Tracer-assisted evaluation of hydraulic stimulation experiments in deep crystalline and sedimentary formations in Germany

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Heat and solute tracer tests accompanying fluid injection experiments can provide additional information on transport properties like fluid velocities and fluid-rock contact surface areas, which are not reflected by pressure signals. This is illustrated for long-term (1a) and short-term (1b) moderate-rate hydraulic stimulations in crystalline formations, as well as for a short-term, high-rate hydrofracturing (2a) and for the design of a sequence of short-, mid- and long-term hydraulic tests following hydrofracturing (2b) in sedimentary formations:

(1a) at the pilot KTB hole (German 'Kontinentale Tiefbohrung' in Bavaria), about 85,000 m^3 of cold water (of which the first 22,000 m^3 to compensate abstractions by earlier pumping test) were injected at rates up to 3.3 l/s over 1 year into a highly-permeable fracture system in 4 km deep crystalline, with the aim of basic research into injection-induced, coupled THM processes in large-scale fault systems of suspected extreme heterogeneity. Heat and solute push-pull tests repeated at similar volume scales before/after injection helped quantify the THM-induced change of fluid-rock contact-surface per-volume areas. Several post-injection heat and tracer push-pull tests conducted at different volume scales provide information on fracture heterogeneity. Late tracer recoveries lower than expected suggest a large-scale drift away from the pilot hole;
(1b) at the Urach pilot HDR site, a tracer push-pull test conducted at the end of a short-term stimulation revealed the gradual change in total fracture appertures and specific surface areas;

(2a) at the pilot geothermal borehole Horstberg in the N-German sedimentary basin, over 20.000 m^3 of cold water were injected at rates up to 15 l/s in 3.8 km depth with the aim of connecting 2 sandstone horizons by a hydrofrac induced in the separating clayey sandstone formation, supposed to provide the basis for a innovative, economical single-well technique of geothermal energy extraction. A multi-tracer slug was added before the last 1.800 m^3 injected into the lower horizon, and the tracer breakthrough curves recorded with the 3.600 m^3 fluid produced from the upper horizon (divergent flow field) enabled estimating the transport properties of the established flow path: fluid residence time (reservoir size), approximate fluid-rock contact-surface area. After 1.5 year shut-in, tracer BTCs recorded during short-term production phases from both the upper (flow-path) and the lower (push-pull) horizon in the still highly-pressurized system provided further information on fluid-rock contact-surface areas in both horizons and transport property changes;
(2b) for the series of hydraulic tests planned by the GFZ Potsdam in 4 km deep sandstone and vulcanite formations at Gross Schoenebeck as of 2007, it is shown how spiking the injected fluid by different tracers at 5 different stages of the test sequence can aid in characterizing the heterogeneous reservoir at different scales.

Tritiated water and 1,5-naphthalene disulfonate, used as tracers in (1a), (1b) and (2a), showed similar transport properties, with differences attributable to matrix diffusion only.