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Reaction and transport in debonded wellbore casing-cement interfaces under CO_2 storage conditions: From batch reaction tests to flow-through experiments on the 2m length scale

Tim Wolterbeek, Colin Peach, and Chris Spiers
Utrecht University, HPT laboratory, Utrecht, Netherlands (t.k.t.wolterbeek@uu.nl)

Debonding at interfaces between wellbore casing and cement is widely recognized as providing potential pathways for leakage from CO_2 storage systems. This study addresses how the transport properties of such debonding-defects are affected by chemical reaction between cement, steel and CO_2-bearing fluids.

Our first set of experiments investigates near-static conditions, representative for stages prior to the formation of a fully connected defect network. Debonded cement-steel interfaces were simulated by constructing composite samples containing a spacer-imposed gap. Each sample was reacted with CO_2 and an aqueous fluid, at 80°C and 14 MPa applied CO_2 pressure, in seven sequential batch reaction runs (cumulative duration: 72 days). Permeability was measured after each run and microstructural analyses were performed after completion of the experiment.

Reaction-induced permeability changes were limited, being less than one order of magnitude for all samples. Corrosion scale (Fe-carbonate, minor Fe-hydroxide) formed within the gap, on the surfaces of both the steel and cement. Here, the observed lack of Ca-carbonates suggests this corrosion scale produced a significant reduction in cement carbonation, similar to the decrease in corrosion rate observed when corrosion scale forms a protective film on steel. In contrast, Ca-carbonate did precipitate on the cement at locations beneath the spacers used to create the gap between the cement and steel plates, where corrosion scale did not form.

Overall, the thin corrosion scale films on the cement surfaces seem to inhibit release of Ca from the cement into the gap and impede the precipitation of Ca- carbonates, which in other studies was found to promote sealing in fractured cement. Our batch reaction results imply that in local debonding-defects where corrosion scale development is insufficient to produce sealing, the scale's retarding effect on further reaction has the potential to maintain an open interfacial pathway. Ongoing changes in the temperature and stress state could lead these defects to propagate and connect, possibly resulting in a long-range pathway.

Our second set of experiments is currently ongoing and addresses how such interconnected debonding-defects are affected by long-range chemical reaction and transport under flow-through conditions. Cement slurry was poured into a coil made of steel tube and was subsequently cured at 80°C. After curing, debonding was promoted by causing the steel tube to lift off the cement, providing us with a sample that contains a 2 m long section of (partially) debonded cement-steel interface.

A flow-through permeameter, maintained at 80°C, will be used to one-sidedly flood the coil with CO_2-bearing fluid, while continuously measuring sample permeability and pump/fluid volume (indicative for extent of reaction). Post-experiment microstructural analysis will be performed on the coil. To our knowledge, this will be the first experimental investigation of the cement-steel interface that includes reactive transport phenomena that occur on the metre length scale.