Electromagnetic Telemetry Improves Drilling Efficiencies at The Geysers Geothermal Field

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ABSTRACT

The Geysers dry-steam field is interpreted as an ancient subduction complex formed as the Farallon plate was subducted by the North-American continent during the Mesozoic to early Tertiary periods. Commercial development of the geothermal resource has been ongoing since the early 1950s. The drilling environment is characterized by a complex, natural-fracture system subject to frequent circulation losses and low penetration rates. Wells are typically drilled with a mud-fluid system to a depth of 3,500 to 5,000 ft, and then switched over to an air-assisted drilling fluid as temperature increases and steam-producing fractures are penetrated.

Frequent circulation losses while drilling upperhole sections with fluid have consistently challenged the effectiveness of negative- and positive-pulse-type motor/measure-while-drilling (MWD) systems for directional control. The pulse-type MWD systems' inherent need for a continuous fluid column often requires costly cement-plugging procedures to maintain full fluid circulation. Another limiting factor for pulse-telemetry systems has been the inability to pump high concentrations of lost-circulation materials through the bottomhole assembly (BHA) without plugging tools, causing additional trip times.

This paper presents case histories detailing the successful deployment of an electromagnetic telemetry system at The Geysers. In one case, fluid-circulation losses were cured with high volumes of lost-circulation material pumped through the system. Directional control was maintained despite frequent loss of a full-fluid column. In a second application, during the air-assisted drilling phase of the well, it became apparent that well trajectory was off target. In the past, this would have required costly plugback cementing and reorienting the well trajectory uphole with full-fluid circulation for a pulse-MWD system. Electromagnetic telemetry successfully enabled correcting the trajectory and maintaining directional control with an air-assisted fluid system to a depth of 4,840 ft.

Introduction

Directional drilling is an essential and sometimes critical component of most drilling projects in The Geysers. Because of limited surface-location sites and the need for strategic bottomhole-location placement in the reservoir, directional drilling and control becomes almost a mandatory part of any drilling program. A unique feature of completions in The Geysers is that mud drilling is typically performed to the top of the reservoir where casing is installed, and then air or mist drilling is continued through the production reservoir to total depth. This change in fluid medium is a result of the highly altered and fractured reservoir rock containing a dry-steam resource.

These two completely different modes of drilling present significant challenges to designing a directional program that accomplishes the intended bottomhole-target objectives. Historically, most all directional-drilling work has been done during the mud phase of operations. This practice was developed almost out of necessity because of the nature and limitations of air-drilling operations regarding temperature effects and MWD-tool performance. This has resulted in minimal directional control during the air-drilling phase of the well and consequently makes the success of a directional-drilling plan even more critical when drilling on mud.

The greatest challenge to realizing this success and achieving the directional objectives is lost circulation. The geology in The Geysers is volcanic in origin, containing a complex system of natural fractures. Characteristically, this results in drilling conditions of sporadic and unpredictable loss-of-fluid circulation into formation rock. This becomes problematic when conducting directional-drilling operations, especially when using MWD systems that use pulse-telemetry technology for survey-data transmission. These tools require a consistent fluid column to transmit data properly, and during periods of lost circulation this fluid column is constantly fluctuating. As a result, the capability to receive continuous survey data can be compromised and is sometimes not even possible, depending on the severity of the fluid loss and drop in fluid level. This occasional inability to receive and maintain consistent and reliable data makes the pulse tool vulnerable and sometimes inadequate during times of severe lost circulation. Conversely, this scenario underscores the distinct advantage of electromagnetic (EM) telemetry technology. This MWD system relies on sending data using a radio-wave signal and does not need or depend on a consistent fluid column. From an operational standpoint, this type of system helps ensure a consistent data flow when drilling in these lost-circulation environments and avoids potential interruption of data that could either cause a premature end to a motor run or prevent critical directional objectives from being completed. Another important feature of the EM system is that its interior design tolerates a much higher concentration of lost-circulation material (LCM), which is typically added to a drilling-fluid system as plugging agents when drilling through fractured rock. This can be an important aspect of uninterrupted drilling, especially when a motor/MWD system is in service and the directional-drilling plan is being implemented.

Historically, there has always been a challenge in The Geysers to maintain directional control during air-drilling operations and preserve the intended bottomhole target. This problem is made even worse because of an inability to perform directional-correction runs when necessary. The lack of any real solution has been traditionally attributed to the limitations of a steerable directional system in a high-temperature, fluid-less environment. The major operational weakness in this application has always been the lack of a reliable survey-data system that would operate in the absence of drilling fluid. The EM tool and its capability to produce survey data without the benefit of a fluid column creates an entirely new application option when a directional-course correction becomes necessary during air-drilling operations. This represents an extremely significant benefit in The Geysers, considering that, on most completions, at least 4,000 to 5,000 ft of formation is drilled with air. This amount of footage almost always results in potential directional-correction opportunities that could better optimize well spacing in the reservoir.

There are several other considerations when evaluating the EM tool as an application option. The specific geology and rock characteristics are vital to facilitating signal transmission and transfer of data. Based on experience to date by the operating company, the local geology does not appear to be a problem regarding signal transmission in The Geysers. These geology influences can also be a function of depth. The operating company has not used the EM tool in enough instances yet to make any judgments on the effects of depth relative to the local geologic conditions. Lastly, there is one other factor that should be considered when assessing benefits and potential risks of this tool. Because of the internal configuration of the EM tool when using signal repeaters, certain fishing options can be limited in the event of stuck pipe.

Electromagnetic Telemetry (EMT)Capabilities

EMT transmits data from a BHA by using a low-frequency electromagnetic wave transmitted into the formation and detected on surface as voltage potential (Figure 1). This system allows MWD operators to transmit directional and logging while drilling (LWD) information without mud flow. 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 used had many advantages over pulse telemetry, which has helped reduce drilling days/costs by a significant margin. Advantages of the EM system include

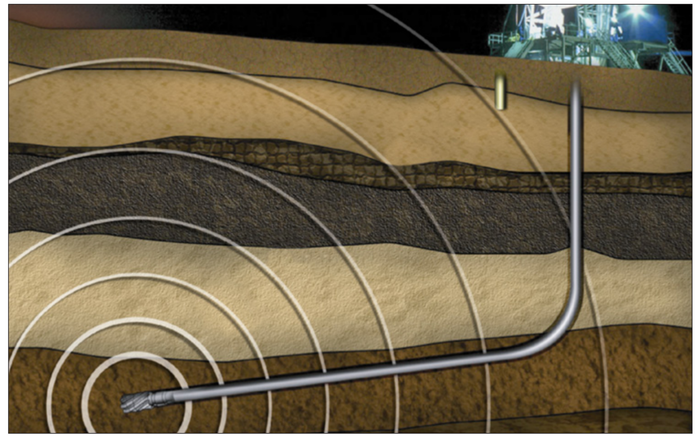

Figure 1. EMT allows data transmission without a continuous fluid column using low-frequency, electromagnetic-wave propagation.

- Improved reliability—no moving parts reduces wear and improves mean time between failure (MTBF) by greater than 3× globally.
- Two-way communication—operators have the capability to survey at any time using an electromagnetic downlink (typical survey will take ~60 seconds). The requested survey provides a temperature, which is critical to monitor while tripping in/out of the hole and while drilling. Electromagnetic surveys can be received without presence of fluid in the drillpipe. This allows for faster tripping times and has been used to mitigate costly tool repairs from exceeding temperature ratings.
- The electromagnetic system used allows for much greater concentrations of LCM to be pumped through the MWD tool. These higher concentrations of LCM can be pre-treated into the mud system and help mitigate lost-circulation incidents. On many occasions, this advantage has eliminated a need for setting cement plugs to regain circulation.
- Survey time is reduced—a typical EM survey will take ~60 seconds versus ~5 minutes for a conventional positive-pulse system. Survey time is often hidden NPT, which does not get considered when attempting to improve efficiencies. About 22.2 hours will be saved by surveying 10,000 ft every 30 ft by EM technology versus positive pulse. This does not include additional temperature surveys, which will be required.
- Increased depth capabilities—the EM signal must propagate through formation and up drill pipe to antenna lines that are placed based on well-plan direction and depth. Some formations attenuate the signal more than others, which can reduce depth capability of the EM tool. If available, field-resistivity logs can be modeled to help determine depth

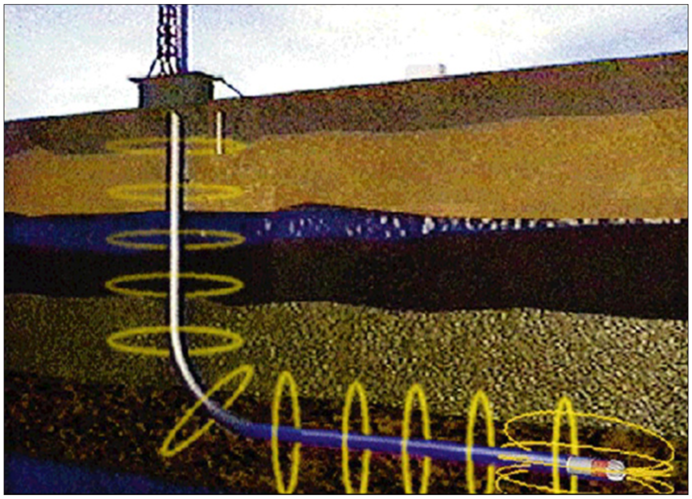

Figure 2. Two-way data communication is achieved via electromagnetic waves transmitted through the formation and the drillpipe. When signal strength is attenuated in deeper applications, a unique "throughbore repeater" can be employed to boost signal amplitude.

limitations in a new field. The system has improved depth capabilities by introducing a repeater placed in the drill string, which repeats commands from surface down to the MWD tool and then back from the MWD tool to surface (Figure 2). Depths greater than 10,000 ft have been drilled without the need for a repeater.

- Underbalanced drilling—The EM system does not rely on a column of fluid in the drill pipe to transmit data. Air, foam, and aerated-mud systems can be used.
- BHA engineering for specific formation types with motor configurations to match bit type has increased bit runs and improved overall rate of penetration. The system used is able to model each BHA and input various drilling parameters to optimize the drilling process. Further efficiencies can be gained by adding vibration and pressure-while-drilling (PWD) sensors to update models in real time. Some drill motors are equipped with a rotor catch and drive-shaft catch devised to help reduce the risk and cost of potential fishing operations. The company used stock oversized stators that are designed for the high-temperature environments tools are exposed to when drilling geothermal wells.

Case History/Application 1: D&V ST3

The project objective was to sidetrack and redrill an existing well from 11 3/4-in. casing at 1,804 ft, establish a new course heading, and then commence air-drilling operations to total depth. A 10 5/8-in. hole was directionally drilled from 1,804 to 2,472 ft (668 ft total) with an unweighted, water-based, low-solids mud system using an 8-in. mud motor and the EMT-survey system. The directional plan included an 83° turn and a 15° change in hole angle. The geology was fractured greywacke 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 complete the well for injection service into a strategic part of the reservoir. 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 15 bbl/hr to total loss throughout the interval. During this time, the mud was being treated with high concentrations of LCM (fiber, sawdust, cottonseed hulls) 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 Geysers, the LCM treatment is only effective up to a point, and then cement plugs are normally used for lost-circulation control. A total of four cement plugs were set from 1,932 to 2,182 ft, with only moderate success. Given the EM-tool capability of producing survey data without the aid of a full-fluid column, the decision was made to drill "blind" (total fluid loss) as much as possible. A total footage of 352 ft (out of 668 in.) was drilled in this manner, including the last 178 ft when it was critical to complete the directional run as planned. 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 previous solution when using pulse-telemetry tools has always been to continue setting cement plugs until full circulation has been regained and survey-data transmission can continue. The EMT tools provide another option and allow drilling and surveying to continue with no circulation, and lessen the need to set costly cement plugs. In the instance of 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.

Case History/Application 2: WHS-27A2

This project was a redrill of an existing well and the new course had significant importance regarding the bottomhole target. Because of lease considerations, the well path needed to remain as close to plan as possible. The well was sidetracked from 2,236 ft inside of 11 3/4-in. casing and a 10 5/8-in. hole was directionally drilled with mud to 2,796 ft. The desired directional heading was established and air-drilling operations immediately continued through the reservoir to 4,511 ft. Because of natural formation tendencies, the well deviated considerably away from its desired azimuth heading. This situation had potentially serious consequences that could have compromised the bottom-hole target and lease objectives.

The difficulty of maintaining directional control through the reservoir while air drilling has always been great, especially with conventional BHAs. The problem has always been compounded by the fact that correction runs using a steerable-motor system has never really been a viable option. Calpine has tried to use motors several times for correction runs using an air/mist mixture with marginal results. Elevated formation temperatures that usually exceed 350°F have always influenced motor performance, and the inability to obtain quick and reliable survey data has usually rendered any motor run relatively ineffective.

The challenge on this well was the critical need to directionally turn the well-course path at least 25° while air drilling and with formation temperatures at 350 to 400°F. Using Halliburtons' high-temperature motor and the EMT system, a 27° azimuth turn was successfully made from 4,511 to 4,840 ft (329 ft). Aerated water was used to power the motor: approximately 100 to 125 gal/min of water together with 2,750 cfm of air. There was no problem with motor performance and the survey data was immediate, reliable, and consistent. This constant flow of data was critical to optimizing motor performance and minimizing the time exposure of the motor to the effects of temperature. There was an initial problem with the signal because of tool vibration, but that problem was quickly resolved with better stabilization and the entire correction run was completed and all objectives were accomplished.

Conclusions

The EMT system has several advantages and cost benefits for directional-drilling applications in The Geysers:

- A directional run can be completed as planned with greater confidence when drilling with mud through severely fractured geology. There is no need for a complete fluid column when transmitting survey data, which makes "blind" drilling a viable option when directional drilling. As a result, there is a greater probability of achieving all directional objectives with fewer cement plugs necessary.
- A greater concentration of LCM can be run through this motor system which, in some cases, can mitigate fluid losses and preserve motor performance and maintain drilling progress.
- Under the right well conditions, directional-course corrections are now a viable alternative when air drilling. This immediately translates into better directional control, a greater probability in achieving the desired bottom-hole target, and optimum reservoir spacing.