SINGLE-WELL AND INTER-WELL TRACER TEST DESIGN FOR CCS PILOT SITE ASSESSMENT (HELETZ, ISRAEL)

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The Heletz site in Israel was chosen for conducting a CO_2 transport experiment within the MUSTANG project [1], whose aim is to demonstrate and validate leading-edge techniques for CCS site characterization, process monitoring and risk assessment. Relevant physical, hydro-geological and hydrogeochemical features of the Heletz site, as were determinable prior to drilling and testing new wells, are described under [2].
The major CO_2 injection experiment at Heletz is to be preceded and accompanied by a sequence of single-well and inter-well tracer tests, aimed at characterizing

- transport properties of the storage formation, following principles described in [3], [4],
- CO_2 – brine – rock interface processes, following ideas proposed by Licha et al. [5].

Generally, **inter-well tracer tests** are used to determine fluid residence time distributions (RTD); 'statistical' moments of RTDs provide important information about the reservoir:

- the zeroth-order RTD moment can tell something about *reservoir boundaries*;
- the first-order RTD moment, or mean residence time (MRT) represents a measure of *reservoir size* (the reservoir volume that can be used for fluid storage, under a certain injection regime);
- higher-order RTD moments provide information about *reservoir heterogeneity*; traditionally, the 2nd-order moment is associated with flow-path dispersion (from hydrodynamic up to reservoir scale); from RTD analysis also a flow-storage repartition (FSR) can be derived, which is sometimes interpreted as representing *reservoir shape* (cf. Shook [6]), with certain limitations when matrix diffusion or kinetic exchange processes become important (as analyzed in [3]).

Complementarily, **single-well tracer push-pull tests** are used to quantify processes other than advection-dispersion: typically, the exchange of some extensive quantity (mass, energy) between fluid and solid/fluid phases by processes like matrix diffusion or sorption/partitioning, whose rate or amount depends on the density (area per volume) of involved fluid/rock interfaces. Flow-field reversal during the 'pull' phase is supposed to largely compensate the effects of flow-path heterogeneity (excepting the hydrodynamic level), and to enhance the effects of tracer exchange processes at fluid/rock interfaces, thus enabling to quantify interface densities from measured tracer return signals; yet this depends on whether the fluid volumes and flow/shut-in durations used in the push-pull test match the system's homogeneity scale and the (a priori unknown) bulk exchange rates. The sensitivity of tracer signals w. r. to interface densities depends upon the type of process that dominates at the space-time scale of the experiment, which can be:

- fast-equilibrium sorption or partitioning between phases,
- kinetic exchange, or matrix diffusion with high diffusivity (typical for heat exchange in fractured hard-rock aquifers),
- slow interface reactions, or matrix diffusion with low diffusivity (typical for most solutes in most rocks, and for heat exchange in unconsolidated, high-porosity aquifers).

At the Heletz site, four tracer tests will be conducted:

1. prior to CO_2 injection: dual-tracer single-well push-pull test (monopole divergent followed by convergent flow field), using several tracers with contrasting sorption and diffusion properties, aimed at characterizing fluid-rock interfaces and estimating fluid-rock interface densities (also serving as an aid in tracer species selection, dimensioning and instrumentation for all subsequent tests);
2. prior to CO_2 injection: brine-phase dual-tracer inter-well circulation test (forced-gradient, divergent-convergent dipole flow field), using two tracers with contrasting sorption or diffusion properties, aimed at estimating storage reservoir size, determining brine RTD and FSR, characterizing reservoir-scale heterogeneity;
3. prior to the main CO_2 transport experiment, but including small-sized CO_2 slugs: dual-tracer, single-well multiple-push of alternating brine/CO_2 slugs, followed by prolonged push stage, using single-phase tracers as well as phase-partitioning tracers, aimed at dynamic characterization of CO_2-brine-rock interfaces, as proposed by Licha et al. [5];
4. during the main CO_2 transport experiment: dual-tracer, inter-well injection-extraction test (forced-gradient, divergent-convergent dipole flow field), using single-phase tracers as well as phase-partitioning tracers, aimed at quantifying the storage capacity, characterizing brine displacement processes, and determining RTD and FSR under two-phase flow conditions.

The poster explains the design and dimensioning of the first, second and fourth tracer test. Unlike the brine-phase spiking we conducted at the Ketzin site in Germany [7], where only passive sampling was possible (yielding so-called 'resident' values of tracer concentration, inconsistent with the reservoir-scale transport equations), the Heletz experiment offers the advantage of fluid extraction at well-defined rates, rendering measured values of tracer concentrations (actually, tracer fluxes) consistent with the transport equations from which parameter inversion is endeavoured. Forced-gradient extraction of fluid is not meant to be representative of how a CCS site would be operated in reality, but it ensures the meaningfulness of measured experiment quantities. The MUSTANG experiment were not worthwhile being conducted just to see 'when' CO_2 will arrive in a certain distance; its aim is not to mimic CCS, but to quantify transport processes, which is not possible without well-defined fluid and solute fluxes. Moreover, fluxes measured at one borehole should reflect reservoir-scale fluid motion, and not just wellbore-scale flow gradients induced by the particular device used to collect fluid samples.

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