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Experimental and numerical investigation of a scalable modular geothermal heat storage system

Johannes Nordbeck, Sebastian Bauer, and Christof Beyer
CAU Kiel, Germany (johannes.nordbeck@gpi.uni-kiel.de)

Storage of heat will play a significant role in the transition towards a reliable and renewable power supply, as it offers a way to store energy from fluctuating and weather dependent energy sources like solar or wind power and thus better meet consumer demands.

The focus of this study is the simulation-based design of a heat storage system, featuring a scalable and modular setup that can be integrated with new as well as existing buildings. For this, the system can be either installed in a cellar or directly in the ground. Heat supply is by solar collectors, and heat storage is intended at temperatures up to about 90°C, which requires a verification of the methods used for numerical simulation of such systems. One module of the heat storage system consists of a helical heat exchanger in a fully water saturated, high porosity cement matrix, which represents the heat storage medium. A lab-scale storage prototype of 1 m^3 volume was set up in a thermally insulated cylinder equipped with temperature and moisture sensors as well as flux meters and temperature sensors at the inlet and outlet pipes in order to experimentally analyze the performance of the storage system. Furthermore, the experimental data was used to validate an accurate and spatially detailed high-resolution 3D numerical model of heat and fluid flow, which was developed for system design optimization with respect to storage efficiency and environmental impacts.

Three experiments conducted so far are reported and analyzed in this work. The first experiment, consisting of cooling of the fully loaded heat storage by heat loss across the insulation, is designed to determine the heat loss and the insulation parameters, i.e. heat conductivity and heat capacity of the insulation, via inverse modelling of the cooling period. The average cooling rate experimentally found is 1.2 °C per day. The second experiment consisted of six days of thermal loading up to a storage temperature of 60°C followed by four days of heat extraction. The experiment was performed for the determination of heat losses during a complete thermal loading and extraction cycle. The storage could be charged with 54 kWh of heat energy during thermal loading. 36 kWh could be regained during the extraction period, which translates to a heat loss of 33% during the 10 days of operation. Heat exchanger fluid flow rates and supply temperature were measured during the experiment and used as input for the 3D finite element model. Numerically simulated temperature distribution in the storage, return temperature and heat balances were compared to the measured data and showed that the 3D model accurately reflects the storage behavior. Also the third experiment, consisting of six days of cyclic operation after five days of continuous thermal loading, a good agreement between observed and modelled heat storage behavior is found. In addition to determining the storage performance during cyclic operation, the experiment will also be used to further validate the numerical model.

This abstract will present the laboratory setup as well as the experimental data obtained from the experiment. It will also present the modelling approach chosen for the numerical representation of the experiment and give a comparison between measured and modelled temperatures and heat balances for the modular heat storage system.