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Long-Term Continuous Magnetotelluric Monitoring of The IDDP-2/RN-15 Engineering (Reykjanes Peninsular, Iceland)

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ABSTRACT

The Horizon 2020 project "Deployment of deep enhanced geothermal systems for sustainable energy business (DEEPEGS)" aims at demonstrating advanced engineering technologies in geothermal reservoirs. During the deepening of the former 2500 m deep RN-15/IDDP-2 well on the Reykjanes peninsular in the framework of the Icelandic Deep Drilling Program to 4659 m depth (RN-15/IDDP-2 well) between August 2016 and January 2017 partly total fluid loss and induced seismicity occurred along the drilling path (Friðleifsson et al. 2017).

With the aim to prove the suitability of electromagnetic methods for monitoring processes occurring during reservoir engineering such pressure changes or induced seismicity, continuous magnetotelluric (MT) monitoring was carried out between December 2016 and July 2017 with a sampling frequency of 512 Hz at the GUN station, which is located about 1 km to the SE of the RN-15/IDDP-2. The station was 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. Single site processing using the "birrp" code (Chave and Thomson 2003) was applied in order to avoid eliminating sought-for high frequency signals induced during reservoir engineering. However, decimation to lower frequencies and appropriate notch filters were applied to increase the signal-to-noise ratio (Haaf und Schill 2019).

First results from the drilling period show significant decrease in electric resistivity at frequencies of 0.25 – 5 Hz occurring about 24-48 hours prior to "major" seismic events ($M_L > 1.0$ or frequencies > 10/d). Furthermore, decrease in electric resistivity in the frequency range of about 0.2 - 0.125 Hz correlates with time periods of large losses of circulation fluids. These insights are compared to the results from the long-term stimulation of the well between end of January to June 2017, when the well was stimulated under different low and high flow-rate condition.

1. INTRODUCTION

An increasing interest in magnetotelluric (MT) monitoring of hydraulic stimulation experiments results from soft stimulation techniques that reduce induced seismicity to a minimum. MT is a passive electromagnetic method that records the ambient electric and magnetic field. The relationship between both fields, transfer function, give information about the electric conductivity of the subsurface. An efficient tool used in reservoir monitoring engineering is to track directional evolution of the reservoir.

Long-term magnetotelluric monitoring of different low-volume and -pressure injection and production experiments at the Rittershoffen geothermal site in Alsace (France) provided a first continuous data set over several month, covering the end of drilling phase of GRT2 as well as production and injection into both wells GRT1 and 2 (Abdelfettah et al. 2018). Transfer functions showed operation dependent variation, i.e. variation in uncertainty, conductivity and phase with a preferential direction sub-parallel to S_{hmin}, i.e. perpendicular to the expected extension of the fractures controlling the reservoir. In particular fluid injection, either into GRT2 or GRT1 causes a strong decrease in resistivity by up to one order of magnitude in the YX component between about 8–25 s of period.

Similar long-term monitoring during the development of the RN-15/IDDP-2 well on the Reykjanes peninsular (Iceland) was carried out from November 2016 to January 2017. In this well, the H2020 project DEEPEGS (https://deepegs.eu) aims at demonstrating advanced engineering technologies. A deep Enhanced Geothermal System at Reykjanes aims injection of fluid underneath the conventional geothermal field to support production. The drilling from August 2016 until January 2017 was accompanied by partial and up to total circulation loss. Earlier MT exploration in the area reveals a typical resistivity structure of a high temperature geothermal system with a low resistive cap layer, here, with up to 2 km thickness. In the vicinity of the well vertical conductive structures hint to a dyke swarm or a sheeted dyke complex as heat source (Friðleifsson et al. 2014). Besides anthropogenic noise, the challenge of processing continuous MT monitoring data are the relatively high-frequency changes in the "perturbed" MT signal. Perturbation in the reservoir are caused during drilling by partial and up to total circulation loss and induced seismicity (Friðleifsson et al. 2017). Here, we present first results from the long-term stimulation phase after drilling.

2. STIMULATION OF IDDP-2/RN-15

After completion of drilling of the well RN-15/IDDP-2, the goal was to stimulate the deepest parts of the 4.5 km deep well. This could not be achieved by the first stage of stimulation during drilling due to circulation losses. Loss zones in the well prevented a deeper stimulation than 3.4 km (Sigurðsson 2018). The second stage of stimulation is shown in Figure 1 with a complete overview of the injection rates from February 2017 until August 2018. The green and the two blue lines correspond to the injection rates of the total amount of fluid in pipe and annulus and of different tested pumps, e.g. line or rig pumps, respectively. After June 2017, the injection rate gave the total amount of fluid in hole, pump and suction. Due to the lack of high flow-rates between Feb and April 2017, no higher rates than 10-20 L/s were achieved, rig pumps were installed and a weekly stimulation schedule started.

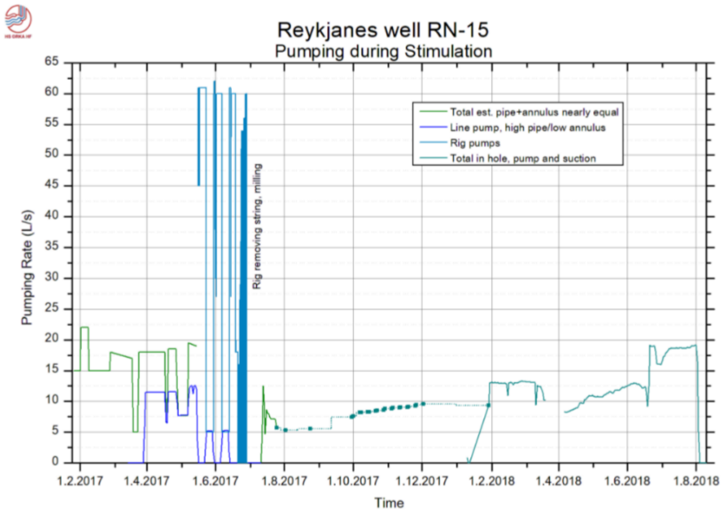

Figure 1 Pumping during stimulation of well IDDP-2/RN-15 (Sigurðsson 2018).

2.1 Rig pumps

A detailed schedule of the rig pumping is shown in Figure 2 from May 16 until June 30 2017. The rig pumps were in operation for 7 days pumping shifts and 7 days off for about 4 weeks. The injection was transferred to the rig pumps on May 16th so that about 15 L/s went to the string at about 82 bar standpipe pressure and about 45 L/s on the annulus, thus in total about 60 L/s. The injection rate is green colored, the kill line pressure in red and the standpipe pressure in blue. With the knowledge that most of the flow into the annulus was lost above 3400 m depth, there was a will to test fluid blockers in an attempt to get more cooling effect and higher-pressure head on the deeper part of the well. With an increase of up to 35 bar at kill line, the fluid blocker was assumed to work. The injection rates are steady while kill line pressure declined after the pumping week. The injection rate was taken slowly down after the pumping and it was observed that resistance in the string mainly caused the standpipe pressure. The injection to the annulus was transferred to HS Orka pump and adjusted to 5 L/s to keep the casing cool during the week off from the rig equipment.

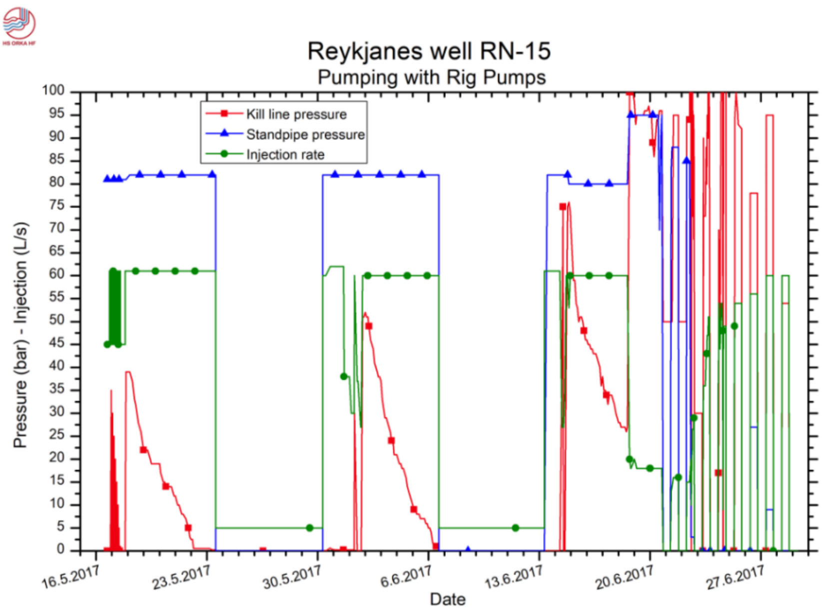

Figure 2: Rig pumps schedule with injection rate in green, kill line and standpipe pressure in red and blue, respectively, (Sigurðsson 2018) .

In total, three cycles of pumping and cooling were performed and two cycles of warming up the well. After removing the rig pumps and the drill string from the well bottom, the well was closed and cooled down. To protect the casing from overheating a small rate of 5-18 L/s was kept in the annulus as shown in Figure 1.

3. COMPARISON OF TRANSFER FUNCTIONS

Figure 3 shows transfer functions from the stimulation operations carried out by the rig pumps. The light blue curve is referred as reference curve. It was measured during the first field survey in Reykjanes over a period of 48 h from September 25th to 26th, 2016. The following operations were carried out at the drilling site during these two days. On September 25, the loss zones in the well were cemented down to 2950 m with mainly with flow rates of 15 and up to 30 L/s. At 3:10 p.m., a seismic event of magnitude 0.86 occurred in the reservoir zone. On September 26, drilling was performed from 2945-2950 m with flow rates up to 45 L/s. The red and the blue curves were measured during the first and third cycle of the rig pump stimulation, respectively and the blue curves was obtained during the warming up before the third cycle.

The figure is divided into two parts: the upper part for the E-polarization (XY) and the lower part for the B-polarization (YX). The first noticeable difference between XY and YX are the size of the uncertainties for YX. The XY error bars increase at a period of 0.6 s for all curves but the reference one. The highest error bars are measured during the stimulation with up to 60 L/s (red curve). This is also observable on a smaller scale for the YX results between 8-10 s. The second observation is the fluctuation in resistivity values for the XY curves during stimulation and warming up. In general, YX has very similar shapes for the transfer functions. Small differences are noticeable in the interval between 0.1-0.6 s. For XY the reference curve has in general higher resistivity values compared to the other XY curves besides the fluctuation between 5-60 s.

Due to single site processed data, the increase in error bars between 1-10 s is expectable with the fact that this is the time interval of the dead band. Consequently, the MT signal is weak in this period. However, in comparison to YX only the curve of the stimulation of the second cycle is slightly affected. The noticeable differences between XY and YX caused the idea of a direction dependent perturbation during the rig pumping.

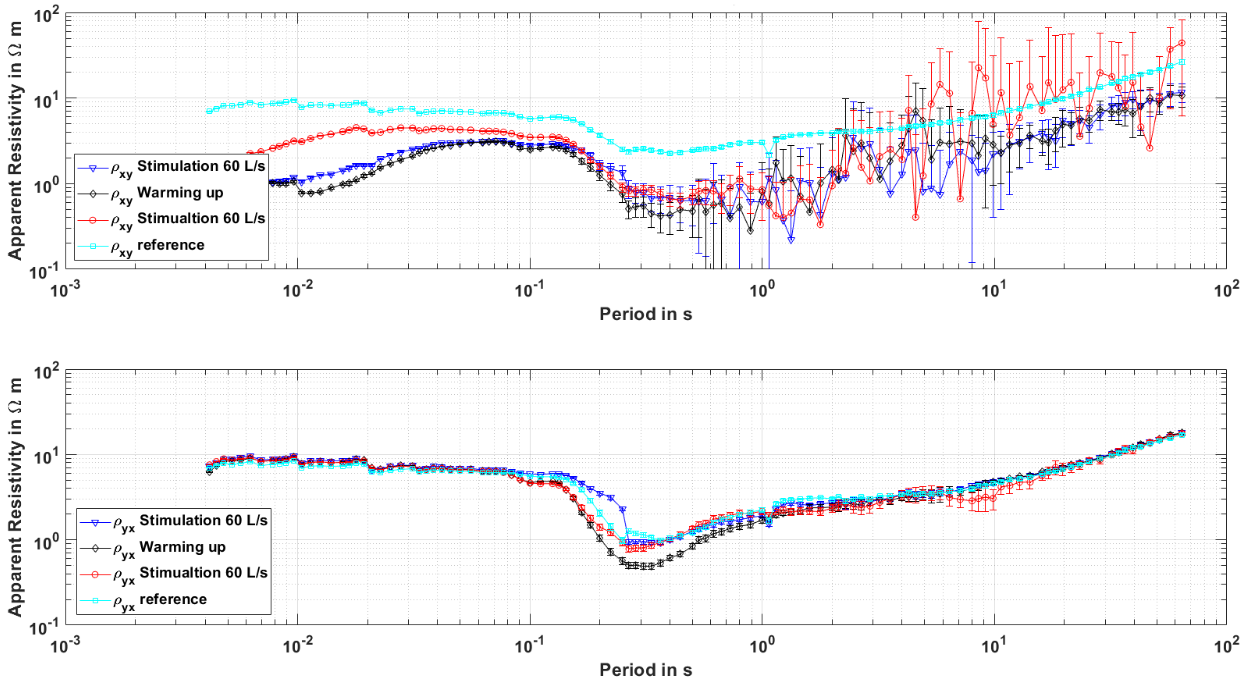

Figure 3: Transfer functions obtained during different operations as stimulation with 60 L/s in blue and red, warming up in black and the reference (baseline) in light blue. The upper part represents the XY- and the lower part the YX-components.

4. CONCLUSIONS

Long-term MT monitoring was carried out in Reykjanes at the drilling site of IDDP-2/RN-15. The stimulation during drilling could only affected the upper part of the well with the main loss zones. Therefore, several pumps were tested to increase the injection rates. Eventually a four weeks treatment with rig pumps achieved that goal. The use of fluid blockers to fill the lower loss zones was successful, so the lower part of the well below 3.4 km could be stimulated. Exemplary transfer functions obtained during the four weeks rig pumps schedule showed a certain pattern. Only one polarization seems to be affected by a direction dependent perturbation. One would assume an increase in uncertainties in the dead band (1-10 s) for single site processed data, but the increase in uncertainties is for longer periods (0.6-64 s) and only visible in the XY components.

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