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Real time micro-CT imaging of gas-gas mixing in the presence of brine

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Hydrogen storage in depleted gas fields is being explored to store large-scale excess renewable energy and alleviate fluctuations in energy demand. The mixing of injected hydrogen with residual natural gas, and the purity of the produced gas stream is controlled by pore-scale mechanisms such as gas-gas mixing through diffusion, dispersion and advection, and large-scale features such as the caprock structure, permeability and brine distribution. The coupled mixing process in partially saturated media is poorly understood.

To this end, we probe the pore-scale mixing of hydrogen in depleted gas fields through time-resolved, two-component, two-phase X-Ray micro-CT experiments in a sandstone rock sample. To resolve the pore-scale gas concentration fields, we use krypton and nitrogen as analogues for natural gas and hydrogen, respectively. The analogue fluids have comparable flow dynamics to their reservoir counterparts (Mobility ratio, Capillary, Bond and Peclet number), but crucially at high pressure, krypton is highly attenuating to X-rays compared to nitrogen. Using the EMCT scanner at Ghent University, we could resolve the relative gas concentrations with a 12-micron spatial resolution and 40-second temporal resolution in a 6 mm diameter sample.

We performed core flood experiments at elevated pressure and temperature, tracking the gas-gas mixing and brine displacement. To mimic the field-scale process, we setup a residual trapped krypton sample (i.e. a depleted gas field), then injected nitrogen (i.e. hydrogen storage) followed by a period of back-production (i.e. hydrogen production), whilst dynamically imaging the core. We performed three experiments, with varying saturation and connectivity of the initial krypton distribution to mimic different field conditions. For the first-time, we were able to visualise and quantitatively analyse the mixing of binary gases in the pore-space, in both connected gas regions, and residually trapped regions. We captured the interplay between advection and diffusion, as well as the simultaneous displacement of brine by both gases. We observed connectivity limited mixing, whereby the connectivity of the gas phase limited the diffusive mixing of the gases, which could play an important role in the field-scale recovery process. We link the mixing statistics to both single and multiphase measures, elucidating the key controls on multi-component multi-phase mixing.

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References

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