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Development of density plumes of dissolved CO_2: Comparing experimental observations with numerical simulations

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The long-term trapping of CO_2 within deep geological storage reservoirs will be dependent upon CO_2-water-rock geochemical reactions. The first, and most important, steps in this process will be dissolution of CO_2 into the reservoir porewater and the transport of this dissolved CO_2 through the reservoir. As part of the CO_2CARE project we have investigated these via laboratory tests using a water-filled porous medium. Key experimental parameters were measured to determine system permeability, so that a high-resolution numerical model could be built in an attempt to reproduce the observed system behaviour.

The Hele-Shaw cell comprised two glass sheets 65 cm wide and 36 cm high, separated by a spacing of 1.1 mm, and filled with closely-packed glass beads 0.4-0.6 mm in diameter. The surface of the glass was treated to prevent the formation of a higher permeability zone along this interface. A pH-sensitive dye was added to the pore-filling water to show where it had been acidified due to the presence of CO_2.

CO_2 gas was introduced to a space at the top of the cell, which created a thin, diffusion-controlled boundary layer of CO_2-rich water below the CO_2-water interface. CO_2 dissolution increased water density, resulting in gravitational instabilities and the formation of many small, downward-migrating plumes. Time-lapse photography was used to track the formation and progress of these plumes. As the plumes grew they increased in length relative to their width, and decreased in number over time. They also became more complex with time, splitting and forming several lobes, whose outer edges became more diffuse as they mixed with the CO_2-poor water.

The onset time of plume development and the horizontal wavelength (spacing) of the descending plumes are diagnostic measures of the system properties, notably permeability. They were analysed from the time-lapse images and expressed as probability density functions based on histograms of the observations. The derived permeability of the system was calculated to be 2.2-2.5 x 10-9 m^2, and this used for modelling work.

Having experimentally reproduced the transition from diffusion-dissolution to convection-dissolution, and from this determined the system properties, we simulated the process in a numerical flow model. A high resolution model of the Hele-Shaw cell was built using the TOUGH2 flow simulator with the ECO 2N fluid property module, with a permeability of 2.5 x 10-9 m^2, and applying laboratory pressure and temperature conditions.

Plume development in terms of onset time, sinking rate and wavelength statistics are closely comparable between experiment and model. This suggests therefore that the numerical flow simulator was able to reproduce the critical process of transition from diffusion-dominated to convection-dominated processes in a realistic way. This further increases our confidence in the suitability of numerical models in making predictions of system evolution within CO_2 storage schemes.