Modeling the Thermal Interference Between Closed Large-Scale Heat Storage Facilities and Groundwater

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Ground-Based Thermal Energy Storage

Large-scale thermal energy storage can be a key technology within the transformation of heating and cooling markets. It is commonly accomplished by installation of large-scale pits or tanks, or geothermal applications that store sensible heat [1]. The focus for planning and managing the application of storages is commonly set on the internal conditions. For example, understanding the short- and long-term behavior of thermal, hydraulic and static conditions within the storage is key for its optimal design and control. Little attention thus far has been set on the interference of storages with the ambient environment. This is relevant in particular for large-scale basins that are installed in the ground and act as permanent heat source for the soil and groundwater. Obviously, the operational temperatures and insulation of the storage are major determinants for the ambient thermal conditions. Insulation, however, is a major cost factor and thus heat losses may be considered acceptable to some extent. This is especially the case when excess heat for storage is available during the loading phase such as by solar thermal energy harvesting in summer.

Challenges in Modeling Closed, In-Ground Thermal Energy Storages

The purpose of our work is the development of a simulation framework that can depict the operational behavior of thermal energy storage systems in their embedded environment. We are interested in particular in the environmental effects that evolve over long timeframes and that may be of environmental concern, e.g., by artificial warming of groundwater bodies. The storage variant studied is a water-gravel filled basin, installed in the subsurface. A major challenge for the simulation is the thermal coupling between the artificial and dynamic storage system on the one side, and the ambient natural soil and groundwater regime on the other. The conditions in both elements follow seasonal trends, but these differ greatly with respect to short-term thermal and hydraulic variabilities and magnitudes.

Coupled Simulation Procedure

In the study, the development of a new numerical modeling tool to simulate the operational behavior of artificial thermal energy storage systems is demonstrated, including their interaction with groundwater flow dynamics. These involve asymmetric boundary conditions, subsurface heterogeneity and transient thermal conditions in the storage device as well as in the ambient ground.

By using a co-simulation approach of a previously developed Simulink/Simscape (MATLAB) model [2] and the COMSOL development environment, the different hydrogeological and thermal processes are implemented in a tailored software configuration. The underlying concept and structure of the model is introduced, including the implemented processes and boundary conditions. Subsequently, a scenario analysis is presented, demonstrating the versatility and robustness of the tool. Different influencing hydrogeological parameters (e.g., porosity, thermal storage capacity, thermal conductivity) on thermal conditions in the ambient ground (Fig. 1), storage behavior, and storage system efficiency (i.e., thermal losses, utilization rates) are identified and evaluated. The presented co-simulation tool allows for improvement of planning processes in the field of ground-based thermal energy storage.

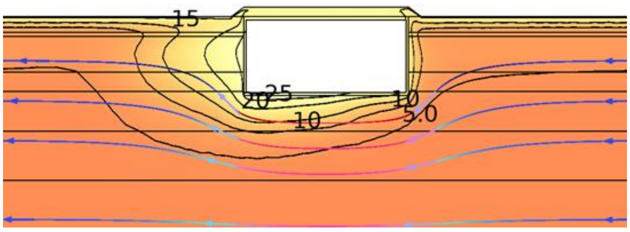

Fig. 1: Heat dissipation plume of a thermal energy storage in a groundwater regime.

References

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