Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Potential of Hydro-thermal Spallation Drilling in Geothermal Scenario

Jayesh Bellani, Harsh K. Verma, Dhruv Makwana

School of Petroleum Technology, Pandit Deendayal Petroleum University, Gandhinagar, 382421, Gujarat, INDIA

E-mail address :jayesh.bbt18@spt.pdpu.ac.in, dhruv.mbt18@spt.pdpu.ac.in, harsh.vbt18@spt.pdpu.ac.in

Keywords: Geothermal Energy, Spallation Drilling, Drilling Fluids

ABSTRACT

The aim of this paper is to compare the different types of drilling technologies with Hydrothermal Spallation Drilling (HSD) based on technical basis and efficiency. These days, HSD method is used over the conventional drilling technologies like cable tool drilling and mud rotary drilling. The HSD is a new, efficient and effective contact-free drilling technology which uses a hydrothermal flame to drill through the rocks. It has been brought in use as it is cheaper than other conventional drilling technologies like Rotary Drilling Technology. This technology creates thermal stress on the upper rock layer which breaks the polycrystalline rock into small disc-like fragments with the help of a highly energetic flame jet. Whereas for drilling of deep geothermal boreholes with kilometres of depth, this technology has to rely on water-based drilling fluid. The maintenance of relatively cooler drilling fluids could lead to the loss of heat before even reaching the rocks and converting them to spalls which is one of the drawbacks of this method. Together, this study discusses the technical aspect and the different processes that are included in this method.

1. INTRODUCTION

Traditional drilling methods are used to drill through the rocks for exploration and extraction of Oil/Gas/Geothermal Systems, since the first extraction by imparting pressure on the rocks which causes stress but also leads to bit wear and limits the penetration rates (Lyu et al., 2018). In the latter half of the last century, the Geothermal energy gained much attention because it became the most feasible energy available in the world and is predicted to contribute around 5% of the global energy by 2050, for which Geothermal wells are to be explored by drilling activities which depends on different types of drilling methods which are differentiated on the basis of costs and effectiveness. Hence some new and innovative methods are discovered for drilling which are economically profitable and technically effective.

One of the new and upcoming drilling technology is Thermal Spallation Drilling, this technology is non-contact, cost efficient and effective over other methods of drilling (Rauenzahn et al., 1985). To understand the new method it is required to first understand the spallation or spalling process which includes spalling i.e. breaking of rocks into smaller fragments by inducing different temperature gradients in the rocks which can be operated to the surface. For deep wells, Hydrothermal Spallation Drilling is used because of different carrier of heat viz. water/air/fuel. This method uses a flame to transfer heat to the rock, heat it up and break it into small spalls. This process can be divided into three stages 1. Initiation, 2. Expansion, 3. Stripping (Lyu et al., 2018; Yan et al., 1999; Tan et al., 2006). As this process is contact free, a longer life, increased efficiency, lower expenses are obtained (Tester et al., 2004). So looking at the economy sector, the expenses of Thermal Spallation drilling increases linearly with depth compared to the other rotary drilling techniques which increases exponentially with depth (Nickele et al., 2004).

This paper discusses about the technical aspects of the recently developed Hydrothermal Spallation Drilling for deep wells.

2. DOWNSIDES OF CONTACT DRILLING

A good amount of variety is found in contact drilling techniques which can be, and are being used to drill a borehole into the ground. Each of them vary with the depth up to which it can drill, penetration rate, type of sample returned and the expenses involved are also taken into consideration for classification of these drilling techniques. Some examples are Rotary Cut, Rotary Abrasive, Rotary Reserve, etc.

Nowadays, while drilling through the hard rock formations for geothermal drilling, the contractors mainly use rotary cone bits which have been sufficient for grinding and crushing the rocks. Taking into consideration the rate of penetration (ROP), drilling depth and other factors the rotary cone bits are less efficient in comparison to the PDC diamond bits which have the ROP twice than that of rotary cone bits. However, downside of the PDC bits is that they are sensitive to bit vibration in the hole, which is a problem in geothermal well drilling associated with increased depths and hard-crystalline rocks (Jennejohn, 2009).

3. METHODOLOGY

3.1 Theory

Cracking of brittle solid into small, disk- like flakes with use of heat on a relatively small fraction of solid is called Thermal Spallation. Thermal stresses on the solid lead to the failure of its structure which causes expansion of the solid. The dimensions of these spalls are really small with thickness varying from 0.1 – 2 mm and the diameters 10-20 times the thickness (Augustine, 2009; Dey and Kranz, 1985). Limestones, shales, basalts and soft sandstones are included in non-spallable or soft category of rocks (Augustine, 2009; Wilkinson and Tester, 1993). No property of a rock can tell if a rock is spallable or not.

Significant amount of proposals were made for the mechanisms describing thermal spallation. Many of them faced failures but the Preston and White model was the first one to build up a correct qualitative explanation of spallation (Stathopoulos and Panagiotis, 2013). Preston developed two criteria for spallation of an unconfined sample:

1. The heated area is to be smaller in comparison to the size of the sample so that no distant displacements at the surface exist and the heated area remains confined.

2. For effective spalling of rock, the heating rate should be sufficient enough to heat the rock surface to attain high temperature before the heat starts spreading across the sample, otherwise expansion will begin which will provide protection to the rock and spalling will not be easy (Rauenzahn et al., 1989).

According to Preston's criteria, compressive stresses form due to the confined surface of heating. The propagation of flaw on the surface starts in the direction of applied stress, parallel to the surface of the rock due to compressive stresses. The spalls are often ejected violently from the surface of the rock, this is interpreted from the high ratio of diameter to thickness of the resulting plate under high stress which undergoes rapid release of the elastic energy of the restricted spall (Augustine, 2009).

However, Rauenzahn and Wilkinson gave the most refined theoretical analysis of the spallation phenomenon and the drilling technology which uses the spallation phenomenon where Rauenzahn applied a statistical model for the brittle failure of rocks to Preston's model (Stathopoulos and Panagiotis, 2013).

3.2 Experimental Method

Wideman et al., (2011). conducted an experiment, from Los Alamos National Laboratory. This experiment was conducted in Pedernal, New Mexico. The field location chosen for this experiment was somewhere in the foothills of Sierra Mountains in Northern region of California, where the required type of granite is found close to the surface Here, they showed the ability to drill 60 cm holes in hard rock by using a 10 cm diameter flame jet which was axially oriented. For creating single axial slots, superheated steam system was used to spall the rock and examine their interaction with the fractures of the rock surface. Further they improvised the process to cut axial slots which were 10 cm wide and the depth exceeded by 25 cm in open-hole sections of granite. The assembly of the system for field trials was as follows:

At the front is the drill head which interfaces with a dynamic seal for stopping the interaction of working fluid with cooling water, after which instrumentation and controls come, followed by tension release and connector assemblies. Here Figure 1 depicts that how the hydrothermal spallation process takes place (Song et al., 2017).

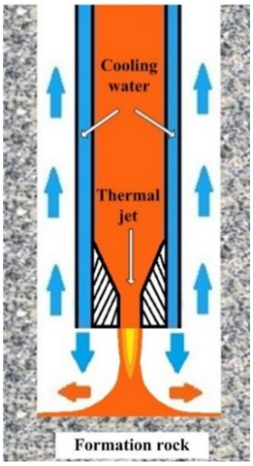

Figure 1: Process of Hydrothermal Spallation Drilling

The results were presented orally at the 2010 Australian Geothermal Energy conference, November 16-19 held at Adelaide (Potter et al., 2010).

4. CHALLENGES FACED IN HYDROTHERMAL SPALLATION TECHNOLOGY

The study of this Hydrothermal Spallation drilling depicts that many limitations are present in this technology out of which it is concluded that, till date, the thermal spallation drilling is limited to drilling only in hard crystalline rocks such as, granites, taconites and hard sandstones.

The thermal spallation drilling technology also has some other obstacles like, it is not yet been implemented in the field i.e. this technology has only been tested in laboratories and till date, the data available is from the laboratories. Another obstacle is the consumption of water. To carry out spallation at different depths, combustion is to be carried out at different level of depths in aqueous environment which also affects the rate of drilling because as the depth increases, the density of water changes and so do the rock properties.

The heat transfer to the rock surface is necessary for spallation which is a challenge because at different depths, various types of nozzles and burner systems are supposed to be used. The type of heat transfer also depends on the operating conditions.

The spalls which are created are to be transported from the treatment zone and the annular zone.

The formations in the sub-surface can be of any type, there may be some soft formations in addition to the hard formations. For drilling through hard formations, hydrothermal spallation drilling which can give up to 30 ft/hr can be used but for drilling through the soft formations, if HSD is used than the ROP will increase and this drastic change in ROP can cause problems during drilling process, to control this, the flame jet speed has to be predetermined and set according to the rock properties (Potter et al., 2010). The conventional rotary drilling process is alternative to drill through the soft formations but then the question comes to the cost which would increase by the use of two drilling processes being used in the same hole.

Also the rock under stress in sub-surface behaves differently than in the laboratory so it can show different behaviour towards this process of drilling due to which there might be changes in the properties of rock formations like it can affect the porosity and permeability of the rocks (Williams, 1986).

Drilling through the air-filled borehole is difficult. Mechanically unstable air filled boreholes can be formed by using this drilling process which can result into their breakout and may eventually collapse. So logging has to be done precisely or else this might cause a big problem in the well bore (Potter et al., 2010).

Due to different rock properties of spalls in soft formations, the spalls might be of different size and density which might lead to collapse of walls of wellbore i.e. sloughing. For this rock properties have to be studied and the properties of water which is being used as a drilling fluid has to be altered accordingly.

5. FUTURE APPLICATIONS OF THIS TECHNOLOGY

For ignition of hydrothermal flame, a new reactor is needed which would create more space for study on hydrothermal jets (Potter et al. 2010). With high temperature hydrothermal flame, this technology can be scaled to drill up to 30,000 ft for production and establishing an universal EGS. Directional drilling can be benefited by this technology which in turn will be helpful for extraction.

6. CONCLUSION

If Hydrothermal Spallation Drilling technology replaces the conventional drilling technology then there will be a great change in the Engineered Geothermal Systems (EGS) because of the efficiency and the cost cutting it offers, higher rate of penetration (ROP) is achieved when compared to the conventional drilling technology. As this technology is non-contact drilling technology, bit wear is reduced and the trajectory control is also increased up to a great extent. The casing intervals also get optimized by the use of this technology. Well-bore Stability increases due to the fewer casing intervals. The geothermal well can be setup easily and efficiently in both technical as well as economical aspects by the use of this method.

REFERENCES

C. R. Augustine: Hydrothermal Spallation Drilling and Advanced Energy Conversion Technologies for Engineered Geothermal Systems (2009).

Edward Williams, R.: The thermal spallation drilling process. *Geothermics,* **15(1)***,* (1986), *17–22*.

Hu, X., Song, X., Li, G., Shen, Z., Lyu, Z., Shi, Y., Zheng, R.: An analytical model to evaluate the heating conditions for drilling in hardrock using an innovative Hydrothermal Spallation Drilling. *Applied Thermal Engineering,* **142**, (2018), 709-716.

Jennejohn, D.: Research and Development in Geothermal Exploration and Drilling. Geothermal Energy Association (2009).

Lyu, Z., Song, X., Li, G., Wang, G., Shi, Y., Liu, Y., and Zheng, R.. Experimental analysis on characteristics of micro-structure and mineralogy changes in thermal spallation drilling. *Journal of Petroleum Science and Engineering,* **167***,*(2018), 100–109.

R. M. Potter, J. M. Potter, T. W. Wideman: Laboratory Study and Field Demonstration of Hydrothermal Spallation Drilling. *Geothermal Resources Council Transactions*, **34**, (2010), 249-252.

Rauenzahn, R. M., and Tester, J. W.: Flame-Jet Induced Thermal Spallation as a Method of Rapid Drilling and Cavity Formation . *Proceedings of SPE Annual Technical Conference and Exhibition,* (1985).

Rauenzahn, R. M., and Tester, J. W.: Rock failure mechanisms of flame-jet thermal spallation drilling—theory and experimental testing. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts,* **26(5)**, (1989), 381–399.

Shingala, J., Vora, N., Shah, M., Sircar, A.: Dual String Drilling: A Novel Approach towards the Geothermal Well Application, *Proceedings*, 44th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California. (2019).

Song, X., Lv, Z., Li, G., Hu, X., and Shi, Y. Numerical analysis on the impact of the flow field of hydrothermal jet drilling for geothermal wells in a confined cooling environment. *Geothermics*, **66**, (2017), 39–49.

Stathopoulos and Panagiotis: Hydrothermal Spallation Drilling Experiments in a novel high pressure pilot plant (2013).

Wideman, T.W., J, Potter, J.M., O'Leary, B., Williams, A.: Hydrothermal spallation for the treatment of hydrothermal and EGS wells: A cost-effective method for substantially increasing reservoir production and flow rates. Transactions - Geothermal Resources Council, **35 (2011)**, 283-285.

Williams, R. E., Potter, R. M., & Miska, S. Experiments in Thermal Spallation of Various Rocks. Journal of Energy Resources Technology, **118(1)**, (1996).