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Understanding Trapping Mechanisms in CO_2 Sequestration by Reservoir Simulation

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CO_2 sequestration in deep saline aquifers is being considered as one method for reducing greenhouse gas concentration in the atmosphere. The method is found attractive because of the large storage capacity of the aquifers and long term entrapment of CO_2 that is induced by a variety of physical and chemical mechanisms. In this work we study the main mechanisms involved in the trapping process by using an equation-of-state compositional simulator capable of simulating fluid flow, geochemical, thermal and geomechanical aspects of the CO_2 sequestration in addition to dissolution of CO_2 into the aqueous phase.

The trapping mechanisms for CO_2 sequestration in deep saline aquifers are: (1) structural trapping, (2) solubility trapping, (3) residual trapping, and (4) mineral trapping. Structural trapping occurs due to the presence of structural closure and a seal in the form of an impervious cap rock, an unconformable surface or a sealing fault. Solubility trapping occurs due to dissolution of CO_2 into the aquifer brine at the prevailing conditions of pressure, temperature and salinity. Convective currents get established as the denser brine rich in CO_2 settles to the bottom part of the aquifer and the lighter brine with lesser CO_2 concentration tries to rise to the top of the aquifer. The process continues until a steady state is reached in the system. In active aquifers the CO_2-rich brine is displaced continually by fresh brine, thus promoting further dissolution of CO_2. Residual trapping is a consequence of a hysteresis effect in the relative permeability of the CO_2-rich gas phase that can occur due to reversal of the saturation direction. This paper shows how this kind of trapping mechanism can be accelerated. Mineral trapping is a consequence of conversion of injected CO_2 into ions and minerals caused by chemical equilibrium and mineral reactions. Although this is a long duration process it is considered to be the most secure trapping mechanism.

In this study we demonstrate the interaction of trapping mechanisms by carrying out a generic, high resolution simulation study to assess different scenarios of CO_2 sequestration. An element of symmetry of a quarter-five-spot pattern (Fig. 1) has been selected to model the process. We present the theoretical aspects in brief followed by a discussion of the simulation model and the results obtained from the evaluation of different trapping mechanisms. An optimization algorithm is used to show the workflow for maximizing the trapping indices.

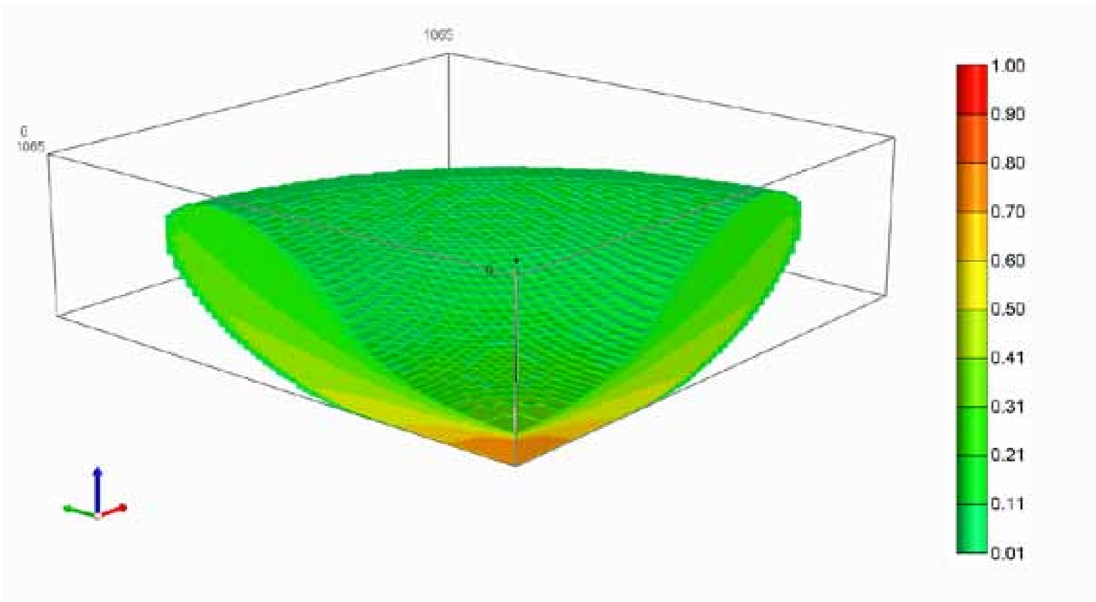

Fig. 1. Evolving residual gas trapping mechanism at the end of 5 years.

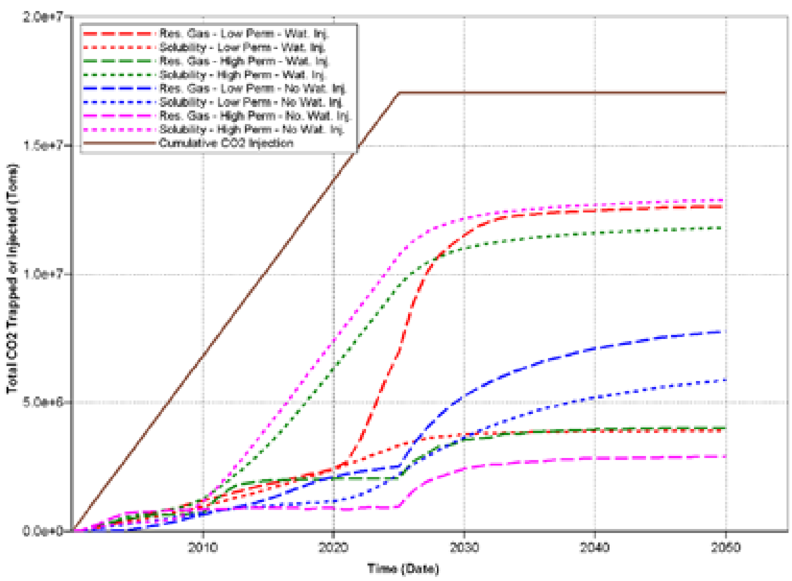

Fig. 2. Amount of CO_2 trapped due to residual and solubility trapping mechanisms.

Solubility trapping of CO_2 in brine is affected by pressure, temperature and salinity. Hysteresis in gas relative permeability promotes residual gas trapping which can be optimized by altering the injection system. We conclude that residual gas trapping and solubility trapping are competing storage mechanisms (Fig. 2). It is found that residual gas trapping is dominant in low-permeability aquifers while solubility trapping is dominant in high permeability aquifers. Geochemical reactions and mineral dissolution/precipitation kinetics are modeled to show the effect of mineral trapping in the CO_2 sequestration process.