Effect of Small Scale Heterogeneity on Multiphase Flow of CO₂ and Brine

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**Motivation**

The goal of the Sequestration Lab is to develop ability to predict spatial and temporal distribution of CO₂ saturation and trapping through an improved understanding of the pore and core scale physics over the life cycle of a sequestration project.

**Focus of this work**

Model behavior of brine displacement by injected CO₂ in a series of core-scale laboratory experiments.

Gain better understanding of the influence of sub-core scale heterogeneity on CO₂ storage.

**Numerical Simulation: Core Description**

**Tough2 MP with EC02N module**

- Used for numerical simulation
- Designed for large-scale simulations
- Robust treatment of thermodynamic and thermophysical properties of CO₂, H₂O and NaCl

**Rock Properties: Porosity Map**

Berea Sandstone
29 lateral images data
Mean Φ=0.203/ Mean k=430 mD
Bedding at a high dip angle

**Experimental Results: Saturation Maps**

- Large part of the core poorly filled with CO₂ even at injection of 100% CO₂
- Want to explain bypass of bottom part of the core near the outlet

**Simulation Input : Relative Permeability Curves**

The relative permeability relation used in the simulation was the following:

\[
k_{r, CO_2} = \left(1-S_{cr, CO_2}\right)^{n_{CO_2}} S_C^{1-S_{cr, CO_2}}
\]

\[
k_{r, brine} = \frac{S_{cr, brine} - S}{1-S}
\]

These power-law functions are used to fit the measured relative permeability data for brine and CO₂ and are used as inputs to the TOUGH2 model.

The four free parameters (Swr, Swrn, nco2, and nw) are determined by the optimization.

**Simulation Input : Capillary Pressure Curves**

- Obtained based on known porosity and permeability data
- Each grid element has a unique pair of porosity and permeability values; hence a unique capillary pressure curve

**Simulation Input : Permeability-Porosity Models**

A number of different porosity-permeability correlation models were tested in order to match the spatial distribution of CO₂ in the experiments. Three models are used to compare the experiments.

**Simulation Results and Discussion**

**Compare Experiment and Simulation at 1.2ml/min**

- The match of the saturation and the pressure drop has been improved a lot
- The middle points such as 34%, 51%, 61%, and 79% are close to the data
- The two end points such as 26% and 100% are off a lot

**Experimental Results: Saturation Maps**

- Measured CO₂ saturation patterns can be qualitatively replicated using simulation models
- Can reproduce absence of CO₂ in lower portion of outlet end of the core

**Compare Porosity Map to CO₂ Saturation Map**

- Similar structural features
- Strong correlation close to the inlet end
- High porosity regions -- high CO₂ saturations
- Low porosity layers act as capillary barriers, resulting in bypass of portions of the core

**Conclusion**

- Spatially varying porosity, permeability and capillary pressure curves are used in the simulations, and CO₂ distribution is controlled by varied capillary pressure curves
- Match CO₂ saturation magnitude and pressure drop quite good
- Measured CO₂ saturation patterns can be qualitatively replicated
- Low φ --> low k --> high capillary entry pressure --> low CO₂ saturation
- Higher degree contrast in rock properties --> greater contrast in saturation
- Higher degree heterogeneity in the core --> lower average saturation

**Future Work**

1. Improve simulations to replicate experiment qualitatively and quantitatively
2. Investigate all the possible factors that may affect CO₂ saturation, such as flow rate effect, gravity effect and length effect
3. Identify and minimize numerical artifacts by different grid size and time step size

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