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Center for Geologic Storage of CO_2

Pore-Scale Phenomena Affecting the Transport and Fate of Supercritical CO_2 in Geological Reservoirs

K. T. Christensen[1,2], A. Valocchi[2,3], C. Werth[4], G. Blois[1,2], J. Botto[4], F. Kazemifar[1,2], A. H. Kohanpur[2,3] and Y. Li[1]

[1]University of Notre Dame; [2]International Institute for Carbon-Neutral Energy Research; [3]University of Illinois at Urbana-Champaign; [4]University of Texas at Austin

Motivation

- Uncertainty regarding the fate CO_2 in a formation during and post injection is one of the primary factors limiting application of geological carbon sequestration.
- Concern exists that CO_2 will remain buoyant, and escape to overlying groundwater or the ground surface through fractures/faults in the cap rock, and leaky well bores.
- Reservoir-scale CO_2 migration is tightly coupled to pore-scale flow/transport which must be understood.

Objectives

- Evaluate the effects of CO_2 properties, injection velocities, pore geometry, and wettability on CO_2 migration in reservoir rock using pore-scale modeling.
- Calibrate the pore-scale models using wettability and flow measurements, accurately simulate CO_2 migration and motivate new flow experiments, and develop upscaled relationships to inform continuum-scale models for more accurate reservoir-scale simulations.

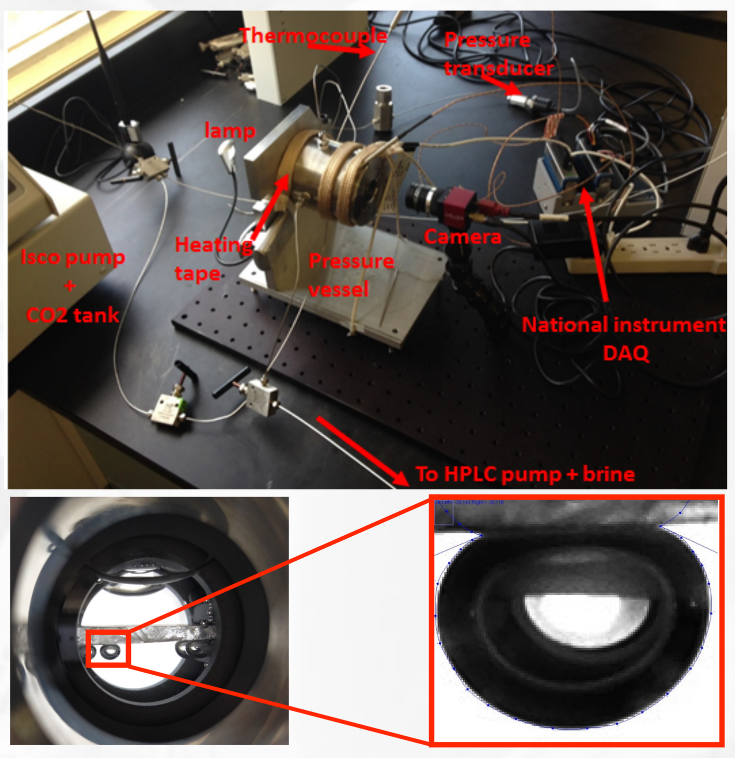
Wettability Studies

Specific Objectives

- Determine the impact of mineral composition, surface roughness and surface charge on the CO_2 wettability of deep saline aquifers.
- Develop predictive models of CO_2 wettability.

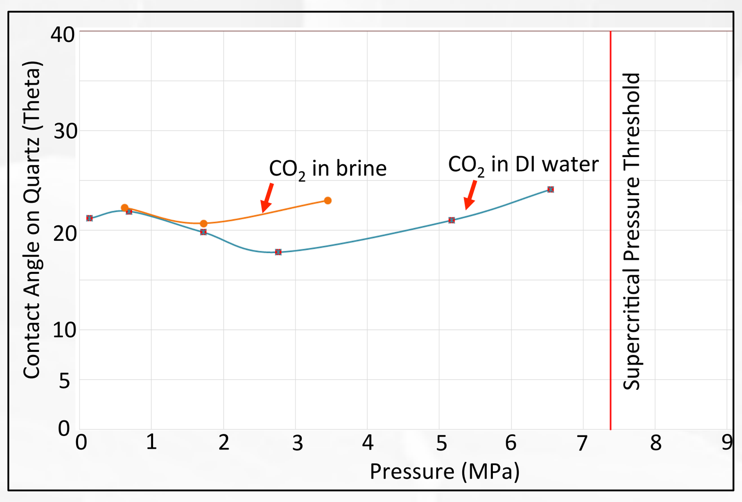
Methods

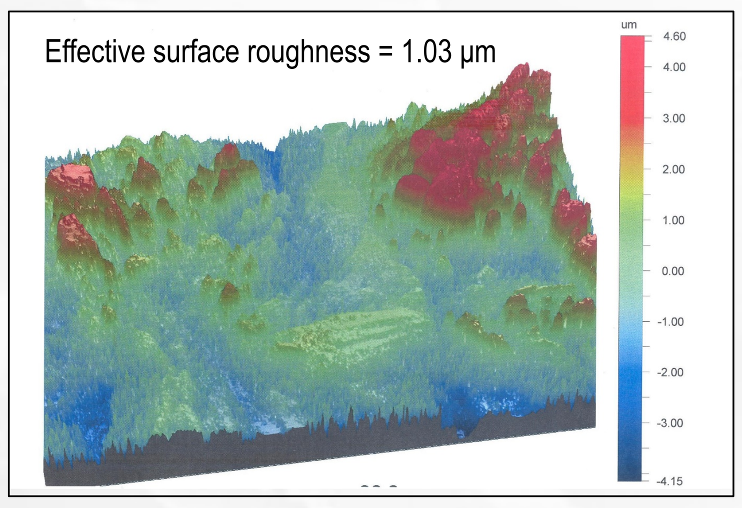
- High pressure and temperature goniometer was fabricated and is being used to measure contact angle on mineral and reservoir samples.
- A Wyko NT 9100 Optical Profilometer is being used to measure mineral surface roughness.



Results

- Contact angles of CO_2 in both DI water and brine on a quartz surface are between 18 and 24°, and are relatively constant with pressure up to 2.7 MPa.
- The effective surface roughness of the quartz sample was 1.03 µm.



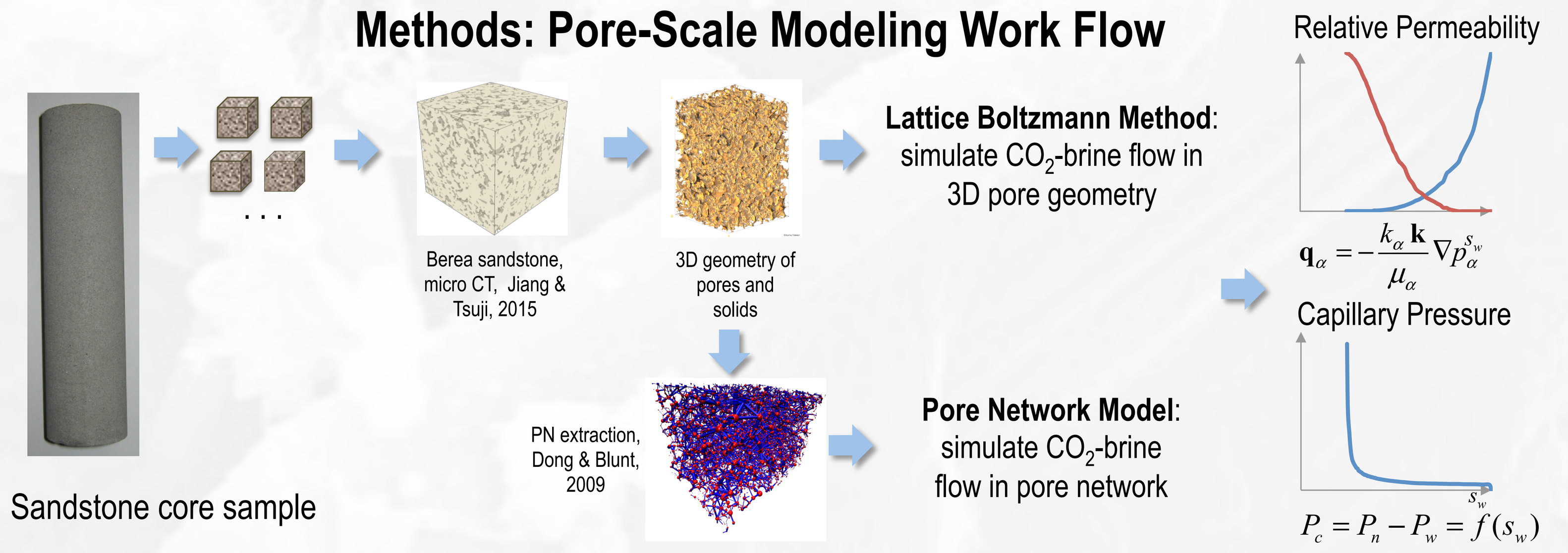


Pore-Scale Modeling

Specific Objectives

- Use CT-images of reservoir core and pore-scale simulation to estimate core-scale constitutive models for capillary pressure, relative permeability, and trapping − compare pore-network and lattice Boltzmann models.
- Investigate impact of pore-scale heterogeneity of wettability upon constitutive models.
- Use lattice Boltzmann models to improve understanding of how pore-scale displacement events affect trapping.

Methods: Pore-Scale Modeling Work Flow

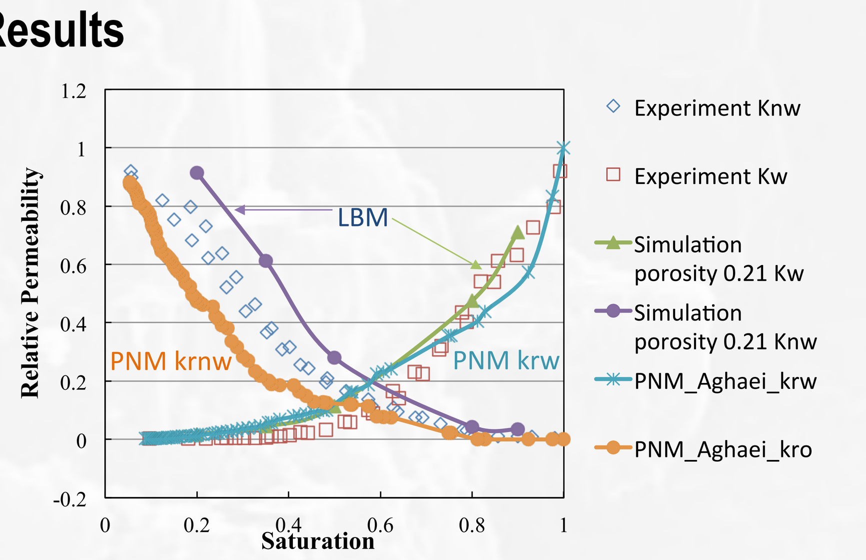


$$\mathbf{q}_\alpha = -\frac{k_\alpha \mathbf{k}}{\mu_\alpha}\nabla p_\alpha^{s_\alpha}$$

$$P_c = P_n - P_w = f(s_w)$$

Results

- Validation for primary drainage relative permeability
- Compare experiment, LBM and PNM for Berea Sandstone
- **LBM**: ~ 400^3, 3.2 µm GPU cluster, 3-4 days CPU
- **PNM**: 10,807 pores, 13,723 pores Multi-core workstation, few hours CPU



Flow Dynamics

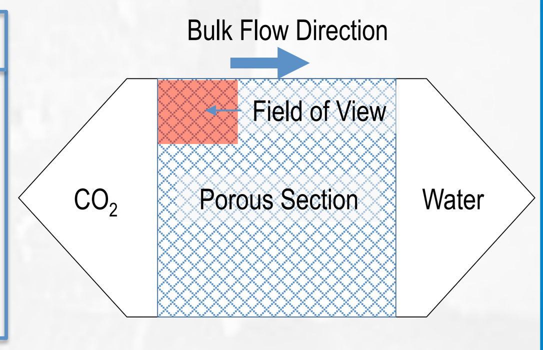
Specific Objectives

- Improve the understanding of two-phase flow of liquid/supercritical CO_2 and water in porous media under realistic conditions using the micro-PIV technique to capture flow dynamics.
- Evaluate trapping mechanisms and assess the mobility of the phases in a quantitative manner.
- Study the effects of rock heterogeneity and wettability on pore-scale flow processes, dynamic transport phenomena and overall CO_2 trapping mechanisms.

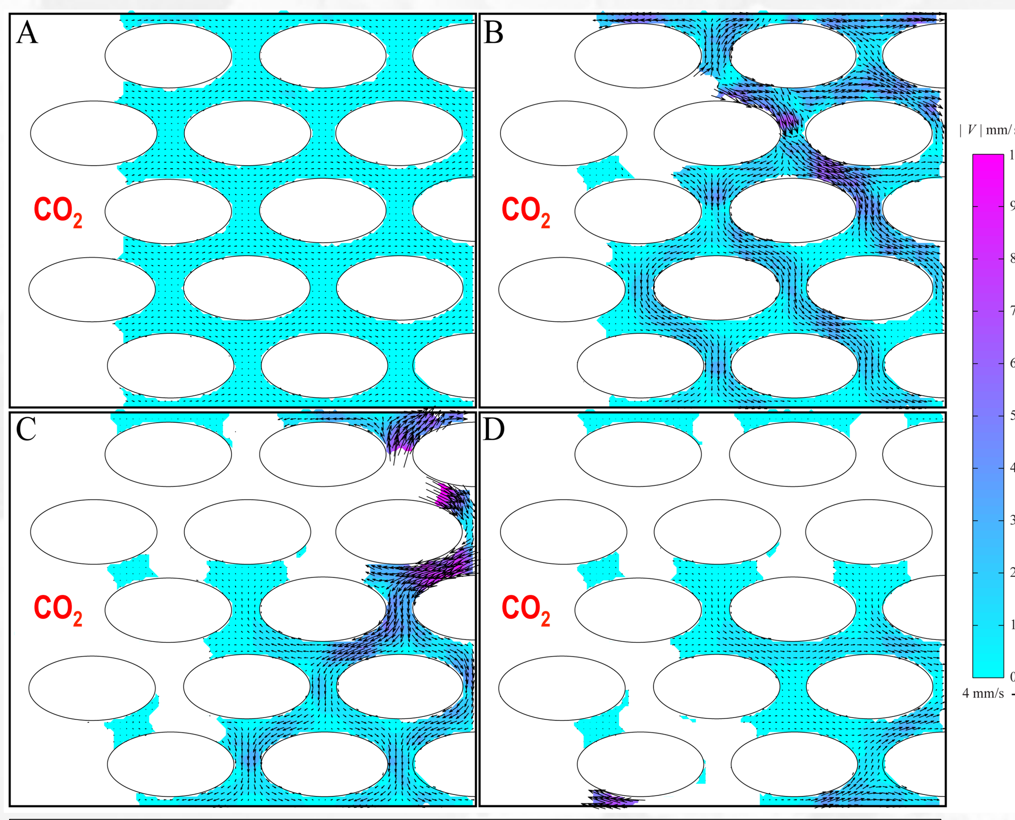
Methods

- 2D micromodels fabricated from silicon; matrix formed from regularly arranged cylindrical/elliptic pillars
- Measurement conducted at reservoir-relevant conditions (*i.e.*, 80 bar, 40°C, see the table below)
- Micro-PIV and fluorescent microscopy: simultaneous measurement of the velocity field in the water and quantification of the spatial configuration of both phases.

Experimental conditions	
P= 80 bar, T= 40°C	M = 0.03
Q = 0.005 ml/min	$Re_{H2O} \simeq 0.1$
U_{bulk} = 0.4 mm/s	$Re_{CO2} \simeq 1$
$Ca = 3.4 \times 10^{-7}$	Δt = 100 ms



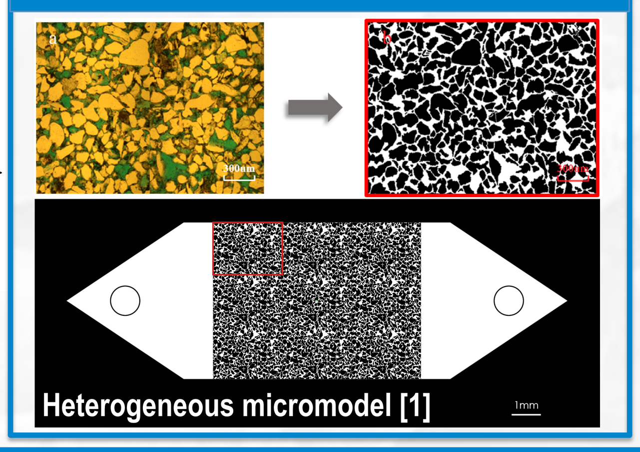
Results*



A	• Flow field is periodic and symmetric
B	• CO_2 suddenly penetrates the water in two separate branches (fingers). • High-momentum pathway highlights the growth direction of CO_2. • Peak velocity during the Haines jump > 10 mm/s, observed both in the bulk flow direction and opposite to it.
C	• Max local Reynolds number: Re_{H2O} = 2.5 – 3; Re_{CO2} > 10.
D	• The flow immediately decelerates and the spatial distribution of the two fluids remains unchanged for the rest of the period.

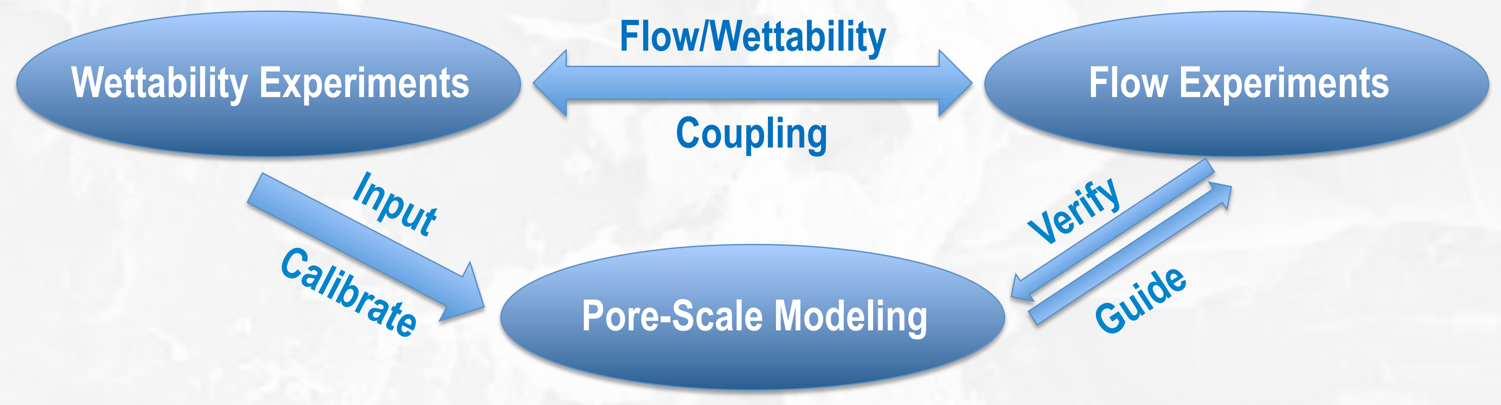
[1] L. Zuo, C. Zhang, R. W. Falta and S. M. Benson, *Adv Water Resour* 53, 188-197(2013).

Next Step: Heterogeneity



Synergy

- Contact angle results will be used as input to a pore-scale Lattice Boltzmann model to simulate CO_2 flow.
- Wettability measurement results are being used to calibrate the pore-scale model in addition to inspiring new flow measurements in 2D micromodels with modified wettability.
- Pore-scale modeling will provide the continuum-scale constitutive relations for capillary pressure, relative permeability, and capillary trapping required by the site-scale modeling group.
- Constitutive models will be developed for different geological facies in the geo-cellular representation of the Mt. Simon site.



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