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Assessment of short-term aquifer thermal energy storage for demand-side management perspectives

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In the last decades, aquifer thermal energy storage (ATES) has been proven to be a reliable renewable energy source. Yet, most of the ATES running systems are designed for seasonal or monthly storage and recovery applications. In the context of demand-side management, we have investigated the ability of such systems to perform short-term thermostatically-controlled load-shifting (storing thermal energy during off-peak periods and recovering it during peak periods) directly in aquifers at real-time, intraday, and interday frequencies. In this study, we mainly focused on the assessment of energy recovery rates for single low- and high-temperature ATES cycles at these typical frequencies.

An aquifer thermal energy storage and recovery experiment was first set up and performed in a shallow alluvial aquifer in Wallonia, Belgium, and monitored through hydrogeological measurements and 4D electrical resistivity tomography. The investigated site is typical of Walloon alluvial aquifers, as being productive and presenting slow ambient groundwater flow (∼12 m/year). Moreover, such alluvial aquifers are the main target for open-loop geothermal systems in Wallonia, Belgium. With this experiment, we have shown that short-term ATES (here, after a 72 hours storage phase) should be considered for DSM applications since up to 90 % of the stored thermal energy could be recovered.

A three-dimensional groundwater flow numerical model was then conceptualised and calibrated under variably saturated conditions, with coupled heat transport processes, in FEFLOW. With this predictive model, 77 simulations of single low- and high-temperature ATES cycles were performed to assess the applicability of short-term DSM applications at low or high temperatures. Simulated low-temperature ATES ($-4 < \Delta T < 11$ K) has 78 to 87 % energy recovery rates, while high-temperature ATES ($\Delta T > 35$ K) has lower energy recovery rates (53 to 71 %) (ΔT being the difference in temperature between initial and injected water). Energy recovery rates decrease with increasing storage duration, this decrease being faster for high-temperature compared to low-temperature ATES. Recovering the absolute injected temperature is barely feasible with a single cycle since exergy lowers quickly. However, the thermal equilibrium and exchange processes between groundwater and the porous medium matrix run over multiple cycles is an optimisation lead. Our study shows that preheating (or precooling) the alluvial aquifer could significantly increase the coefficient of performance of ATES systems, allowing for example to store heat during off-peak periods and to recover it during peak periods. The direct use of heated water without the need of a groundwater heat pump (high exergy) is not possible with a single ATES cycle and further developments are needed to optimise the system at higher temperatures.