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Geochemistry

Developing the ability to model acid-rock interactions and mineral dissolution during the RMA stimulation test performed at the Soultz-sous-Forêts EGS site, France

Développement des capacités de modélisation des interactions acides-roche et des dissolutions de minéraux au cours des tests de stimulation acide de type RMA réalisés sur le site SGS de Soultz-sous-Forêts (France)

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ABSTRACT

The Soultz Enhanced Geothermal System (EGS) reservoir's response to chemical stimulation is assessed by numerical simulation of coupled thermo-hydraulic-chemical processes. To assess chemical interactions between host rocks and a mixture of HCl and HF as well as its potential effects on the Soultz EGS reservoir, new modelling efforts using the FRACHEM code have been initiated. This article presents the model calibration and results. Simulations consider realistic conditions with available data sets from the EGS system at Soultz. Results indicate that the predicted amount of fracture sealing minerals dissolved by injection of a mixture of acids Regular Mud Acid (RMA) was consistent with the estimated amount from the test performed on GPK4 well at Soultz EGS site. Consequently reservoir porosity and permeability can be enhanced especially near the injection well by acidizing treatment.

RÉSUMÉ

L'impact de la stimulation chimique sur le réservoir du Système Géothermal Stimulé (SGS) de Soultz est évalué par simulation numérique des processus couplés thermo-hydraulique-chimique. Les modélisations 2-D simplifiées du réservoir ont pour but d'interpréter et de prévoir les interactions acides-roche dans le granite fracturé du système géothermal stimulé de Soultz-sous-Forêts. Pour évaluer les interactions chimiques entre la roche hôte et un mélange de HCl et HF, ainsi que les effets potentiels du traitement chimique sur le réservoir SGS de Soultz, une nouvelle calibration du code FRACHEM a été intégrée. Les résultats de la simulation indiquent que la quantité prévue de minéraux

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dissous par injection d'un mélange d'acides *Regular Mud Acid* (RMA) est comparable au montant estimé lors du test de stimulation chimique du puits GPK4 sur le site SGS de Soultz. Par conséquent, la porosité et la perméabilité du réservoir peuvent être améliorées près du puits d'injection par la stimulation chimique.

1. Introduction

The Soultz-sous-Forêts Enhanced Geothermal System (EGS), established in the Rhine Graben, north of Strasbourg (France), has been investigated since 1986. Three wells (GPK3 as a central injection well and GPK2 and GPK4 as production wells) were drilled to 5000 m depth in the crystalline basement to build the EGS system. The shallow geology (0 to 1400 m depth) consists of sedimentary layers, overlying the crystalline basement of Late Paleozoic granites containing hydrothermally altered and fractured zones related to graben normal faults (Genter, 1990; Traineau et al., 1991). It has been observed that deep fluid circulation is supported by the network of permeable fractures. Extensive research has been made to characterize the properties of the fractures. Geophysical borehole measurements including borehole image logs, coring and cuttings analysis showed that nearly-vertical fractures, which show a low permeability, are oriented in an almost north-south direction (Dezayes et al., 1995,2005; Genter et al., 1995). Moreover, it appears that most of the fractures are sealed by hydrothermal deposits, mainly calcite, silica and clays, giving a random distribution to the overall permeability of the system.

The development of EGS depends on the creation of permeable and connected fractures. The Soultz wells have been stimulated hydraulically and chemically in order to develop the underground reservoir (Gérard et al., 2006). The first hydraulic stimulations of the three wells were carried out between 2000 and 2005, and resulted in an improvement of the productivity index of wells GPK2 and GPK4 by a factor of approximately 20 and of GPK3 by a factor of approximately 1.5 (Nami et al., 2007). Although the limited performance of hydraulic stimulation, with high costs and public concern about induced seismic events, provided an important set of reasons for undertaking chemical treatments as additional or even alternative method to hydraulic stimulation, the main argument for chemical stimulation was the evidence, based on drill cuttings and cores analysis as well as on geophysical logs, of fracture filling by carbonates and other soluble minerals.

Removal of secondary mineral filling natural or induced fractures from granitic formation in the near-wellbore vicinity can be accomplished by injecting strong acids (such as HCl and mixtures of HCl-HF). Acid treatments have been successfully applied in many cases to increase or to recover geothermal wells production rates to commercial levels (Entingh, 1999). In order to dissolve the hydrothermal deposits (like carbonates, clay, feldspars and micas) present in the main fracture and porosity zones of the Soultz granite to improve their permeability, Regular Mud Acid (RMA), a mixture of HCl and HF widely used in oil and gas wells, was injected in GPK4 well.

FRACHEM, a thermo-hydraulic-chemical coupled code, was developed especially to forecast the evolution of the EGS project at Soultz-sous-Forêts. FRACHEM can simulate thermal, hydraulic and fluid-rock interactions within the fractures connecting the injection and the production wells, and determine the dissolution/precipitation reactions of carbonates, pyrite and silicated minerals in the Soultz granite (André et al., 2006; Bächler, 2003; Durst, 2002; Portier et al., 2007). The FRACHEM code has been improved to simulate the propagation of reacting fluids and to gain insight into the effectiveness of the acidizing treatment as a well stimulation technique. The RMA stimulation method has been applied by numerical modelling to the Soultz EGS system, to investigate its impact and effectiveness.

In this article, we first present the results of RMA injection performed at Soultz-sous-Forêts. Then we discuss the principle of minerals dissolution using RMA solution, and the calibration of a dissolution model using the FRACHEM code. Finally, we present simulation results of this stimulation method to assess chemical interactions between host rocks and a mixture of HCl and HF as well as its potential effects on the Soultz EGS reservoir. Simulation considers realistic conditions with available data sets from the EGS system at Soultz.

2. Field test: stimulation of GPK4 with Regular Mud Acid

Hydrofluoric acid (HF) is the only common acid that dissolves clay, feldspar and quartz fines. For years, mixtures of HF and HCl (RMA treatment) have been the standard acidizing treatment to dissolve these minerals that cause damage (Kalfayan, 2001). In sandstone acidizing treatments, a preflush of HCl varying between 7.5 to 15% is usually injected ahead of the HCl/HF mixture to dissolve the carbonate minerals and avoid precipitation of calcium fluoride (CaF_2). The minimum volume is determined by assuming that the HCl-carbonate reaction is very fast so that the HCl reaction front is sharp.

RMA was injected from the wellhead through the casing string in GPK4 well. The stimulation zones were therefore the whole openhole section of the well (500 to 650 m length). In May 2006, the RMA treatment was carried out in four steps with addition of a corrosion inhibitor when needed. Before the injection of RMA, 2000 m^3 of cold deoxygenated water were introduced in the well at 12 L/s, then at 22 L/s, and finally at 28 L/s. Later, to avoid CaF_2 precipitation that can lead to well damage, a preflush of 25 m^3 of a 15% solution of HCl in deoxygenated water (3.75 tons of HCl) was pumped ahead of the HCl-HF acid mixture for 15 minutes at 22 L/s. A main flush consisting of a total of 200 m^3 of 12/3 (wt%) RMA was then injected at a flow rate of 22 L/s for 2.5 hours. Finally, a postflush of 2000 m^3 of cold deoxygenated water, at a flow rate of 22 L/