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Numerical simulation of cyclic high temperature borehole thermal energy storage systems: Methodology and first applications

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Full utilization of the potential of renewable energies (wind, solar) and industrial waste heat as heat sources requires the storage of large amounts of fluctuating heat in urban areas. The geological subsurface offers large potential storage capacities, which can be used under various geological site conditions, as e.g. clay or sand formations, by installing Borehole Thermal Energy Storage (BTES) systems. These consist of an array of ground-coupled heat exchangers, through which heat is stored in and extracted from a geological formation by heat conduction only.

This talk presents a methodology for the numerical simulation of BTES systems to enable their design, construction and the prediction of potential environmental impacts using an open-source software framework (OpenGeoSys). Due to the high temperatures used and the strong temporal fluctuations, as well as the interference between different borehole heat exchangers and the spatially varying geological conditions, analytical solutions cannot be used to describe these systems with high accuracy. Because heat exchange is governed by conduction, the thermal gradients at the heat-exchangers have to be reproduced with very high spatial and temporal resolution. In order to achieve this within reasonable run time, a methodology has been established where simplified, but for our purpose equivalent geometric (cubic, concentric) representations of single heat exchangers are identified. A representative heat exchanger is then individually simulated and the result up-scaled to a complete BTES system. A BTES system can then be simulated in high resolution by using high performance computing methods. Simulation results of the single heat exchangers as obtained with a very detailed real geometry and the equivalent geometries are compared with each other and show, that the simplified models yield close approximations of the real systems to within a few percent.

The methodology is presented using a feasibility study for the computational center of the University of Kiel, which plans to use seasonal geological heat storage with a highly temporally varying heat source and demand to operate the cooling of the computational center and the heating of an adjacent office building. The simulations consider the local geological conditions and the real heat load curve and present a possible design for a BTES storage system.