CO_2 STORAGE

Global Climate & Energy Project
STANFORD UNIVERSITY

Rapid Prediction of CO_2 Movement in Aquifer, Coal Beds, and Oil and Gas Reservoirs

Investigators

Franklin M. Orr Jr., Professor, Petroleum Engineering
Anthony R. Kovscek, Assistant Professor, Petroleum Engineering

Objective

The earth's crust offers three major classes of geologic formation that appear suitable for long-term storage of CO_2: deep formations containing salt water, unmineable coalbeds, and oil and gas reservoirs. If greenhouse gas (*e.g.,* CO_2) injection into geologic formations is undertaken on a large scale, physically-accurate and high-resolution, but low computational cost, numerical methods are needed to predict CO_2 flow and to optimize injection operations.

This study will develop ultra-fast computational methods and tools to predict the movement of CO_2 through geologic formations suitable for greenhouse gas storage.

Background and Approach

Simulating CO_2 flow behavior in geologic media is difficult because of the interplay between phase behavior, complex mixture compositions, reservoir heterogeneity, and the computational demands these physical mechanisms impose. Fully-compositional, finite-difference simulation techniques are commonly used, but are notoriously slow, especially when grid dimensions are made sufficiently fine to begin to resolve the coupling between flow and phase behavior. Streamline methods hold great promise for aiding the design of efficient injection and storage processes. Streamline methods are based on the idea that the flow can be represented by a series of 1D displacements along streamlines.

Activities

Research is underway to explore the effects of gravity in the simulation of CO_2 into saline aquifers, inclusion of capillary effects, using CO_2 to enhance condensate recovery, and simultaneous optimization of oil recovery and CO_2 storage.

Effects of Gravity: A new method for including gravity effects in compositional streamline simulation was recently developed. The method makes use of operator splitting to account for both pressure driven and gravity induced multiphase flow. It is implemented in the research code compositional streamlines simulator (CSLS) of the Petroleum Engineering Department. CSLS forms the basis for the development of an efficient and accurate tool for prediction of flow performance during CO_2 injection in saline aquifers.

Effect of Capillarity: A method has been developed for the introduction of capillary forces into a streamline simulator. Capillary effects are responsible for the phase pressure difference between wetting and nonwetting fluids. They may alter significantly the displacement character, especially, in low-permeability and heterogeneous porous media. The new method is based on a recently introduced capillary-viscous potential, which is used instead of the phase pressures during solution of the pressure equation. To date, the work has been oriented toward prediction of the flow of oil and water and is quite encouraging. (See Figure 1.) The formulation requires 5 to 10 times fewer pressure updates as compared to finite-difference simulation.

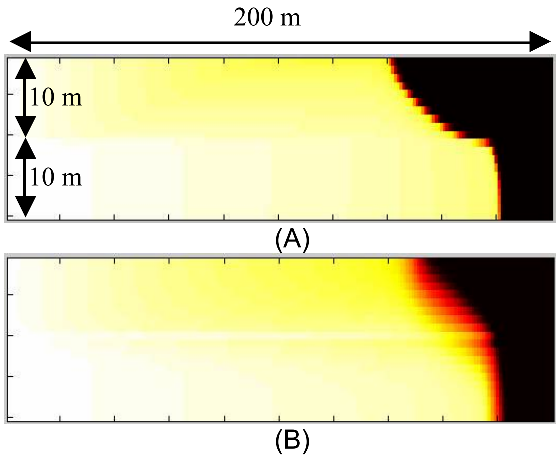

Figure 1. (A) Displacement front without accounting for capillarity: Illustrates the introduction of capillary effects during water flooding in a two-dimensional two-layer oil reservoir. The top layer is less permeable than the bottom. White shading represents water and dark shading represents oil. Injection is across the entire left side. **(B) Displacement front with capillary effects:** Demonstrates greater sweep and the delayed breakthrough time, with respect to conventional finite difference simulation.

Enhanced Oil Recovery (EOR) and Sequestration: It is well known that carbon dioxide enhances the recovery of hydrocarbons. Techniques being studied co-optimize oil recovery and the amount of reservoir volume filled with CO_2. These efforts are currently focused on (1) exploring injection-production techniques that meet the new design criteria and produce at least as much oil as conventional recovery efforts, and (2) expanding the range of candidate reservoirs considered for CO_2 injection.

Gas Condensate and CO_2 Utilization: There is a balance between technical and economic factors, with respect to the recovery of condensate from retrograde reservoirs. Recovery of liquids must be maximized while minimizing costs associated with operating a gas injection scheme. In many operations, the costs associated with deferred gas production versus the value of incremental condensate recovered make such schemes uneconomic. CO_2 is very effective at condensate recovery. Surface forces often render the condensate immobile, and the only means to recover efficiently these hydrocarbons is through vaporization into a mobile phase. An analytical solution for the recovery of a condensate uses 100% CO_2 through a series of vaporizing shocks. Analytical solutions are mapped along streamlines to obtain a powerful tool for quick assessments of gas injection schemes for condensate vaporization.

Future extensions to streamline methodology are varied. Work will continue to represent the effects of gravity, capillarity, and three-phase displacement on multiphase flow, and testing to ensure that physics are incorporated accurately. The importance of capillary effects during compositional displacement will also be investigated. Specific work in the area of aquifer sequestration includes development of a phase behavior module that honors the effects of salinity on the solubility of CO_2 in brine, and that calculates density, and viscosity of brine as a function of salinity and temperature. Impact of capillary effects on the injection process and the arrangement of CO_2 and brine within the aquifer will also be investigated. Additional work will be done to evaluate computational approaches appropriate to the period after completion of injection. For example, the relatively slow processes of CO_2 diffusion through brine, the slow gravity overturn that results when dissolved CO_2 increases the density of the brine slightly, and chemical reactions among mineral species.