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2022 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGIES OFFICE

Summary: Drilling Technology Evaluation

1. Drilling Technology Evaluation

- Organization or Affiliation: Sandia National Laboratories[1], Albuquerque, New Mexico
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- Subcontractors and/or Participating Organizations: OSU; Integrated Measurement Solutions LLC
- Project Start and End Date: 10/01/2020 – 06/30/2022

2. Project Objectives and Purpose

The objective of this project is to evaluate drill bit and drilling performance on recent Utah FORGE wells 16A(78)-32, 56-32 & 78B-32 using surface parameter data to monitor overall drill bit performance and health.

The purpose of this work is to improve geothermal well construction processes and reduce the cost of geothermal drilling. Results from this work can be used to improve rock reduction technologies and drill bit response for future geothermal drilling.

3. Project Timeline (with milestones and/or decision points, as applicable)

The project timeline comprised the following:

- Project commenced with a request from the University of Utah for Sandia National Laboratories to assist Utah FORGE with bit evaluations (09/2020);
- A Statement of Work was negotiated with DOE-EERE-GTO and the project was funded (10/2020);
- Sandia accessed Electronic Data Recording (EDR) measurements via Nabors RigCloud interface to the Frontier Drilling Rig 16; EDR data and daily drilling reports were acquired for Utah FORGE well 16A(78)-32 as it was being drilled (11/2020);
- Sandia personnel setup a Bit Master Record to track drilling progress, bit records, and drilling operational parameters (11/2020);
- EDR data access facilitated development of spreadsheet templates for data evaluations (11/2020);
- Rig surface parameter data was fit to a rock reduction constraint model (12/2020);
- Evaluations continued for Utah FORGE wells 56-32 (02/2021) & 78B-32 (07/2021) using Pason US Data Hub;
- A MATLAB routine was developed to allow efficient processing of EDR data (10/2021);
- A SAND report was developed summarizing bit performance findings (02/2022);
- A Technical Interchange Meeting was hosted with the Utah FORGE community of practice (4/2022).

4. Technical Accomplishments

Sandia pursued data collection activities:

- EDR data successfully acquired for Utah FORGE wells 16A(78)-32, 56-32 & 78B-32;
- Bit performance profile catalogued for range of bits used;

Sandia applied rock reduction constraints to evaluate the Utah FORGE drilling data:

- Rock reduction constraint model applied to data;
- Identified response of fixed cutter bits used throughout the Utah FORGE drilling program;
- Method used to track bit wear and presence of drilling dynamics;
- Interval costs estimated based upon penetration rate response and bit life;

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Sandia communicated findings to DOE geothermal rock reduction research community of practice:

- GRC Conference paper published and presented, October 2021;
- SAND Report developed;
- Technical Interchange Meeting (TIM) scheduled with bit Subject Matter Experts (SMEs).

5. Technical Barriers and Targets

This project is addressing the technical challenges with hard rock drilling for geothermal well construction. Fixed cutter bits can successfully drill hard rock characteristic of geothermal formations. However, drilling dynamics can lead to impact loading of cutting structures that can lead to chipping, bulk cutter failure, and catastrophic bit damage. Real time vibration data is not available from downhole due to the limitations of drilling telemetry and is further limited by the high temperature limitations of geothermal drilling. Use of surface rig parameter data must be made to circumvent these barriers to discern the downhole bit response.

Planned technical targets include summary reporting of bit penetration rate and bit life. Targets additionally include an understanding of bit limitations and mechanisms contributing to failure. Accomplished activities include acquire surface rig parameter data; use data to perform advanced analytics on bit response; and interpret downhole conditions in light of observed bit response within constraint model.

The approach is applicable to a wide range of bit sizes and drilling conditions. The Specific Energy / Drilling Strength derived from the Detournay model domain evaluations have been applied to a variety of bit sizes on the Utah FORGE dataset.

6. Technical Approach

The project objective to monitor overall drill bit performance and health was achieved using a rock reduction model that represents a constraint of the forces on a drill bit. A rock reduction model developed by Detournay et al ("A Phenomenological Model for the Drilling Action of Drag Bits," Detournay and Defourny, *Int. J. Rock Mech,* Vol 29., 1992) using Sandia cutter data, herein referred to as the DD model, has been used to interpret the EDR data. This model is a constraint on the mechanical forces governing bit response. It has been validated in the Sandia Hard Rock Drilling Facility using representative drag bits in hard rock samples. It allows an objective standard of comparison for fixed cutter drag bits relative to the ideal performance of a single polycrystalline diamond compact (PDC) cutter. Use of the DD model was expanded on the Utah FORGE data set. The model was used to address the compressive strength of the formation, the aggressiveness of the bit, the overall wear progression of the bit, and the presence of downhole dynamics contributing to bit cutting structure damage.

Efforts are presently underway to accurately assess the green bit response of the bit – a key issue in understanding the response of the bit throughout its drilling interval. This is an important parameter that assesses the sharp condition of the bit when initially on bottom that can be used to monitor performance deviations as the bit drills the target interval.

7. Challenges to Date

One variance for this project relative to typical field drilling project evaluations was nearly all of the data collection and analysis was done remotely. First-hand observation drilling conditions and bit assessments may have aided in the overall determinations. A Sandia employee made a brief visit to the Utah FORGE drill site to become familiar with the overall drilling configuration and data acquisition methods.

While EDR data provides the benefit of remotely monitoring drilling operations, it also presents challenges in correctly interpreting the data represented. It is important to understand the full range of operations and events that contribute to the measured response so as not to incorrectly interpret events in the data. EDR data provides

insight into the overall drilling response; scatter in the data can be difficult to interpret. Some level of filtering is necessary to correctly interpret the data. On the other hand, variation in the data can be indicative of downhole drilling dynamics contributing to the variability.

To address these challenges, data from the Sandia Hard Rock Drilling Facility was used to further understand variations in the measured response and how drilling vibrations can contribute to scatter in the measured EDR data. By controlling the compliance in the laboratory simulation on a single axis; the variation in the measured response can be observed. Preliminary evaluations have been conducted in this area; additional work is needed to fully understand the range of conditions.

8. Resilience to COVID-19 and Diversity, Equity and Inclusion plans

COVID-19 was concurrent with project timeline and compromised efficient execution due to maximum telework mandates. Personnel were limited from normal travel to the Utah FORGE worksite due to mission critical travel restrictions.

Diversity, Equity and Inclusion was embraced as part of normal work operations internally at Sandia and externally with project partners. M.S. mechanical engineering candidate and student intern, Jaiden Norton, contributed substantially to the data management efforts at Sandia.

9. Conclusion and Plans for the Future

Use of rig parameter EDR data in rock reduction constraint models can be successfully used to evaluate the overall bit response even though downhole data are unavailable. This approach has been successfully used to evaluate the range of fixed cutter bits deployed on the Utah FORGE drilling campaign on wells 16A(78)-32, 56-32 & 78B-32. Plans are underway to refine the data analytics algorithm and apply the method to production drilling operations on future DOE-community geothermal well construction projects.

10. DOE Geothermal Data Repository

The SAND Report on the Utah FORGE bit evaluations will be uploaded to the GDR upon completion.

11. Other Dissemination of Research

A Technical Interchange Meeting (TIM) is scheduled for April 20-21, 2022 to address findings and promote mutual understanding of drill bit response in hard rock drilling to Subject Matter Experts in the energy services industry and DOE community of practice.

12. Publications and Presentations, Intellectual Property (IP), Licenses, etc.

- "Advanced Analytics of Rig Parameter Data Using Rock Reduction Model Constraints for Improved Drilling Performance," D. Raymond, A.Foris, J. Norton and John McLennan, *GRC Transactions*, Vol. 45, 2021.
- Analysis of Rig Parameter Data for Utah FORGE Wells 16A(78)-32, 56-32 and 78B-32 Using Drilling Process Modeling Constraints, SAND Report, D. Raymond, A. Foris, and J. Norton, 2022.

13. Supplemental Information- Optional

N/A