Measurements for two- and three-phase flow systems have shown that the counter-current mobility of all phases is less than the corresponding co-current values. However, in numerical calculations for subsurface flows, e.g. CO$_2$ injection into saline aquifers, one set of mobility functions (drainage–imbibition) is commonly assigned to both phases that are based on co-current flow observations. In this study, we combine experimental observations and displacement calculations to investigate the impact of mobility reductions during counter-current flow on the migration dynamics of CO$_2$ that is injected into the subsurface for storage purposes. We investigate the migration dynamics of CO$_2$ that is injected from a vertical well into a heterogeneous domain with variable correlation in the permeability. It is observed that during the injection period, counter-current flow is a dominant flow mode in the vertical migration of CO$_2$, while flow in the horizontal direction is primarily co-current. Explicit representation of transitions between co-current and counter-current fluid mobility based on the prevailing flow mode results in an increase in the residual entrapment of CO$_2$. The relative increase in the fractional entrapment of CO$_2$ depends on the ratio of the average vertical to horizontal permeability of the formation. We present a series of counter-current gravity segregation experiments performed in a vertical glass-bead pack with brine and iC$_8$ as analog fluids. Four-electrode resistivity measurements are used to monitor the migration of the non-wetting phase by relating the resistivity index (RI) to the brine saturation. The observations are compared with numerical calculations to demonstrate that co-current mobility functions, that were measured directly, are inadequate to reproduce the experimental observations. A reduction in the mobility of both phases is required to improve the agreement between experimental observations and numerical calculations. Our study clearly indicates that both co-current and counter-current mobility functions must be used in the prediction of CO$_2$-Brine displacement processes to delineate the migration of a CO$_2$ plume properly and further promote effective design and risk assessment frameworks for storage projects.

Speaker Bio
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