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THC simulation of halite scaling in deep geothermal single well production

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ABSTRACT

Using abandoned wells from oil and gas industry or dry holes, geothermal single well applications enable the prevention of drilling costs and prospecting risks which are crucial inhibitions in geothermal development.

Recently, deep geothermal single wells were numerically investigated for their thermal and hydraulic performance. For the first time, we now include the chemistry of the produced brine in a fully coupled THC model for studies of scaling formation. As a case study, the 2011 circulation test of the GeneSys well Gt1 Groß-Buchholz (Hanover, Germany) was modeled successfully using the fully coupled THC code TOUGHREACT. High salinity requires application of the Pitzer ion interaction model which was verified for this particular chemical system using literature data.

Modeled wellhead temperature is in very good accordance with measurements. Also simulated depth of scaling formation and total scaling volume fit to onsite observations. Evaluation of initial reservoir brine composition reveals its large impact on the range of depth where scaling occurs. Furthermore, it is shown that the presence of $CaCl_2$ reduces halite solubility considerably and favors scaling formation.

Results show that our modeling concept is capable of quantifying the complex coupled THC processes in single wells.

1. Introduction

Geothermal power and heat production are considered to play an important role (Sawin, 2012) for the future energy mix, with an annual worldwide electricity generation of 1′400 TWh and 1′600 TWh of thermal energy production being predicted (Beerepoot, 2011). Although still facing scientific and technical challenges, its highly flexible controllability and capability of meeting baseload demands make geothermal energy assume an outstanding position among the renewables.

Doublet and multi-well configurations are classical approaches to exploiting geothermal energy. They are applied at numerous geothermal fields and in a broad range of different geological settings all over the world. The aim of these concepts is to establish a subsurface heat exchanger. A geothermal fluid is produced and after heat withdrawal, it is reinjected into the reservoir via a second well. Continuous fluid circulation requires a highly permeable reservoir to ensure flow from the injection well to the production well. The reservoir development therefore is a critical factor for the success and profitability of an EGS project. It is necessary to target preexisting structures and to enhance their permeability by hydraulic and chemical stimulation.

Recently, a number of studies investigated a more unconventional approach, where a single borehole is applied for fluid production as well as for reinjection. Commonly, a coaxial borehole heat exchanger is used by circulating a working fluid in a closed loop in the borehole (Franco and Vaccaro, 2013; Kohl et al., 2000, 2002). Authors also suggested open systems, where the fluid is circulated in the host rock (Jung et al., 2005; Orzol et al., 2005; Wang et al., 2009). Typically, fluid is produced in a coaxial configuration by a deep-reaching inner pipe and reinjection is achieved via the annulus ending at more shallow depth. This concept entails several advantages. As there is no need to target a highly permeable formation or structure, exploration risks are eliminated. The technology also allows for the use of already existing deep boreholes like abandoned oil and gas wells. Hence, no high-risk initial investment is needed for drilling and well completion.

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The GeneSys project in Hanover, Germany, was planned to demonstrate the exploitation of geothermal energy from hydraulically tight sediments by operating such a single well (Jung et al., 2005; Orzol et al., 2005). A previously performed feasibility study in the nearby well of Horstberg Z1 which has a very similar stratigraphy (Jung et al., 2005) demonstrated the creation of a reservoir in low-permeable sedimentary rock by performing a massive water frac as well as heat production of such one-well systems (Tischner et al., 2010).

The project has been suspended after the failure of the production test of Gt1 Groß-Buchholz, when large amounts of halite scalings precipitated and formed a massive salt plug which clogged the well completely.

Scaling is a common and widespread challenge known from numerous deep geothermal projects. There is a large diversity of minerals forming scaling. Most common groups are carbonates (Ståhl et al., 2000; Bjørnstad and Stamatakis, 2006), silica (Gunnarson and Arnorsson, 2003), sulfates (Schröder et al., 2007; Nitschke et al., 2014), and sulfides (Schmidt et al., 2000; Holl et al., 2003). Scalings can substantially affect geothermal exploitation by reducing heat transfer and by physically clogging pipe systems. They have to be removed regularly, resulting in additional operation costs and downtimes of the plant.

In oil and gas industry, also halite scalings occur. Deep high-temperature/high-pressure wells are particularly vulnerable (Frigo et al., 2000; Kleinitz et al., 2003). Heat withdrawal is considered to be the controlling mechanism for halite scaling formation, as halite solubility is primarily governed by fluid temperature (Guan et al., 2008; Wylde and Slayer, 2010). The usually large quantities of formed halite scalings often result in a complete clogging of the well or surface installations (Guan et al., 2008; Crabtree et al., 1999; Wylde and Slayer, 2010).

The aim of this study is to numerically investigate and quantify the thermo-hydraulic-chemical (THC) processes of geothermal single well operation. Therefore, the production test of well Gt1 Groß-Buchholz which led to the formation of the halite plug and subsequent failure and suspension of the GeneSys project was investigated as a case study. To model the complex interaction of temperature, flow, permeability and precipitation/dissolution, the THC code TOUGHREACT-Pitzer was used. It provides fully coupled simulation of those processes and is suitable for the application in highly saline systems.

2. The GeneSys single well project

GeneSys was planned as a pilot project to demonstrate geothermal production of a single well. The plant should cover the heat demand of the BGR (Federal Institute for Geosciences and Natural Resources) buildings in Hanover. The strategy pursued was to produce geothermal fluid from a large-volume frac in the Buntsandstein, which had been created by a massive hydraulic stimulation, using a coaxial pipe configuration. It was intended to establish a cyclic operation state, consisting of alternating injection and production phases, the so-called huff-puff scheme (Tischner et al., 2010). According to the concept, freshwater was to be injected into the fracture via the production string. After heating up, the fluid would have been reproduced via the same string and reinjected through the annulus into the shallower and more permeable Wealden formation. Then, a new cycle would be started with repeated injection of freshwater into the reservoir.

Gt1 Groß-Buchholz was drilled to a depth of 3901 m near the BGR buildings in 2009. Local stratigraphy reflects the horizontal sedimentary sequence of the North German Basin (Orzol et al., 2005). The Triassic units are covered by Jurassic, Cretaceous and Quaternary sediments. A simplified scheme of the geology and the well completion is shown in Fig. 1.

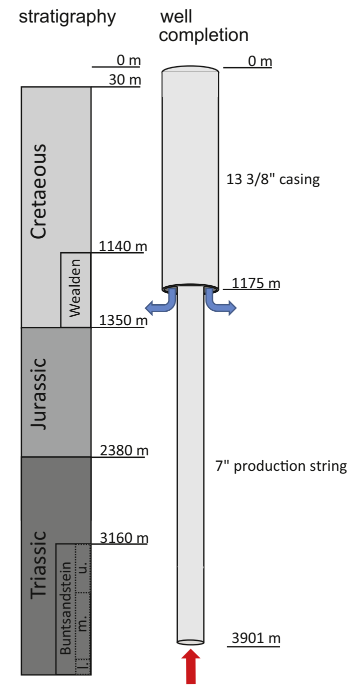

Fig. 1. Scheme of well completion and simplified stratigraphy. Arrows indicate fluid flow during production.

For coaxial well completion, a 7" casing as inner production string was set extending to bottomhole depth. From the surface down to 1175 m depth, it is enclosed by a 13 3/8" casing. The annulus between both strings acts as the reinjection string. The well reaches into low-permeable layers of the Buntsandstein formation (<1 mDarcy) with a bottomhole temperature of about 170 °C. The injection horizon is the hydraulically conductive Wealden Sandstone (Lower Cretaceous), where the annulus ends. Reservoir development took place in May 2011, when 20 000 m^3 of freshwater were injected to create a massive frac in the Buntsandstein. The reservoir obtained is assumed to extend over a fracture area of approximately 1 km^2.

After the creation of the reservoir in May 2011, pressure was shut in. The injected fluid remained in the reservoir for 6 months. A production test was performed from Nov. 10 to Nov. 17, 2011 (T111110), producing a total volume of 577 m^3. Due to the high positive differential pressure, generated during injection, the regain of fluid took place by artesian outflow. The production test was carried out in three major cycles which were interrupted by downtimes (Fig. 2). Once the borehole volume had been produced, salinity of the fluid increased sharply. The Na-Ca-Cl brine had a minimum TDS value of 452 g/kg_w, with 5.3 mol/kg_w Na^+ and 7.8 mol/kg_w Cl^- representing the major chemical components. When injectivity of the Wealden Sandstone decreased significantly during the 3rd cycle, production rate was reduced in a stepwise manner (Fig. 2) to prevent the maximum permissible injection pressure of 188 bar at depth from being exceeded. Finally, with continuously decreasing injectivity, production had to be stopped. The annulus was flushed with freshwater to remove potential precipitations and increase accessibility to the Wealden formation. After flushing, any attempt to resume production failed. A massive salt plug had formed in the production string. It consisted predominantly of NaCl. Other compounds like KCl, $CaCl_2$, and $(BaSr)SO_4$ were present in trace amounts only. The plug clogged the well completely and extended from 655 m to 1350 m depth. Technical details concerning the Gt1