XVIII International Conference on Water Resources
CMWR 2010
J. Carrera (Ed)
CIMNE, Barcelona 2010

THE BUOYANT RISEOF CO_2 &TWO-PHASE GRAVITY CURRENTS

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Summary. Seismic images of geological CO_2 storage show the rise of CO_2 is influenced by horizontal flow barriers. The large number and small scale of these barriers makes the prediction of the CO_2 migration path and hence the magnitude of CO_2 trapping very challenging. We present experimental and theoretical results for a simple model problem, where buoyant CO_2 spreads beneath impermeable barriers as a gravity current until a gap allows its upward migration. We show that steady buoyancy dominated flows in complex geometries can be modeled as a cascade of flux partitioning events, and analyze the two-dimensional plume dispersal from a horizontal injection well. The plume spreads laterally with height y above the source according to $(y/h)^{1/2} L$, where L is the width of the shales and h is their vertical separation. The fluid volume below successive shale layers, and therefore the magnitude of trapped CO_2, increase as $(y/h)^{5/4}$ above the source. Upscaling small scale flow barriers through by reducing the vertical permeability, common in numerical simulations of CO_2 storage, does not capture the dispersion and trapping of the CO_2 plume by the flow barriers.

The partitioning of the flux around a horizontal flow barrier is determined by a steady two-phase gravity current. We derive a gravity current model from the fractional flow theory under the assumption large aspect ratio, so that the current is driven by gradients in hydrostatic pressure. We also assume that the saturation profile is given by vertical gravity-capillary equilibrium. The saturation profile in combination with the relative permeability determines the dynamics of the two-phase current. The two-phase model improves estimate of the vertical sweep of the two-phase current, and the flux partitioning across the barriers. The saturation distributions within the current allow improved estimates of residual CO_2 saturations via the Land trapping model.

This two-phase model provides an important improvement over previous sharp-interface models and provides the groundwork to effective and efficient characterization of storage reservoirs and promise to illuminate the underlying physical processes governing the propagation of sequestered CO_2 in the subsurface.