PROCEEDINGS, Thirty-Sixth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 31 - February 2, 2011
SGP-TR-191

ADVANCED ELECTROMAGNETIC MWD TELEMETRY AND PDM SYSTEMS IMPROVE DRILLING PERFORMANCE IN A CALIFORNIA GEOTHERMAL WELL

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ABSTRACT

The service company and operating company worked together to improve penetration rates, wellbore placement and reliability in drilling operations by utilizing a specially designed positive displacement motor (PDM). The specialized PDM impacts the borehole construction process by addressing hole quality while achieving superior directional performance over conventional PDM assemblies, and an advanced electromagnetic telemetry (EMT) MWD system allows data transmission without a continuous fluid column. Operating the Coso geothermal field located in Kern County presents some of the most difficult drilling conditions in the world; the tremendously hard, abrasive and fractured formations are susceptible to lost circulation incidents and create a harmful environment to directional drilling equipment. High amounts of lost circulation material (LCM) must be pumped through the bottomhole assembly (BHA) in order to cure partial losses. At deeper depths, air drilling is utilized which renders conventional pulse tool telemetry useless.

The electromagnetic (EM) MWD system has many advantages over conventional mud-pulse telemetry including improved reliability, unlimited concentration of LCM, reduced survey time which minimizes non-productive time (NPT), and ability to operate with numerous fluid systems including air. This paper presents a case history where the EM MWD and PDM systems advantages have proven effective to help reduce drilling days and lower total well costs for the operating company.

INTRODUCTION

The Coso Geothermal Field

The Coso geothermal field is located in the Coso Range between the eastern flank of the Sierra Nevada and the western edge of the Basin and Range tectonic province of southeastern California, distinguished by having a coherent history of deformation different from that of neighboring regions.

The Basin and Range tectonic province is an area of high heat flow and seismicity, characterized by a fault-block landforms separated by valleys filled with fluvial water deposits. To the west, the Coso Range is separated from the Sierra Nevada by the southern extension of the Owens Valley, and to the north, bounded by the saline playa at Owens Dry Lake. (Newman 2008). On the east, the range is bounded by Darwin Wash and the Argus range, a long and narrow mountain chain along the west side of Panamint Valley., and on the south by Indian Wells Valley (Fig 1.)

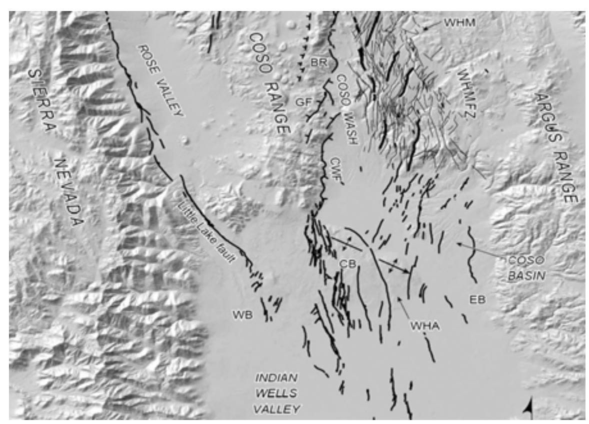

Figure 1: Coso Geothermal Field (Newman 2008)

The basement of the Coso Range is dominated by fractured Igneous rock derived from magma that has cooled and solidified, intruded by a large number of fine-grained magmatic dike swarms, and partly covered by Late Cenozoic volcanics consisting of basalts and rhyolites. During the most recent volcanic phase, 39 rhyolite domes were place in position in the central region of the field, along with a relatively small amount of basalts. (Manley and Bacon 2000). A partially molten magma reservoir is believed to be the heat source of the Coso geothermal system. This seismically active area has two mayor fault sets, recognized to control the geothermal system. The first set of faults strike WNW and have a vertical dip, while the other set of faults, strike NNE and dip to the east. The NNE set of faults have been successfully targeted in the development of the Coso geothermal field (Sheridan 2003). Reservoir fluid recharge is limited in the Coso reservoir making reinjection of fluids critical for sustained productivity.

Geothermal Drilling

Well construction activities usually begin with the drilling of shallow holes to obtain a temperature gradient before drilling a deeper exploration hole, and a production well. In some regions shallow and intermediate cored drilling is performed to obtain a temperature profile and measure thermal conductivity. With production well success rates at 25%, improvements in drilling technology directly impact a geothermal prospect viability, because the drilling of production wells accounts for a significant portion of project costs. (Jennejohn 2009).

Drilling in the Coso Geothermal Field

Drilling in the Coso field is challenging because rocks are hard, fractured, and formation fluids are often corrosive, hot and underpressured. (Sison-Lebrilla and Tiangco 2005).

While geothermal wells have been drilled in this field for over 22 years, lost circulation has always been one of the major issues with successfully drilling these wells—often requiring more than 10 lost circulation plugs per well to regain returns. This procedure can add weeks to the drilling process, thereby significantly increasing costs. Because of the severity of the losses, air-drilling technology is commonly used with a hammer system to make hole.

These factors impact the cost of geothermal well construction, typically, much higher than oil and gas wells of comparable depth.

Lost Circulation Challenge

To overcome lost circulation challenges, an electromagnetic (EMT) MWD system was used, which allows high concentrations of LCM to be pumped through the MWD system without packing off. This allowed partial losses to be cured without the need to set cement plugs. In a conventional positive pulse MWD system, high concentrations of LCM would plug off the MWD system, causing additional trips, non productive time and premature equipment failure. (Steffen and Evanoff 2010). Using the EMT MWD System—which does not rely on a column of fluid to transmit data to surface the service company was able to directionally control the wellbore trajectory in the production interval when air drilling is used. The operator also required a solution to reduce destructive vibration and improve rates of penetration (ROP) while drilling this troublesome formation. An advanced positive displacement motor (PDM) was implemented as a solution that improved ROP while mitigating the destructive vibration mechanisms.
The implementation of the EM MWD system has been a huge success, reducing drilling times by over one week and resulting in significant financial savings.

ADVANCED POSITIVE DISPLACEMENT MOTOR (PDM)

The advanced PDM system demonstrates a new level of drilling performance by integrating an enhanced performance motor power section between the rotary steerable system and the MWD system. The advanced PDM motor has an optimized stator design that delivers more than double the power of a conventional motor with less vibration (Fig. 2), resulting in faster ROP and increased reliability. The intense delivery of power directly to the bit dramatically reduced the occurrence of stick-slip and other types of undesirable bit dynamics. The advanced PDM system demonstrates the ability to achieve higher penetration rates while minimizing casing wear by decoupling the bit speed from the drill string speed. The result is increased drilling efficiency and reduced drilling costs. Increased RPM improves hole quality and decreases requirements for backreaming, while vibration-related damage is reduced by minimizing stick-slip and by decoupling the MWD tool from damaging shocks and torsional vibration.

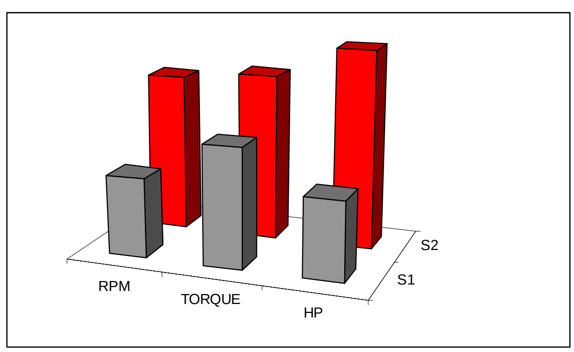

Figure 2: The advanced PDM produces significantly higher speed, torque, and horsepower than conventional power sections for faster drilling and longer life

When drilling with mud motors, there are many occasions where bit rotation reduces and increases or the bit/motor may even stall for an instant. There is often no evidence at the surface for these events, even with detailed observation of the standpipe pressure. The "smoothing out" of fluctuations in drill bit rotary speed and the more consistent torsional loading of the bit can maximize ROP and reduce wear and tear of internal motor components.

The advanced PDM is designed to offer the highest possible torque throughout the range of maintainable operating differential pressures. Drilling torque is directly proportional to the operating differential pressure across the motor; the higher the operating differential pressure, the higher the output torque.

The PDM torque benefits include the following: 1) greater torque output than conventional motors; 2) more consistent RPM and torque applied to the bit, increasing ROP, motor life and bit life; 3) higher operating temperature ratings for 4 3/4-inch tools (350°F) and 6 3/4- and 9 5/8-inch tools (320°F); 4) improved reliability and performance in harsh environments; 5) reduced vibration, improved performance and steerability, increased bit life and better hole quality; 6) higher dogleg capability than conventional motors of similar torque output; and 7) more resistance to failures associated with chemical-induced swelling.

ELECTROMAGNETIC TELEMETRY (EMT) OPERATION AND CAPABILITIES

The EMT system operates by encoding data into electromagnetic waves with frequencies in the 2- to 15-Hertz range. The signal is transmitted from the bottom hole assembly (BHA) through the drill pipe and formation, and detected at surface as a low voltage potential between the wellhead and a remote electrode (**Figure 3)**. This system allows the transmission of directional and logging data while drilling, without a column of drilling fluid. MWD operators communicate to the BHA using EMT generated from surface power amplifiers. This two-way communication allows specific information to be transmitted on demand. The MWD system has many advantages over pulse telemetry, which helps reduce drilling costs. Advantages of the EMT system include the following:

1. Improved reliability—no moving parts reduce wear and improve mean time between failure (MTBF), resulting in higher reliability, less trips and lower NPT.
2. Two-way communication— EMT system establishes a two-way communications link between the surface and the BHA. The system facilitates high-speed bi-directional data transmission between the surface and the BHA through the formation at anytime. As electromagnetic surveys can be received without presence of fluid in the drill pipe, enabling faster tripping times and mitigation of costly tool repairs from exceeding temperature ratings.
3. No lost circulation material restrictions - EMT system allows for much greater concentrations of LCM to be pumped through the MWD tool. These higher concentrations of LCM can help mitigate lost-circulation. This advantage can minimize the need for setting cement plugs to regain circulation.
4. Higher data transmission rates—Survey time is reduced. Typical EMT survey is five times faster than a conventional positive-pulse system. Survey time is often hidden NPT, which is often neglected when attempting to improve efficiencies. (Steffen and Evanoff, 2010)
5. Increased depth capabilities—Some formations dampen or attenuate the data signal more than others, which can reduce depth capability of the EMT tool. The system has improved depth capabilities by introducing a through-bore repeater placed in the drill string that optimizes signal strength, which repeats commands from surface down to the MWD tool and then back from the MWD tool to surface without impeding downhole applications that may require full bore access to the drill pipe. (Figure 4).
6. Underbalanced drilling—The EMT system does not rely on a continuous column of fluid to transmit data, providing an alternative to negative and positive pulse systems, helping make underbalanced drilling more cost effective, especially when drilling with air or gasified drilling fluids, in which conventional mud pulse telemetry systems cannot function.
7. BHA optimization—Engineering for specific formation types with motor configurations to match bit type has increased bit runs and improved overall rate of penetration. (Figure 5).
8. Overbalanced drilling — The EMT system is not limited to underbalanced drilling. The system can be used in overbalanced applications where high data density and low survey time are key factors to successful drilling operations.

Future of Geothermal Drilling Technology

The continuous improvement of existing geothermal drilling technology will continue to address high-temperature, corrosion and lost circulation challenges. Advancements in electronics and monitoring technology with fiber optics and high temperature tools as well as advances in drill bit design and hydraulics and drill string dynamics will continue to be developed. New computer simulation software and advanced materials are likely to enable greater development in this area.

MWD and LWD capabilities will continue to improve. (Sison-Lebrilla and Tiangco 2005).

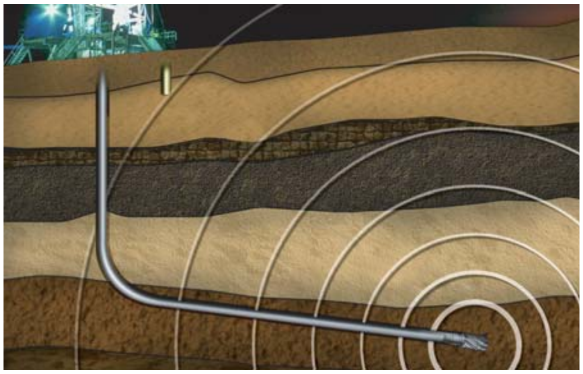

Figure 3: EMT allows data transmission without a continuous fluid column using low frequency, electromagnetic wave propagation. Two-way data communication is achieved via electromagnetic waves transmitted through the formation and the drill pipe.

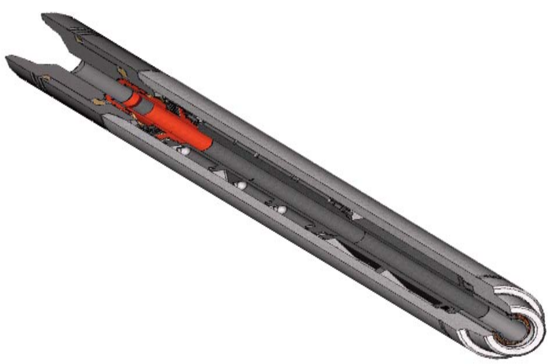

Figure 4: When signal strength is attenuated in deeper applications, a unique "throughbore repeater" can be employed to boost signal amplitude

CASE HISTORY: APPLICATION OF EMT

The project objective was to drill a well vertically to 3900 ft, kick off at this depth and sidetrack with 2-degree doglegs at a 195-degree azimuth, building to 3.6 degrees by 4080 ft, then rotate through the tangent keeping the same inclination and azimuth to 6100 ft. At this depth, the driller would build and turn the hole 11 degrees at a 240-degree azimuth with 2-degree doglegs to 6541 ft, then rotate to a total depth (TD) of 8125 ft, keeping same inclination and azimuth.

Drilling operations were performed with an unweighted, water-based, low-solids mud system using an 8-in. mud motor and the EMT-survey system. The geology was fractured rock with a past history of severe lost circulation. It was important to complete the directional run as planned to establish a proper directional course and successfully complete the well. The challenges were to complete the directional run with a high probability of lost circulation and to obtain consistent survey data during this time.

Mud losses ranged from 20 bbl/hr to total loss throughout the interval. During this time, the mud was being treated with high concentrations of LCM to help mitigate the fluid loss with no detrimental effects to the motor or survey system. However, with the type of fractured rock typically encountered in the Coso field, the LCM treatment is only effective up to a point, and then cement plugs are normally used for lost-circulation control. Given the EM tool capability of producing survey data without the aid of a full fluid column, the decision was made to drill blind (as much as possible. There was no problem with tool signal or interruption of survey data during these times of total fluid loss, and this continuous flow of data was critical to completing the directional plan as planned and establishing the desired target heading.

In summary, when directional drilling through fractured geology and encountering significant fluid loss, the conventional solution when using pulse-telemetry tools was always to continue setting cement plugs until full circulation has been regained and survey-data transmission can continue. The EMT tools provide a better option and allow drilling and surveying to continue with no circulation, decreasing the need to set costly cement plugs. In this well, the entire directional run was completed as planned and survey data was consistently recovered, even in an environment of continuous fluid loss and unknown fluid column.

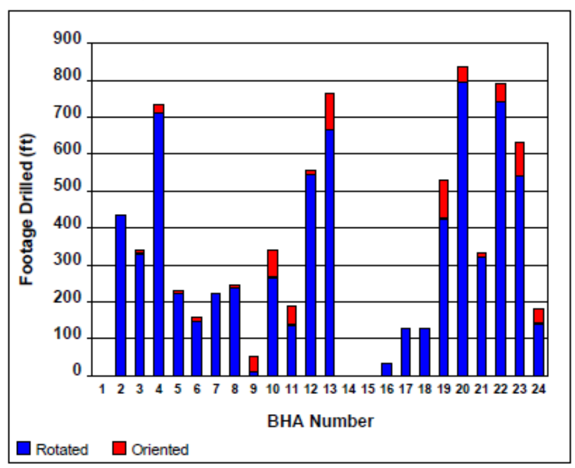

Figure 5: Footage drilled vs. BHA number.

CONCLUSIONS

Advanced EMT systems and PDM technologies used in oil & gas well construction can be implemented successfully in geothermal environments where harder rock formations; corrosive formation fluids and under-pressurized formations encounters lead to frequent lost circulation and other challenges.

Temperatures associated with geothermal wells are typically higher, with the result that fewer tools are available. Drilling technology limitations have not prevented geothermal development, however the use of EMT and PDM help improve drilling success rate and help reduce the costs of drilling geothermal wells. High drilling costs continue to be an issue. Advanced well construction technologies will likely be developed in the future due to the increasing pressures and temperatures encountered by the oil & gas industry. EMT systems do not require a complete fluid column when transmitting survey data, which makes blind drilling a viable option when directional drilling. There is a greater success ratio of achieving all directional objectives with fewer lost-circulation cement plugs. A greater concentration of LCM can be run through this EMT system that can mitigate fluid losses and maintain the drilling progress.

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