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Approach to develop a soft stimulation concept to overcome formation damage – A case study at Klaipeda, Lithuania

Maren Brehme[a], Guido Blöcher[a], Simona Regenspurg[a], Harald Milsch[a], Sigitas Petrauskas[b], Robertas Valickas[b], Markus Wolfgramm[c], Ernst Huenges[a]

(a) Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany

(b) UAB GEOTERMA, Lypkių g. 17, LT-94100 Klaipėda, Lithuania

(c) Geothermie Neubrandenburg GmbH, Seestraße 7A, 17033 Neubrandenburg, Germany

brehme@gfz-potsdam.de

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ABSTRACT

Geothermal reservoir stimulation is a standard technique for enhancing naturally low permeable reservoirs or to overcome formation damage. Hydraulic, chemical or thermal stimulation are applied as standard procedures. Those are supposed to solve individual problems, which might lead to only short-term reservoir enhancement. Constraints in geothermal systems are often more complex and change with time. Therefore, we developed a Feedback Adjustment Procedure for sustainable soft stimulation concepts. The procedure starts with a multidisciplinary database and pre-evaluates potential scenarios. The most important step in the procedure is a re-evaluation loop after each treatment that ensures regularly updated knowledge on site-specific processes. The loop ensures an adapted stimulation concept ending in sustainable reservoir enhancement.

At our geothermal test site in Klaipeda (Lithuania) four wells target a highly permeable Lower Devonian sandstone reservoir at about 1 km depth with 39°C warm, highly saline fluid. The geothermal system delivers 41 MW_{th}. Since start of injection in 2001, rates constantly decrease in both injection wells. Several treatments have been used to enhance the injectivity. However, those applications have not yet resolved injectivity decrease.

Thus, we applied a new approach incorporating all relevant processes and adjusting the scenarios based on multidisciplinary observations. Most potential scenarios at the Klaipeda site are ranked based on a Feedback Adjustment Procedure. Most probably reasons for injectivity problems at the site are clogging of filter screen and/or pores by precipitation of minerals, by corrosion-particles, by biofilm, by injection of finest particles or pollution by drilling mud. In a next step, borehole logs, camera inspection and production and injection tests will be used to further rank scenarios. Specific stimulation treatments will be selected after re-evaluation for each scenario. Precipitations and biofilm will be removed and lifted by chemical-mechanical cleaning. Finest particles and corrosion material will be removed by long-term production tests. A mud cake will be hydraulically stimulated with frac-packs. Any new observation requires a re-evaluation and ordering of scenarios based on updated database. Therefore, the Feedback Adjustment Procedure will guarantee a sustainable overcome of formation damage.

1. INTRODUCTION

Geothermal systems are highly sensible environments that are controlled by different geological, hydrological, chemical and thermal boundary conditions. Due to this sensitivity, a small change in those boundary conditions can lead to a huge negative influence on productivity and sustainability of the geothermal systems, e.g., equipment losses or formation failures. Furthermore, geothermal systems might also be placed on unproductive fields, which do not pay off the invested infrastructures. Both cases require a reservoir treatment depending on the individual constraint.

Various techniques have been developed to ensure a productivity and sustainability of geothermal systems. Generally, reservoir treatment techniques are adapted from approaches that are widely used in the oil and gas industry. Those approaches can be classified mainly into hydraulic, chemical and thermal stimulations. Hydraulic stimulation aims at opening pre-existing fractures that are oriented in accordance with the local stress field (Veatch, 1983). Chemical stimulation acidifies and dissolves rock particles to enlarge fluid flow pathways (Kalfayan, 2008). Thermal stimulation expands the fractures cooling down the medium (Grant et al., 2013).

The described stimulation techniques are built on standard single problems predesigned for specific constraints. However, constraints in geothermal systems are often more complex and change with time. Therefore, we developed a Feedback Adjustment Procedure for stimulation treatments in geothermal reservoirs. Re-evaluation after each observation guarantees the best stimulation concept for each individual site.

The approach is currently applied within the DESTRESS-project (Demonstration of soft stimulation treatments of geothermal reservoirs) at our test site in western Lithuania. Soft stimulation aims to achieve enhanced reservoir performance while minimizing environmental impacts including induced seismicity. Soft stimulation includes cyclic/fatigue stimulation, multi-stage stimulation, chemical stimulation and thermal stimulation.

Out test site the Klaipeda Geothermal Demonstration Plant (KGDP) delivers 41 MW_{th} to the local heating system of the city (Fig. 1) (Zinevicius et al., 2003). It is running from October to March depending on seasonal heat demand. Four wells target a Lower Devonian sandstone reservoir at about 1 km depth. Sandstones have a high permeability of 6 Darcy and high porosity of 36 %, however, are interbedded with clay- and siltstones. A highly saline fluid is produced at 39°C.

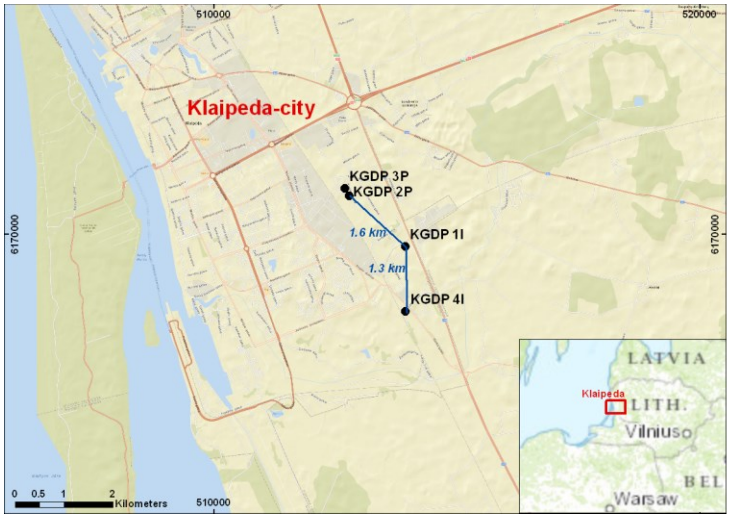

Figure 1: Location of the Klaipeda site

The injection rates in both injection wells decreased significantly since 2004 down to 1 $m^3/h/bar$ (Fig. 2). In the meanwhile, production rates from the same wells are 40 times higher than the injection rates. Several standard treatments have been conducted to enhance the reservoir performance. Effects resulted in short term increase of injectivity. However, no sustainable reservoir stimulation could have been achieved. This requires an adapted stimulation concept in order to overcome formation damage at the Klaipeda geothermal site.

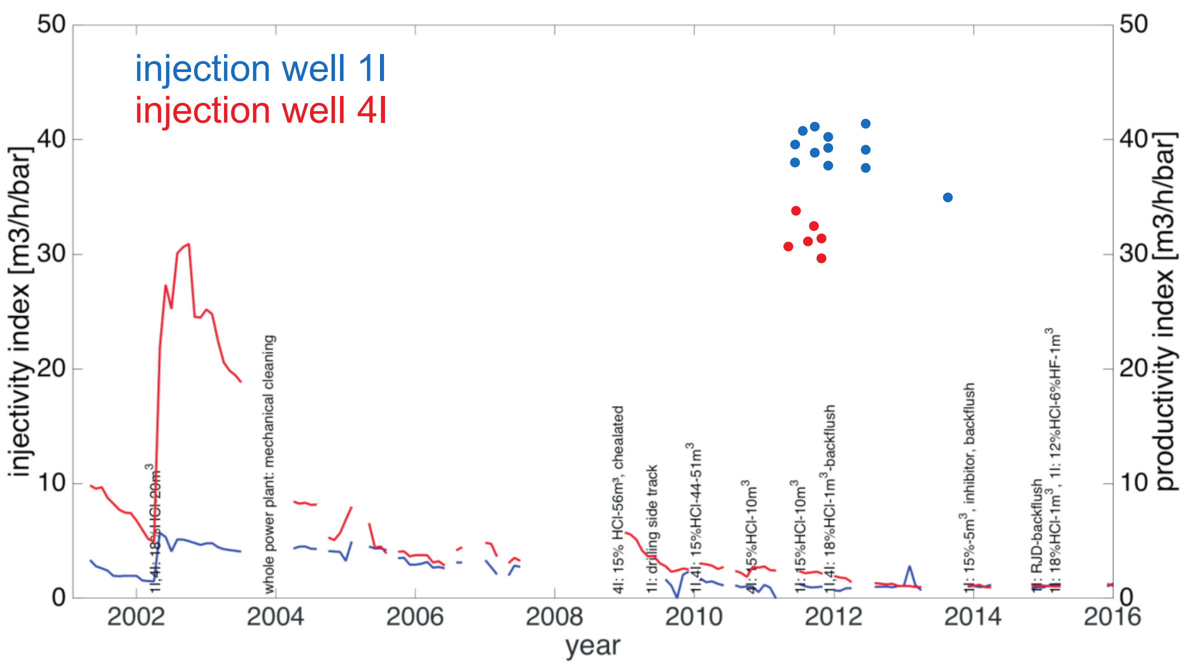

Figure 2: Operation data showing injectivity decrease over time in two injection wells (1I and 4I) including time and type of stimulation treatments, productivity from production tests in both injection wells (12h, 50 m^3/h)

2. FEEDBACK ADJUSTMENT PROCEDURE

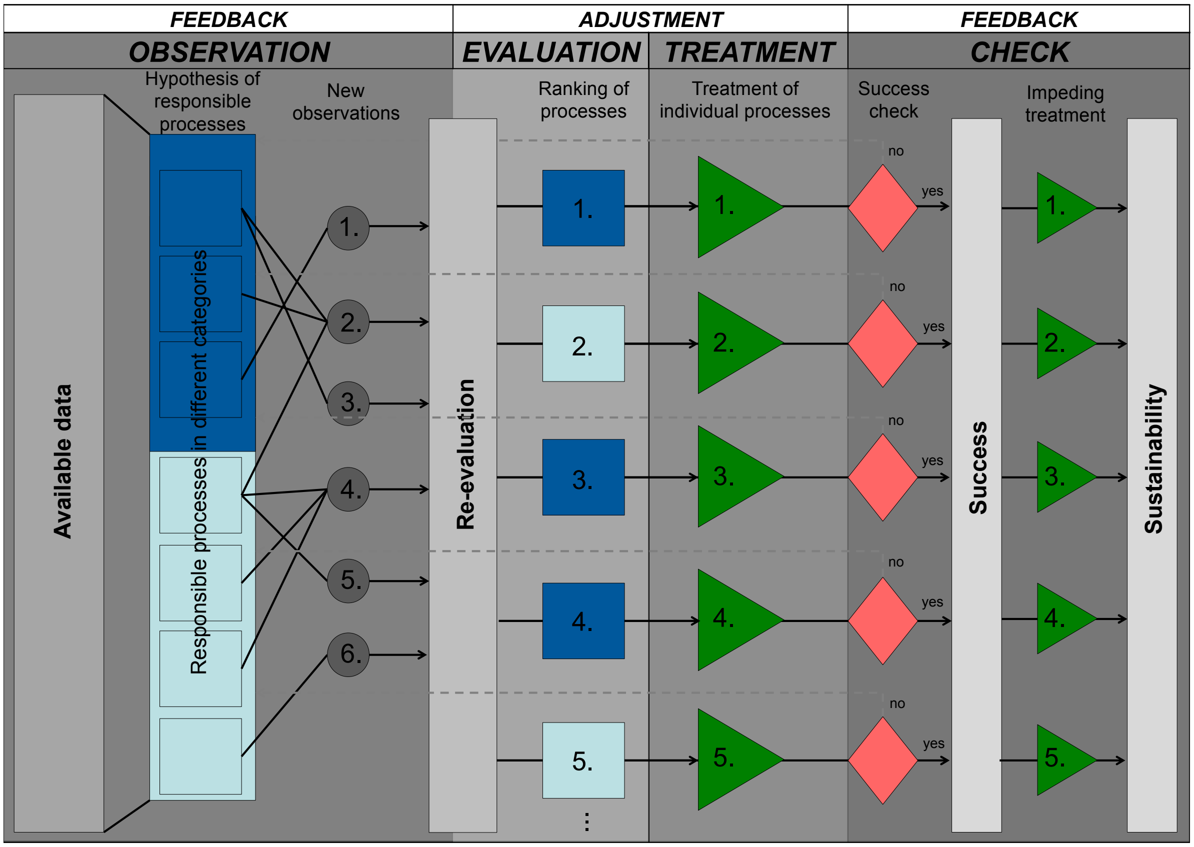

Figure 3: Feedback Adjustment Procedure for developing geothermal stimulation treatments

2.1 Observation

The first step of a Feedback Adjustment Procedure is to analyze all available data (Fig. 3). These include historical knowledge, measurements onsite and experiments determining geothermal properties of a specific site. Those are analyzed comprehensively in order to elaborate on processes leading to low reservoir performance. These processes are classified in different categories, e.g. location/case dependent.

The database for the Klaipeda geothermal site consists of long term injection and production rates, interpretation of well logs, observation of surface equipment of the power plant, chemical and microbiological content of water, gas composition, chemical, microbiological and hydraulic properties of reservoir rock, analysis of filter residual and size measurements of particles in fluids. Combination of all those information allowed having a broad view on the investigated reservoir to determine potential processes causing the injection problems.

Potential processes have been classified based on location of the flow barrier causing injection problems, i.e. far and near the wellbore. A potential reason for low injectivity in case of large distance to the wellbore is a pressure increase due to a limited or compartmentalized reservoir. In contrast, potential processes nearby the wellbore causing reduced fluid flow are clogging of filter screen and/or pores by precipitation of minerals, by corrosion-particles, by biofilm, by injection of finest particles or pollution by drilling mud.

In the Klaipeda reservoir the fluid barrier is assumed to be direction dependent due to the high difference between injectivity and productivity. The observed contrast may be explained by unidirectional flow obstruction in pores of ca. 10 µm and larger as indicated by a Carman-Kozeny-type (effective medium) permeability model. The same analysis applied to the dominant pore size fraction (3 to 40 µm) indicates a rock permeability of around 6 D. Thus, if no skin is effecting the reservoir the potential productivity would be ~60 m^3/h/bar. However, the low injectivity could be caused by clogging of pores by secondary minerals. Hydrochemical modeling shows oversaturation of several minerals at reservoir condition. Oversaturation even increases when acidifying with HCl. The pores could furthermore be blocked by finest particles. Their input is proven by gamma ray logs and particle size analysis in fluids.

In a second step, further observations are undertaken to prove existence of potential processes (Fig. 3). Ambiguous processes that might be provided by the same observation are further investigated in this step to overcome singularity. Here, observations are sorted according to order of accomplishment. This sorting highly depends on on-site technical and operational aspects.

At the Klaipeda site, borehole logs, camera inspection, bailer sampling as well as production and injection tests are needed to further investigate case ambiguity. Camera inspection is used to prove the existence of the clogging of filter screen and/or pores by precipitation, finest particles or biofilm. Bailer sampling is used to give information on type of precipitation and microbiological activity. Borehole logs are used to check long-term pressure increase, finest particle mobilization, existence of a mud cake and precipitation or corrosion inside the borehole. Finally, injection and production tests including flowmeter measurements are used to verify permeable sections of the reservoir and directional dependency of the flow barrier.

2.2 Evaluation

Any new observation requires a re-evaluation of processes based on an updated database. Remaining processes are ranked by their potential. The first process is most probable responsible for low reservoir performance.

At the Klaipeda site the most probable process is a direction dependent fluid barrier. Pores are free during production but blocked during injection. This effect is caused by clogging of pores by finest particles, precipitations and/or biofilm.

2.3 Treatment

In the next step several treatments will be applied according to the most potential processes. These treatments can be pre-designed and be finalized after further observations. This procedure allows short-term and precise adaption of the stimulation concept.

Pre-designed treatments for the Klaipeda site are chemical, mechanical and hydraulic stimulation. Combined chemical-mechanical cleaning with lifting at specific depths is expected to dissolve precipitations and biofilm in and near the wellbore. Long-term production tests are supposed to discharge finest particles and corrosion material. Sealing of clayey layers will, in a further step, avoid new input of finest particles. Near wellbore flow barriers which are not dissolvable could be hydraulically stimulated with frac-packs. General improvements at the power plant could be changes in the surface filtering system, use of bactericides, use of corrosion inhibitor or adaption of injection temperature.

2.4 Check

Each treatment is afterwards checked by new observations. Sustainable enhancement of a reservoir is achieved only if the treatment overcomes the formation damage. If the treatment was not successful, new observations are added as feedback to the database and all processes are re-evaluated.

For the Klaipeda site, post-treatment observations will potentially be borehole logs, camera inspection as well as production and injection tests. A sustainable reservoir enhancement will be achieved in the best case. Thus, camera inspection will show clean filter screens, borehole logs will indicate an increase of permeable reservoir thickness and injection and production rates will be increased to the same level. If one of treatments fails, the procedure starts with a re-evaluation of all potential processes.

After successful treatment of formation damage, impeding treatments will guarantee sustainability (Fig. 3). Impeding treatments are general changes in the geothermal cycle.

At the Klaipeda site, impeding treatments are i.e. sealing of clayey layers to avoid new input of finest particles. Changes in the surface filtering system will hinder injection of finest particles. The use of bactericides or corrosion inhibitor will stop microbiological or chemical processes. The adaption of injection temperature will prevent of mineral precipitation. In case of a compartmentalized reservoir, the sustainability can only be maintained by regularly relocating injection wells.

3. CONCLUSION

Stimulating geothermal reservoirs aims at enhancing reservoir performance. Treatments are used to increase formation permeability or to overcome formation damage. Hydraulic, chemical or thermal stimulation are applied as standard procedures. Those are supposed to solve individual problems, which might lead to only short-term reservoir enhancement. Here, we introduced a new procedure to ensure sustainable enhancement of geothermal reservoirs at the test site Klaipeda.

For the last 15 years, the Klaipeda geothermal site faces injectivity decrease. Several stimulation treatments have been applied to enhance the injectivity in two different injection wells. Mechanical cleaning, chemical dissolution of precipitation and radial-jet drilling have been used to overcome formation damage. However, those applications have not yet resolved injectivity decrease. Thus, we developed a flexible approach incorporating all relevant processes and adjusting the scenarios based on multidisciplinary observations.

Developed procedure, so-called Feedback Adjustment Procedure, provides sustainable soft stimulation concepts. The procedure starts with analyzing all available data and pre-evaluates potential processes. The most important step in the procedure is a re-evaluation loop after each treatment that ensures regularly updated knowledge on site-specific processes. The loop ensures an adapted stimulation concept which considers interaction of different processes ending in sustainable reservoir enhancement.

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