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Multiple scale physical and numerical modeling for improved understanding of mechanisms of trapping and leakage of CO_2 in deep geologic formations

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The fundamental processes associated with trapping and leakage of CO_2 in deep geologic formations are complex. Formation heterogeneity manifested at all scales is expected to affect capillary and dissolution trapping and leakage of gaseous CO_2 to the shallow subsurface. Research is underway to improve our fundamental understanding of trapping and leakage. This research involves experimentation in multiple scales and modeling focusing on effects of formation heterogeneity. The primary hypothesis that drives this research is that when the effects of heterogeneity on entrapment and leakage are understood, it will be possible to design more effective and safe storage schemes. Even though field investigations have some value in understanding issues related to large scale behavior and performance assessment, a fundamental understanding of how the heterogeneity affects trapping is difficult or impossible to obtain in field settings. Factors that contribute to these difficulties are the inability to fully characterize the formation heterogeneity at all scales of interest and lack of experimental control at very high depths. Intermediate scale physical model testing provides an attractive alternative to investigate these processes in the laboratory. Heterogeneities can be designed using soils with known properties in test tanks and the experiments can be conducted under controlled conditions to obtain accurate data. Conducting laboratory experiments under ambient pressure and temperature conditions to understand the processes that occur in deep formations poses many challenges. This research attempts to address such challenges and demonstrates how this testing approach could be used to generate useful data. The experiments involve the use of test systems of hierarchy of scales from small to intermediate scale tanks ($\sim$ 5 m) and long columns ($\sim$ 4.5 m). These experiments use surrogate fluids to investigate both capillary and solubility trapping in homogeneous and heterogeneous systems. A traversing x-ray scanning system is used to monitor the advancement of the plume during and after injection and to measure the residual (trapped) CO_2 saturation. Dissolution of a surrogate non-wetting fluid in a surrogate wetting fluid is analyzed in small and large tanks. We test the numerical models that are capable of simulating two-phase flow and density driven flow as a result of dissolution by using the experimental data. Verified models are used to further evaluate the effect of capillary and solubility trapping in complex heterogeneous environments. During leakage, under different pressure and temperature conditions, dissolved CO_2 may come back out of solution (exsolve), but the fundamental triggering mechanisms of this process in porous media are not yet well understood. An extensive series of column experiments has been conducted to investigate the factors that control the rates of CO_2 gas bubble nucleation, growth, and migration. Results indicate that the saturation pressure (i.e. the amount of CO_2 dissolved into the injected water) and heterogeneity both significantly affect the gas formation and migration, whereas the injection rate has less of an effect. These column experiments will soon be upscaled to an intermediate-scale two-dimensional tank to investigate the behaviour of the CO_2 gas-water-soil system in more complex geological environments.