GEOLOGIC STORAGE OF CARBON DIOXIDE: MECHANISTIC UNDERSTANDING AND TOTAL SYSTEM PERFORMANCE ASSESSMENT

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ABSTRACT

Carbon capture and sequestration (CCS) is an option to mitigate impacts of atmospheric carbon emission. Numerous factors affect the overall effectiveness of long-term geologic storage of carbon, including leakage rates, volume of storage available, and system costs. In this presentation, I will first provide an overview of state of the art of geologic storage of carbon dioxide (CO_2). I will then present our recent work in two important areas of geologic carbon storage: capillary trapping and total system analysis. Capillary trapping of a non-wetting fluid phase in the subsurface has been considered as an important mechanism for geologic storage of carbon dioxide. This mechanism can potentially relax stringent requirements for the integrity of cap rocks for CO_2 storage and therefore can significantly expand the range of candidate host rocks. We have applied ganglion dynamics to understand the capillary trapping of supercritical CO_2 ($scCO_2$) under relevant reservoir conditions. We show that, by breaking the injected $scCO_2$ into small disconnected ganglia, the efficiency of capillary trapping can be greatly enhanced, because the mobility of a ganglion is inversely dependent on its size. Supercritical CO_2 ganglia can be engineered by promoting CO_2-water interface instability during immiscible displacement, and their size distribution can be controlled by injection mode (e.g., water-alternating-gas) and rate. We also show that a large mobile ganglion can potentially break into smaller ganglia due to CO_2-brine interface instability during buoyant rise, thus becoming less mobile. The mobility of $scCO_2$ in the subsurface is therefore self-limited. Vertical structural heterogeneity within a reservoir can inhibit the buoyant rise of $scCO_2$ ganglia. The dynamics of $scCO_2$ ganglia we developed provides a new perspective for the security and monitoring of subsurface CO_2 storage. To evaluate the effectiveness of a geologic storage system, we have also developed a probabilistic total system performance assessment framework. With built-in optimization and Monte-Carlo simulation capabilities, this framework allows us to run a performance assessment model in both forward and inverse mode to support real-time site monitoring and operational optimization. Monitoring data can be continually fused into a performance assessment model through model inversion and parameter estimation. Model calculations can in turn guide the design of optimal monitoring and carbon-injection strategies (e.g., in terms of monitoring techniques, locations, and time intervals). The capabilities of this framework have been demonstrated with a hypothetical carbon storage system. The work presented here lays the foundation for the development of new generation performance assessment tools for effective management of carbon storage activities. Finally, I will provide a personal perspective for the future development of long-term geologic carbon storage.