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Cyclic high temperature heat storage using borehole heat exchangers

Anke Boockmeyer, Jens-Olaf Delfs, and Sebastian Bauer

Christian-Albrechts-University Kiel, Institute of Geosciences, Kiel, Germany (sebastian.bauer@gpi.uni-kiel.de)

The transition of the German energy supply towards mainly renewable energy sources like wind or solar power, termed “Energiewende”, makes energy storage a requirement in order to compensate their fluctuating production and to ensure a reliable energy and power supply. One option is to store heat in the subsurface using borehole heat exchangers (BHEs). Efficiency of thermal storage is increasing with increasing temperatures, as heat at high temperatures is more easily injected and extracted than at temperatures at ambient levels. This work aims at quantifying achievable storage capacities, storage cycle times, injection and extraction rates as well as thermal and hydraulic effects induced in the subsurface for a BHE storage site in the shallow subsurface.

To achieve these aims, simulation of these highly dynamic storage sites is performed. A detailed, high-resolution numerical simulation model was developed, that accounts for all BHE components in geometrical detail and incorporates the governing processes. This model was verified using high quality experimental data and is shown to achieve accurate simulation results with excellent fit to the available experimental data, but also leads to large computational times due to the large numerical meshes required for discretizing the highly transient effects. An approximate numerical model for each type of BHE (single U, double U and coaxial) that reduces the number of elements and the simulation time significantly was therefore developed for use in larger scale simulations. The approximate numerical model still includes all BHE components and represents the temporal and spatial temperature distribution with a deviation of less than 2% from the fully discretized model. Simulation times are reduced by a factor of $\sim$10 for single U-tube BHEs, $\sim$20 for double U-tube BHEs and $\sim$150 for coaxial BHEs.

This model is then used to investigate achievable storage capacity, injection and extraction rates as well as induced effects for varying storage cycle times, operating conditions and storage set-ups. A sensitivity analysis shows that storage efficiency strongly depends on the number of BHEs composing the storage site and the cycle time. Using a half-yearly cycle of heat injection and extraction with the maximum possible rates shows that the fraction of recovered heat increases with the number of storage cycles used, as initial losses due to heat conduction become smaller. Also, overall recovery rates of 70 to 80% are possible in the set-ups investigated. Temperature distribution in the geological heat storage site is most sensitive to the thermal conductivity of both borehole grouting and storage formation, while storage efficiency is dominated by the thermal conductivity of the storage formation. For the large cycle times of 6 months each used, heat capacity is less sensitive than the heat conductivity.

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