Electric impulses fragment hard rock

New process uses high-voltage impulses for deep geothermal drilling

Until now, roller bits have been used for drilling in deep-lying rock. These only advance slowly through crystalline formations and wear out quickly. That makes drilling measures more expensive and is particularly an economic problem for deep geothermal projects. Researchers in Dresden (Germany) are therefore developing an alternative drilling method for hard rock where a high-voltage impulse fragments the rock. Up to 30 % lower drilling costs are possible.

Depending on the rock type and depth, the drilling operations in deep geothermal projects account for up to 90 % of the investment costs. In addition there is the exploration risk: will the drilling actually find the required temperature level at the selected location and the calculated depth, or will it be necessary to start again at another location? Each technical improvement and cost reduction for the drilling process therefore brings interesting geological heat reservoirs within reach that were previously unreachable for economic reasons.

In cooperation with partners from science and industry, researchers at Dresden University of Technology have developed a new drilling system that utilises the Electric Impulse Technology (EIT). It is specially designed to meet geothermal energy requirements in hard rock and expands the range of possible drilling methods. The EIT drill bit consists of a drill motor, generator, surge voltage source and two electrodes with different electrical potentials. These are loosely positioned on the rock to be drilled and are immersed in non-conductive drilling fluid. These electrodes are used to generate a high-voltage impulse of 400 kV, similar to a lightning flash in nature, through the rock at the base of the well. In the impulse’s breakdown channel, the pressure and temperature within the rock swiftly increase, the rock fractures, and the drill cuttings are carried to the surface with the mud. The researchers from Dresden have developed a prototype of the EIT drill bit and tested
Conventional drilling technology

Conventional drilling rigs are designed to meet the requirements of oil and gas production and their wellbores are usually made in sedimentary rocks. In crystalline rocks, such as granite, classic drill bits only advance at a rate of about 1 m/h and with special cutting tools. The drill bits are subject to considerable wear and, under certain circumstances, have to be replaced after 50 to 60 hours of use. With a 3,000 metre-deep wellbore, such a tool change can take up to 20 hours to complete. All this slows down and increases the cost of drilling in crystalline rock. The EIT method has a more favourable energy balance than conventional methods. The electric impulse destroys the rock from the inside. It therefore overcomes the tensile strength of the rock, which is only about 10% of the compressive strength. Roller bits, on the other hand, have to overcome the compressive strength when they crush the rock from the outside.

it on a test stand under conditions similar to a wellbore. The currently ongoing follow-up project is aimed at optimising the entire system and carrying out trial operations in a well.

Withstanding the temperature and pressure

In addition to the harsh, everyday drilling conditions, the EIT drill bit must in particular be designed to cope with the temperature and pressure conditions at the target depth. The developers have specified a temperature of 200 °C and a pressure of 1,000 bar for the later drilling rig. All the electrical and mechanical components used and the drilling fluids must be able to withstand these conditions. The second challenge lies in the limited space afforded by a 12 ¼-inch well (ø 31.1 cm). All components must be dimensioned accordingly and, despite the compact design, operate reliably for as long as possible.

In crystalline rocks, such as granite and gneiss, it is intended that the EIT drill shall advance at twice the speed as conventional drilling rigs. The developers are aiming for a cutting life of 500 hours. This is the time that the EIT drill bit should be able to work without interruption underground without having to be brought back up to the surface for time-consuming tool changes. The long cutting life is primarily made possible by the low-wear electrodes. The new drilling system is designed so that it is compatible with conventional drilling rigs.

Bringing electricity underground

The energy is supplied to the EIT drilling system below ground in a manner similar to that used for supplying measurement equipment with conventional drilling rigs. Here the drilling fluid is pumped with overpressure and in large volumes through the drill pipe into the depths. At the drilling base level, the hydraulic force of the fluid drives a drilling motor connected through a gearbox to a generator. The output voltage generated is used via a transformer and a rectifier to supply the surge voltage source. This impulse voltage generator operates according to the Marx generator principle. Put simply, capacitors are charged in parallel and then swiftly connected in series via spark gaps. The charge voltages of the individual capacitors are therefore combined together. The impulse then shoots into the rock via the high-voltage electrode and flows to the grounded electrode. During the course of their work, the researchers from Dresden have tested various geometric electrode shapes in order to find an optimum. One of the aims here is to transmit the greatest possible amount of energy into the rock to increase the forward movement. The shape of the electrodes has a direct impact on the drilling speed and the energy requirements per fragmented rock volume. The impulse penetrates through the rock only when the voltage build-up is also very fast, i.e. less than 150 ns, and the drilling fluid has a low electrical conductivity. Such a steep voltage build-up is only possible if the electricity is generated locally and does not have to flow through a cable several thousand of metres in length. On the test stand, however, the power supply is still provided by cable. The EIT system has a power consumption of 20 kW; with conventional rigs several hundred kilowatts is quite normal.

Simulating a wellbore

Based on the preliminary studies, the focus of the work has been on developing and testing the drill bit. For this purpose the scientists have devised a test stand that offers conditions similar to a wellbore (Fig. 2, 3). The aim is to use impulses to cut the largest possible volume of rock from a granite
Geothermal energy generation

Geothermal water and, with increasing depth, hot layers of rock can be found in the deep strata of the earth. These can be used for providing heating and in power plants. Water requires a temperature of at least 150 °C for use in geothermal power plants. This is usually found at a depth of 3,500 to 5,000 metres. 27 plants are currently operating in Germany (as of 2015), which are all based on the extraction of geothermal water. However, 95 % of the useable geological heating resources are found in crystalline rock.

In geothermal plants, water is fed through an extraction well and one or more injection wells as part of a circuit. Hot water reaches the surface where it is used for energy in special power plant processes and in heating units, before being pumped back below ground.

Outlook

In a follow-up project, the researchers from Dresden are currently developing a complete drilling system. This is being tested in a real wellbore. Other materials for the electrodes are also being tested and matched more closely to the high-voltage source. The developers expect that high temperature-resistant electrical components and capacitors with long-term stability will soon be available on the market. The drilling rig will have a greater circulation rate and remove the drill cuttings, whereby it is planned to use water-based instead of oil-based mud. The electric power of the complete system will be increased to 25 kW. All these measures in combination are aimed at achieving the targeted drill speed of 2 m/h.

### Fig. 3 Comparison of the selected conditions and results on the test stand with the development objectives of the entire system

<table>
<thead>
<tr>
<th>Conditions and values on the test stand</th>
<th>Development goals of the EIT drilling system</th>
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<tr>
<td>Generator output</td>
<td>20 kW</td>
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<td>Output voltage</td>
<td>400 kV</td>
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<tr>
<td>Impulse per second</td>
<td>10 Hz</td>
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<tr>
<td>Drill speed</td>
<td>0.5 – 1 m/h</td>
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<tr>
<td>Cutting time</td>
<td>350 h</td>
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<tr>
<td>Mud circulation rate</td>
<td>200 l/min</td>
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<td>3,000 l/min</td>
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Fig. 3
Comparison of the selected conditions and results on the test stand with the development objectives of the entire system

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### Fig. 4 A hole drilled in a granite block with the EIT drill bit has relatively smooth edges.

block. A pressure vessel enables tests with a temperature of up to 200 °C and a pressure of up to 20 bar. The rig also has a container for the drilling fluid (mud); a circulation pump circulates 200 l/min of this fluid in a closed circuit. One of the tasks of this circulating mud is to collect the drill cuttings, i.e. the fragmented rock, at the base of the wellbore and to transport it to the surface. To simplify the test operation, the drilling fluid was not filtered on the test stand and thus the drill cuttings remained in the fluid. This fact and the low mud circulation rate compared with practice have hampered the drilling progress under experimental conditions. The EIT method is more impaired by residual cuttings than conventional systems, since the electric impulses continue to fragment the drill cuttings remaining at the base rather than splitting new areas of rock. Other components of the EIT system will be tested on the test stand at a later point.

So far conventional structural steel has been used for the electrodes. There is little evidence of material wear, because they do not rotate and can withstand several thousand electric discharges without burning. The EIT method works when the electrodes are only loosely positioned on the rock. This is advantageous for the EIT drill bit with sidetracked and horizontal drilling because it requires no pressure. The electrodes are nevertheless designed for a pressure of five tonnes because in daily drilling operations they are not positioned under visual conditions, but mechanically.

A key aspect is the selection of an appropriate drilling fluid. This needs to simultaneously cool the rig, be resistant to high temperatures and also non-conductive. An oil-based mud with special additives was therefore used on the test stand. This withstood the tests without any appreciable ageing. The tests have showed that nearly all the components in the drill bit meet the requirements for a cutting life of 500 hours. The only exceptions are the capacitors, which achieve just 350 hours at the moment. Improved examples with greater durability under high temperatures are, however, already in development.
Geothermal energy research goals

In Germany, four deep geothermal boreholes and 27 hydrothermal plants are currently in operation in 2015. Of these, 20 plants are located in the Bavarian Alps. In order that geothermal energy can make a greater contribution to energy supplies, further technical and economic developments are required. The funding announcement by the German Federal Ministry for Economic Affairs and Energy from 8 December 2014 names the current focus of the research work.

In addition to the EIT method there are also further concepts in drilling technology. One of them is Laserjet Drilling, in which a combination of water and laser beams can be used to drill boreholes underground without any wear. Another focus is on pump technology. High temperatures and the sometimes very salty water found in geothermal systems cause conventional pumps that were mostly developed for oil and gas production to quickly reach their limits. Funding has therefore been provided to enable pumps specially designed for geothermal energy and customised sensors to be developed and tested on a high-temperature test stand. The systematic preparation and compilation of existing geological data helps to reduce the exploration risks, whereby one alternative is provided by the geothermal information system GeotIS (BINE Projektinfo brochure 09/2011).

Geothermal development measures as well as extraction and injection activities interfere in the natural geological conditions. With some plants that has led to perceptible earthquakes. Plants therefore undergo comprehensive monitoring in which sensors systematically record the pressure conditions, flow rates and other operating conditions as well as all small and minute earth movements. The aim is to research how specific operating conditions influence the vibrations in order to detect problems early on and also prevent them in future. Other research projects are aimed at improving the energy output and reducing the environmental impact. This would enable specific planning and operational concepts to be cost-effectively simulated in advance on the computer.