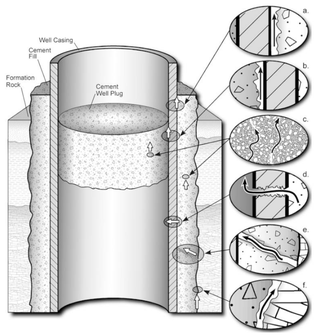
Coupling Reactive Transport, Geochemistry, and Geomechanics in Wellbore-Cement/Carbonated-Brine Systems

Jaisree Iyer, Stuart D. C. Walsh, Yue Hao, Pratanu Roy, Joseph P. Morris, Susan A. Carroll
Lawrence Livermore National Laboratory, Livermore, CA, USA

Motivation

- Fractures in cement used to seal wells are potential leakage pathways in the wellbore.
- Chemical reactions and mechanical deformation affect the permeability of these fractures.
- We have coupled transport, chemistry, and mechanics in GEOS to predict permeability evolution of leakage pathways.

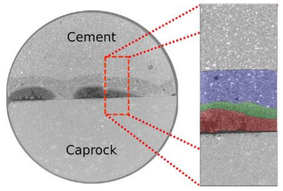


Wellbore leakage pathways[1]

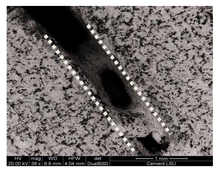
[1] Gasda et al., *Environ. Geol.*, 2004, 46(6-7):707–720.

Cement and CO_2 Interactions

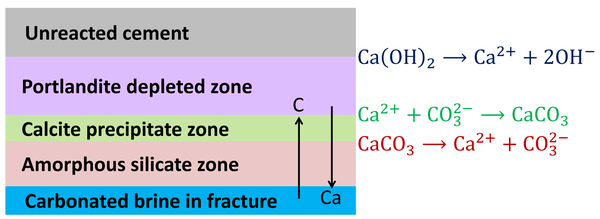
- Reaction between cement and carbonated brine results in dissolution of portlandite, and precipitation of calcite leading to altered cement layers.
- These layers have different mechanical and petrophysical properties.
- Calcite can also precipitate within the fracture.



Altered layers in cement[1]



Calcite precipitate in fracture[2]



Reactions associated with the altered cement layers

[1] Walsh et al., *Int. J. Greenhouse Gas Control*, 2014, 22:176-188.
[2] Yalcinkaya et al., *Energy Procedia*, 2011, 4:5335-53342.

Reaction Front Model

- Chemical interactions between cement and CO_2 is captured using a reduced physics model. The assumptions of the model are:
  - Reactions only occur at the fronts.
  - Transport between the fronts is via diffusion:

$$\frac{\partial}{\partial x}\left(D_{eff}\frac{\partial[\mathrm{E}]}{\partial x}\right) = 0.$$

  - Effective diffusion coefficient for each layer depends on its porosity and tortuosity.
  - Front movement is controlled by diffusion or reaction based on which phenomenon is slower:

$$\underbrace{[[c_{\mathrm{E}}(1-\phi)]]v_{front}}_{\text{Change in moles of solid across the front}} = -\underbrace{\left[\left[D_{eff}\frac{\partial[\mathrm{E}]}{\partial x}\right]\right]}_{\text{Change in diffusive flux across the front}} or \underbrace{-r_{\mathrm{E}}}_{\text{Reactive flux at the front}}.$$

Mechanical and Hydraulic Coupling

- Altered cement has lower stiffness and yield stress, which may also lead to fracture sealing. This is captured by coupling the mechanical response to the extent of reaction.
- The reaction fronts propagate radially into the asperities and decrease their effective stiffness.

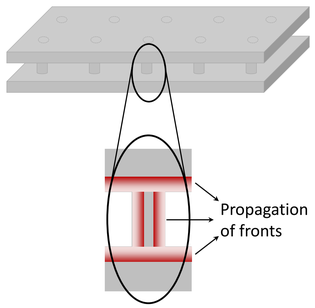
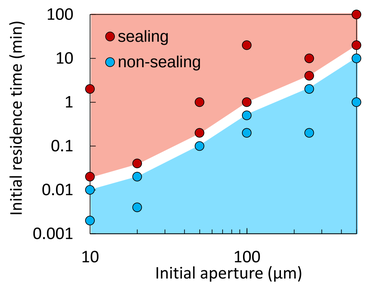


Illustration of the mechanical model for altered cement

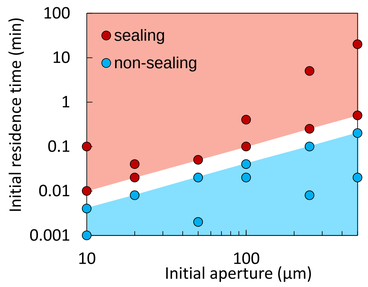
- Deformation of the altered cement reduces the aperture. The velocity is accordingly modified using the Darcy formulation for single or two phase flow.
- The linear and Corey relative permeability models have been implemented for two phase flow.

Chemical and Mechanical Sealing

- Sealing occurs at longer residence times as the brine stays in the fracture longer and becomes saturated.
- Smaller apertures seal at shorter residence times due to significant flow rate reduction upon precipitation.
- Fractures seal at lower residence times under stress as deformation reduces aperture, which reduces flow rate.



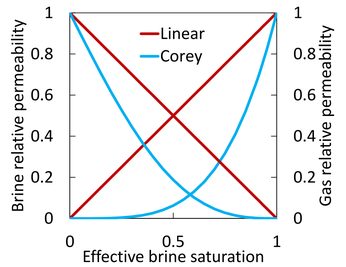
Chemical sealing



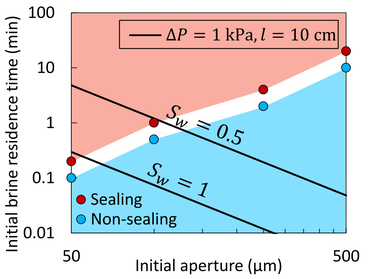
Chemical and mechanical sealing

Single and Two Phase Flow

- Fracture sealing is helped by reduced brine saturation as the reduced brine permeability increases residence time.
- However, two-phase flow can increase CO_2 leakage rates as CO_2 has higher mobility and lower density.



Relative permeability curves



Operating pressure curves on the sealing map for different saturations

Acknowledgements

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