GeoTHERM-Journal – Band 2 (2024)

Monitoring geothermal wells: from HT directional, pressure and temperature while drilling to advanced casing integrity services.

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ABSTRACT

Nowadays the energy sector is undergoing a milestone turn into more environmentally responsible green industry to comply with ''net zero by 2050'' regulations. The clear goal is to reduce the footprint of the global greenhouse gases to alleviate the ongoing climate change. Through this transformation, the geothermal energy plays an essential part by emitting significantly less harmful carbon dioxide, being more environmentally friendly than fossil fuel energy sector. Apart from the differences in the design and overall approach from the geothermal wells with respect to the oil and gas wells, safety and integrity is invariably the uppermost common denominator. With this view, the monitoring of a well throughout its entire life is the most powerful instrument: from the early stage of drilling operations, to optimize trajectory and acquire formation evaluation data in real time to be able of taking immediate informed decisions, until the later stages of casing and cement operations, to evaluate the shear bond quality and inspect the casing integrity condition even after years.

https://doi.org/10.53196/gtj-2024

This article describes a new set of high-temperature Logging-While-Drilling (LWD) and Pressure-While-Drilling (PWD) technologies for operating up to 210°C and will continue with defining the conventional methods as well as the state-of-the-art modern E-Line technologies for a comprehensive overview of the casing/cement integrity.

Keywords: geothermal well, drilling, cement, casing integrity, LWD and high temperature.

1. INTRODUCTION

The use of directional drilling in a geothermal field is usually dictated by various objectives: geological targets, for example, to intersect as many or as less formation fractures as possible, or the perimeter lease boundaries, institutional, legal, or topographic issues, and lastly but with major economic efficiency importance, it allows to drill several wells from one prepared surface site while avoiding collisions. The difficulties inherent in directional drilling are aggravated in the geothermal wells because of 2 major reasons: the electronic tools and elastomer elements in the motors, susceptible to high temperature. HeatWave™ Logging-While-Drilling (LWD) tools are introduced here: a new set of directional, pressure and temperature, gamma ray, resistivity, density and porosity to operate in temperatures up to 200 – 210 °C. The HeatWave™ HEL Measuring-While-Drilling (MWD) tool enables the operator to safely control wellbore trajectory and orient the downhole motor for sliding up to 180°C in large hole sizes, down to 12 ¼”, and up to 200°C for smaller hole sizes, like 8 ½” and below. In our case, MWD was also equipped with the Bore and Annular Pressure (BAP) sensor (Fig. 1), a high temperature Pressure-While-Drilling (PWD) sensor that provides bore and annular pressure and temperature in real time. The system was used in some high enthalpy deviated geothermal wells where lost circulation was expected, mainly related to the presence of natural highly productive fracture system.

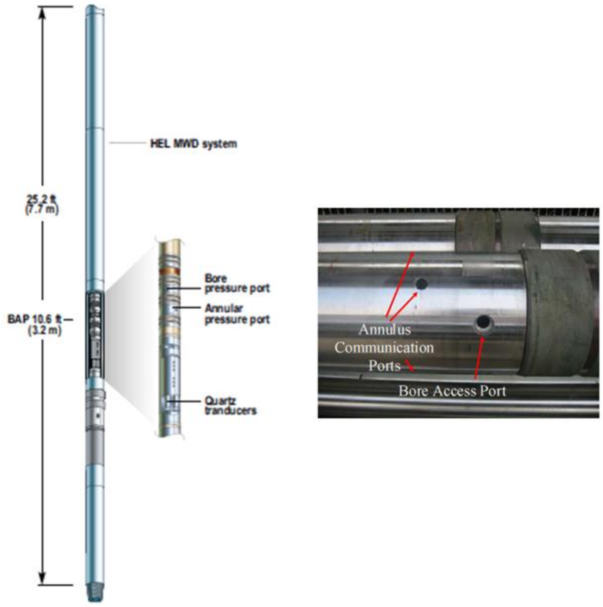

Fig. 1: HeatWave™ HEL MWD tool equipped with the Bore and Annular Pressure (BAP) sensor.

In addition to the applications commonly used in wells, the real time and cost-effective measurement of downhole pressure and temperature was attempted to be used to better understand hydraulic conditions of the reservoir, improve accuracy in fracture characterization and position, and prevent downhole equipment damage or NPT.

Casing can be run shortly after the well section is drilled and assessed, possibly using LWD data, in order to separate the formation and prevent borehole collapse events. Once the casing is set, a cement job can be performed. Historically the integrity of wellbores was assessed based on the temperature and cement bond log (CBL) surveys run on the electric cable. Mechanical caliper tool was run to assess condition of the inner side of the casing. These logging methods even though extremely reliable for qualitative analysis have been lacking in azimuthal sensitivity and overall resolution, that is required to get a complete picture of the wellbore conditions to successfully maintain the integrity of wells. Over the last decades, developments in the E-Line technologies resulted in the broad range of the cased hole measurements portfolio offered by various service companies. Among these, Weatherford provides SecureView®, a single-trip casing and cement evaluation service, which is one of the most competitive offerings on the market. In just one trip it provides high-definition logs of inner casing, outer casing, cement strength, and cement bond, which can reveal casing and cement anomalies and wellbore problems quickly and efficiently (fig. 2).

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Fig. 2: SecureView®, single-trip casing and cement evaluation service answers

2. DELIVERING HIGH-RESOUTION TRIPLE COMBO LWD LOGS IN ULTRAHIGH-TEMPERATURE WELLS

As drilling moves into deeper and hotter environments, even high-temperature LWD systems can't handle the heat. Operators often settle for extensive temperature-mitigation measures, additional operating time and expense, or the prospect of receiving no data at all. The HeatWave™ Extreme service brings reliable LWD measurements to the most challenging drilling environments on Earth. Jointly designed and field-proven with a major E&P company, the service acquires high-quality LWD data in temperatures up to 200°C and pressures up to 30,000 psi. Each HeatWave Extreme service component, from electronics to elastomers, was completely redesigned for optimal reliability and robust resistance to ultra-high temperatures, high pressures, and vibration. The result is the first LWD service to reliably acquire gamma ray, resistivity, neutron porosity, bore and annular pressure, and density data at high temperatures (fig. 3) without wireline runs, extra trips, or temperature mitigation.

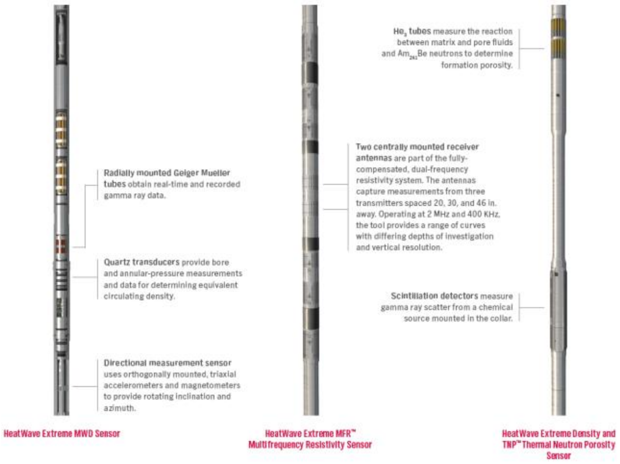

Fig. 3: The complete HeatWave™ Extreme triple-combo LWD service.

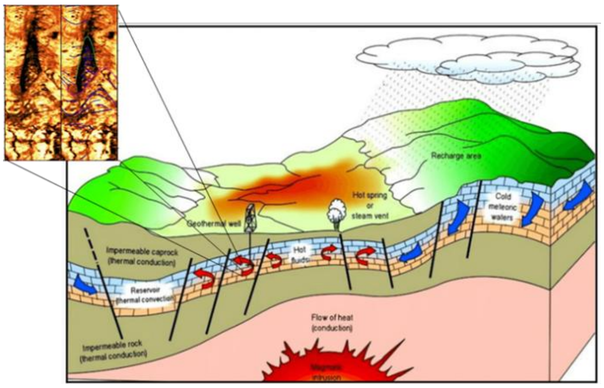

Fig.4: Schematic model of a fracture driven geothermal system (modified from the web).

3. WHILE DRILLING MEAUREMENTS AND APPLICATIONS IN HIGH ENTHALPY GEOTHERMAL WELLS

A combination of mud motor (PDM), MWD and BAP (pressure-while-drilling sensor), was used to drill and steer the 8 ½" sections of some high enthalpy (>200°C) geothermal wells. In this fields, lost circulation was expected mainly related to the presence of natural highly productive fracture system (Fig. 4).

The wells were successfully drilled up to a wellbore inclination of 30 degrees and a maximum recorded temperature of 184 °C. Close to the end of the well it was necessary to run a single shot due to the occurrence of total losses and MWD not able to take surveys. The pressure and temperature data recorded by the BAP sensor was analyzed and some interesting behaviors were observed, and possible specific applications were highlighted. It was noticed that, while drilling deeper into the well, there were two main different temperature trends during periods of suspended circulation or pump off necessary to take survey or run single shot. In particular, until a specific depth, the temperature during pump-off was increasing even if fresh water was pumped into the annulus to cool the well and hold annular

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pressure to keep water mud level. At some point the temperature during similar interval of pump off was stable. The lack of temperature increase was interpreted as a more effective cooling effect on the reservoir and formation related to the presence of highly injective and connected fractures intercepted during drilling. The “open” system created by the presence of fractures allows to cool a larger volume of the reservoir during drilling and circulation in the annulus (Fig. 5), avoiding the effect of the “closed” system, like an “hot pot”, whose temperature is controlled by the thermal gradient (Fig. 6). In some cases, after drilling deeper, the “hot pot” effect was resumed indicating that the fractures had been closed by cuttings or that the water column was below fracture and not able to effectively decrease the temperature.

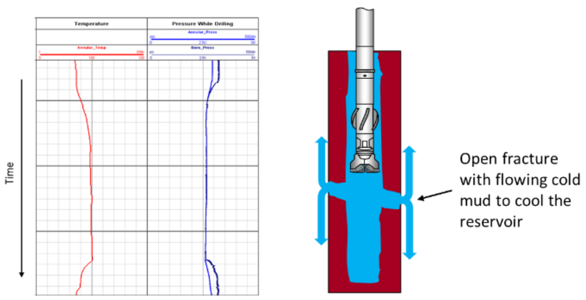

Fig.5: Temperature is stable at 100°C after 2.5 hours without circulation, indicating the presence of highly injective and connected fracture.

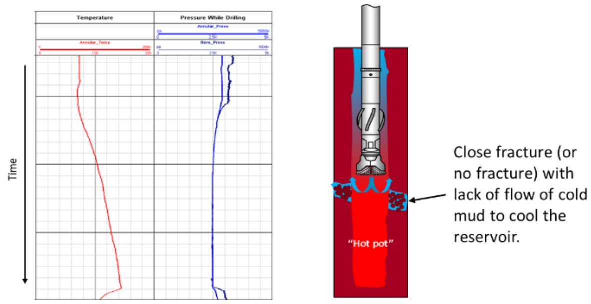

Fig.6: Temperature increases from 70°C to 145°C in 2.5 hours, indicating mud fluid is not cooling the formation (“hot pot”).

The awareness about which of the two conditions we have inside the wellhole is particularly important. In an “hot pot” situation motor and MWD failures are highly likely to occur because of the temperature, especially when tripping back into the hole. The ability of a top-drive unit to circulate while tripping into or out of the hole is a significant advantage for this operating method. As the tool can also send maximum and minimum temperature during pumps off, we are able to understand the heating gradient and make same interpretation in real time. As shown in Figure 7, we can also interpret the depth position of the fracture looking at the boundary between the two conditions.

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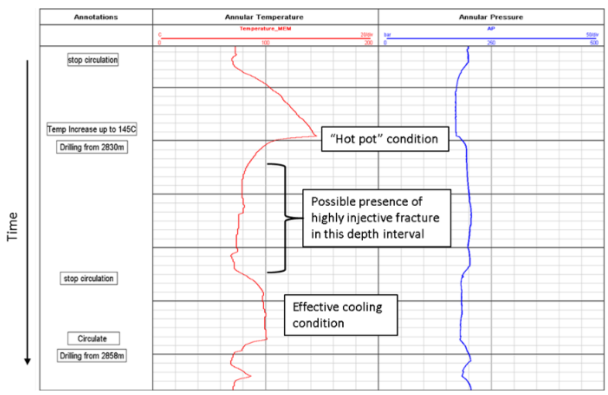

Fig.7: Based on transition between the two trends we can interpret fracture depth between 2830 and 2858 m MD.

Another observation is about the pressure as we noticed a large decrease of annular pressure, that does not correlate to rig operations, which can indicate presence of highly injective fracture and steam hot water or steam influx that causes a decrease in EMW and, consequently, of the pressure. Figure 8 shows a sudden decrease of pressure, also when drilling, between 3106 and 3125 m MD and, after that, tendency of the temperature to increase quickly as soon as circulation is off. This may indicate the presence of fracture with hot water or steam influx.

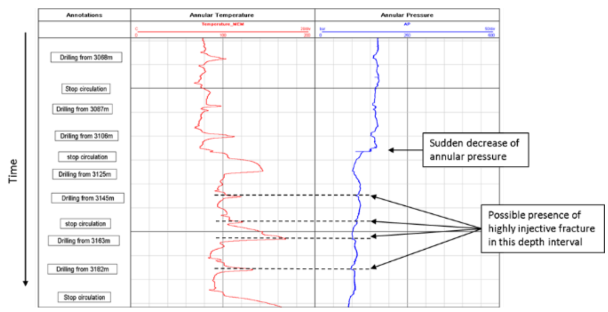

Fig.8: Temperature increase and pressure decrease indicating steam influx from fractures.

In conclusion, we have explored new potential application for MWD pressure-while-drilling tool (BAP) applied to geothermal wells. In addition to the applications commonly used in oil and gas wells, the real time and cost-effective measurement of downhole pressure and temperature was attempted to be used to better understand hydraulic conditions of the reservoir, improve accuracy in fracture characterization and position, and prevent downhole equipment damage and NPT. Although there are multiple variables to take into consideration, the concept proves to be valuable and deserves further discussion and case history. If zones with fractures must be sealed in the upper intervals of the well, cement is usually the treatment of choice but is hard to place accurately. It is much more important to repair loss zones where casing will later be set than in production intervals. If the loss zones cannot be effectively repaired

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before casing is run, more complicated cementing procedures must be used to accomplish an effective casing cement job.

4. WELL INTEGRITY WIRELINE LOGGING IMPORTANCE THROUGH THE GEOTHERMAL WELLS

At certain stage, each of the wellbore needs to be cased and cemented to keep them stable and to preserve hydraulic isolation of the penetrated wellbore from the surrounding formations. In that matter Weatherford's state-of-the-art modern E-Line technologies called SecureView® offers the means for a comprehensive overview of downhole condition as a necessary step to plan further remediation actions. SecureView® is a combination of advanced versions of the tools currently available in the market - UltraView®, CalView®, FluxView® and BondView® (Fig.9). These tools can be run in tandem which significantly reduces logging time and can positively impact overall performance of the workover operations. By utilizing cutting edge technologies SecureView® can identify the wellbore integrity problems that conventional tools standalone cannot do.

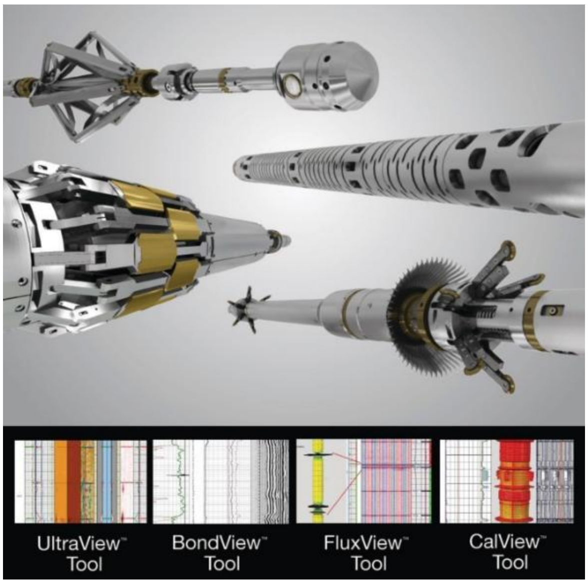

Fig.9: SecureView® suite

As most of the geothermal wells contain CO_2, H_2S and other corrosive elements it is extremely important to precisely monitor conditions of the tubulars to ensure safe and responsible wellbore utilizations. Pulsed echo ultrasonic measurement (UltraView®) provides circumferential casing thickness, radii, and amplitude maps. When combined with a highest resolution in the marked multi-finger caliper (CalView®) and electromagnetic tools (FluxView®) it can identify any type of casing imperfection, from general corrosion or wear towards small size pitting, including casing scale or solids buildup. That also involves any types of casing deformation caused by increased pressures, commonly observed in geothermal wells. Acoustic impedance of the material behind the casing from pulsed echo ultrasonic tool provides the means for detailed high resolution 360 degrees coverage cement evaluation with the option to quantify and differentiate between water, cement and gas content within the casing annulus. This poses a high importance as the quick temperature cycling in the geothermal wells affects the effectiveness of the cementing job, creating leak paths like channels or micro-annulus that might compromise the integrity of the wellbore. Combination of the advanced UltraView® with conventional BondView® (CBL) measurements gives a complete picture of casing-cement and cement-formation bond quality. Broad range of the ultrasonic tool head sizes are increasing its application from small size API casings to large completions, dictated by the needs of high flow rates in geothermal wells. Applications of the UltraView® is not limited to the conventional wellbores completion based on steel or metal alloys and it can be successfully run as well through fiberglass casings, extremely thick casings or to evaluate light weight foamed cements.

SecureView® extent far beyond the conveyance logging methods and equipment. Proprietary software, processing algorithms, sophisticated reporting and interactive 3D data manipulation and presentation formats make SecurView® a comprehensive solution for identification of well integrity problems and recommendations on remedial options (Fig.10).

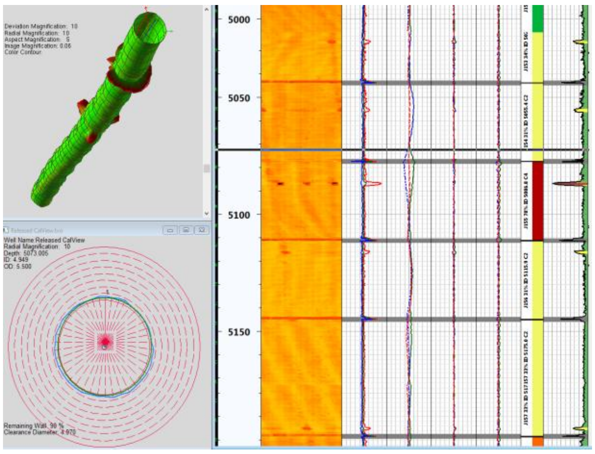

Fig.10: CalView® data presentation - 3Dview of the casing shape, 2D cross-section as well as joint summary log plot

5. CITATIONS

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