Figure 1. As one of Indonesia's largest, continuous geothermal projects, the Sorik Marapi geothermal field holds the potential to produce 240 MW of geothermal energy.

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maps out drilling solutions which can overcome challenges to geothermal energy extraction.

BRINGING

THE HEAT

As the global demand for reliable renewable energy intensifies, geothermal power emerges as a vital solution for sustainable, baseload energy production. The Sorik Marapi geothermal field in Indonesia stands as a prime example of this potential. Tapping into geothermal resources, however, poses significant drilling challenges in one of the most extreme environments on the planet. From high temperatures and corrosive fluids, to complex geological formations, operators must confront these obstacles head-on to unlock geothermal energy's full capacity.

The Sorik Marapi geothermal field, situated west and northwest of the active Sorik Marapi volcano perched on the Sumatra Fault Zone in Indonesia, holds immense potential. Geologists estimate its geothermal energy capacity at 240 MW, which makes it one of Indonesia's largest, continuous geothermal projects.[1] The field holds approximately

39 exploration and development wells with depths of up to 2715 m and temperatures up to 617˚F (325˚C).

These high temperatures present big challenges in geothermal wells. The harsh drilling environment, characterised by extreme heat and hard, abrasive rock, poses risks to equipment. The intense temperatures can cause wear and potential damage, and drilling through the tough rock requires tools specifically built to withstand the harsh forces. Hot, corrosive fluids known as acidic geothermal brines impact equipment integrity as well. When operators conduct geothermal drilling, they encounter lost circulation zones, which can impact well stability and result in tool failures mid-operation.

The Sorik Marapi field lies in an active tectonic zone, and operators must prepare for seismic vibrations from earthquakes and tremors to observe activity. These vibrations stress wellbores and equipment. Permeability variations throughout the geothermal field mean that some areas allow efficient fluid flow, while others resist it. Operators must adapt their drilling strategies for the variations.

The ability to understand geological formations is also important; operators must decipher subsurface intricacies and use tools to identify permeable zones, fault lines, and fractures. Only then can operators position wells in the most strategic places to maximise energy extraction.

Geological assessment of the formation poses challenges

Operators evaluated the geological formation in the Sorik Marapi field with traditional methods when they drilled the original 39 exploration and development wells. These methods involved measurement-while-drilling (MWD) and steerable motors. However, basic telemetry from these methods restricts data availability in geothermal environments; operators only gain access to data from directional, pressure-while-drilling (PWD), temperature, and vibration sensors. This creates data gaps and excludes data on parameters such as resistivity, porosity, and fluid composition. Operators need this data since:

- High resistivity often corresponds to impermeable rocks, while low resistivity indicates more porous formations. Changes in resistivity can signal the presence of fluids within the rock.
- High permeability and fractures in geothermal reservoirs assist in the movement of geothermal hot brines. However, high permeability also causes the loss of drilling fluids in the formation.[2]
- Knowledge of fluid composition helps identify the type of geothermal resource available, such as liquid-dominated or vapour-dominated. Fluid composition affects mineral deposits (scaling), corrosion within wells and surface equipment, and impacts energy conversion efficiency.

The lack of comprehensive data led to several challenges that threatened to increase the cost of geothermal exploration in the Sorik Marapi region. For instance, total circulation loss, where drilling fluid escaped into the formation instead of returning to the surface, hindered progress and increased costs. Unpredictable drilling conditions and more complicated instabilities of wellbores arose with the intersection of the Sumatran Fault System into the geothermal field created a complex fracture network. Alteration mineralogy and well test results revealed a two-phase zone in the field, where both liquid vapour phases coexist, which affected pressure and temperature conditions in the well.[2]

Insights to drive geothermal success

The circulation losses highlighted the need for better drilling techniques, more advanced drilling fluids, and lost circulation materials to manage fluid loss. Fault networks and two-phase zones underscored the importance of thorough geological surveys before drilling, as well as comprehensive subsurface knowledge to improve well design and adjust drilling and well completion strategies.

Given the unique challenges of the Sorik Marapi field and the requirements for data points to guide geothermal exploration, reservoir management, and operational decisions, operators must rely on more advanced tools and measurements to assess the formation. This will help ensure successful drilling and production.

For example, massive circulation losses at the reservoir's upper section complicated drilling and impacted well stability. Volcanic formations and the risk of severe vibration also influenced borehole stability. Permeability varies a lot in different field areas, from high-temperature zones with good permeability in one pad, to cooler less permeable conditions in another. One of the wells provided a prime example of this process with unique mineral formations and an impermeable barrier that hinders fluid movement within the geothermal field. In addition, the presence of hydrothermal alteration minerals affects operators' interpretations of subsurface conditions.

Figure 2. Advanced logging while drilling tools can help operators pinpoint high-permeability areas and potential loss zones, which helps provide more effective drilling outcomes.

For successful exploration and development of the Sorik Marapi geothermal resource, operators looked for specialised drilling techniques and equipment. They recognise the significance of the identification and mapping of drilling challenges against the different geothermal formations. This improves subsurface comprehension, optimises drilling and geothermal resource production, and helps avoid drilling failures experienced prior to the ability to obtain high-quality data and measurements. A comprehensive profile of the formation helps operators deliver services under high-temperature conditions and optimise drilling and geothermal production.

LWD solutions can provide more effective drilling outcomes

Logging-while-drilling (LWD) offers a cost-effective solution for geothermal operators. These tools enhance knowledge about formation-specific challenges within the field, such as permeability variations, and help operators address those challenges in an effective manner. Through analysis of real-time data, operators can pinpoint high-permeability areas and potential loss zones. Swift adjustments to drilling parameters and the use of tailored lost circulation materials become possible.

LWD services monitor downhole conditions on a continuous basis and provide measurements of density, porosity, and other formation properties. This real-time data enables operators to make proactive decisions that help maintain the integrity of drilling equipment and prevent wellbore collapses or stability issues. In addition, LWD solutions assess formation resistivity and other indicators of permeability changes to help optimise well placement and refine reservoir characterisation. They detect shifts in formation composition and the presence of alteration minerals, which increases operators' knowledge of subsurface conditions and allows them to adapt the drilling process accordingly.

Through proactive management of drilling challenges with real-time LWD data, operators can reduce operational disruptions. Here is how an operator in Indonesia used advanced technology, which includes LWD solutions, to assess and mitigate problematic conditions encountered in the region.

Case study: LWD caliper and drilling mechanics reveal distinct formation characteristics

In the Sorik Marapi field, the operator embarked on a more thorough geothermal formation evaluation through the procurement of a minimal LWD application. This approach aimed to enhance cost-effectiveness in drilling operations in static temperatures of up to 617˚F (325˚C). The operator recognised the requirement for deeper insights into formation-specific challenges and devised a dual strategy: data acquisition amid drilling and reservoir tests.

Data acquisition at the well

The operator focused on a single well to gather formation data while it supplied steam and hot water to the power plant under development simultaneously. Real-time measurements from a Halliburton ultrasonic acoustic caliper sensor equipped with three transceivers captured temperature and other critical parameters. A pressure-while-drilling sensor with quartz transducers monitored internal (bore) and external (annular) pressures. This data facilitated equivalent circulating and static density monitoring, crucial to help anticipate kicks and blowouts, the avoidance of formation damage, and the optimisation of drilling efficiency.

Directional insights and project optimisation

Accelerometers, magnetometers, and gyroscopes enhanced the operator's knowledge of the subsurface conditions. Accelerometers capture vibration data, while magnetometers and gyroscopes measure rotational speed (the 'stick-slip indicator'). One set of sensors detected changes in the X, Y, and Z-axis that reflect impacts between the bottomhole assembly and the borehole wall. Another set of sensors combined accelerometers and magnetometers to provide data for directional drilling, recording total gravity, magnetic field, and dip angle measurements.

These measurements allowed the operator to refine directional insights and achieve more precise drilling paths, optimise targeted hits to the appropriate reservoir areas, and map the underground landscape for improved project planning.

The addition of caliper measurement capabilities and a high-resolution vibration sensor helped illuminate the unique challenges of each well drilled. The operator could classify the different types of vibration and assess borehole quality.

Paving the way for a sustainable energy future

As the geothermal energy sector gains momentum around the globe as a viable source of renewable baseload power, its growth relies on technological advancements that enhance the cost-effectiveness and reliability of geothermal drilling. Challenges posed by high temperatures, abrasive rock, and lost circulation zones, as observed in Sorik Marapi, extend beyond Indonesia to resonate across geothermal fields worldwide.

For the geothermal industry to scale and meet growing global energy demands, advanced LWD solutions can offer a blueprint for addressing the geological and operational hurdles that have historically limited geothermal development. Precise data on subsurface conditions provided by these tools reduce the risks associated with drilling and enhance the ability to tap into previously unreachable geothermal reservoirs.

Geothermal energy, harnessed through innovative solutions and strategies, can pave the way for a sustainable and resilient energy future.

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