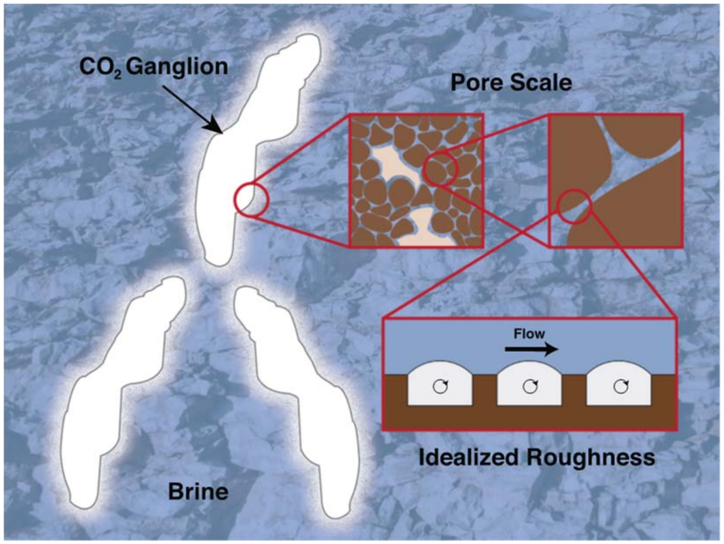
The Influence of Interfacial Slip on Two-Phase Flow In Rough Pores



Conceptual roughness model where buoyantly-driven $scCO_2$ ganglion propagate through a reservoir initially saturated with brine, where brine or $scCO_2$ may become trapped in surface roughness features in the individual pores of the reservoir.

Publication:

Kucala, A., Martinez, M.J., Wang, Y., Noble, D.R. (2017) ***Water Resources Research***. (in review)

Work was performed as part of the **Center for Frontiers in Subsurface Energy Security**.

Geological Carbon Storage

Estimating the permeability characteristics of the subsurface is important in the prediction of flow paths and storage rates in geological carbon storage efforts. Surface roughness at the pore-scale may influence the permeability for two-phase flow in the subsurface.

The CFSES Research Challenges

1. Sustaining large storage rates.
2. Using pore space efficiently.
3. Controlling undesired/unexpected behavior.

Rationale for this review paper

Interfacial slip occurs at the immiscible two-phase interface between supercritical CO_2 ($scCO_2$) and brine trapped in roughness features at the pore-scale. Using computational fluid dynamics (CFD), we characterize the interfacial slip as an "effective permeability" (K_E), a measure of the change in permeability relative to a smooth pore.

Fluid Slip and Permeability (General)

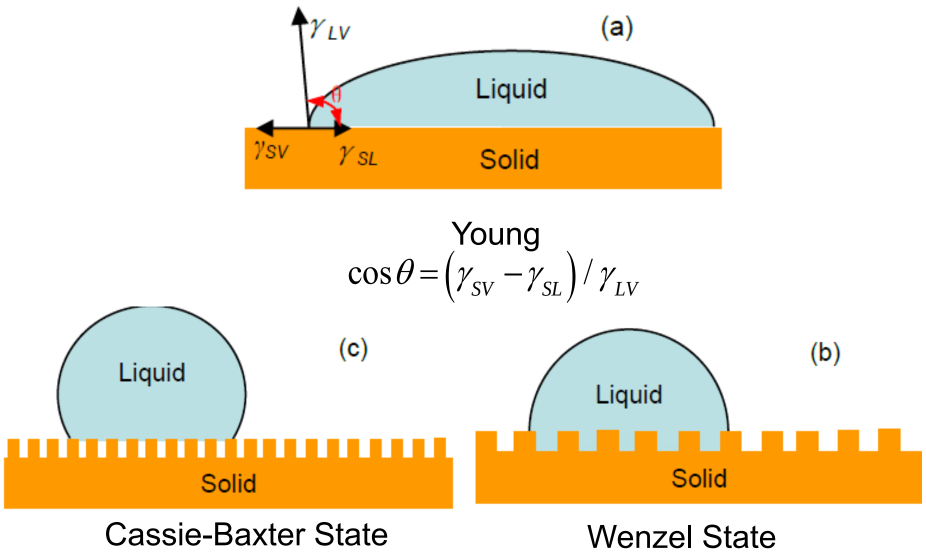
- Surface roughness can introduces slip flow at the liquid/gas interface in the vicinity of the surface roughness
  - Wenzel State
  - Cassie-Baxter State

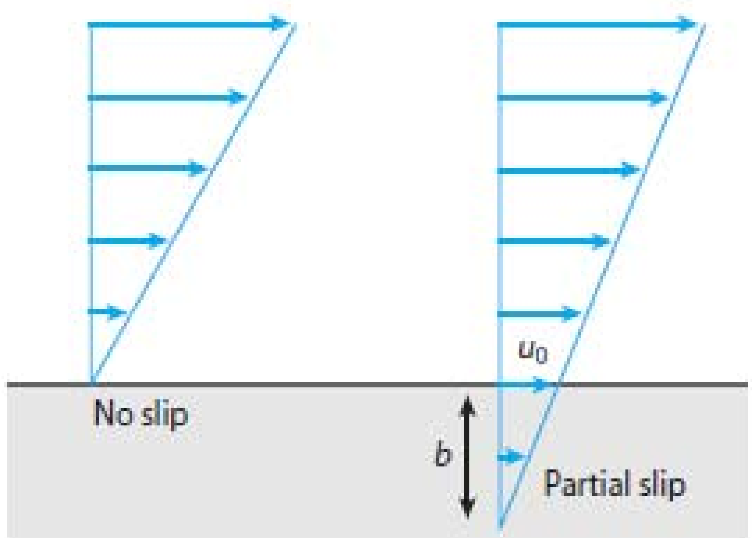
- Slip length (velocity) can change depending on surface roughness and fluid configuration

$$u_w = b \left|\frac{\partial u}{\partial y}\right|_w$$ **Slip length**

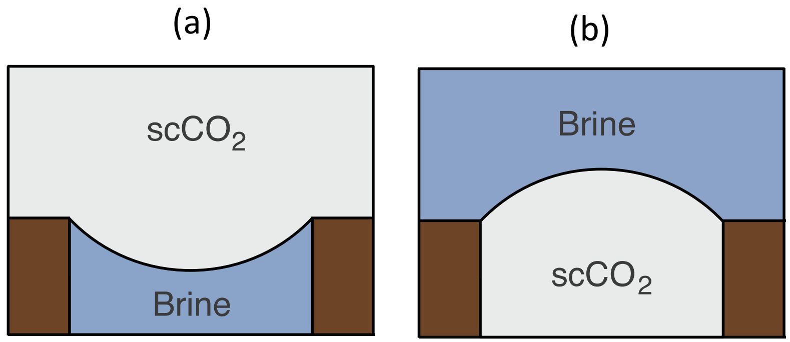
$$K_S = \frac{h^2}{4}\left(\frac{1}{3} + \frac{b}{b+h}\right)$$ **Permeability of channel with slip**

$$K_E = \frac{K_S}{K_{NS}} = 1 + \frac{3b}{b+h}$$ **Effective permeability**

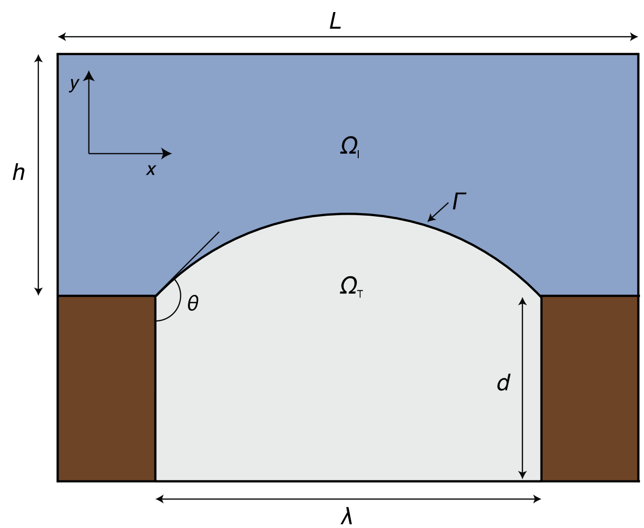




Conceptual Model for Roughness



Possible configurations of trapped brine and $scCO_2$ interfaces in a rough pore; (a) Drainage (b) Imbibition



Unit cell geometrical parameters

Configurations

- Brine or $scCO_2$ may be trapped in the roughness elements dependent on drainage or imbibition scenario
- The shape of this interface (convex or concave) may influence the permeability of the pore

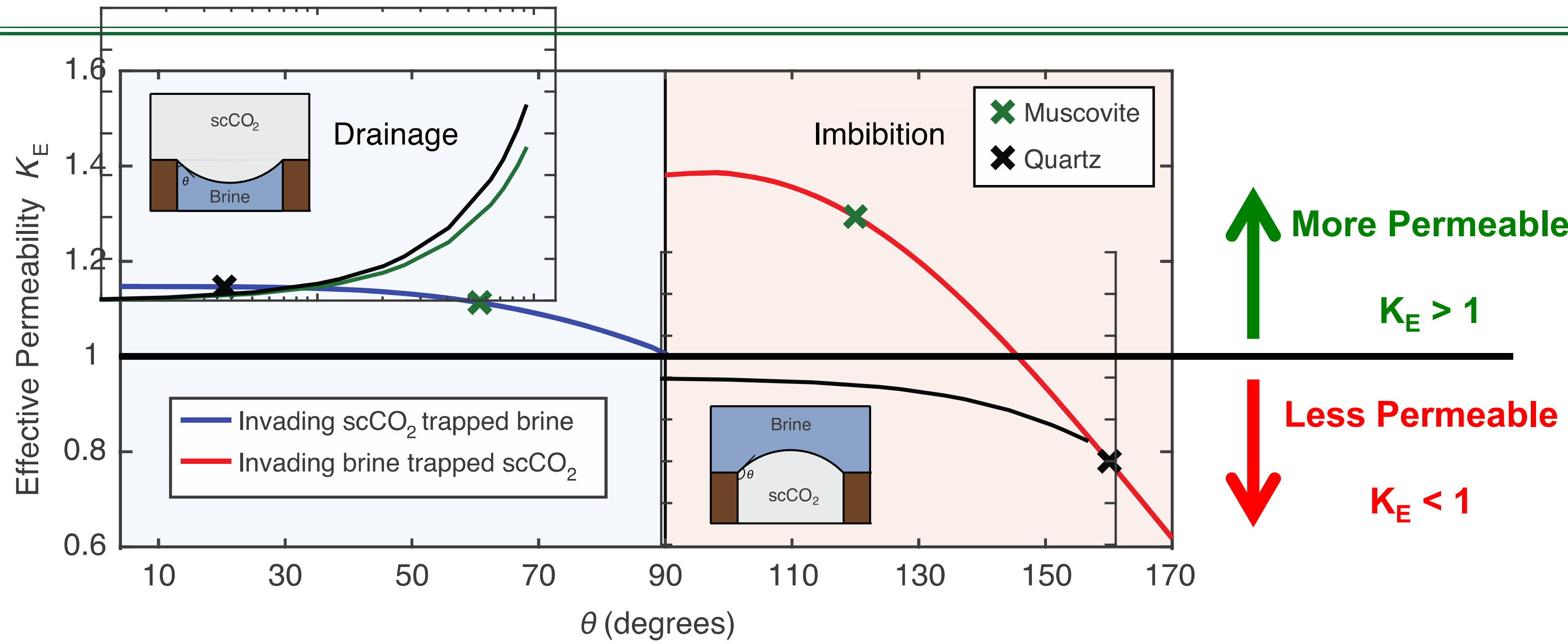
Computational Model

- Use finite-element method to solve two-dimension Navier-Stokes fluid equations.
- Incorporate surface tension effects into the model

Methodology

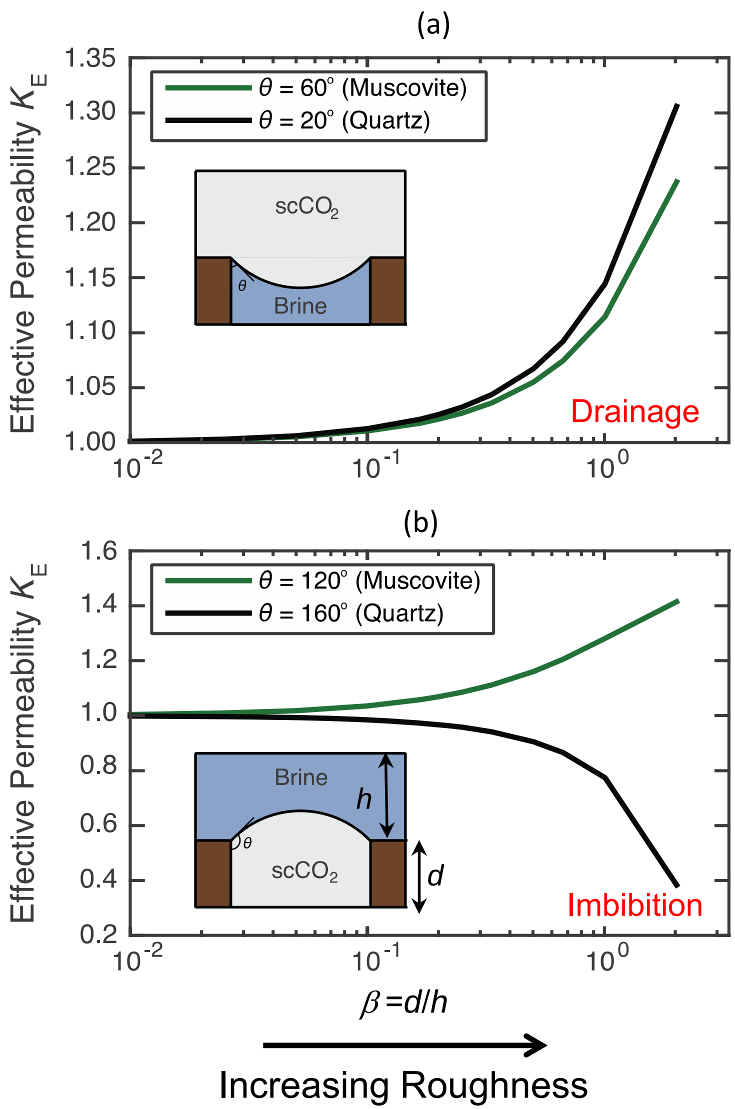
- Assume immiscible $scCO_2$-brine interface with constant surface tension
- Change pit depth (d), spacing (λ), and contact angle (θ) to assess enhancement or diminishment of permeability (K_E)

Permeability as a Function of Wettability



- Results for fixed geometry, varying wettability
- In drainage (blue), permeability is always enhanced in the presence of surface roughness
  - Interface tends to recede into the pit and enhancing permeability
- In imbibition, permeability can be enhanced or diminished depending on the wettability
  - Interface protrudes out into flow at various angles depending on wetting angle
  - Less wetting muscovite tends to enhance permeability (green mark)
  - More wetting quartz tends to diminish permeability (black mark)
- Crossover from enhanced to diminished permeability can occur in the subsurface due to mixed wettability via mineral heterogeneity in a pore-network

Influence of Roughness Feature Depth



Pore-scale Roughness

- The degree of pore roughness plays a pivotal role in permeability enhancement or diminishment
- For very rough pores (d > 0.1h), fluid slip at the interface can greatly enhance or diminish permeability
- For smoother pores, permeability is not affected in any meaningful way
- Bifurcation of effective permeability in drainage (b) becomes large with increasing pore roughness

Scientific Achievement

- Investigated the influence of interfacial slip in rough pores on permeability enhancement or diminishment dependent on pore-scale geometric length scales and wettability for GCS applications.

Significance and Impact

- Insight on the pore-scale physics of immiscible fluids trapped in rough pores, which can affect CO_2 mobility in the subsurface.

Acknowledgement

This material is based upon work supported as part of the Center for Frontiers of Subsurface Energy Security, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award Number DE-SC0001114 .

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.