Iceland Deep Drilling Project. The first IDDP Drill Hole Drilled and Completed in 2009

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ABSTRACT

Deep Vision (the steering committee) of the Iceland Deep Drilling Project (IDDP) announces that the first IDDP-well should have been completed to target depth (4.5 km) by early July 2009. However, after series of drilling problems and several weeks delay in proceeding as planned, the drilling operation abruptly had to be terminated on 24th June, once it became clear that an active magma body existed below 2104 m depth. Rhyolitic volcanic glass (obsidian) was retrieved with the circulation fluid after the third attempt to drill below 2104 m depth in a sidetracked well labeled as IDDP-1C. Prior to that the IDDP-1 well had been sidetracked twice and a cemented casing inserted to 1958 m depth. When drilling into the magma for the third time, under total circulation loss condition, the drillers narrowly managed to avoid getting permanently stuck at that depth for the third time. Volcanic glass began returning to the surface for several hours during cooling, until all circulation fluid was lost again into the feed zone just above the magma body. The lowest 20 m of the well was plugged by obsidian. Deep Vision decided to complete the well by inserting a production/protection casing, partly cemented to the anchor casing, with a slotted liner in the lowest 120 m of the well. This enabled a flow test that was scheduled for autumn 2009. The wellhead valve is class 2500 as are the flow testing equipments, capable to deal with the expected superheated dry steam, which could be 400-500°C hot and at pressures well over 100 bars.

The purpose of this paper is to provide an overview of this drilling and discuss the future of the IDDP project, while the result of the first flow test need be discussed at the WGC-2010 conference. The details of the various topics of the IDDP progress will be described in a series of

The aim of the IDDP drilling was to penetrate into supercritical geothermal fluids and to study them as a potential source of high-grade geothermal energy. The concept behind the Iceland Deep Drilling Program is to flow supercritical fluid to the surface in such a way that it transitions directly to superheated >450°C hot steam at subcritical pressures, with up to 10 fold energy output of some ~50 MWe, as compared to average high enthalpy geothermal wells. By flow testing the IDDP-1C well under the current condition we still expect to get superheat dry steam but at somewhat lower pressure than aimed for. The experiment at Krafla may develop from conventional dry steam production, if the well does not sustain production, into the world hottest EGS experiment, by watering the magma body.

Funding for the IDDP-1 well was secured by Landsvirkjun and Alcoa down to 3.5 km, and by them including the IDDP consortium, deepening the well to 4.5 km, flow testing it and pilot studies for energy production. Wells IDDP-2 and IDDP-3 are planned to be drilled in 2010-2012 in the Hengill central volcano and into the Reykjanes volcanic system, both in SW-Iceland. Funding for these wells to some 4 km depth, including cement of the 9 5/8" production casings will be secured by the energy companies the Reykjavik Energy for IDDP-2 and HS Orka hf for IDDP-3. Funding for the drilling and testing these wells in the supercritical regime remains to be accomplished. As only part of the allocated fund from the IDDP consortium was needed for the IDDP-1 well, Deep Vision will consider transferring it to the IDDP-2 and IDDP-3 wells.

1. INTRODUCTION

The IDDP is a project of an international industry-government consortium consisting of the three leading Icelandic power companies, HS Orka hf, Landsvirkjun, Reykjavik Energy, together with Orkustofnun (the National Energy Authority of Iceland), Alcoa Inc. (an international aluminum company) and StatoilHydro (an international oil and gas company). The first four founded the IDDP consortium, whereas Alcoa and StatoilHydro joined it in 2007 and 2008 respectively (Friðleifsson et al., 2005, 2010). The aim of the consortium is to improve the economics of geothermal energy production by producing supercritical geothermal fluids. A broad range of technical challenges will be met during this attempt to drill into and investigate the little understood supercritical environment. In addition to three technical groups, dealing with drilling technique, fluid handling and evaluation and geosciences, the consortium has welcomed the inclusion of basic scientific studies in the IDDP (Friðleifsson and Albertsson, 2000; Friðleifsson et al. 2010). Already in 2001 this resulted in the participation and funding support by the International Continental Scientific Drilling Program (ICDP) and in 2005 additionally by the US National Science Foundation (NSF) (Elders and Friðleifsson 2010).

The IDDP-1 well is located in the Krafla high-temperature geothermal system in NE-Iceland, drilled towards a magma chamber within the Krafla caldera. This magma chamber could be expected to be met by drilling at any depth below about 4 km at drill site, but more likely somewhat deeper. The well was targeted towards relatively young inclined volcanic eruptive fractures. The younger of these dates back to AD 1724, while the older, and closer, is about 2000 year old. The results from a new MT survey and newly drilled wells in Krafla lead the research team to believe that the brittle/ductile boundary, or a magma chamber, could be met at 4 to 4.5 km at the IDDP-1 drillsite.

Funding for the drilling, flow testing and pilot studies for energy production is already secured for well IDDP-1 in Krafla. The IDDP consortium also has plans to drill IDDP wells number 2 and 3 by 2010-2012, within the Hengill-and the Reykjanes high temperature fields respectively (Figure 1). Funding for drilling these wells to production casing depth (~ 4 km each) is also secured, while drilling into the supercritical regime and subsequent flow tests and productions tests remains to be accomplished. These near future drilling plans will be discussed in relevant details at the WGC-2010 convention.

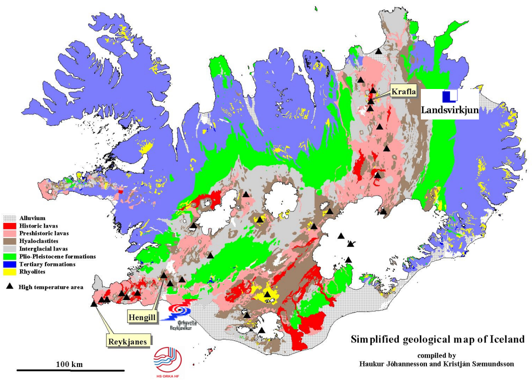

Figure 1: Simplified geological map of Iceland showing the volcanic rift zone through the island and the three active volcanic systems where the IDDP drillholes will be drilled, IDDP-1 at Krafla, operated by Landsvirkjun, IDDP-2 at Hengill operated by Reykjavik Energy and IDDP-3 at Reykjanes operated by HS Orka hf

2. THE IDDP-1 WELL AT KRAFLA

At the IDDP-1 drillsite in Krafla, below some 1100-1200 m depth, the pressures and temperatures of the geothermal reservoir follow the boiling point with depth curve (BPD-curve). The reservoir fluid is almost pure water, slightly modified meteoric water containing less than 2000 mg/l of total dissolved solids with some admixture of magmatic gases. By following the BPD curve to depths the critical point for this reservoir water could be reached at depths as shallow as about 3.5 km. The plan was to cement the last casing to approximately 3.5 km depth in the first IDDP-1 well, and anticipate that supercritical conditions will be reached soon after drilling out of the 3.5 km deep casing.

However, after a series of drilling problems and about two months delay, one of the primary reason for the drilling problems became clear. We were drilling too close to an active magma chamber or a magma body large enough for the magma to stay liquid for over 25 year, assuming it related to the 1975-1984 volcanic episode at Krafla. Finally, in the third attempt to bypass the 2104 m depth "threshold" in the well, it became clear that hot magma was involved, presumably about 1000°C hot judging from the volcanic glass of rhyolite composition (obsidian) that was returned to the surface. This magma body had not been identified or interpreted as present by any of the geophysical methods applied earlier. In addition, two drillholes, K-25 (70 m away) and K-36 (4-500 m away) had reached deeper, about 1-2 m deeper in the former well, and about 100 m deeper in K-36. No abnormal drilling problems had been involved during drilling of either well K-25 or K-36. In both these cases, as well as in other nearby wells, LV had been drilling in a close vicinity of this magma. Therefore it was no wonder that drilling into a magma at 2104 m depth in IDDP-1C came as a big surprise. Hitting magma too early, e.g. at 3-4 km depth, would have been considered as bad luck in our attempt to drill down into supercritical regime, but not as surprising. Our target all along has been to drill towards the margin of a magma chamber, searching for a hydrothermal reservoir at supercritical condition. The details of the IDDP-1 drilling operation, scientific implication, the well design and the flow testing designs, are described in other papers at this WGC-2010 conference (Hólmgeirsson at al., 2010, Elders and Friðleifsson 2010, Þórhallsson et al., 2010, Ingason et al. 2010).

Production from the above mention K-36 well, nearby IDDP-1, had shown the deepest aquifer at >2 km possibly to be superheated or at least at temperatures determined by the BPD-curve, and very gas rich. Wetting dry steam from that feed point by mixing it with a two-phase feed zone at shallower depth, resulted in acidification and the creation of a very corrosive liquid. The field operator later cemented off the bottom-feed zone in that well. The IDDP research team was very well aware of this situation, and had concluded before the IDDP-1 well was drilled, that a similar and agitating gas-rich fluid should be expected, while the IDDP concept has been to deal with such fluid at superheated condition in order to prevent acidification downhole. Now, having a 1958 m deep production casing and a slotted liner below open to 2080 m depth, and open into a feed zone of total loss (>60 l/s), enables IDDP to test the superheated gas-rich steam just above the magma chamber. In that sense, a part of the IDDP goal of dealing with a superheated steam above 450°C may have been achieved, while the reservoir pressure is expected to be far lower than anticipated, by some 50 bars or more. Result from our first flow test is awaited with excitement and will be reported at the WGC-2010 conference.

Landsvirkjun, the operating company at Krafla, was to fund the drilling and casing the IDDP-1 well down to 3.5 km, with a fixed financial support from Alcoa. Most of this fund was needed to complete the IDDP-1 well to the 2104 m depth. Below that depth the IDDP consortium was to fund the well completion to 4.5 km depth and the subsequent tests. However, the funds allocated for deepening in the IDDP-1 well has not been used, so the consortium will consider transferring part of those funds to the next IDDP well.

Further on funding, the NSF and the ICDP are jointly have granted funds for coring and sampling in the first IDDP well for scientific studies. The first of some 10 drill cores was planned at about 2700 m depth in IDDP-1, and then at bit changes and zones of scientific interest to target depth. However, it never came to coring, apart from an unprecedented opportunity that the PI's got to re-drill a major feed zone at 2040-2050 m depth by coring, an opportunity accepted by the PI's and ICDP. This coring attempt however turned out to fail, as neither was the well nor the drilling tools in proper condition at the time for successful coring, a lesson learned after having tested it (Elders and Friðleifsson, 2010). Nevertheless, we had all the reasons to believe that a spot coring at this depth could be successful after a very successful IDDP coring test in well RN-17B at Reykjanes few months earlier (Skinner et al., 2010). As far as the ICDP and NSF funds are concerned, DeepVison anticipates that the ICDP and NSF consider transferring the funds to the near future IDDP wells at Hengill and Reykjanes.

The initial geological result of the IDDP-1 drilling will be described in more detail by Elders and Friðleifsson (2010) at the WGC-2010 meeting, where the most important part relates to the close encounter with the magma. The design of the flow testing equipments, as well as the first result of the flow test, will be described by Ingason et al. (2010).

It is clear to the IDDP consortium that by the IDDP-1C well we have a very challenging geothermal situation at hand and under control. Firstly, having an open feed zone 20-30 m above a 1000°C hot magma chamber is something very unusual. Secondly, a perforated liner into this feed zone enables access to the environment both ways. And thirdly,by having a safety casing cemented to about 1950 m beneath the surface enables production of an energetic dry steam without wetting The situation enables a proper flow tests to be performed, the result of which may yield superheated steam viable for energy production without further modification? If the steam production from the well does not turn out to be sustainable due to pressure decline, the situation should call for alternative tests. The first that come to mind would involve experiment to created “the world hottest engineered geothermal system” (EGS) just above this living magma chamber. Discussion on that is premature here but surely worth considering closer.

We close this discussion with a nice photo from the IDDP-1 drill site in Figure 2.

Figure 2: A view to the IDDP-1 drillsite across the Viti explosive and volcanic crater which was formed in AD 1724. The IDDP-1 well hit rhyolite magma at 2104 m depth on the platform just west of this crater. The site may be consider as ideal for attempts to create the world hottest engineered geothermal system

3. THE IDDP FUNDING AND FUTURE DRILLING

The guiding principle in the funding of the IDDP drilling and testing program has been that the IDDP consortium funds the basic operational cost of the program and the drilling as well as the flow testing the wells, while the incremental costs of core drilling and sampling for the science program, and their subsequent study, should be met by the scientific community. The estimated operational cost for the IDDP-1 drilling project and flow testing was estimated close to US $ 30 million. Approximately half of this has already been borne by Landsvirkjun alone, with a contribution from Alcoa. The funds for drilling the IDDP-1 well below 3.5 km, allocated by the IDDP consortium for deepening the well, have not been used.

The cost of spot coring, amounting to US $ 3.6 million, from ICDP and NSF has only partly been used for purchasing the spot coring equipment, some drilling related and petrographic tools, and for the two coring attempts. Additionally StatoilHydro contributed directly to the science program. The PI’s will request the ICDP and NSF to transfer these funds to the next IDDP wells at Hengill or Reykjanes.

During 2010-2012 the other Icelandic energy companies intend to drill wells IDDP-2 at Hengill, and IDDP-3 at Reykjanes, both wells down to production casing depths (~ 4 km), at their own cost, with or without associates. Already, Reykjavik Energy has purchased all the casings to production depths and the 2500 master valve. The cost of each of the new IDDP wells is expected to be of similar magnitude as IDDP-1. Both these wells will be made available for deepening into the supercritical zone by the IDDP, and hopefully with participation by the scientific community. As yet, the funding issue for the deepening of wells IDDP-2 and IDDP-3 is an open issue. As before the IDDP consortium welcomes international participation in our effort to study the natural supercritical hydrothermal regime. In addition to the lessons learned at IDDP-1 at Krafla, it will be the first opportunity worldwide to directly investigate supercritical hydrothermal processes in volcanic systems in a mid-ocean ridge-like environment. If the goal of producing supercritical fluids is successful in Iceland, the same approach could be applied worldwide wherever suitable high temperature geothermal reservoirs occur. Improving the economics of the geothermal energy industry by producing supercritical geothermal systems could be significant, whereas the cost of mastering the technique will be relatively high to begin with. Once mastered, the costs should decrease and become proportional to the depth range covered by the wells.

CONCLUSIONS

The industrial aim for the IDDP is to improve the economics and availability of geothermal energy, an environmentally benign form of alternative energy. If the IDDP approach of using deeper, hotter, supercritical resources is successful, it will make a positive impact on the geothermal industry worldwide, wherever supercritical conditions occur at drillable depth.

The drilling of the well IDDP-1 took an unexpected course by meeting live magma at the shallow depth of 2104 m. The IDDP program was adjusted to flow test a superheated feed zone just above the magma chamber. Once accomplished the initial results will be disclosed at the WGC-2010. The IDDP-1 well and the neighbor wells have a potential to become the world hottest engineered geothermal system.

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