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Development of reacted channel during flow of CO_2-rich water along a cement fracture

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Risk assessment of CO_2 sequestration projects must assign a likelihood of leaking wells and both an estimate of the leak magnitude and change in flux over time. Experiments are essential for characterizing coupled reactive transport phenomena along a leak path. In previous work we found self-reinforcing behavior that tended toward self-limiting in a leakage path representative of a likely field situation (a rough-walled fracture within cement) using dilute mineral acid to represent CO_2-saturated brine. In this work we show that leakage of CO_2-rich water (composition typical of storage conditions) through fractured cement also exhibits self-forcing behavior. In the hydrodynamic conditions likely to apply in sequestration, this behavior should tend toward self-limiting or self-sealing of leaks.

To create a leakage pathway, we use Class H neat cement cores and generate a single natural fracture using the Brazilian method. The sample is then placed into a Hassler cell and elevated confining and pore pressure are applied. The injected aqueous phase is pre-saturated with CO_2, and the carbonic acid in the water reacts with cement during injection. The series of experiments reported here were designed to maximize dissolved CO_2 by using deionized water and operating at ambient temperature. During the experiment pressure differential is recorded and effluent samples are collected for analysis. Post experiment scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS) are conducted on the fracture surface.

For all but one experiment, injection rate was held constant. For these experiments pressure differential across sample showed little fluctuation. In one experiment pressure differential was held constant and showed a significant decrease in flow rate. Effluent compositions imply carbonic acid reaction with cement and calcium liberation. Visual analysis of each sample's fracture surface shows reaction is strongly localized along discrete channels. SEM images showed distinctive textures in reacted, transition, and unaltered zones. In the reacted zone, a fine grained porous texture with polygonal joints is present. In the transition zone, calcium bearing minerals have precipitated. In the unaltered zone, typical cement textures are present. EDS analysis supports effluent composition results which show that calcium is leached from reacted zone, leaving the zone relatively enriched in silicon.

A key result of our work is that no experiment showed a sustained decrease in pressure differential over time, which would imply self-enhancing of the leakage pathway conductivity. SEM/EDS observations are qualitatively identical to previous work with mineral acid. In that work, precipitation of minerals along the boundary of the reacted channel led to self-limiting of flow path. A similar mechanism is proposed for the present work, where calcium is liberated in the reaction pathway and precipitated as calcite along the slow flow channel edges where velocity is lower. Development of reacted channels appears to be controlled by coupling between the geochemistry and local heterogeneity of flow through the rough-walled fracture. These observations suggest that leakage of CO_2-saturated brine from a storage formation along a cemented wellbore into shallow formations is unlikely to become worse with time, and could even be self-sealing.

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