The Application of THC Code TOUGHREACT-Pitzer on Failure Conditions of Geothermal Project GeneSys

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Introduction

The GeneSys project aimed to demonstrate the feasibility of utilizing geothermal energy from deep-seated tight sediments to supply the buildings of the BGR in Hanover with heating energy. The idea was to establish a coaxial single borehole system, where the geothermal fluid is produced from the inner string and injected via the annulus of the same well.

Therefore in 2009 Groß-Buchholz Gt1 was drilled down to 3901 m yielding a downhole temperature of 170 °C. To supply the heat demand of the buildings 2 MW of geothermal heat extraction were planned.

For the development of a reservoir in the virtually impermeable sediments of the Middle Buntsandstein in May 2011 a frac was created by injecting 20 000 m^3 of fresh water. The created frac is assumed to extend over a fracture area of 1 km^2 (TISCHNER et al. 2013).

After about 6 month of shut in period a circulation test was carried out. Fluid was produced during three major cycles from the Buntsandstein reservoir and was then reinjected without heat extraction into the permeable more shallow Wealden Sandstone in 1175 m of depth.

Immediately after exchanging the production string volume, the brine salinity strongly increased up to an oversaturated state with respect to halite for the achieved production temperatures (HESSHAUS et al. 2013). Halite started to precipitate in the surface installation as well as in the wellbore. As a result injectivity into the Wealden formation has strongly decreased during the 3rd cycle, whereupon production was stopped. The annulus was flushed with freshwater in order to dissolve the precipitations. Thereafter it was not possible to resume production. In the production string a massive salt plug has been formed between 655 m and 1350 m depth (HESSHAUS et al. 2013). This plug completely clogged the well. Production was no longer possible and operations had to be stopped until further notice.

This study focuses on the numerical modelling of the conditions within the well leading to the salt plug. The goal is to build up a coupled chemical reactive transport model of the well Groß-Buchholz Gt1.

Methods

For the numerical calculation TOUGHREACT-Pitzer V2 (ZHANG et al. 2006) was used. The code enables to model chemical reactive non-isothermal multiphase transport. To handle the strongly elevated salinities of the brine (halite saturation for 170 °C brine temperature is almost 7.6 mol/kg_w) the classical ion dissociation theory is invalid.

The application of the Pitzer ion interaction model is necessary. The Pitzer extension for TOUGHREACT uses the Harvie-Moller-Weare formulation (HARVIE et al. 1984), to calculate ion and water activities, which is equivalent to the original Pitzer formalism (PITZER 1973) but more comfortable in its handling for numerical modelling. Ion interaction parameters were taken from WOLERY et al. (2004).

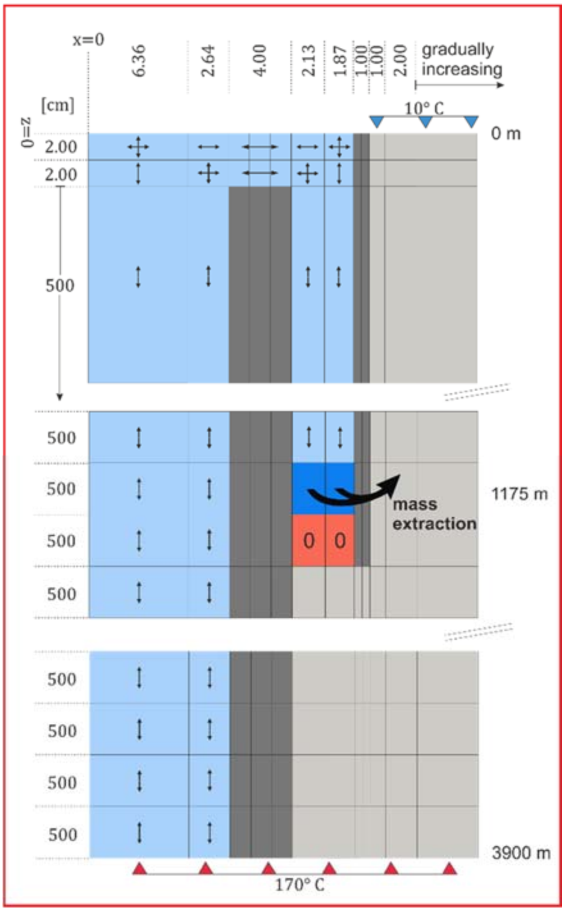

Fig. 1: Meshing concept and boundary conditions. Arrows indicating the assigned permeabilities. (blue: flow path (pipe strings), dark grey: pipe walls, red: barrier cells (permeability = 0), light grey: rock)

Precipitation and dissolution reactions were considered to be fully equilibrium controlled. Kinetic effects were ignored.

For the spatial discretization of the borehole geometry a radial symmetrical mesh was applied (Fig. 1). It has a total of 13260 elements, assembled by 780 elements in z-direction and 17 elements in x-direction.

The dimensions of this particular problem intrinsically effects strongly elongated mesh elements with ∂z = 5 m. Only both uppermost layers, which represent the horizontal deflection from the production string to the injection string are smaller (∂z = 0.02 m), for not affecting flow velocity. The x-direction is discretized much finer. In the inner parts, i.e. the wellbore strings, the pipe walls and the immediate adjacent rock, the aspect length of the element is in the range of a few centimeters. It increases with increasing distance to the well. The outermost element has an aspect length of ∂x = 6.5 m.

Initial temperature conditions were set by applying a linear gradient from 10 °C at the surface to 170 °C downhole temperature in a pre-run where Dirichlet-type boundaries were assigned in the uppermost and the bottommost cells. As halite solubility is predominantly controlled by temperature (DUAN & LI 2008), the simplification of ignoring any pressure effects on chemistry was applied. Therefore initial pressure conditions were isobaric within the entire model.

For the actual simulation, the bottommost cells remain Dirichlet-type as well as the cells at the surface except for the elements representing the horizontal part of the pipe. They were changed to ordinary cells.

The production of fluid is achieved by setting Neumann-type boundaries at the end of the injection string (annulus) where mass is extracted. Therefore hydraulics are controlled by the flow rate.

Results and Discussion

The cyclic production test in 2011 was modelled applying the measured flow rates (Fig. 2). Fluid temperature was measured at

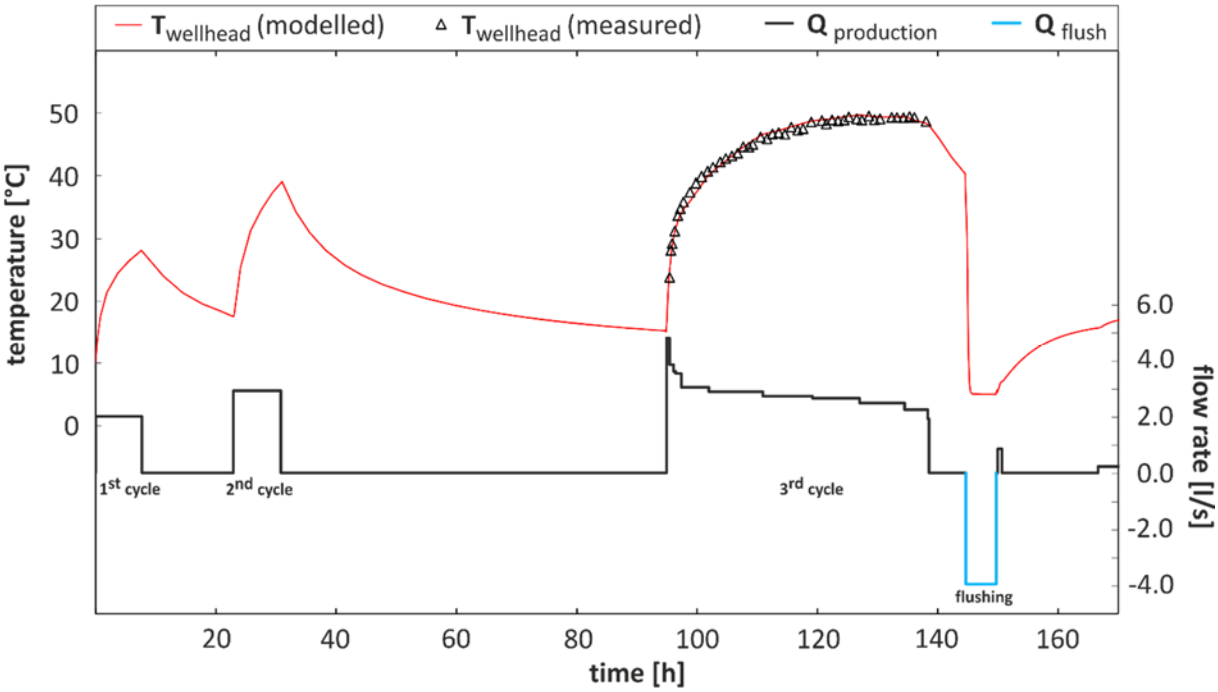

Fig. 2: Temperature evolution at wellhead for the entire production test. Open triangles represent measured temperature values, which were used to calibrate the model.

surface. This data (from 3rd production cycle) was used to calibrate the model (Fig. 2).

Due to rather low flow rates during the production test temperatures not exceed 50 °C at wellhead but staying far below for most of the time. Temperature evolution was modelled in very good agreement to measured data during the test.

As halite account for more than 95 % of the precipitated solids (TISCHNER et al. 2013) chemical calculations were firstly reduced to the system Na-Cl-H_2O. Figure 3 displays the volumetric abundance of precipitated halite in depth within the production string in dependence of the initial NaCl concentration. It is found that an initial concentration of 6.8 mol/kg_w NaCl results in a salt plug which shows in terms of its location best accordance to the plug on-site. This applies for the depth at which fluid reaches saturation and precipitation starts as well as for the depth at which the amount of precipitated solids is highest.

Modelled halite abundance clearly displays the important role the contrary flow concept plays.

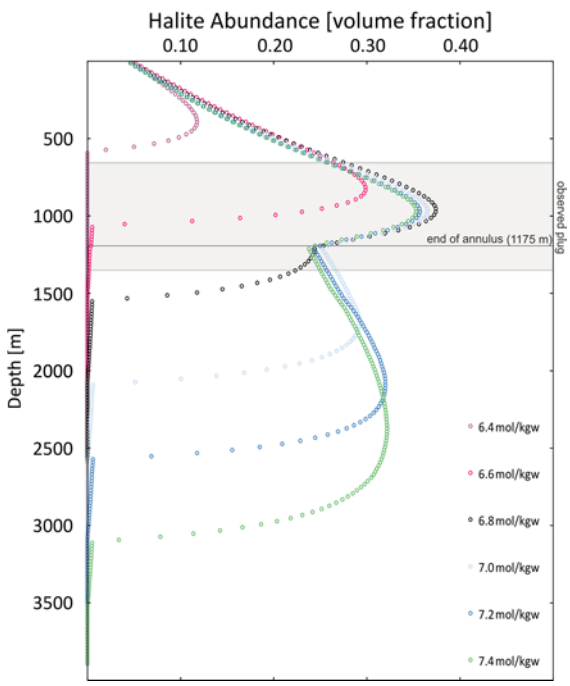

Fig. 3: Modelled precipitated halite abundance (volume fraction) depending on initial brine salinity. Grey area indicates depth were salt plug was observed, black line marks 1175 m depth, where the annulus ends.

Salt amounts immediately increase when the upstreaming fluid reaches the opposed fluid stream, as a result of the intensified cooling.

It is shown that for equilibrium controlled modelling, like it is performed here, the maximum volume fraction being precipitated does not exceed 0.40. Therefore a steeper temperature gradient, i.e. a more abrupt cooling, would be necessary. Also by increasing the initial NaCl concentration of the brine at least 60 vol.-% of the respective pipe element remain unclogged. A concentration increase only results in a shift of the location where precipitation starts towards greater depth.

Solids were formed also above 655 m of depth. Here the precipitated amount is independent from initial brine concentration. Precipitation amounts per element are just representing the thermal gradient within the borehole, which is controlled by the flow rate. The missing precipitated salt above 655 m on-site, where the model differ from observation, may be due to the possible sinking of further above formed solids in a stagnant water column, which cannot be modelled.

The borehole volume for the 695 m where the salt plug has been observed corresponds to a volume of nearly 17 m^3. The modelled total precipitated salt volume is about 12 m^3 for an initial concentration of 6.8 mol/kg_w NaCl. As it is reported that the salt plug on-site showed interruptions (HESSHAUS et al. 2013), mass balance considerations indicate a rather good agreement of real world processes and the applied model.

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