radiation. These scattering and reflective properties of the rock indicates energy losses that occur apart from absorbed energy. Therefore minimizing the fraction of scattered and reflected energy losses, maximize the energy transfer to the rock for drilling purpose.

The mineral present in the rock composition begins to melt when the rate of heat dissipation by the rock exceeds the rate of energy absorbed by the rock. Therefore it raises local temperature of the mineral, by energy accumulation with time, and then melt it. Melt generated is the function of the mineral present along with the porosity of the rock matrix. Some minerals also decompose and produce gas when the LASER system applies high energy as a function of time.

Rock having lesser porosity have higher heat conductivity. Therefore, the formation of having low porosity is susceptible to better radiation energy absorption. This result shows that LASER is relatively more advantageous in the hard formation faced in extended reach drilling program.

The energy required for removal of unit rock volume is benefitted by impact of fracture formed during drilling process. However, pre-existing fracture represents losses of energy, acting as porosity, which results in higher energy requirement for drilling forward. The behaviour of the fracture depends on the factor such as mineralogy, porosity, stress applied, and thermal properties of the rock.

Clay contains water, which evaporates quickly from the pores. This evaporation causes the increases the pore pressure and can fracture the rock. This fracture can be expected more in sandstone and shales due to their higher thermal conductivity due to quartz and clay content. Whereas, limestone has less clay and quartz content; therefore, it is less prone to the fracture.

Fractures created in sandstone is regular, not random. At high temperature from the radiant energy cause quartz grain to expand. At 600°C quartz grain expands by almost 1.75% of the original size (Salehi et al. 2007). Therefore in tight sandstone, having less porosity, fracture creates more quickly because of the low volume available to expand.

Mineral	100 °C	200 °C	400 °C	600 °C
Quartz	0.14	0.3	0.73	1.75
Plagioclase	0.09	0.14	0.22	0.83

Figure 2: Single axis thermal expansion of sandstone minerals (as percent of original size) at different temperatures (Bararsek et al. 2004)

4. CHARACTERISTICS OF CONVENTIONAL DRILLING AND LASER DRILLING

Drilling costs account for 30%-70% of initial costs (Teodoriu and Cheuffa 2011). Additional costs of geothermal well are caused due to drilling relatively large casing, deep well drilling in case of EGS, encountering hard rock formation or sensitive areas while drilling through faults, and heat sensitive environment. According to a GRI study conducted in 1990, 48% of the drilling time of a typical well is spent on making hole, 27% of the time spent changing bits or putting steel tubular casing in place, and 25% of the time spent measuring well and formation characteristics. Drilling costs can be reduced exponentially by increasing the drilling speed and reducing the drill string removal requirements for casing setting and replacement of bit (Maurer et al. 1990).

The major problems faced in conventional drilling are sticking of cementation problems, drill string and mud losses, casing lowering, wellbore instability, drilling through sensitive formations, stimulation problems, risks associated with true depth and temperature uncertainty in geothermal well. In well completion operations, perforating with a shaped charge gun causes reduced production by damaging the formation around the perforated tunnel.

Compared to conventional drilling, LASER drilling significantly improves the drilling efficiency and solves the problems of conventional drilling. The weight of LASER drilling devices is light, and so it not only can be transported to the well sites by trailers, but also narrows the well site. If we can drill a deep borehole with a diameter, there will be a substantial reduction of the drilling devices size. Moreover, LASER drilling does neither need bits, components nor equipments which are essential for rotary drilling, and so it reduces the drilling cost greatly. It can shorten the drilling cycle, improve the drilling efficiency and reduce the drilling cost.

Meanwhile, LASER drilling can form a glassy protective layer around the borehole. This protective layer can reduce the need of coaxial casing string to minimum or eliminate, and prevent the fluid in the well from entering into the formation or else it will cause pollution in the environment. The well bottom and the surface are connected through the cable, so we can achieve a more effective navigation drilling by taking use of the down-hole television or other forms of sensor to transmit the down-hole information to the ground. The LASER photons of LASER drilling travel in a straight-line path, so it can control the well path effectively and avoid the well deflection (Huang et al. 2010).

5. GEOTHERMAL WELL COMPLETION TECHNOLOGY USING HIGH POWER LASER DEVICE

The LASER tool can melt the target formation and remove the molten debris. Therefore depending on the size of the hole required and the radiant energy transmitted to the laser, permeability of the borehole can be adjusted. LASER can penetrate the larger hole with a constant diameter of the borehole in the desired direction, which increases the surface area exposed for the production while decreasing the pressure gradient nearby the open section of the well (figure 3). LASER technology is also suitable to drill through the casing, cement and the formation, with one tool in and out.

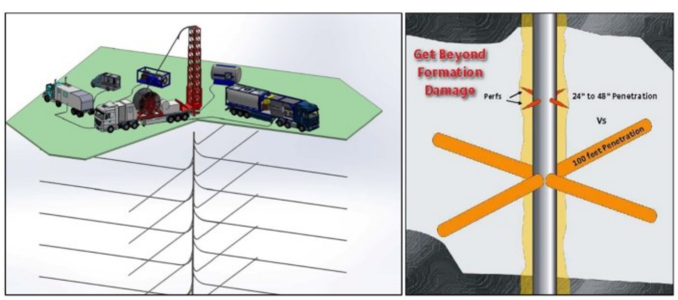

Figure 3: Laterals drilled in Any Desired Direction (Bajcsi et al. 2015)

The measurement of the permeability can also used to determine the increment in the production rate from the well. 8 laterals drilled of length 10-80 feet can increase the production rate up to 280% (figure 4).

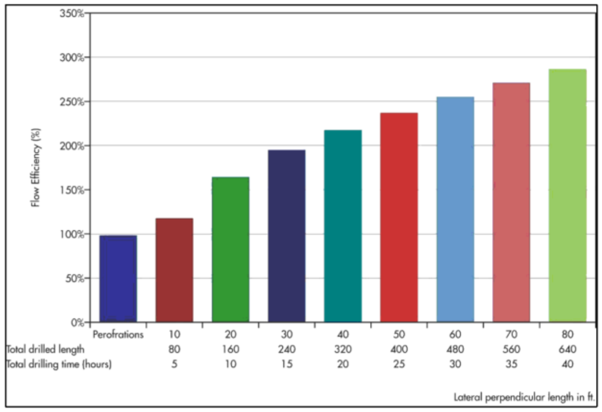

Figure 4: Calculated Productivity Increase of a Well Due to Laser Drilled Laterals Compared to Jet Perforation (Bellarby, 2011)

6. DRAWBACKS OF LASER DRILLING

The advantages of LASER drilling over conventional methods are numerous. However, several drawbacks determined are drilling during complex formation, borehole cleaning formation and well control problem (Huang et al. 2010).

The conditions of complex formation for better simulation of formation conditions in laboratory, we do experiments while make the core immersed in water, brine, crude oil and exert the level or vertical stress. Specific energy required for effective penetration for the core saturated with fluid is greater than that in air. Hence, fluid acts as a hindering medium as it increases required energy for removal of unit rock volume.

Also, the rocks saturated with fluid will recover gas when encountered with LASER, the composition and volume of gas has to be evaluated, and conduction of cleaning of borehole for improvising removal process of debris at the bottom by LASER technology. Execution of this method, without affecting speed of drilling operation is preferred.

7. APPLICATION OF IOT IN GEOTHERMAL SECTOR

The vast database is generated daily in geothermal drilling operations due to the advancement in recording sensors. Numerous operational and economic challenges faced by drilling industry such as the detection of physical presence in a drill string, leakage into the formation, and optimization of pumping process and maintenance of pipes and wells, monitor equipment wear, minimize the risks of HSE, corrosion and improvisation of production performance by cost reduction.

SCADA systems cannot detect these problems due to lower density in time and space; they are costly in terms of maintenance, time-consuming control process, inadaptable to software change for additional parameters, and are limited to certain control usage.

To overcome these anomalies, the proposal of IoT based architecture, for accurate, efficient and reliable measurement of various operations in the geothermal sector with on-field data evaluation, transfer and storage. IoT based reliable monitoring system that involves several devices installed on various assets of geothermal fields to facilitate various operations. This system, with the minimum human intervention, will provide better workplace safety and maintenance of capital assets. In case of equipment failure or need for variation in operation, this system will predict required changes by analyzing sensed data and indicate the cost-effective model for operation (Khan et al. 2017).

IoT is an amalgamation of different parameters with the internet using multiple sensors that exchange detected information and communicate to the surface monitoring systems. It employs intelligent identification of the location tracking for monitoring and analysis. It can monitor the changes in temperature of the geothermal asset due to temperature sensors that are buried underground, which sense the change and transmit the data through networking (Yu and Zou 2013).

For enhancement of drilling operation, the fiber optics LASER can be hybridized with IoT for faster and reliable data analysis and transmission. Readings obtained at each point of a fiber optic element using Optical Time Domain Reflectometer (OTDR) detects losses along the length of optical fiber. Time taken for reflective light to return to the source indicates the precise position along the fiber where measurement is being taken using Raman backscattering. At specific pulse rate and operating parameters, LASER can melt one formation while vaporizing other formation, generating data, which can be inspected through IoT network and can modify LASER operating parameter as per requirement.

8. CONCLUSION

The problems faced by conventional drilling can be reduced using LASER drilling technology. To increase the efficiency and data transmission, a hybrid model of IoT and LASER drilling is reviewed. Through this model, the time and costs can be reduced while the speed of drilling can be increased. A further study is also required to overcome some drawbacks of well control and borehole cleaning problem.

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