

2012 Geothermal Technologies Peer Review Summary: EGS Drilling Systems

1. Technology Development and Field Trials of EGS Drilling Systems

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Subcontractors and Participating Organizations:

United States Navy Geothermal Program Office; China Lake, CA
Barbour Well, Inc; Henderson, NV
Prospect Geotech; Albuquerque, NM
PrimeCore Systems; Albuquerque, NM
NOV Downhole (formerly Reed Hycalog); Conroe, TX
Atlas Copco Secoroc, LLC; Ft Loudon, PA

2. Project Objectives and Purpose

The primary objective of this project is to develop and demonstrate Enhanced Geothermal Systems (EGS) drilling solutions based upon mature, proven rock penetration systems that have been used in the oil and gas and mineral drilling industries for well construction to penetrate hard rock formations. Conventional geothermal drilling is hampered by the challenges of hard/abrasive/fractured rock, high temperatures, and the frequent loss of circulated drilling fluids to the formation. In the past, this drilling difficulty has been a point of distinction between geothermal and oil and gas applications. Recently this difference is less pronounced as the oil and gas industry encounters more difficult drilling conditions. This synergy can benefit the geothermal industry as technology developed for oil and gas, backed by significant research and testing, can be adapted for use in geothermal drilling. This project demonstrates mature oil and gas/minerals drilling technologies on actual geothermal well construction projects. Polycrystalline diamond compact (PDC) bits are routinely used in the oil and gas industry for drilling increasingly harder rock but have not been adopted for geothermal drilling, largely due to past reliability issues and higher purchase costs. Pneumatic down the hole hammers (DTHH) are routinely used in the mining industry and the oil and gas industries for penetrating hard formations. These technologies can be specifically tailored for use in geothermal drilling and demonstrated on a production geothermal drilling project. Ultimately, the objective is to achieve development of fit-for-purpose EGS drilling solutions (hard/abrasive/fractured rock, high temperature, deep drilling) for geothermal exploration and production drilling.

The outcome of this work will be improved drilling technologies to reduce geothermal well construction costs by drilling faster with improved tool life, capabilities for improved hard stringer penetration, and suitability for deep drilling applications. To the DOE Geothermal Technologies Program, this means improved rates of penetration (ROP), bit life, and viable access to deep EGS reservoirs resulting in a reduction in well construction costs supporting economic development of geothermal resources. To the geothermal industry/market, this will result in specialized

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product support from the drilling services industry specifically for geothermal drilling. Ultimately this will result in: 1) an increase in the number of tools/ options available for geothermal well construction, 2) service companies being more engaged in the geothermal market, and 3) an enhanced drilling experience base to help de-risk and support continued geothermal well construction.

3. Technical Barriers and Targets

This work seeks to address the following technical challenges and barriers that inhibit new geothermal well drilling technologies from being adopted for routine application in geothermal well construction.

Risk Reduction - Like other drilling sectors, the geothermal drilling industry is very risk adverse. This is not surprising given the small number of geothermal wells annually drilled within the US. This project seeks to reduce the risk borne by a geothermal driller/operator in attempting new technologies by bearing the testing burden within the DOE funding framework as opposed to the risk of private investment. This project bears the cost of these technologies and offers them to the drilling contractor for companion testing in a geothermal exploration and/or production well construction project for in situ evaluation.

Limitations of Laboratory Testing - Rock reduction technologies have long been demonstrated in the laboratory. Yet the laboratory does not address all situations or failure scenarios that may be encountered. Field testing in an actual geothermal well construction environment is needed to prove out these technologies. PDC bits have been demonstrated to be abrasion resistant in the laboratory and have also been used in controlled field trials to drill hard rock. Likewise, percussive hammers have been used to drill hard rock but their use in high temperature drilling has been limited. This project allows a representative field evaluation of candidate concepts.

Service Company Investment - A significant barrier with geothermal drilling is the drilling products developed are largely intended for oil and gas and minerals drilling and this standard product line is subsequently offered to the geothermal drilling industry. The project engages the service companies collaboratively in the problems faced by the geothermal drilling industry. This engagement forges a participation that develops fit-for-purpose solutions specifically for the geothermal drilling industry.

Drilling Industry Acceptance - By reducing the risk, demonstrating applicability, and engaging the service companies, this project eases acceptance by the geothermal drilling industry. Industry sees first-hand that these technologies are available and considers using them on future drilling projects resulting in concomitant drilling cost reductions.

The technical targets & performance metrics pertaining to this development are addressed by improvements in rock reduction performance. Reduced drilling costs are realized by a balance of improved rate of penetration and bit life. The choice to improve ROP or bit life depends upon the economics of the existing technology. Sometimes a greater reduction in drilling costs is realized by an improvement in ROP; other times an improvement in bit life is necessary. The relative improvements in these metrics depend upon present economic performance to realize cost reductions. A baseline performance standard for geothermal drilling is the sealed roller cone bit. Widely used in the geothermal industry, it typically drills at 10-20 ft/hr with a nominal life of 40 hours in hard abrasive geothermal conditions. The performance of the present technology is compared to this nominal baseline performance. The Geothermal Technologies Program has a specific goal of developing drilling systems with a 3-fold improvement in rate of penetration over conventional rotary drilling methods to a depth of 10 km and 300C. The underlying technical performance metric is to catalyze the geothermal drilling industry via improved deep hole access to EGS reservoirs.

4. Technical Approach

The overall approach consists of a three-year work plan to address each of the respective phases. In year one (recently completed), field trials of candidate drilling systems were conducted with preliminary modifications deemed necessary for their applicability to geothermal drilling. The objective of the early field trials is two-fold:

1) demonstrate the drilling performance that can be realized with these technologies and 2) identify their existing shortfalls for geothermal drilling. An industry partner has been identified among geothermal operators and drillers and a well of opportunity identified. Drilling and support equipment was provided and operated by an industry partner. Major service companies provided current technology product offerings to drill the subject well. Sandia oversaw operations and provided data collection, analysis, and reporting while candidate drilling systems were deployed. Identification of limitations is key to providing input to correcting design deficiencies in the second and third year of the project to improve the performance of these technologies to support EGS drilling.

Year two will address design improvements to make these drilling systems more relevant for EGS environments. This will include an assessment of failure criteria to be corrected, custom development for application, and qualification testing in laboratory test fixtures to validate the design improvements.

Finally, year three will address development and demonstration of the improved EGS Drilling Systems based upon these design improvements. Follow-on testing will be conducted in a comparable geothermal exploration and production drilling project for verification and validation. The objective of the second field trial is to demonstrate technology readiness for geothermal drilling and verify the design improvements realized in year two.

Sandia worked with the US Navy (USN) to accomplish the subject demonstration on a geophysical test hole sponsored by the US Navy Geothermal Program Office (GPO). As a component of its evaluation of the geothermal energy potential of the Chocolate Mountains Aerial Gunnery Range (CMAGR), CA (MCAS Yuma, AZ), the USN Geothermal Program Office embarked upon the construction of a deep geophysical test hole to further investigate the temperature field and potential hydrothermal alteration in the Camp Billy Machen/Hot Mineral Spa region. This is an area of apparent geothermal significance and this test hole was drilled to identify and document geothermal manifestations otherwise undetectable at the surface. The geologic and geophysical data collected from the holes was compiled and analyzed to provide necessary insight into potential geothermal resources. The Navy plan called for drilling to a depth of 3000 ft with acquisition of geophysical logs over the entire length of the hole.

Cooperative work between the USN GPO and Sandia was covered by a Memorandum of Understanding between the Department of Defense and the Department of Energy addressing collaborative development of renewable energy resources. The USN GPO drilling contractor, Barbour Well, agreed to collaborate with Sandia in evaluating the subject drilling technologies during production drilling of the geophysical test hole. Sandia, Prime Core, and the Barbour Well mud logging company, Prospect Geotech, fielded instrumentation on the Barbour rig to allow monitoring of drill rig parameters during the drilling process. Sandia worked with bit manufacturer, NOV Downhole (Reed Hycalog), to recommend commercially available bits for consideration. NOV provided the drill bits, readily available from their commercial product line, and also provided knowledgeable personnel on-site to counsel the drilling contractor during the production drilling runs. The Sandia/NOV team coordinated with the USN GPO and Barbour Well throughout the well construction process to monitor bit performance and recommend preferred implementation methodologies for the drill bits. The basement rock at the Chocolate Mountains, including granite and andesite, represents some typical formations that can be encountered during geothermal drilling. Phase 1 results are discussed below. Key issues currently being addressed include analysis of field test data, investigation of observed damage mechanisms and Phase 2 design and development.

5. Technical Accomplishments

The technical approach described above was realized in testing conducted at the Chocolate Mountains Aerial Gunnery Range with the USN GPO in November and December 2011. Given the uncertainty with formation characteristics, the drilling contractor preferred to use PDC bits over pneumatic hammers to provide wellbore stability. Accomplishments to date are briefly summarized below.

The first PDC bit - a Reed Hycalog (DSR813M-G2A) 8-blade, 8.5 inch diameter bit with RH "Raptor" cutters, depth control components, and four (4) No. 14 nozzles & Four (4) No. 10 nozzles - was deployed at a well depth of 1345 ft. Additionally, a downhole instrumentation sub equipped with accelerometers was positioned above the bit to monitor and record downhole conditions for post drill processing. It was programmed for 80 hours of continuous recording at one averaged sample per 2.56 seconds with high frequency (400 Hz) 10-second bursts at uniform time intervals of 2.5 minutes. The total time on bottom for this bit was approximately 41 hours and it drilled an interval of 725 ft with an average penetration rate of 26.5 ft/hr. The outside diameter of the bit was measured "at gage." Bit inspection indicated some slightly chipped cutters; the up-reamers and gage pads were in good condition.

Additionally, a second bit with seven blades (RH DSR713M-B21) was used to drill an additional 566 ft at an average penetration rate of 20.4 ft/hr. The second bit was intended to be more aggressive than the eight-blade bit yet actually drilled slower and suffered from significant impact damage during drill-offs associated with insufficient rig torque for the bit design. With sufficient rig torque the bit would have drilled much faster than the eight-blade design. Together the test bits drilled 1291 ft of the overall well depth and were in the well just over four days. The downhole data was successfully retrieved from both bits and downloaded for subsequent analysis. Sandia is working with NOV Downhole to evaluate damage mechanisms and improve the bit design/materials for subsequent demonstration on another geothermal production drilling project. A roller cone bit was tripped back in after the second PDC bit and produced an average penetration rate of 10.7 ft/hr over three stands. The relative improvement in penetration rate with the PDC bit can allow for significant well cost savings in spite of the higher lease cost associated with their use. Pathways to greater penetration rates for the 8-blade bit and increased durability for the 7-blade bit are currently being addressed.

These results have overcome barriers associated with these technologies. This project has reduced the risk of PDC bit use in geothermal well construction; highlighted the importance of field testing in identifying capabilities and limitations; achieved significant service company interest in the geothermal market; and garnered synthetic diamond acceptance within the geothermal drilling industry. A 2.5-fold improvement in average rate of penetration has been demonstrated over conventional geothermal drilling technology in granitic basement rock

6. Challenges to Date

Significant difficulty was encountered in identifying a geothermal operator and/or driller to support field testing; this is not surprising given the barriers identified. The USN GPO proved to be an ideal partner with their presence in the industry. During the course of the drilling tests, problems were encountered with availability of adequate rig torque to drive the PDC bit. This is not deemed to be a limiting problem but highlights how advanced geothermal drilling solutions will need to be paired with available capabilities of geothermal drill rigs. PDC bits can be specified for geothermal solutions provided the surface system capabilities and the specific formation targeted are considered.

7. Conclusion and Plans for the future

Future work on this project will include the completion of surface and downhole data reduction activities from the Phase 1 field drilling demonstration. Phase 2 work has been initiated to identify bit design deficiencies and engineer improvements. This includes development of designs for both an aggressive 8-blade and a durable 7-blade bit followed by fabrication and testing in the NOV Pressurized Drilling Laboratory (PDL). Modified bit performance will be compared to baseline bit performance under comparable test conditions. Field performance verification and validation testing will be conducted in year 3, in accordance with the original project plan, and will be proposed to DOE outside of the existing ARRA project framework. Sandia continues to seek partnership opportunities for field testing the second generation bit designs at other opportunistic well sites.

8. Publications and Presentations

Results and findings will be submitted as a technical paper for publication in the Geothermal Resources Council Transactions. Project news reports have been released through Sandia Media Relations.