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Dual-tracer, single-well push-pull method for determining fluid-rock interface densities in geo-reservoirs

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Whenever dealing with fluids in geo-reservoirs, it is likely that their residence times (in sub-systems or compartments of interest) and fluid-rock interface densities will play some, often significant role. In particular,
(a) the reservoir size or transport-effective porosity (as resulting from fluid residence time averaging),
(b) reservoir heterogeneity (as expressed by fluid residence time distributions), and
(c) fluid-rock interface densities (area-per-volume ratios)
represent controlling parameters in geo-technical applications like deep-ground waste disposal, CO2 capture and sequestration (CCS), geothermal energy extraction, or spent radionuclide depositing.
To quantify (a), (b) and (c), fluid spikings (tracer tests) provide the method of choice. Hydraulic and geophysical methods cannot provide good access to fluid transport parameters, because the signals they detect do not essentially correlate with fluid motion, nor with material fluxes through rock surfaces.

In the context of CCS, tracer tests are not only indispensable for candidate site assessment and characterization, but also potentially useful for intra- and post-injection monitoring purposes. For instance:
(i) single-phase conservative tracers with well-defined diffusion and sorption properties enable to determine single-phase fluid residence times and fluid-rock interface densities;
(i') liquid-phase tracers added closely before CO2 injection enable to quantify the displacement of native reservoir liquids by the CO2 plume;
(ii) conservative tracers partitioning between two fluid phases enable to determine phase interface areas or the volume of one of the phases;
(iii) reactive tracers with specific milieu-dependencies of their reaction rates enable to assess temperature, pH, redox potential values or other physico-chemical parameters along their flow path.

In contrast with seismic, geophysical and hydraulic methods, the use of tracer tests for characterizing deep geo-reservoirs, and especially the use of single-well spikings is rather new in Germany. Elsewhere worldwide, single-well injection-withdrawal (SWIW) techniques have been used for various practical and theoretical purposes in sub-surface investigations: for determining residual oil saturations (Tomich et al. 1973), in-situ biodegradation and/or sorption rates (Istok et al. 1997, Schroth et al. 2001), heat exchange parameters (Kocabas and Horne 1987), for quantifying multi-rate diffusion in heterogeneous porous media (Haggerty et al. 2001), important aspects of SWIW test interpretation being analyzed by Neretnieks (2007).

We present the development and application of dual-tracer techniques for determining fluid-rock interface densities in multi-porous media. The single-well, tracer push-pull procedure was found to be particularly suited for reducing the ambiguity of determination between advective-dispersive and non-advective parameters, when natural flow is negligible compared to applied forced-gradient flows. The SWIW procedure can be designed both as a 'dual-tracer' and as a 'dual-scale' method:

(A) using solute tracer pairs with different diffusion and/or sorption coefficients enables to characterize fluid-rock interface densities at scales comparable to that of hydrodynamic dispersion;

(B) using solutes and heat as a tracer, effective interface densities can be quantified at different scales across the flow direction;

(C) using either comparable tracers with different fluid flushing ('push') volumes allows to characterize transport at different scales along the flow direction (sufficient 'pull' volume provided).

We illustrate the application of these principles with results from deep geo-reservoir testings in Germany.

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