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A fundamental study of migration an entrapment of supercritical CO2 in heterogeneous deep geologic formations: intermediate scale testing and modeling

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Geological storage of carbon dioxide in deep geologic formations is being considered as a technical option to reduce greenhouse gas loading to the atmosphere. The processes associated the movement and stable trapping are complex in deep naturally heterogeneous formations. Three primary mechanisms contribute to trapping; capillary entrapment due to immobilization of the supercritical fluid CO2 within soil pores, liquid CO2 dissolving in the formation water and mineralization. Natural heterogeneity in the formation is expected to affect all three mechanisms. The primary goal of the research presented here is to improve our understanding of capillary and dissolutions trapping during injection and post-injection process, focusing on formation heterogeneity. This knowledge will also help to develop site characterization methods targeting on capturing the most critical parameters that captures the heterogeneity to design strategies and schemes to maximize trapping. The primary hypothesis that drives this research is that when the effects of heterogeneity on trapping are understood, it will be possible to design more effective storage strategies. It is our contention that a fundamental understanding of how the heterogeneity affects trapping is difficult or impossible to obtain in real field settings in deep formations. A number of factors contribute to these difficulties, primarily of which are the inability to fully characterize the formation heterogeneity at all scales of interest from pore to large scale and lack of experimental control at very high depths. Intermediate scale testing provides an attractive alternative to investigate these processes under controlled conditions 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 for process understanding and modeling. Conducting laboratory experiments under ambient pressure and temperature conditions to understand the processes that occur in deep formations with much higher pressures and drastically different temperatures pose challenging questions. The experimental plan that is proposed involves the use of test systems of hierarchy of scales from small to intermediate scale tanks under homogeneous and various heterogeneous packing configurations. This paper presents results from analysis from a set of experiments that was conducted in a small test tank as a preliminary step to future experiments that will be conducted in large test tanks. The goal is to develop experimental methods and obtain data that will be used as benchmark for more complex experiments conducted under different heterogeneous packing configurations and injection scenarios in a 4.8 m long tank. A part of development of experimental methods includes the selection of surrogate test fluids that can be used in the laboratory under ambient temperatures and pressures. The approach involves the use of dimensionless numbers such as Capillary number (Ca) and the Bond number (Bo) to extrapolate the data to conditions that occur in the field under high temperatures and pressures in deep geologic formations. Methods are also developed to measure the entrapment saturations using x-ray attenuation methods that we have used in our past research in multiphase fluid behavior in heterogeneous media. The modeling analysis to verify whether existing models can capture the observed processes was carried out using TOUGH2/ECO2N codes developed by the Lawrence Berkeley National Laboratory. The results of these model analyses are presented.