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Experimental investigation of thermal interactions in high-temperature borehole thermal energy storage using cyclic heat loads

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High temperature and short-term subsurface heat storage using BTES is a promising option and emerging technology for increasing the fraction of renewable energy in the heat sector and supplying stored heat at high and directly usable temperatures. For this, investigation of thermal interactions of multiple BHEs employed for high-temperature cyclic storage operations is required to understand the system behavior and the relevant thermal processes involved. This work therefore presents highly controlled meso-scale experiments for high temperature borehole thermal energy storage.

The experiment is set up at Kiel University, using a sand pit with two meters depth and a volume of 30 m³ filled with partially saturated fine sand. Five BHEs are constructed, with four positioned at the edges of a square of 0.7 m side length and the fifth one in the center. Temperatures were measured at 224 locations at varying distances and depths to the center BHE. For the tests, inflow temperatures of the BHEs were set to mimic a high temperature storage system for both stationary and cyclic heat loads by using 70°C and 10-15°C inflow temperature for heating and cooling cycles, respectively. Cycles ranged from 12 to 120 hours.

Thermal characteristics of the boreholes and the sand medium have been determined using constant temperature Thermal Response Tests for the individual boreholes, yielding an average thermal conductivity of about 1.8 W/m/K and typical heat injection/extraction rates of 0.2 kW per meter of BHE length. Subsequently, all BHEs were jointly operated using the same inflow temperatures, in order to determine their thermal interactions in a storage operation. Thermal interaction due to the simultaneous operation of the other BHEs reduced the heat transfer rate by about 30% after 12 hours of continuous heating in the center BHE, while for the outer BHEs the heat transfer rate was reduced by approximately 24%. After about three days of continuous heating, heat transfer rates have stabilized at about 60% in the outer and 40% in the center BHE. Based on these values, a thermal recovery factor of 55% is obtained. For the cyclic heat storage experiments, similar utilization ratios were found, although average heat transfer rates for the individual BHEs increase with decreasing cycle time. Furthermore, although heat transfer rates are lower in the joint operation of the BHEs, temperatures in the sand are actually higher. Temperatures in the sand at 0.2 m from the center BHE increase from 30°C for individual BHE operation to 57 °C in the joint operation, thus providing higher storage temperatures.