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A coupled two-phase flow and transport model for CO_2 dissolution trapping in saline aquifer stimulated by gravitational instability

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Dissolution trapping of CO_2 in deep saline aquifers is very promising for long-term carbon geo-sequestration because the heavier mixture of CO_2 and brine migrates downward due to gravity. However CO_2 is injected in supercritical or liquid-phase, which may be much less dense than the brine. So in the early stage the injected supercritical $CO_2$is likely to move upward and may be of concern as the pressure in the overlying caprock may increase and possibly leak. Most existing studies on CO_2 dissolution consider single phase flow with a constant flux of CO_2at the top of the domain. These studies explore the downward migration of dissolved CO_2, associated gravitational instability, fingering and slumping. In other studies, fixed interfaces between CO_2 and brine were considered. The two phase studies either ignored the dissolution of CO_2 in brine or modeled dissolution with a pre-existing capillary transition zone in the reservoir. In the present study, we have modeled continuous injection of supercritical CO_2in the reservoir at a certain depth from the top boundary. This allowed the CO_2 to migrate in all possible directions. The numerical simulation of this problem is more challenging because it includes the effect of capillarity, dissolution, and diffusion of CO_2in brine, buoyancy driven flow, and gravitational instability.

We have performed numerical simulations for different injection rates, reservoir permeabilities, capillary entry pressures and pore size distributions. For higher injection rates, supercritical CO_2spreads in all directions because injection pressure is higher and it controls flow pattern. At very low injection rates, supercritical CO_2 predominantly moves upward due to buoyancy force and spreads laterally below the impermeable top boundary. The concentration of CO_2 in brine increases with time due to dissolution and diffusion. When the density of the solution becomes sufficiently large, a gravitational instability occurs and fingers form. After the onset of fingers, the ratio of dissolved CO_2 over injected mass of CO_2 grows rapidly. The shape and growth rate of fingers depends primarily on reservoir permeability, capillary entry pressure, and pore size distribution. The onset time of fingering is proportional to $k^{-0.85}$ where k is the reservoir permeability. The values of capillary entry pressure and pore size distribution control the thickness of capillary transition zone. In case of higher capillary entry pressure (p_{c0}) and narrowly distributed pore (larger van Genuchten exponent, n), supercritical CO_2 saturation front is flat and dissolved CO_2concentration front travel faster. Subsequently the fingering pattern is also affected by $p_{c0}$and n. capillary entry pressure and pore size distribution. However the onset time of fingering is very less sensitive to $p_{c0}$and n.