SAGA REPORT No. 11

Introduction

An IDDP-2 Way Forward Workshop (WFW), a joint effort of the IDDP-Consortium and DEEPEGS, was held 20-21 March 2018. The meeting agenda is shown in Appendix 1, and a list of the 55 participants is shown in Appendix 2. The meeting was opened by the IDDP-Principal Investigator (PI) and the DEEPEGS-Coordinator, Guðmundur Ó. Friðleifsson, who began by briefing the participants on the meeting agenda, its purpose, and on the IDDP history, which extends for more than 18 years. In 2005 the IDDP plan was to deepen to 5 km depth well RN-17 in the Reykjanes field operated by HS Orka. However, prior to IDDP deepening, this 3.1 km deep drill hole collapsed during a flow test and the well could not be reconditioned. The IDDP activity thus moved to the Krafla field, operated by Landsvirkjun, and well IDDP-1 was drilled there in 2009. That well was terminated at only 2.1 km depth as it penetrated into 900°C magma, and so further drilling could not be attempted. The IDDP-1 well however was extensively tested and became the world's hottest production well for a while, yielding 452°C hot superheated steam at 140 bar pressure with production potential of up to 36 MWe. The lesson learned was most valuable and will be used for further development of the Krafla field, while in January 2014 a Special Issue of the journal Geothermics was devoted to the engineering and scientific results of the IDDP-1 well.

The IDDP-2 well took advantage of HS Orka´s well RN-15 which was 2,500 meter deep production well. The first phase of the IDDP-2 project was to deepen the RN-15 well to 3,000 meters and cement a steel casing firmly into the surrounding formations. The deepest existing geothermal wells at Reykjanes are about 3,000 meters deep so the IDDP-2 has the deepest casing in any well in Iceland. From there the well was deepened to its final slant depth of 4,659 m from rig floor. The drilling of the IDDP-2 well at Reykjanes began 11th August 2016 and ended 25th of January 2017 after 168 days of drilling operation. Temperature at the bottom of the well was measured at 426°C, during drilling 3d January 2017, at fluid pressure of 340 bars. It immediately became clear that the bottom of the well had reached fluids at supercritical conditions, so the main drilling phase objective of the IDDP project had been achieved. In May 2017 temperature logs during and after a warm period of only a few days suggested a stable bottom hole temperature at least 535°C.

From the very beginning the drilling operation experienced a total loss of the circulation of drilling fluid, which was injected as 50-60 l/s of cold water with intermittent addition of small doses of polymer liquid to lower the viscosity slightly. The total circulation loss was not so surprising at the beginning, but after having cemented in the production casing (to 2941 m depth), total loss of circulation fluid continued more or less to the end of the drilling at 4659 m depth. Some 12 separate cementing jobs were attempted that were unsuccessful to cure the loss zone. After almost 1 month. the decision was made to give up on curing the leakages and drill blind to the total depth. This exceptionally extensive blind drilling for almost 2 km is surely a record in Icelandic drilling experience. Apart from drill cutting samples between 3.0-3.2 km depth, the only rock samples we retrieved were sparse drill cores recovered from 13 separate coring attempts.

Altogether some 27.3 m of drill cores were sampled, the best of which were retrieved from the very bottom of the well from within the supercritical zone.

After having inserted a perforated liner to the bottom, a 3 ½" drill string for stimulation was inserted close to the bottom and left in the hole for 5 months – until July 2017. This stimulation effort injected cold water to the bottom with the aim of enhancing the permeability deep in the supercritical regime, below 4 km depth. As part of that effort an Altavert degradable circulation loss blockage material was inserted into the annulus to seal off the main leakage zone at 3.4 km depth. This proved to be too successful because in the fourth period of insertion the well was totally blocked for downflowing cooling fluid and that resulted in an unintended week-long heating-up of the production casing. During that time the production casing was damaged between 2,307-2,380 m depth adjacent to the former main feed zone of the old RN-15 production well at 2,360 m. This was discovered by downhole logging after the stimulation drill string had been removed from the hole, that showed that fluid was leaking into the IDDP-2 hole at that depth.

This damage on the production casing – as well as a severe corrosion on the lowest part of the stimulation drill string, resulted in a delay in the planned forward implementation of the IDDP-2 project. The idea had been to continue stimulation by using a 6" packer in the open bottom hole zone below the liner and continue stimulation through the 3 ½" drill string as well as injecting gas tracers to test if a connection exists between the deep permeable supercritical zone and the upper conventional part of the Reykjanes geothermal reservoir. Accordingly, this test had to be abandoned, and efforts turned to assessing the damage to the production casing and considering strategies to repair it. It became evident that it would be very difficult and expensive to repair the damage or replace the casing. After several months delay a decision was made to move forward – and the first step was to conduct the IDDP-2 Way Forward Workshop – which is the topic of this SAGA Report.

The current situation and the forward plan for the IDDP-2 well is the following:

1. Injection of about 12 l/s of cold water is still ongoing
2. The well was P-T logged down to 2.3 km depth 15.02.2018
3. NS-1 liquid tracer has been purchased and will be injected in April 2018.
4. Hot water injection may begin in April, and can be controlled at 50°C up to 180°C.
5. The tracer(s) will be monitored for about 4 months by sampling selected wells near to IDDP-2.
6. After that the re-injection water temperature may be raised before stopping injection for a heat-up period until flow testing becomes ready
7. Preparation for wellhead and flow line final design has begun and will be completed next autumn

8. Construction on well site could be completed December 2018
9. Flow testing is planned for 1st Quarter 2019 - and will be running throughout 2019
10. Power production Pilot Testing of some sort may be added to the flow line as relevant during 2019
11. P-T monitoring and fluid sampling will be conducted through 2019 as needed
12. Reporting and abstract writing for WGC 2020 should be dealt with and completed in 2019
13. DEEPEGS may possibly be expanded for few months into 2020?
14. DEEPEGS should be completed within 2020

The IDDP-2 Way Forward Workshop

The workshop held in Reykjavik, Iceland, on 20-21. March 2018, reviewed the status of the project and discussed the way forward, especially the necessary flow tests to sample the deep fluid and investigate its potential as an energy source for electricity generation (See the attached Agenda). The first plenary session of the workshop discussed the status of the well. The well has at least two fluid feed zones, a dominant one at 3.4 km depth and a second smaller one at 4.5 km. Although the drilling and completion of the well proceeded according to plan, a problem developed later. After injection of cold water designed to enhance the permeability of the deeper hottest zone had proceeded for some months in 2017, damage was discovered at a depth of between 2,307 to 2,380 m, where a contriction in the production casing prevents deploying logging tools deeper. The plan is therefore is to carry out comprehensive flow testing without repairing this damage zone, beginning early in 2019. Accordingly there was considerable discussion about inserting 3.5 or 4.5 inch drill pipe past the constriction to allow deployment of logging tools and downhole samplers beyond the constriction. A drilling rig will be onsite in August 2018 to insert this drill pipe to allow these measurements to be made, and remove it before the flow testing.

High-temperature tracer tests and reservoir modeling will also be carried out before the flow testing. Meanwhile petrological and rock physics studies of the cores recovered are advancing. Spot coring provided the only deep rock samples from the well as drilling continued without recovering drill cuttings. These cores are characteristic of a basaltic sheeted dike complex, with hydrothermal alteration mineral assemblages that range from greenschist to hornblende hornfels, and pyroxene hornfels, allowing the opportunity to investigate water-rock interaction in the active roots of an analog of a submarine hydrothermal system. The deep fluids have not yet been sampled from the IDDP-2, so their chemistry is unknown at present. It was pointed out that the approach to high enthalpy geothermal systems by the IDDP is applicable to many other superhot geothermal resources worldwide.

Presentations followed on conceptual geological models of the subsurface environment of the IDDP-2 based on joint inversions of well logs and predrill information on porosity, magnetization, and potential fields, etc., that allow prediction of subsurface temperature distribution and the location of the brittle/ductile transition underlying the current producing geothermal field.

Considerable effort has already gone in to the design of the surface valves, flow line, and surface testing equipment necessary for testing very hot, and potentially corrosive solutions. Acid resistant alloys and cladding of valves will be employed and specifications for basic material selection, and pressure class of the equipment are being finalized.

The afternoon session began with presentations on the lessons learned from the IDDP-1 drilling at Krafla. The flow test was challenging. Wet scrubbing of acid in the superheated steam was successful but silica particles in the superheated steam abraded the wellhead valves. One important lesson was not to try sample or run sensitive experiments during the first hours of flow when the steam is contaminated. Other lessons were - to document everything, make monitoring constant, maintain a high degree of superheat of the steam, have a clear risk management plan at the site, aim for simple and proven solutions, and be ready for unexpected happenings. Finally, and above all, avoid closing the well.

This look back at IDDP-1 was followed by looking ahead by an introduction to the status of planning for the IDDP-3 well at Hellisheidi geothermal field, its scope, conceptual and reservoir modeling, planning and licensing, its objectives, alternatives for well and surface equipment, and discussion of five potential well locations. The plan is to start drilling in 2021.

The workshop then changed format with participants joining one of four parallel working groups on (1) Geosciences, (2) Reservoir engineering, (3) Fluid Chemistry, and (4) Flowline and pilot plant. The charge of each breakout group was to make specific recommendations that list(a) its priority, (b) its timeline (c) if the activity is in-hole or not in-hole (d) if it requires drill rig time, (e) its feasibility, (f) its personnel and individual in charge, and (g) its tentative budget.

RECOMMENDATIONS

During the final plenary session, the following items and recommendations were brought up by each panel as a result from the panel discussion. These notes took some modification during the discussion, which each panel will then use in the "Way Forward" implementation. For the record we just keep the listed items as brought forward.

GEOSCIENCES

- Vertical seismic profiling using downhole seismometers is desirable as we still lack a great deal of detail about the structure around and below the IDDP-2 well, such as the nature of faulting and of the brittle/ductile transition.
- More numerical modelling of existing geophysics is required.

- We need to complete the physical properties measurements of the core and use them to interpret downhole logs and surface geophysics.
- Detailed laboratory analyses and studies of isotopic ratios in minerals, rocks and fluids are very necessary. For example, hydrogen and oxygen isotopic ratios could indicate the degree of magmatic contributions to the fluid, and the amount of water/rock reaction, etc. These could take many months to complete.
- Fluid inclusions studies of the cores could give detailed information on fluid compositions, and temperatures of reaction in mineral formation at specific depths. Deep in the well fluid inclusions are vapor dominated and will be difficult to study and require advance techniques (e.g. laser ablation and ICP mass spectrometry, etc.) However, this is a high priority and should begin at once. This was also a high priority of the fluid chemistry panel.
- By analyzing the chemistry of co-existing mineral pairs in the cores we can use mineral geo-thermometers to understand the present state and evolution of the system. This requires microprobe and ion microprobe analyses that could take some months depending on the availability of personnel and access to equipment.
- Determining the age of intrusions in the series of sheeted dikes by study of zircons or possibly by Argon isotopic ratios could shed light on the timing and evolution of the geothermal system as an input to conceptual modeling.

FLUID CHEMISTRY

- The first task is prediction of fluid chemistry of the 4600 m feed zone using fluid inclusions, downhole samples (using a downhole sampler deployed through the drill pipe), geothermometry of secondary minerals in cores and experiments.
- Secondly the fluid chemistry group should provide the flow test group with worst case scenario for flow line design. At 3400 m the fluid should have seawater salinity, but at 4600 it could have up to 25% TDS. As for silica, the maximum quartz solubility could be ~ 800 mg/kg. Sulfide and pH will require more work.
- How do we determine the deep fluid chemistry?
  - Flow test program at different pressures and flow rates
  - Can we detect contributions from the deepest aquifer based on chemical composition, isotopes (Sr, B, Li) or by other means?
  - A background sample is desirable for comparison, preferably from downhole.
  - Can we identify “red lights” for fluid composition during well flow?
- The group should provide the flow test group with preferences on sample port number, types and locations.

Pressure/Temperature relation suggest that the deep fluid is either vapor+NaCl or two liquids. Fluid inclusions in the core are bimodal and either vapor-rich or vapor-rich with abundant salt crystals, but the bottom-hole core suggests an iron rich brine may be present. Characterization of the fluid might be possible by downhole sampling, using the Thermochem fluid sampling tool, if a 4 ½“ drill string can be installed, but the well needs to flow first to clean up the injected water. Temperatures might be deduced from the magnetite-ilmenite pairs in the cores. The temperature of the 3400 m aquifer might be deduced from fluid inclusions in rocks and rubble from that depth interval. The “vapor-like” part of the two-fluid scenario is likely to have seawater salinity (as $NaCl^0$), and contain HCl^0, SiO_2 etc. whereas the ionic components will be in the brine with possibly 20-25% NaCl.

RESERVOIR ENGINEERING

- Estimate static P and T below CSH without new downhole logging
  - Consider televiewer and/or camera to top of obstruction
  - Team to discuss what other datasets than direct T logs during injection are temperature sensitive
  - Can the well caliper be extracted from spinner data to strengthen Statoil lithology models
  - Modeling for T(z) and P(z) with various models and datasets
- Estimate static P and T below CSH with additional logging
  - 4.5“(76.2 mm) drill string preferred to 3.5“ (61 mm) for larger ID
  - ISOR to supply OD of K10 PTS, sonic and televiewer with centralizers
  - Run tools on E line in case they get lost – always have the data on surface
  - Consider step rate injection test and tracer slug injection if rig on well
- Repeat injectivity test, P(t) at 2000 m, two tests, allow well to heat up in between? If rig on well, get 3rd rig pump and maximize injection at 90 l/s.
- Flowing well models for estimating output curves
- Conceptual and numerical reservoir models, 1, ideally 2 and best 3-D

FLOW LINE AND PILOT PLANT

The panel has developed the following timeline for the necessary tasks in view of the extensive work already completed:

ITEM	MILESTONE
• Final design of wellhead and flowline begins early April	01.04.2018
• Deadline for ordering materials	15.05.2018
• Design ready	30.05.2018
• Drill string out of hole	01.09.2018
• Well closed. Gas release	23.09.2018
• All materials available	31.12.2018
• Flow test	01.04.2019

Waiting for possible output curves
Waiting for chemistry range of the discharged fluids
Need information on requirements for fluid testing:

- Flow rate requirements for each test
- Duration of each test

CONCLUSION

Following the Way Forward Workshop the IDDP steering committee continued the discussion for about 1 hour and concluded that each working group should continue their way forward implementation towards the flow test as discussed during the plenary meeting. The committee also concluded that a drill rig to insert a supporting pipe, to enable access and detailed logging of the entire well below the damaged zone in the casing, should be brought into the IDDP-2 well site in July 2018. This would enable detailed find and purchasing of desirable logging tools and downhole tools to ease the logging string through the damaged zone.

Unanimously the WFW-participants recognized the IDDP-2 - DEEPEGS demonstration hole a Reykjanes as a unique opportunity to influence the geothermal industry worldwide. Therefore, a significant effort should be made by the DEEPEGS and IDDP teams to subtract all possible industrial and scientific data from this demonstration well. Some of it will require significant additional funding for implementation. Each group intends to address that during the following weeks.

The temperatures being exposed to deep sections of wells IDDP-1 and IDDP-2 reflect an environment where available casing materials and cementing technologies are at or exceeding their limits. Significant thermal movement of steel is the norm and owners need to prepare for operating wells with damaged casings or liner sections. Such wells are nevertheless able to transport fluid between surface and their deepest feed zones. A supercritical well primary success criterion is thereby achieved. The forthcoming flow test of IDDP-2 provides an excellent opportunity to test such a well concept.

Future supercritical drilling projects therefore should prepare for not gathering sufficient volume of deep well thermal recovery data to accurately assess the reservoir undisturbed pressure and temperature condition. Instead various and diverse logging data sets, like those already collected in IDDP-2, become an opportunity for advanced modeling studies. For example, a large volume of disturbed downhole temperature data exists in the IDDP-2, spot cores provide a temperature range and the Weatherford logging while tripping tool has gathered resistivity data that are sensitive to the deep reservoir porosity and temperature. These data sets alone are insufficient in accurately estimating the deep reservoir temperature. However, when coupled together in an inverse modeling suite with supercritical capacities and transient heat flow, an accurate temperature profile as a function of depth can be determined. This should be regarded as a doable and cutting-edge modeling study, for IDDP-2 analysis and in planning logging activities in future deep drilling projects.

Appendix 1

AGENDA – DAY 1 – MARCH 20

Reykjavík Energy – Bæjarháls

09:00 Opening and introduction to IDDP-2 Way Forward Workshop (GÓF)

09:15–12:15 Introductory presentations of status

- Well interventions, how to secure access to the deep part of IDDP2 - (ÞG) 15 min
- Tracer test (KVM) 15 min
- Logging opportunities (based on opened well) (HSO, ISOR, Statoil) 20 min
- Reservoir modelling - (GrB-Keshvad-Andri-ÓS) 20 min.
- Break, 15 min.
- Petrological studies (Robert & Wilfred) - 20 min
  Preliminary results – (RAZ) 10 min
  How could IDDP make a worldwide impact on science and geothermics? – (WAE) 10 min
- Conceptual geological model including well log interpretations and thin section analysis (Kati, Alex and Claudia will be supported by video) 30 min

- Flow line and surface testing equipment (Geir-Albert-Verkís) 15 min

12:15-13:15 Lunch
13:15-14:15 Lessons learned from IDDP-1 (BP-SHM-KE)

14:00-14:15 OR – IDDP-3 preparation (ESPA) 15 min

14:15-14:30 Objectives for initial Working Group discussions - 4x4 (WAE-GrB-FÓ-AA)

14:30-15:30 Break-out into Working Groups

1. Geoscience
2. Reservoir engineering
3. Chemistry, fluid characterization
4. Flowline and pilot plant, incl. sampling and in-line material testing

15:30-15:45 Coffee break
15:45-17:00 Plenary - 1st Presentations by working groups

AGENDA - DAY 2 - March 21

Orkugarður - Grensásvegi 9

09:00 - 10:00 Víðgelmir – plenary (recap - goal and agenda – split into working groups)
10:00 – 12:00 2nd Working Group meetings
12:00-13:00 Lunch
13:00-15:00 Plenary meeting
15:15 End of workshop

Appendix 2

List of Participants

HS-Orka:
Albert Albertsson
Ari Stefánsson
Geir Þórólfsson
Guðmundur Ómar Friðleifsson
Guðjón Helgi Eggertsson
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Ioan Alexandru Merciu (remote)
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Ragnar Gunnarsson
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