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Physics-based numerical evaluation of High-Temperature Aquifer Thermal Energy Storage (HT-ATES) in the Upper Jurassic reservoir of the German Molasse Basin

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Concepts of High-Temperature Aquifer Thermal Energy Storage (HT-ATES) (> 50 °C) are investigated for system application in the Upper Jurassic reservoir (Malm aquifer) of the German Molasse Basin (North Alpine Foreland Basin). The karstified and fractured carbonate rocks exhibit favorable conditions for conventional geothermal exploitation of the hydrothermal resource. Here, to further assess the sustainability of HT-ATES development in the Upper Jurassic reservoir, a physics-based numerical analysis is performed. With an estimated heating capacity of ca. 21 MW over half a year, our approach aims at determining numerically the efficiency of heat storage under the in-situ Upper Jurassic reservoir conditions and locally feasible operation parameters.

The numerical models build upon datasets from three operating geothermal sites at depths of ca. 2000-3000 m TVD located in a subset of the reservoir which is dominated by karst-controlled fluid fluxes. Commonly considered as a single homogeneous unit, the 500 m thick reservoir is subdivided into three discrete layers based on field tests and borehole logs from the three considered sites. This introduced vertical heterogeneity with associated layer-specific enhanced permeabilities allows to examine potentially arising favorable heat transfer, and in combination with the facilitated high operation flow rates to evaluate thermal recoveries in the multilayered reservoir.

Computation results reveal that the reservoir layering induces preferential fluid and heat migration primarily into the high-permeability zone, while thermal front propagation into the lower permeable rock matrix is restricted. The simulations further display the gradual temperature increase in the warm wellbore and its surrounding host rock, and the consequent progressive improvement in the heat recovery efficiencies. Despite the elevated permeability that may trigger advective heat losses, heat recovery factor values range from ca. 0.7 over the first year of operation to over 0.85 after 10 years of operation. An additional scenario is examined with fluid injection solely in the high permeable zone, in order to quantify potential improvement in the recovery efficiency by omitting fluid injection in the lower-permeability layers where heat propagation is diminished. This is due to the geometrical shape of the thermally perturbed rock volume as heat losses occur at the interface between thermal front and adjacent reservoir rock. Consequently, conclusions on the performance of the two different system designs under this

layered reservoir setting are derived. All simulations account for density and viscosity variation through the IAPWS (International Association for the Properties of Water and Steam) thermodynamic property formulations. Results show that density-induced buoyant fluxes which would considerably decrease thermal efficiencies are inhibited, and thus the prevailing heat transport mechanism is forced convection.