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Heat storage in a fractured limestone aquifer: Experimental protocol's proposal based on field experiments and numerical simulations

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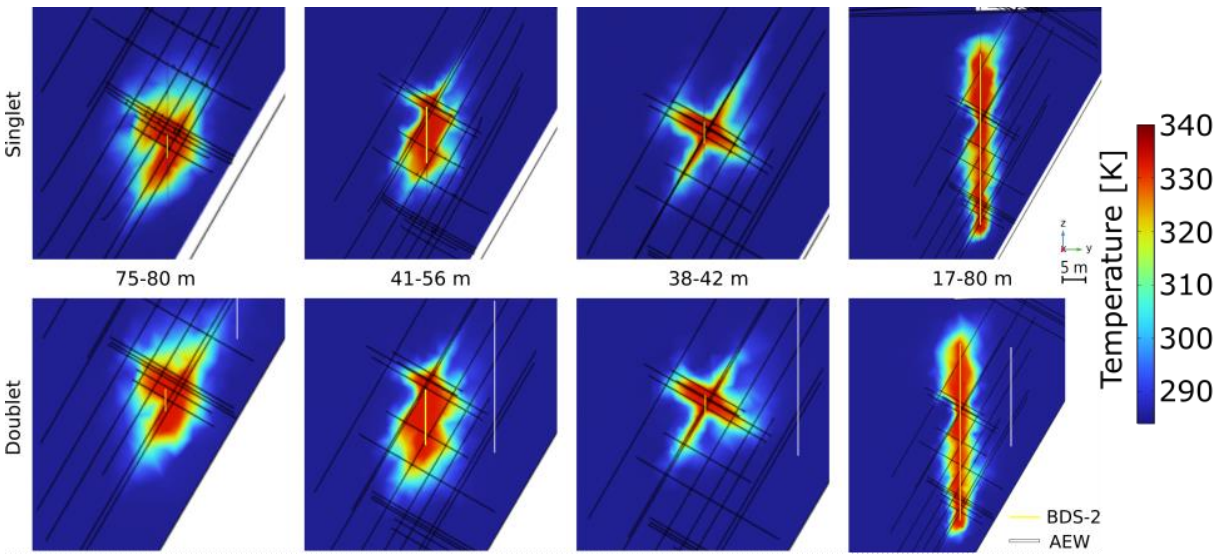
As new forms of energy production emerge to reduce fossil fuel usage, needs for heat storage solutions becomes crucial to address potential temporal mismatches between energy's demand and production. Underground Thermal Energy Storage (UTES), when properly designed, enables storage of substantial heat quantities with minimal impact on landscape, groundwater, and human activities. This study's scope is to develop an **experimental protocol for an Aquifer Thermal Energy Storage** (ATES) experiment in a **fractured limestone formation at Mt. Terri** International Rock Laboratory. The underground laboratory settings offer privileged access to the experimental volume and various measuring instruments already installed. However, the presence of tunnels drains the aquifer and modify the natural hydrogeological conditions. It is thus essential to assess and quantify the **impact of the tunnels on the experimental volume**. This was achieved through a comprehensive literature review, an in-situ well logging campaign, field experiments and numerical simulations.

A "double porosity model" (Nelson, 2001) is used to conceptualize hydraulic and heat flows in this heterogeneous environment. This approach is complemented by characterizing the rocks forming the matrix (literature review, well logging campaign, and outcrop analysis) and characterizing the fractures' network (ABI and OBI log's description and statistical analysis of fracture data). A "Discrete Fractured Matrix" (Berre et al., 2019), involving explicit representation of the fractured domain and accounting for host rock's properties, has been developed for creating a numerical model using COMSOL Multiphysics software. In-situ drainage flow measurements have been used to calibrate the numerical aquifer's representation, particularly for determining host rock's and fractures' hydraulic permeability values. Noble gas injection and more conventional tracer injection experiment involving Uranine have been conducted in order to gain knowledge on the HF aquifer's response to water injection and improve numerical model's calibration.

In order to propose an experimental protocol for ATES experiment, heat transfer physics was introduced in HF's numerical representation. This allowed understanding and observe **advective and diffusive processes**, matrix/fracture exchanges, and tunnels' drainage effect on hot water injection. The modeling results emphasize the importance of using a down dip doublet configuration to isolate the experimental volume and enhance matrix heating. Furthermore, it reveals the necessity of isolating the active well's segment from the tunnel's drainage effect using packers. Additionally, this tool facilitated characterization of the most suitable parameters (temperature, timing, etc.) for a successful experiment.

Based on the insights gained from the different parts of this study, a detailed ATES experiment protocol was proposed. A second well's location for doublet configuration has been identified to enable advection and diffusion processes' observation while

minimizing energy losses. Timing, temperature and injected flow parameters have been identified to propose an experiment that will allow observation and analysis of the hot water injection's impact on natural groundwater thermal and hydraulic dynamics. Using distributed detection equipment, such as optic fiber temperature sensor, will enable detailed monitoring of the well and aquifer responses to the experiment. This proposal takes advantage of Mt. Terri rock laboratory study site to advance knowledge on ATES technology in the Dogger fractured limestone aquifers.



Different experimental scenarios using BDS-2 well for singlet injection compared to doublet set-up using a second well (ATES Experimental Well, AEW). In order to observe fractures' and tunnel's drainage effect on advection and diffusion dynamics, different well depth have been activated. Temperature distribution at the end of the injection phase are plotted with a color scale.