The Iceland Deep Drilling Project geothermal well at Reykjanes successfully reaches its supercritical target

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The Iceland Deep Drilling Project passed a significant milestone in the geothermal industry when its IDDP-2 well at the Reykjanes Peninsula in Iceland reached the depth of 4,659 meters on the 25th of January 2017, after 168 days of drilling. The IDDP-2 achieved its initial targets, (a) to drill deep enough to reach supercritical conditions (4 to 5 km), (b) to measure the fluid temperature and pressure, (c) to search for permeability, and (d) to recover drill cores. After only 6 days of heating, the temperature measured at the bottom of the well was ~427°C, with fluid pressure of 340 bars, and indications of permeability at depth (Figure 1), and drill cores were retrieved. It’s clear that the bottom of the well reached fluids at supercritical conditions, so that the main objective of the drilling phase of the project had been achieved.

The critical point of fresh water occurs at 374°C and 221 bars. The reservoir fluids currently produced from the Reykjanes field have the salinity of seawater which has a critical point of 406°C at 298 bars. The fluids at the bottom of the IDDP-2 well when the PT log shown in Figure 1 was measured were a mixture of injected surface water and formation fluid. Although we do not yet know the salinity of this mixture, it is hard to argue that it was not at supercritical conditions during the logging operation.

The Iceland Deep Drilling Project (IDDP)

The IDDP is a long-term project by a consortium of Icelandic energy companies aimed at greatly increasing the production of usable geothermal energy by drilling deep enough to reach the supercritical conditions believed to exist beneath existing high-temperature geothermal fields in Iceland. Modeling indicates that a well producing from a supercritical geothermal
reservoir could produce an order of magnitude more usable energy than that produced by a conventional high-temperature (~300°C) geothermal well. This is because of both the higher enthalpy of supercritical fluid and its more favorable flow properties, due to its very low viscosity.

When the IDDP consortium was formed, three geothermal fields in Iceland were chosen as suitable to search for supercritical resources, Krafla in the north-east of Iceland, and Hellisheiði and Reykjanes in the south-west (Figure 3). The first attempt to drill into a supercritical reservoir was made in 2009 in the Krafla caldera, but the IDDP-1 well did not reach supercritical fluid pressures because drilling had to be suspended at a too shallow depth. This is because 900°C rhyolite magma flowed into the well at only 2,100 m depth. However, the IDDP-1 was completed with a liner set above the rhyolite intrusion. When the well was tested, it produced superheated steam at 452°C at a flow rate and pressure sufficient to generate about 35 MWe. After two years of flow testing, unfortunately repair of the surface installations was necessary, and the well had to be quenched due to failure of the master valves. This caused collapse of the well casing and abandonment of the well.

The IDDP-2

The IDDP consortium then decided to make the Reykjanes geothermal system the focus of its next attempt at drilling to supercritical conditions. HS Orka, the field operator at Reykjanes, led the drilling of the IDDP-2 well, in close collaboration with other project partners, Landsvirkjun, Orkuveita Reykjavíkur, and the National Energy Authority in Iceland, together with Statoil, the Norwegian oil and gas company. The IDDP has also received funding from the EU H2020 (DEEPEGS), and science funding from International Continental Drilling Program (ICDP) and US National Science Foundation (NSF). The drilling contractor was the Iceland Drilling Company.
The Reykjanes geothermal field lies near the southern tip of the Reykjanes Peninsula, which is the landward extension if the Mid-Atlantic Ridge. Some 34 production, injection, and observation wells supply steam to a 100 MWe power plant, from a 300°C reservoir at 1 to 2.5 km depth. It is unique among Icelandic geothermal systems in that its reservoir fluid is modified seawater, and that seawater is used to cool its steam condensers. Figure 2 shows a conceptual model of the drilling target of the IDDP-2 well, based on the existing extensive well and geophysical data. The IDDP-2 well took advantage of an existing production well, the RN-15, which was 2,500 meters deep. This well was deepened and cased to 3,000 m depth and then deepened to the total depth of 4,659 m. The deepest existing geothermal wells at Reykjanes are about 2.5 km deep. The IDDP-2 has the deepest casing and is also the deepest well in Iceland. Figure 3 is a map showing the track of the well as actually drilled, together with the tracks of existing wells.

The IDDP-2 was drilled vertically down to 2,750 meters and below that drilled directionally to the southwest to intersect the main upflow zone of the Reykjanes system as indicated by geophysical surveys. The bottom of the well has a vertical depth of about 4,500 meters, and is situated 738 meters southwest of the well head.

Various challenges arose as the drilling progressed, there were weather delays, problems with hole stability that required frequent reaming, and the drilling assembly becoming stuck several times. Each instance was successfully solved as it happened. However, the major unsolved problem was a complete loss of circulation below 3,060 m depth, that could not be cured with lost circulation materials, or by multiple attempts to seal the loss zone with cement. As cementing was not successful, below 3180 m, drilling continued without any return of drill cuttings to the surface. Consequently, the drill cores were the only deep rock samples recovered. In the beginning, we had difficulties recovering drill cores and overall only a total of 27.3 meters of core were retrieved in 13 attempts. These cores indicate that the IDDP-2 drilled through a basaltic sheeted dike complex that shows progressive metamorphism from greenschist, to lower amphibolite facies, consistent with hydrothermal alteration at temperatures of up to 450°C, with low water/rock ratios. The deepest core, returned from the bottom of the well is quite fresh dolerite, with minor intrusions of felsite. The main indications of hydrothermal alteration in this rock are quartz + biotite + hematite mineralization on fracture surfaces.

Another interesting aspect of the temperature log in Figure 1 is that, in addition to the major loss zone at 3,400 m, there are lesser permeable loss zones at 4,450 m and just below 4,500 m depths. After that PT logging run, a 7” perforated hanging liner was inserted to the bottom. Subsequently a 7” sacrificial casing was lowered from surface down to 1,300 m, and cemented up to the surface. Casing shoes were then drilled out and the well deepened by 6” bits, ending with 3 successive coring runs to the 4,659 m final depth. After the deepest coring run, a 3 ½” drill string was lowered to the bottom of the hole. The aim is to enhance the permeability
deep in the hole by pumping in cold water for several months through the 3 ½” drill string. There are already some positive indications of enhancement of injectivity. Tests made after the last coring runs showed that cold water injection increased the injectivity index from 1.7 (l/s)/bar to 3.1 (l/s)/bar. We expect that continued deep stimulation with cold water is likely to further improve the fracture permeability at depth.

While this “soft” stimulation is going on, a surface test bed, with two parallel flow lines, will be designed and constructed ready for long term flow testing. Only after these fluid handling and flow tests are concluded can we determine the nature of the formation fluids, their enthalpy and flow characteristics, and hence estimate their engineering and economic potential. The total loss of circulation below 3 km depth was unexpected, but the existence of large permeability, a kilometer deeper than the current production zones at Reykjanes, may have implications for the future development of the geothermal resource that are independent of supercritical production.

Significance of the IDDP-2

The geological environment of the Reykjanes geothermal field is of great interest to the scientific community, situated as it is on the landward extension of the Mid-Atlantic Ridge that forms part of the world-encircling system of divergent plate boundaries, or oceanic spreading centres. These are regions of frequent volcanic eruption, high heat flow, and submarine hot springs. The IDDP-2 is a unique opportunity to examine the roots of a black smoker.

In future, our demonstration that it is possible to drill into a supercritical zone could have a large impact on the economics of high-temperature geothermal resources worldwide. By extending the available economic reservoir downwards we can extend the lifetimes of existing producing fields. As higher enthalpy fluids have greater power conversion efficiencies, fewer turbines are required for a given power output. Similarly, as fewer wells are need for a given output, we can increase the productivity of a geothermal field without increasing its environmental footprint.

Iceland is fortunate in having several likely sites for such developments. Planning for drilling the IDDP-3 well at Hellisheidi is already underway, and, subject to the availability of funding, drilling could begin in 2020. However supercritical conditions are not restricted to Iceland, but should occur deep in any young volcanic-hosted geothermal system. Deep wells drilled in geothermal fields such as Kakkonda in Japan, Larderello in Italy, Los Humeros in Mexico, and The Geysers and Salton Sea in USA, have encountered temperatures above 374°C. Development of supercritical geothermal resources could be possible there and in many other volcanic areas worldwide.

More information on the IDDP can be found at www.iddp.is and www.deepge.eu.