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Single-well and inter-well dual-tracer test design for quantifying phase volumes and interface areas in subsurface flow and transport systems

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Technology-relevant georeservoirs in the realm of energy production (such as: spent-radionuclide repositories, gas-storage, geothermal, as well as CCS candidate reservoirs) contain mobile and immobile fluid regions, and often also different fluid and solid phases. The lifetime of a particular reservoir (from a hydraulic, thermal, geomechanical and/or hydrogeochemical point of view) depends on the volumes and/or interface areas of some of these regions and/or phases. Mostly, their lifetime-effective values cannot be measured by geophysical and hydraulic methods. Since they essentially relate to fluid-based transport processes, attempting to measure them by tracer tests is a sensible endeavour. However, in designing and dimensioning such tracer tests, one should keep in mind that not every tracer test is sensitive w. r. to every fluid transport parameter. A certain complementarity exists, w. r. to parameter sensitivity,

- between single-well and inter-well methods,
- between equilibrium and kinetic exchange processes,
- between volume and area parameters.

Mobile-fluid volumes can be measured from inter-well conservative-tracer tests, whereas single-well push-pull tests are generally insensitive w. r. to mobile-fluid volumes.

Immobile-fluid volumes, in single-phase systems, are rather difficult to measure, by either kind of test. Different-phase volumes can be determined from inter-well tests using partitioning tracers at equilibrium exchange between phases; whereas single-well tracer push-pull tests are rather insensitive w. r. to tracer exchange processes at equilibrium.

Im-/mobile fluid, or inter-phase interface areas can be determined from single-well tracer push-pull tests relying on kinetic exchange processes between compartments or phases. Single-well tests are often believed to be more sensitive w. r. to such processes than w. r. to advective-dispersive processes, and than inter-well tests.

Inter-well tests are not physically insensitive w. r. to kinetic exchange processes, but they are strongly affected by ambiguity between dispersion and non-advective non-equilibrium processes. (Actually, this ambiguity also impedes upon single-well tests.)

An interesting compromise between the advective- or equilibrium-dominated parameter sensitivity regimes, and the advection- or equilibrium-insensitive regimes is obtained when using *in-situ tracer creation in a time-dependent manner* (from another initially-injected tracer with different phase-partitioning properties), as had been originally proposed by [1] for determining residual-oil saturations.

The poster presents a model set-up enabling to directly compare the sensitivities of the different tracer-test methods w. r. to the different parameters for a given system, and to reshape the concept of [1], from its originally intended oilfield application, to a possible new application for CCS site characterization.

We illustrate the latter by simulating such dual-tracer tests for the pilot site of a CCS-related 'MMV Experiment' (Measuring, Monitoring, Verification) at Heletz in Israel. The target storage formation at Heletz is assumed to consist of a number (3–6) of permeable sandstone layers (with porosities $\sim$12–17%) separated by shale layers (with porosities $\sim$3–5%), whose permeabilities contrast by factors $\sim 10^3$–10^4. While single-well tracer tests are rather insensitive w. r. to porosity and permeability stratification details, they can yield information about gas-phase saturations and gas-brine interface densities within selected layers; using the in-situ creation of a dual tracer in the sense of [1], the sensitivity of single-well tests in the low-saturation (residual-saturation) range can be enhanced significantly. A inter-well conservative-tracer test, with depth-resolved monitoring at the 'arrival' well (as intended

at the Heletz site), can additionally yield the effective-porosity profile, which can be used to better constrain the single-well test inversion. With bulk (not depth-resolved) tracer monitoring, a inter-well conservative-tracer test still yields very valuable information, which can be poured into the shape of a flow-storage repartition[2],[3]. Furthermore, considering a CO_2 plume with the radius–thickness relationship derived by [4], and 'integrating' it 'over' the particular-site stratigraphy, with the 'weighting' defined by the flow-storage repartition (cumulative distribution function for q against $B\phi$) that was derived from the inter-well, conservative-tracer test, we get:

$$A\,(\,t\,,\theta^{\circ}) \;\approx\; (t/\pi)^{1/2} \times [\,\mu(\theta^{\circ}) + 1/\mu(\theta^{\circ})\,] \times \Sigma_i\,(q_i B_i/\phi_i)^{1/2}\;,$$

from which the evolution of CO_2–brine interface areas (A) during early injection regimes (immiscible displacement) can roughly be estimated as a function of time t and temperature θ°, with $\mu(\theta^{\circ})$ denoting the mobility ratio between CO_2 and brine (mobilities being taken at each one's saturation).

The comparison of CO_2 plume volumes and CO_2–brine interface areas predicted for the Heletz MMV experiment under different stratigraphy assumptions demonstrates the importance of brine-phase (single-phase!), conservative-tracer tests for characterizing the 'transport-effective hydrogeology' of a candidate CCS site, prior to initiating any experiments involving a CO_2 phase.

References:

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