EGU21-9823
https://doi.org/10.5194/egusphere-egu21-9823
EGU General Assembly 2021

A High Temperature Heat Injection Test – Numerical Modelling and Sensitivity Analysis

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With the transition of the heating sector towards renewable energy sources technologies are needed to compensate for the seasonal mismatch between heat supply and demand. Aquifer thermal energy storage (ATES) is considered a promising candidate for that purpose. Especially high temperature ATES (HT-ATES) with temperatures up to 90 °C has the advantage of higher storage capacities and allows for the direct use of the stored heat without intermediate heat pumps. In order to improve the understanding of processes induced by HT-ATES and to validate numerical tools for the prediction of storage capacities, storage rates as well as thermal impacts, a heat injection field test with an injection temperature of 75 °C was conducted, densely monitored and numerically simulated. This work presents a sensitivity analysis of the governing processes and parameters, from which the parameters on which the simulation results are most dependent are derived and thus identified for future site characterization and monitoring studies.

The heat injection test took place at a shallow aquifer with a low natural groundwater flow velocity of 0.07 m/d. Hot water was injected at a borehole using flow rates of 14 l/min for 4.5 days and the resulting thermal plume was monitored by a dense arrangement of thermocouples. Previous to the experiment, the field site was thoroughly investigated for the thermal and hydraulic parameters by standard hydrogeological methods, such as pumping tests, hydraulic head measurements, Hydraulic Profiling Tool (HTP) employment, liner sampling and laboratory measurements. A coupled heat transport and fluid flow model was set up and the heat injection test was simulated using high resolution numerical modelling of the coupled thermo-hydraulic processes using the OpenGeoSys (OGS) simulation code.

The comparison of measured and simulated temperature breakthrough curves showed a good correspondence, indicating the capability of the model to predict the general thermal behaviour of the heat injection test. The accuracy was higher for larger distances to the injection well and at the longer time scale, while the largest deviations occurred close to the injection well and shortly after the injection. The model was then used to estimate the sensitivity of the simulated temperature distribution on thermal and hydraulic aquifer parameters, which were varied according to the span of measurements. The thermal plume development is most sensitive on the hydraulic conductivity, since this parameter influences the intensity of buoyancy driven flow and was measured in the large range 3.00E-05 to 7.15 E-04 m/s. The dispersivity and the anisotropy in hydraulic conductivity effect the same process and show a significant impact on the result as well, together with the thermal conductivity. The sensitivity of the simulated temperature distribution on the groundwater flow velocity and the specific heat capacity is a little lower compared to the previously mentioned parameters, while the result is insensitive to the specific storage. It is shown, that a heat injection test in combination with numerical simulations is suitable for identifying parameter sensitivities also on small scales, thus showing the investigation needs for HT-ATES projects.