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Modeling porous medium modification through induced calcium carbonate precipitation

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Fluid storage in the subsurface is important to reduce climate change (sequestration of CO2) or for energy storage (CH4, H2) to cope with the intermittent, unpredictable production of renewable sources like wind and solar. However, the fluids have the potential to leak through damaged cap rocks or wellbores. One method to remediate these problems is inducing calcium carbonate precipitation (ICP). Currently, most applications of ICP rely on urea hydrolysis by microbes (MICP) to promote precipitation within the porous media. However, precipitation may also be induced by injection of extracted or plant-based sources of the enzyme urease (EICP) or at elevated temperatures (TICP). The applicability of a certain method of ICP is largely determined by the depth below ground surface and the local geothermal gradient. MICP has been demonstrated to have immense potential to seal leakage pathways, even at field scale [1] but is only effective within a limited temperature range, as it relies on the activity of living bacterial cells. As a consequence, the other ICP methods EICP and TICP have to be developed and demonstrated in the field. To assist experimental investigations on EICP and TICP, a previously developed numerical model for MICP [2,3] is generalized and adapted for the new precipitation-inducing processes. As the models are intended for the use in predicting the leakage mitigation for subsurface gas storage, they account for two-phase flow. Additionally, a variety of different components and processes are necessary to describe ICP, the specific number of components and processes being dependent on the precipitation-inducing process. All models are implemented in the open-source simulator DuMuX [4]. The primary variables solved are the aqueous-phase pressure, mole fractions of each component in the water phase, temperature, and, for the solid phases, the volume fractions. The mass balance equations are solved fully implicitly and are coupled through the source and sink terms due to the reactions. The new kinetic rate equations for the developed EICP and TICP models were fitted to experimental data obtained from batch experiments at Montana State University. The porosity and permeability reduction due to calcium carbonate precipitation and accumulation of biomass or enzyme are accounted for by updating the porosity using the volume fractions of the solid phases and for the permeability by using the updated porosity and a Verma-Pruess-type relation [5]. The new models for EICP and TICP will be calibrated and validated using column experiment data, similarly to the procedure outlined in [3], which will then be used to determine the optimal mineralization method and injection strategy for given boundary conditions.

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