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Field-scale mathematical modelling and simulations of biofilm effects in hydrogen storage

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Underground hydrogen storage (UHS) allows for large-scale energy retention using depleted hydrocarbon reservoirs, saline aquifers, and salt caverns. Biofilms, defined as an aggregate of microbes enclosed in a matrix of extracellular polymeric substance (EPS), are sophisticated systems where different biological, chemical, and physical processes occurs such as growth, erosion, sloughing, attachment, formation of metabolites, etc. While in some applications we can benefit from biofilms (e.g., food industry, water quality), biofilms can also become an obstacle, especially for UHS regarding injectivity and hydrogen loss. Numerical simulations can assist on a better understanding of the interactions between biofilms and hydrogen in cyclic operations involving injection, storage, and withdrawal periods.

The aim of this work is to develop and implement a mathematical model to perform field-scale UHS simulations including biofilm processes. We can find in literature comprehensive multi-component bio-reactive models for UHS (e.g., Hagemann et al. (2016)). Since field-scale simulations require running the model on large spatial and temporal scales, then simplified models are suitable to deal with the heavy computational burden. Still, the simplified model must capture the key processes and quantities. Here, the main mechanisms related to microbial activity are the consumption of hydrogen by the biofilm, porosity reduction due to the development of the biofilm, and biofilm detachment because of higher flow velocities. To this end, the fluid is modelled as a two-phase (liquid and gas), two-component (water and hydrogen) system, while the biofilm is modelled as a solid phase attached to the rock, which grows due to hydrogen consumption and suffers erosion due to the flow.

The mathematical model is implemented in the industry-standard simulator Open Porous Media (OPM) Flow (Rasmussen et al., 2019). The existing hydrogen module implementation is extended to include biofilms, which allows for flexibility to account or neglect the biofilm effects on the simulations. For example, in Strobel et al. (2019) the authors presented a history matching study where microbial activity was identified in the field during hydrogen injection, leading to a successful match after adjusting the initial biofilm density.

We apply the model to assess the hydrogen loss under different injection strategies and microbial parameters. The complexity in the geological models is increased from core samples to layered heterogeneous field-scale reservoirs. We use the pyopmnearwell software (Landa-Marbán and von Schultzendorff, 2023), an open-source framework for creating the required input files by OPM (e.g., corner-point grids, tables for the saturation functions, injection schedules) via configuration files, to perform the simulations, which allows for reproducibility of the results and further studies (e.g., history matching, optimization).

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