Initiation of discontinuities by thermal and hydraulic stimulation in the near-well area in well RN-15 (Reykjanes, DEEPEGS): A numerical investigation.

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1 Introduction

The DEEPEGS project aims at demonstrating the feasibility of enhanced geothermal systems (EGS) for delivering energy from renewable resources in Europe. Testing of stimulating technologies for EGS in deep wells in different geologies will deliver new innovative solutions and models for wider deployments of EGS. The first demonstrator currently being deployed is located in Reykjanes (Iceland). The drilling of RN-15/IDDP-2 has been successfully completed on January 2017. The final measured depth of the well is 4659 m (True Vertical Depth 4460 m). The temperature measured at depth under disturbed conditions was 426°C, which gives an order of magnitude of the high temperature reached. Short time injectivity index was estimated to be around 1.7 $L.s^{-1}.bar^{-1}$ at the end of the drilling operation. This confirms the necessity of stimulation methods to enhance the injectivity, as expected.

Well stimulation methods are based on the activation of hydraulic, mechanical, thermal and/or chemical mechanisms that enhance reservoir permeability either on pre-existing discontinuities or on newly created fractures. Thermal and hydraulic stimulations are favored for stimulation of the well RN-15/IDDP-2. Numerical simulations were carried out to investigate the possible initiation of discontinuities by thermal and hydraulic stimulation in the near-well area in the context of well RN-15.

2 Modeling approach

In order to model the initiation of stimulation cracks in the near-well area, it is proposed to use the Discrete Element Method (DEM), and more specifically bonded-particles model. It is indeed known that petrographic characteristics (including grain size, grain shape, packing density, packing proximity, degree of interlocking, type of contacts, amount and type of cement and/or matrix and mineralogical composition) affect mechanical properties. Besides, one of the causes of thermal damaging is the heterogeneity of grains rock contraction. Thus, simulations at the granular phase level (micro scale) with DEM seem adapted to capture the thermo-mechanical processes induced by rock cooling in the near-well area and to understand the impact on the mechanical behaviour at metric scale.

The code PFC2D (© Itasca Consulting Group) was used for the implementation of the DEM. PFC2D models the movement and interaction of stressed assemblies of rigid circular particles using the Distinct Element Method. The model is composed of distinct particles that represent mineral particles and that displace independently from one another. Particles interact at contacts or interfaces between them. From a thermal viewpoint, heat can be stored in particles and circulates by conduction between particles through thermal pipes when particles are in contact. The macroscopic behaviour depends on the particles properties (e.g. stiffness, thermal expansion coefficient, specific heat) and contacts properties (e.g. tensile strength, cohesion, thermal conductivity).

3 Model description

The objective is to build a realistic model, corresponding to the beginning of thermal stimulation at Reykanes in well RN-15 (IDDP-2). We assume that a cold fluid (30°C) is injected in the well in a diabase of the Reykjanes field. The injection takes place at a depth of 4600 m, where the rock temperature is around 430°C and the pressure in the well is 34 MPa. Since the rock mass is considered impermeable (except for fractures), the main heat transfer process considered is conduction. We study the initiation of the failure in the rock mass in the near-well area in a 2D plan perpendicular to the well.

The elaboration of the numerical rock model is a preliminary essential task. Based on the rock description (pyroxene 40 %, plagioclase 55 %, titomagnetite 5%, grain size around 3 mm), an analogue rock with available macroscopic properties was identified. Several calibrations were necessary to obtain numerical macroscopic properties that fit quite well the analogues properties. The PFC model size is 1.05 m×1.05 m, integrating more than 141 500 particles, and is embedded within a 5.25 m×5.25 m continuous model to avoid the influence of boundary conditions. The near-well model is run in three main steps: the mechanical effects of drilling are modelled by removing the particles located on the well surface, then the hydraulic pressure is applied and finally the thermal loading is applied.

Considering the high level of uncertainties and the limited number of possible simulations (linked to the high computation time), it was decided to focus the parametric study on a limited number of parameters, considered as ill-known:

- the stress state (a pure strike-slip regime, 2 pure extensional regimes and a transtensional tectonic regime),
- the hydraulic pressure (between 0 and 94 MPa) in the well,
- the heat transfer coefficient (1,000 W/m²/K and 10,000 W/m²/K).

4 Results overview

Figure 1 illustrates the kind of results that will be further analysed during the presentation: cracks and possible associated fractures are recorded depending on time, as well as the temperature field. Simulations highlight fracture initiation or well breakout, if any.

During the drilling phase, for the case studies investigated, little to no borehole breakouts is observed (only the more critical case with strike-slip regime drives to the apparition of a slight breakout in the direction of the minimum stress).

Regarding the impact of hydraulic pressure, we observed no significant impact on the fracture development while the pressure remains below the minimum stress. A tensile fracture starts to propagate perpendicular to the minimum stress direction when the pressure in the well becomes close to the minimum stress. The propagation of the fracture above this value is becoming increasingly important as the pressure in the well increases.

Thermal stimulation also drives to initiation of discontinuities. The cracks propagation speed and the cracks repartition are strongly influenced by the cooling rate: a slow cooling drives to slower propagation of fractures, and allows the focusing of the crack within a single fracture, while very fast cooling creates several tortuous fractures. The stress state has also a direct impact on the intensity, kinetics and shape of damages. With high deviatoric stress the fracture propagates in the direction of the maximum stress while in the more isotropic cases, fractures develop around the well without preferential direction.

5 Acknowledgement

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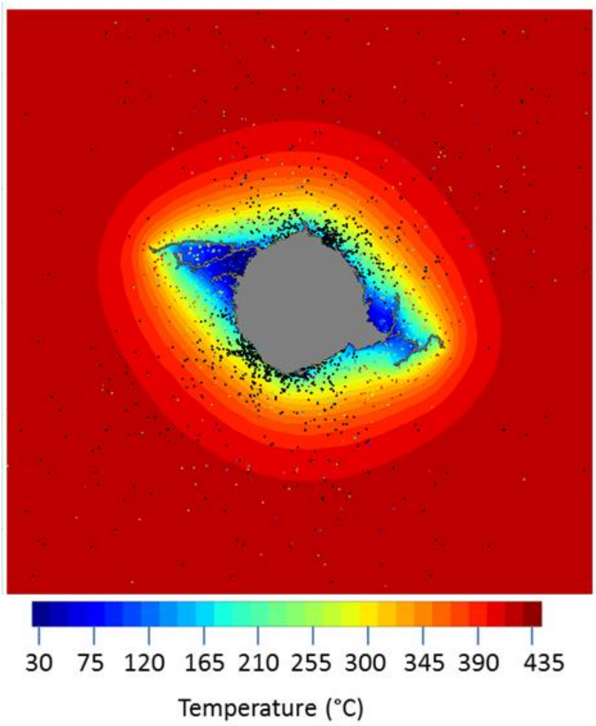

Figure 1 – Overview of a simulation result: view of temperature field with cracks represented by points (for the strike-slip stress state, with a well pressure of 34 MPa and a slow cooling rate, after 2 hours of thermal stimulation). A fracture propagates in the direction of maximal stress. Cracks accumulation in the direction of the minimum stress reveal slight break-out.