Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.31020

Investigating the effects of high-temperature thermal energy storage on aquifer biogeochemistry

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High-temperature aquifer thermal energy storage (HT-ATES) is a key technology for reducing greenhouse gas emissions related to space heating and cooling by storing seasonal energy in the subsurface. However, such process could significantly affect aquifers geochemistry and microbial communities. Elevated temperatures influence geochemical equilibria, changing mineral solubility, potentially leading to clogging, organic matter or trace elements mobilization, while simultaneously affecting microbial community structures and functions. Biogeochemical processes in HT-ATES remain poorly understood, making dedicated laboratory experiments crucial to assess their operational and environmental impacts.

As part of the Horizon Europe PUSH-IT project (https://www.push-it-thermalstorage.eu/), this study investigates how repetitive heating and cooling cycles induced by HT-ATES affect biogeochemical processes in the subsurface. To simulate HT-ATES conditions, a pressurized flow through experiment is conducted where groundwater from a monitoring HT-ATES well at TUDelft (Netherlands) is injected through aquifer sediments at varying temperatures.

Preliminary analysis of aquifer sediments and water composition provide initial insights. Sediments are quartz rich with detectable amounts of carbonates and clay minerals. The groundwater is brackish Na-Cl type (~6 g/L salinity) under reducing conditions. Dissolved gases such as CH_4 and CO_2 are present, along with Fe, Mn, NH_4 and elevated organic carbon concentrations. Initial microbial analysis showed a cell concentration of $\sim 10^6$ cell/mL and revealed a dominance of bacteria (89%) with key genus *Nitrospina*, a nitrite-oxidizing bacteria, suggesting a role in nitrogen cycling, alongside other taxa (six major phyla identified) potentially involved in metal and sulphate reduction and organic matter degradation.

Throughout the experiments, geochemical parameters (pH, redox potential, conductivity, key redox-sensitive compounds) and microbial community composition (qPCR, 16S rRNA Illumina sequencing) are monitored in both circulating water and sediments. These results help understand the impacts of HT-ATES on biogeochemical evolution of storage aquifers and assess the long-term stability of these systems and implications on groundwater quality.

Acknowledgements: Funded by the European Union under grant agreement 1011096566 (PUSH-IT project). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor CINEA can be held responsible for them.