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Oxygen reactivity in aquifer storage of compressed air and biomethane-natural gas blends: from pilot to modeling

IRINA SIN[1], LAURENT DE WINDT[1] AND ANÉLIA PETIT[2]

[1]Mines Paris, PSL University, Center for Geosciences and Geoengineering

[2]STORENGY, Geosciences & Solution Mining Department

The air containing 8 mol% oxygen was injected during 3 years as a cushion gas into a natural gas reservoir, a carbonate-cemented sandstone aquifer located in the Paris Basin (France). 10-year survey showed that: $O_2(g)$ was fully depleted several months after injection completion, meanwhile $CO_2(g)$ was detected around 2–6 mol%; the pH decreased from 8 to 6, while reducing conditions shifted to mildly oxidizing ones with increasing concentration of sulfates in equilibrium with gypsum. 3 years after injection completion, the pH gradually returned to its near initial state and sulfates were reduced by 2 to 3 times. Release of trace metals (Ba, Cu, Pb, Zn) during and after the test was also studied. Multiphase reactive transport modeling based on these field data [1] allowed to reproduce 1/ the full depletion of the injected $O_2(g)$ due to pyrite oxidation, 2/ leading to acidity production and dissolved sulfates, 3/ acidity buffering by calcite dissolution, 4/ followed by gypsum precipitation and $CO_2(g)$ exsolution.

This field-based model was used to study the geochemical impact of injecting a gas mixture with biomethane containing oxygen into two deep aquifers. Multiple scenarios with O_2 content up to 1000 ppm in the injected gas were modeled to assess the resilience of geological storage to oxygen presence and predict the evolution of stored gas and formation water quality. Multiphase reactive transport simulations [2] revealed that gas injection caused acidification of the solution, lowering from pH 8 to 6. However, the primary acidification factor in this case was the presence of 1 mol% $CO_2(g)$ in the gas mixture. The model demonstrated that the pH buffering capacity of sandstone aquifers relied on 1/ calcite dissolution, 2/ feldspar dissolution and 3/ clay dissolution and sorption capacity. These buffering mechanisms were effective for oxygen contents ranging from 10 to 1000 ppm. More locally than the pH impact, redox conditions became mildly oxidizing. Model indicated that gas injection could induce minimal but long-term change in mineralogy without significantly affecting porosity. Overall, the gas quality was preserved in both sandstone reservoirs.

[1] Sin et al., 2023 http://dx.doi.org/10.1016/j.scitotenv.2023.161657

[2] Banc et al., 2024 https://doi.org/10.1016/j.jgsce.2024.205381