Evolution of Fractures in Wellbore Cement under Dynamic Flow Conditions Relevant to Geological Carbon Sequestration

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Abstract
Interaction between wellbore cement and injected CO2 is one of the important processes that can potentially alter cement properties and potentially affect gas and liquid leakage pathways during geological carbon sequestration. This work investigates the property evolution of a cemented sandstone core during the continuous flooding of CO2-saturated brine under pressure and temperature conditions relevant to carbon sequestration. Interconnected cracks and voids in the cement zone represent defective wellbore cement conditions and are examined as a single, complex fracture structure. Changes in fracture volume and structure were visualized and quantified using X-ray micro-CT imaging. Within an eight-day flow-through period, cement fracture volume increased significantly while the best sandstone remained intact. The rate of volume increase was faster in early times than at later stages. It has been observed that fracture apertures located near the core inlet experienced more severe cement degradation than those closer to the core outlet. In-situ permeability of a parallel sample was measured to increase by a factor of eight after ten days of flooding under the same condition. Findings from this work will provide valuable insights for the development of predictive models and for risk assessment under conditions relevant to CO2 sequestration.

Methodology
• Composite rock-cement core sample preparation
• CO2-saturated brine core flooding experiment with the aid of Micro-CT Imaging

Introduction
Motivation
• Intensive awareness of carbon capture and sequestration
• Wellbore integrity threatened by poor completion, formation damage and wellbore cement alteration
• Environmental impacts of CO2 leakage: recombination of toxic metals and deterioration of drinking water quality

Objective
• Understand the spatial and temporal changes of fracture during CO2-cement-brine interactions by using advanced pore-scale analysis from X-ray micro-CT imaging
• Quantify the degree of cement alteration and analyze the evolution of wellbore cement properties when subjected to chemical reaction
• Provide resource data for developing predictive models for reactive transport process

Experimental Setup

Results

Vertical fracture void volume profile with time

- bottom section has the largest normalized volume increase and steepest slope
- fracture section has smallest increase

Evolution of fracture void volume and surface area with time

- greatest increase in effective permeability by a factor of eight

Summarization and Future Work

• The cement zone experienced chemical alteration evident through color changes.
• Detailed mapping from X-ray micro-CT imaging provides spatial and temporal evolution of the fracture structure during CO2-cement interations.
• The overall fracture volume increases over time due to the cement dissolution.
• The extent of fracture volume increase is a function of both time and space. The rate of volume increase is fast early on and decreases over time.
• The fracture surface has been smoothed significantly, with a decrease in specific surface area by a factor of 1 to 5, depending on specific locations.
• A parallel 10-day flow through experiment carried out using a similar fractured cement core sample under the same flow conditions revealed an increase in effective permeability by a factor of eight.
• Future practice will focus on investigating cement alteration in well-bonded rock-cement samples under different pressure and temperature conditions.

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