Geophysical Research Abstracts
Vol. 16, EGU2014-2271, 2014
EGU General Assembly 2014

CO_2 exsolution – challenges and opportunities in subsurface flow management

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In geological carbon sequestration, a large amount of injected CO_2 will dissolve in brine over time. Exsolution occurs when pore pressures decline and CO_2 solubility in brine decreases, resulting in the formation of a separate CO_2 phase. This scenario occurs in storage reservoirs by upward migration of carbonated brine, through faults, leaking boreholes or even seals, driven by a reverse pressure gradient from CO_2 injection or ground water extraction. In this way, dissolved CO_2 could migrate out of storage reservoirs and form a gas phase at shallower depths. This paper summarizes the results of a 4-year study regarding the implications of exsolution on storage security, including core-flood experiments, micromodel studies, and numerical simulation.

Micromodel studies have shown that, different from an injected CO_2 phase, where the gas remains interconnected, exsolved CO_2 nucleates in various locations of a porous medium, forms disconnected bubbles and propagates by a repeated process of bubble expansion and snap-off [Zuo et al., 2013]. A good correlation between bubble size distribution and pore size distribution is observed, indicating that geometry of the pore space plays an important role in controlling the mobility of brine and exsolved CO_2. Core-scale experiments demonstrate that as the exsolved gas saturation increases, the water relative permeability drops significantly and is disproportionately reduced compared to drainage relative permeability [Zuo et al., 2012]. The CO_2 relative permeability remains very low, 10-5$\sim$10-3, even when the exsolved CO_2 saturation increases to over 40%. Furthermore, during imbibition with CO_2 saturated brines, CO_2 remains trapped even under relatively high capillary numbers (uv/$\sigma\sim$10-6) [Zuo et al., submitted]. The water relative permeability at the imbibition endpoint is 1/3$\sim$1/2 of that with carbonated water displacing injected CO_2.

Based on the experimental evidence, CO_2 exsolution does not appear to create significant risks for storage security. Falta et al. [2013] show that if carbonated brine migrates upwards and exsolution occurs, brine migration would be greatly reduced and limited by the presence of exsolved CO_2 and the consequent low relatively permeability to brine. Similarly, if an exsolved CO_2 phase were to evolve in seals, for example, after CO_2 injection stops, the effect would be to reduce the permeability to brine and the CO_2 would have very low mobility.

This flow blocking effect is also studied with water/oil/CO_2 [Zuo et al., 2013]. Experiments show that exsolved CO_2 performs as a secondary residual phase in porous media that effectively blocks established water flow paths and deviates water to residual oil zones, thereby increasing recovery.

Overall, our studies suggest that CO_2 exsolution provides an opportunity for mobility control in subsurface processes. However, the lack of simulation capability that accounts for differences between gas injection and gas exsolution creates challenges for modeling and hence, designing studies to exploit the mobility reduction capabilities of CO_2 exsolution. Using traditional drainage multiphase flow parameterization in simulations involving exsolution will lead to large errors in transport rates. Development of process dependent parameterizations of multiphase flow properties will be a key next step and will help to unlock the benefits from gas exsolution.

ACKNOWLEDGEMENT

This work is funded by the Global Climate and Energy Project (GCEP) at Stanford University. This work was also supported by U.S. EPA, Science To Achieve Results (STAR) Program, Grant #: 834383, 2010-2012.

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