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THE IMPACT OF LOCAL-SCALE PROCESSES ON LARGE-SCALE CO_2 MIGRATION AND IMMOBILIZATION

Sarah E. Gasda[*], Jan M. Nordbotten[†] and Michael A. Celia[††]

[*] Environmental Sciences and Engineering,
University of North Carolina at Chapel Hill, Chapel Hill, NC 27599 USA
e-mail: sgasda@unc.edu

[†] Department of Mathematics,
University of Bergen, Bergen, Norway

[††] Department of Civil and Environmental Engineering,
Princeton University, Princeton, NJ 08544 USA

Summary. Storage security of injected carbon dioxide (CO_2) is an essential component of risk management for geological carbon sequestration operations. During the injection and early post-injection periods, CO_2 leakage may occur along faults and leaky wells, but this risk may be partly managed by proper site selection and sensible deployment of monitoring and remediation technologies. On the other hand, long-term storage security is an entirely different risk management problem—one that is dominated by a mobile CO_2 plume that may travel over very large spatial and temporal scales before it is trapped by different physical and chemical processes. In the post-injection phase, the mobile CO_2 plume migrates in large part due to buoyancy forces, following the natural topography of the geological formation. The primary trapping mechanisms are capillary and solubility trapping, which evolve over thousands to tens of thousands of years and can immobilize a significant portion of the mobile, free-phase CO_2 plume. However, both the migration and trapping processes are inherently complex, involving a combination of small and large spatial scales and acting over a range of time scales. Solubility trapping is a prime example of this complexity, where small-scale density instabilities in the dissolved CO_2 region leads to convective mixing that has that has a significant effect on the large-scale dissolution process over very long time scales. Another example is the effect of capillary forces on the evolution of mobile CO_2, an often-neglected process except with regard to residual trapping. As the plume migrates due to buoyancy and viscous forces, local capillary effects acting at the CO_2-brine interface lead to a transition zone where both fluids are present in the mobile state. This small-scale effect may have a significant impact on large-scale plume migration as well as long-term residual and dissolution trapping. Using appropriate models that can capture both large and small-scale effects is essential for understanding the role of these processes on the long-term storage security of CO_2 sequestration operations.

There are several approaches to modeling long-term CO_2 trapping mechanisms. One modeling option is the use of traditional numerical methods, which are often highly sophisticated models that can handle multiple complex phenomena with high levels of accuracy. However, these complex models quickly become prohibitively expensive for the type of large-scale, long-term modeling that is necessary for risk assessment applications such as the late post-injection period. We present an alternative modeling option, the VESA model, that combines vertically-averaged governing equations with an upscaled representation of the dissolution-convective mixing process and the local capillary transition zone at the CO_2-brine interface. With this modeling approach, we demonstrate the effect of different modeling choices associated with dissolution and capillary processes for typical large-scale geological systems.