First results from stimulation assessment and monitoring of the 426°C geothermal well RN-15/IDDP-2 (H2020-DEEPEGS project)

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Abstract

The RN-15/IDDP-2 deep geothermal well of the DEEPEGS EU project on the Mid-Atlantic ridge at Reykjanes, Iceland, is a unique site for geothermal research. With a bottom hole temperature of approximately 426°C, it is one of the hottest geothermal wells ever drilled aiming for fluids at supercritical condition. Consequently, down-hole measurements are reliable to a depth of about 3.5 km, only. Pressure and temperature condition in the reservoir can be inferred using the newly developed wellbore simulator WellboreKit.

Due to complete fluid loss, the well has been drilled at flow rates that reach hydraulic stimulation condition. After the drilling, the well was stimulated further by applying different concepts ranging from high flow rate hydraulic stimulation to long-term but low flow rate hydraulic stimulation to increase the reservoir performance at around 4.6 km depth. Thermo-hydro-mechanically coupled numerical modelling was performed to predict the performance response and thus, develop a well stimulation schedule. Processes related to drilling and stimulation are monitored using seismic and magnetotelluric methods to characterize and understand the processes ongoing during injection.

Keywords: DEEPEGS, Reykjanes, Enhanced Geothermal Systems, Monitoring, Stimulation, Numerical Simulation, EU-H2020 Project

Introduction

The DEEPEGS project is a European H2020 demonstration project with the overall goal to increase the use of Enhanced Geothermal Systems (EGS) in Europe. The concrete objectives of the project are to test stimulating technologies in deep wells in order to deliver new innovative solutions and models for wider deployments of EGS reservoirs, to demonstrate the feasibility of EGS for delivering energy from renewable resources in Europe and to make deep geothermal resources a competitive energy alternative for commercial use. Three different demonstration sites: Reykjanes (Iceland), Valence and Vistrenque/Riom (France) which are representative of different locations and geological formations in Europe have been selected to drill deep geothermal wells and stimulate them. [1]

A large number of wells down to < 3,000 m (Fig. 1) exploit the Reykjanes geothermal field that is located on the seismically active Mid-Atlantic Ridge. The concept of using a deep EGS well at Reykjanes comprises injection of fluid underneath the conventional geothermal field to support production. Therefore, the 2,500 m deep RN-15 production well was deepened to 4,659 m depth in the framework of the Icelandic Deep Drilling Program IDDP-2. The drilling operation IDDP-2 was completed after 168 days on January 25th, 2017. Complete loss of circulation fluid occurred below 3,200 m. Temperature and pressure measurements at the well bottom suggest P/T condition of 340 bars and 426°C and thus, supercritical condition of the fluid. Well logging highlights a large permeable zone above 3,400 m and smaller feed zones at 4,450 m and 4,500 m. A number of 13 sections at different depths were cored [2].

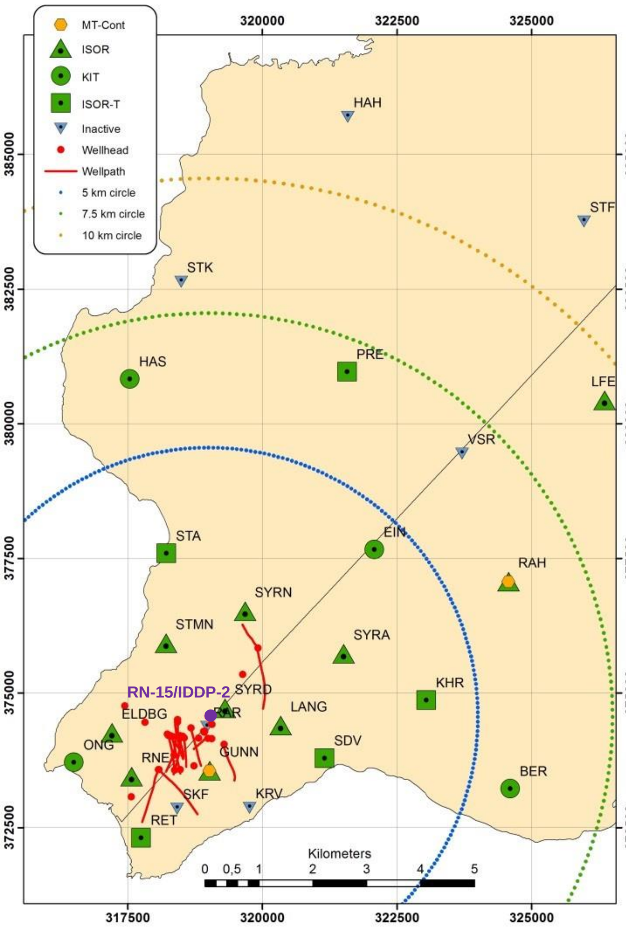

Fig. 1: Distribution of continuous monitoring stations and wells in the conventional geothermal field at the Reykjanes site (Iceland). A total of 19 seismic and two magnetotelluric stations were deployed in a 10 km radius from the RN-15/IDDP-2 well.

The conditions that are inferred from temperature and pressure measurements and analyses of the cores point to the assumption that besides brittle also ductile, i.e. slow and aseismic deformation occurs during reservoir engineering. In this study, we present for the first time results from hydraulic stimulation assessment and monitoring in such extreme condition.

Seismic and Electromagnetic Monitoring

The existing permanent seismic network at Reykjanes was supplemented by nine temporary stations, five from HS-Orka/ISOR and four from KIT in September 2016. For this purpose, the existing infrastructure of a former project could be used, hence the possible positions of the temporary stations were already known. Among all of them, the best locations were chosen to provide an optimal azimuthal and inclination coverage of the zone of interest by the final network. As a result, the seismic network during drilling and stimulation consists in a total of 19 active stations within a 10 km radius from the well (Fig. 1). The main objectives of the seismic monitoring are i) the reservoir characterization with insight on the fractures created or reactivated during drilling and stimulation, ii) the investigation of changes in the physical processes induced by drilling and stimulation, e.g. seismic slip vs. aseismic creep, iii) the characterization of the local stress field with the help of focal mechanisms, and iv) possibly the identification of the brittle-ductile transition zone in the reservoir. Preliminary analyses show that induced seismicity occurred during the drilling of the well in a zone that was formerly identified as aseismic. Further detailed analyses are currently on-going to better localize the seismicity and hence gain detailed spatial and temporal information.

Magnetotelluric monitoring is carried out at RAH and GUNN stations (Fig. 1) since December 2017, each equipped with two electric dipoles in N-S and E-W direction, as well as three magnetic sensors oriented in N, E and vertical direction. Magnetotelluric monitoring during massive hydraulic stimulation may reveal information on the directional development of the reservoir and the evolution of preferential hydraulic connectivity. First results from the late drilling phase have been processed. Figure 2 shows two representative examples of electric resistivity as a function of the period measured at the GUNN station and acquired between January 13th and 17th, 2017, when a core section was drilled between 4,634 m and 4,642.8 m depth. Note that the period can be related to depth following the concept of skin depth of the electromagnetic signal; therefore, the resistivity-period distribution is a function of the resistivity distribution with depth. Low resistivity in conventional geothermal reservoirs indicates either a clay cap layer that seals the reservoir at its top or the reservoir itself (e.g. Uchida, 2005) [4]. The results are decomposed into to XY and YX components that represent different directional components of the electric and magnetic fields. They show rather homogenous resistivity of about 10 Ωm down to periods of about $2{\cdot}10^{-1}$ s. Below resistivity drops by up to 1 order of magnitude with preference in the YX component. While in the example 13-14/01, two minima at $5{\cdot}10^{-1}$ s and 5 s are observed, the second one disappears on 16-17/01. From 10 seconds on, resistivity increases with depth. The periods between 10^{-1} and 10 s corresponds to the reservoir depth.

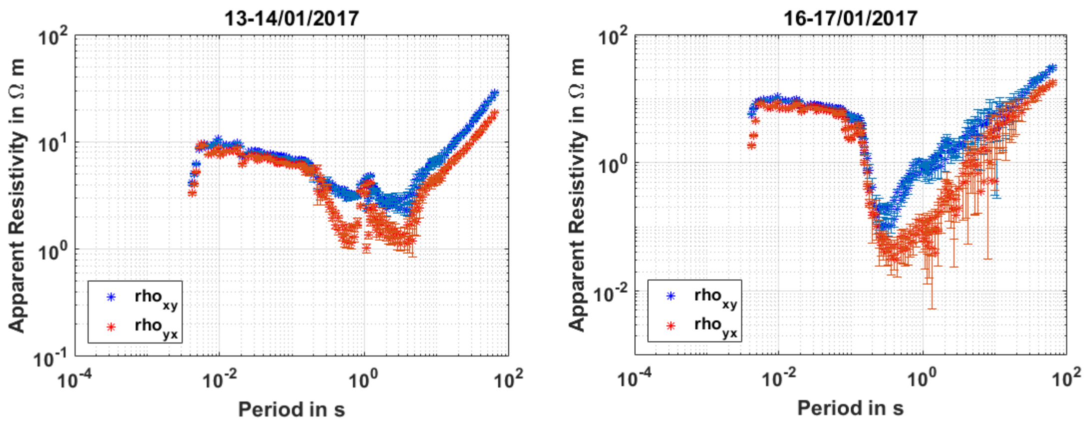

Fig. 2: Electric resistivity versus period from the magnetotelluric monitoring of January 2017 at station GUNN. Blue curves show the XY-component, the red curves the YX-component.

THMC Numerical Simulation of Stimulation

The finite element software REDBACK [3] allows the implementation of the dynamic evolution of damage, permeability and coupling effects between thermo-hydro-mechanical-chemical (THMC) processes that are incorporated into the constitutive relationship of a creeping material. Special attention is paid to the introduction of the multi-physics and multi-scale processes that operate at the scale of single grains at the borehole wall up to the entire reservoir. For such highly non-linear applications, a parallel high-performance computing infrastructure is needed. Here, we numerically study the borehole breakout pattern along ductile shear bands emerging from the borehole wall upon fluid injection.

To predict and understand the processes during the stimulation of RN-15/IDDP-2, the objectives are the THMC numerical modeling of fluid injection in the well, finite element simulations of the near wellbore region using creep damage mechanics, extended analyses of mixed brittle-ductile rheologies and nearby fault zones and upscaled fully-coupled reservoir-scale simulations based on the structural model. These investigations will result in a proposal for a stimulation protocol. Further objectives are the analyses of well logs for ambient stress field determination and micro-structural analyses of deep core samples. The major scientific challenge is the identification of evidences of the brittle-ductile rheological transition zone at depth.

Wellbore Simulation with WellboreKIT

WellboreKit is a new simulator for multiphase thermo-hydro-chemical coupled processes along geothermal boreholes. It is unique in its capability for geothermal fields and is applied to RN-15/IDDP-2. WellboreKit will be open source and consists of modules linked to the solver ELMER [5].

Challenges for the application are the highly saline water in Reykjanes geothermal field, super-critical conditions under high pressure and temperature and the small database for the calibration of the numerical model due to total loss of circulation fluid during drilling. One main objective is to study heat and pressure propagation in the wellbore, and validate them with real data from RN-15/IDDP-2. Another main objective is to predict chemical deposition along the wellbore casing to minimize negative impact on the efficiency of the well. Thus, long-term behaviour of the well operation and efficiency will be studied with WellboreKit.

As first results, the temperature and pressure logs of RN-15 production well are validated successfully. The effects of a two-phase flowing fluid on pressure drop and heat transfer between rock and fluid are observed. As there are no measurement data about scale formation process at the site, investigation into the impacts of different factors on chemical deposition within the borehole is carried out only qualitatively at the current stage. Such factors include different mixture components in the aqueous and non-aqueous geothermal fluids, electrolyte concentration, wall fraction, operation parameters such as mass flow rate during production/injection and injection temperature. The present results confirm the effects of the above-mentioned factors on the pressure-temperature profile, the amount and the position of mineral deposition along the borehole.

Conclusion

The RN-15/IDDP-2 deep geothermal well in the Reykjanes field is unique in many regards and the outcome of this EGS project could imply major redistribution of the geothermal energy in the European energy mix. The extreme pressure and temperature conditions in the well requires the application and the development of non-invasive techniques to describe and exploit as best as possible the geothermal reservoir. This strongly multi-disciplinary work reaches the limits of the current state of the art and thus promotes highly collaborated research. The first results obtained from a couple of monitoring techniques deployed at the surface as well as from thermo-hydro-mechanical-chemical modelling tools at or around the well are promising and support further work.

Acknowledgements

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