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High resolution numerical modelling of high temperature heat storage in geological media

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Increasing use of energy stemming from renewable sources, such as wind or solar power plants, requires development of new and improvement of existing energy storage options on different time scales. One potential storage option is high temperature heat storage with temperatures of up to 100°C in the geological subsurface using borehole heat exchanger (BHE). Numerical scenario simulations are performed to assess feasibility and storage capacity and, furthermore, to predict the effects induced. To allow for accurate and reliable results, the BHE must be represented correctly and realistic in the numerical model. Therefore, a detailed model of a single BHE and the surrounding aquifer, accounting for the full geometry and component parametrisation (circulating working fluid, pipe and grout), is set up. This model setup is used to simulate an experimental data set from a laboratory sandbox by Beier et al. (2011), containing an 18 m long single U-tube BHE centered horizontally along it. Temperature curves observed in different radial distances as well as at the pipe outflow can be matched well with the model setup used, which is thus verified.

Potential geological formations for high temperature heat storage are located in greater depths below fresh water aquifers that are used for drinking water. Therefore, the above model is adapted to represent a 100 m long vertical double U-tube BHE placed in an average depth of 500 m. The processes of heat transport and groundwater flow are coupled by water density and viscosity, which both depend on pressure and temperature. A sensitivity study is done to quantify the effects of the thermal parameters of grout and aquifer on the amount of heat stored and the temperature distribution in the aquifer. It was found that the amount of heat stored through the BHE is most sensitive to the heat conductivity of the aquifer. Increasing the aquifer heat conductivity by 50 % increases the amount of heat stored in the numerical model by 30 %. In contrast, only 3 % more heat can be stored in the system when increasing the grout thermal conductivity by 50 %. Temperature distribution in the aquifer is most sensitive to the thermal conductivity of the grout, resulting in higher temperatures when increasing the grout thermal conductivity. Increasing the aquifer thermal conductivity leads to higher temperatures at first and lower temperatures after a longer time period. Grout heat capacity, however, neither influences the amount of heat stored nor the temperature inside the aquifer.

Occurrence and magnitude of the induced convection in the sand aquifer that surrounds the BHE depends on the given permeability as well as temperature gradients and therefore density differences in the model area. Increasing the vertical permeability from k=5×10-13 m2 to k=5×10-11 m2 results in induced convection with lower temperatures in the aquifer and a doubling of the amount of heat stored.

Reference:

R.A. Beier, M.D. Smith and J.D. Spitler. Reference data set for vertical borehole ground heat exchanger models and thermal response test analysis. Geothermics, 40, 79-85, (2011).