Baker Hughes

Case study: Iceland

300°C directional drilling system drilled deepest, hottest geothermal well in Iceland

Geothermal wells in Iceland are typically directionally drilled to a depth of around 6,561 ft (2000 m) measured depth (MD). Formations encountered are igneous, mainly hard and often faulted basalt. Conventional directional drilling bottomhole assemblies (BHA) consisting of positive displacement motors (PDM) and roller cone bits have been used in the past. More recently, hybrid bit technology has shown significant performance advantages over roller cone bits. Polycrystalline diamond compact (PDC) bits have limited success due to high levels of vibrations when drilling at low rates of penetration (ROP) in hard rock.

Enhanced/engineered geothermal systems (EGS) are systems in which water flows between at least two wells, through the hot rock of the reservoir, forming heat exchangers. EGS reservoirs represent a viable energy source with minimal environmental impacts. However, drilling geothermal wells for EGS requires precise placement of injection and production wells to make the operation economical. The optimal orientation of the wells in relation to the main fracture direction conclude that horizontal wells reduced uncertainty in developing geothermal resources.

An operator in Iceland wanted to harvest energy from deep-seated geothermal reservoirs at supercritical conditions. This involved precise deep drilling through three conventional high-temperature production fields and producing superheated steam at temperatures ranging from 752 to 1,112°F (400 to 600°C). The problem was few conventional tools and technology—which max out around 437°F (225°C)—could withstand such extreme downhole environments. The operator was forced to deploy sub-optimal drilling systems, resulting in unnecessarily high overall wellbore construction costs, short runs, downhole tool failures, and poor drilling rates. The operator needed a solution that could operate at 572°F (300°C) for at least 50 hours and at depths up to 32,808 ft (10,000 m). At the same time, Baker Hughes was working on geothermal technology for ultra-high temperature environments and jumped at the chance for a field trial to showcase the new technology in a commercial well since all testing prior was in lab/controlled setting.

Geothermal drilling systems consist of a drill bit, steerable drilling motor, and a drilling fluid for an 8½-in. borehole. Deep drilling operations such as this one in Iceland use PDM motors as downhole drives. Conventional PDMs use stators with elastomeric material, but no elastomer can withstand the higher temperatures in conjunction with the high dynamic loads and chemical attacks in this section.

In 2018, Baker Hughes developed an industry-first, metal-to-metal (M2M) mud motor with a mud-lubricated bearing assembly and titanium transmission. Without the elastomer, fluid leakage will occur but engineers developed a prototype M2M motor that successfully could endure extreme downhole environments with predictable and controllable results. There was wear on the rotor/stator

Challenges

- Re-enter existing well and drill to TD of 16,404 ft (5000 m)
- Overcome extreme downhole temperatures

Results

- Drilled to a TD of 15,285 ft (4659 m)
- Proved new drilling system technology was capable of operating at extreme downhole environments
- Developed new downhole cooling system for MWD platform
- Experienced no health, safety and environmental (HSE) issues or nonproductive time (NPT)

due to metal-on-metal contact, but the mud lubricant helped to minimize the effect.

In order for a Vulcanix™ geothermal tricone bit to survive at circulating temperatures of up to 550°F (288°C) and a full-metal bit capable of 572°F (300°C), it was necessary to address areas of potential failures, and Baker Hughes scientists zeroed in on the elastomers and grease. The key technologies in the new roller cone bit include all-metal cone seals, all-metal bellows for grease pressure compensator, and a new grease that maintain lubricity at high temperatures.

Even with a new drilling system, however, an operator is drilling blind if there isn't a compatible measurement-while-drilling (MWD) system—complete with a downhole directional measurements packer with power source and telemetry—to guide it. There is no existing commercial MWD capable of providing downhole measure-while-drilling/logging-while-drilling (MWD/LWD) instrumentation that meets the requirements for operations in deeper, hotter wells. To overcome this challenge and protect the equipment, engineers developed and lab-tested an active, high-temperature downhole cooling system for drilling. This system consists of a water evaporation cooling system that operates at temperatures up to 572°F (300°C) while keeping electronics and sensors below 347°F (175°C).

With the new drilling system in place, the operator identified the well. It was an existing conventional high-temperature well which had been drilled to a MD of 8,202 ft (2,500 m). With the 13 3/8-in. casing set at 2,604 ft (794 m) and 12 ¼-in. open hole drilled to 8,202 ft (2,500 m), the plan was to re-enter this wellbore and deepen it to between 14,763 and 16,404 ft (4,500 and 5,000 m) where static downhole temperatures of up to 1,022°F (550°C) were expected.

Baker Hughes field personnel deployed the new drill bit, steerable drilling motor, and drilling fluid into the wellbore, and, after 168 days, reached a total depth (TD) of 15,285 ft (4,659 m). The highest temperature measured as 798°F (426°C) at 14,960 ft (4,560 m) and 340 bar pressure, achieving supercritical condition. The well was drilled vertically down to 9,022 ft (2,750 m) then built inclination to 30° and drilled tangentially to TD. Continuously pumping fresh seawater significantly lowered the downhole temperatures while drilling.

The successful operation turned out to be the deepest and hottest well ever drilled in Iceland. The performance of all the components developed for this project met and exceeded goals, and the new technology enabled controlled directional and horizontal drilling of challenging EGS wells.

In additional, the new 572°F (300°C) technology expands the possibilities of temperature sensitive drilling and measuring technology for oil and gas wells, offering the potential for improved durability and reliability in temperatures not urgently manageable with conventional oil and gas drilling technologies.

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