Abstract

• Residual trapping is generally accepted as an important mechanism for immobilizing CO2 and thus, contributing to storage security, but, few studies have questioned whether trapping is permanent. The goal of this study is to examine the stability of residually trapped CO2 at the pore scale with respect to the Ostwald ripening mechanism.
• The mechanism is decoupled in time so that evolution can be predicted in realistic pore network models and physical insights gained.

Pore Network Modeling Approach

• Problem becomes 1D and pore space is a graph:
  • Nodes are bodies (spheres).
  • Edges are throats (union of conical frustrums).
• Use analytical expression for capillary pressure as a function of local pore radius.

GENERATING REALISTIC PORE NETWORK MODELS

• An algorithm was developed to generate stochastic pore network models [5].
• Network statistical properties match those of a pore network extracted from microCT images of a Berea sandstone [4].

Simulation Framework

• The ripening mechanism can be decoupled into two processes that operate on different time scales.
  1. Internal equilibrium problem (fast)
    • Pressure must be the same everywhere in a CO2 ganglion.
    • Brine pressure is assumed uniform so interfacial curvature on unsupported interfaces must be constant.
    • For a given volume, what is the equilibrium radius?
  2. Mass-transfer (slow)
    • Find diffusion paths to neighbors (using a variation of the Breadth-First Search Algorithm).
    • Estimate mass transfer rate between each pair of ganglia based on Henry and Fick’s laws.
    • Use superposition theorem to calculate mass transfer rate to each ganglia.

Motivation

• A system of two bubbles of CO2 in saturated brine is thermodynamically unstable, as shown by direct application of three physical laws: Laplace, Henry and Fick.
• In porous media, Laplace’s law links capillary pressure to throat radius, so equilibrium seems theoretically possible, but under what conditions and for what type of rock?

Results

• Solving the internal equilibrium gives us information on the pore space.
  For each pore, we can calculate a range of volumes of gas it can accommodate as well as a corresponding range of capillary pressures.
• Key additional assumptions:
  • Ganglia span at most one pore.
  • Ganglia can only be stable if they are interacting with the walls.
  • We do not simulate for evolution but rather look for possible stable equilibria with disconnected ganglia.
• For a given interface radius, how many ganglia could exist in the network, based on the internal equilibrium plots? What CO2 saturation do those ganglia represent?

Discussion

• Our simulation framework can be used to predict the evolution of systems governed by the ripening mechanism and estimate evolution time scales. The methodological approach extends the simulation capabilities of classic pore network modeling and provides a tool to study multi-ganglia systems governed by inter-cluster diffusion.
• If there are stable multi-ganglia equilibria with saturations higher than 8% in the presented network (statistically equivalent to a Berea sandstone), at least some of the ganglia must span multiple pores.

Conclusion

References


Acknowledgments

Funding for this research is supported by the Department of Energy, Office of Basic Energy Sciences Energy Frontier Research Center under contract number DE-AC02-05CH11231