Geophysical Research Abstracts
Vol. 16, EGU2014-8150, 2014
EGU General Assembly 2014
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Tracer-based quantification of individual frac discharge in single-well multiple-frac backflow: sensitivity study

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Within the deep-geothermal research project at GroßSchönebeck in the NE German Basin, targeting volcanic rocks (Lower Rotliegend) and siliciclastics (Upper Rotliegend) in the Lower Permian by means of a well doublet with several screening intervals between 3815 and 4247 m b.s.l., several artificial fractures with different geometric and hydraulic characteristics were created at each well, aiming to increase reservoir performance [1], [2].

It could not be told a priori which of the various fracturing treatments was to prove as most promising in terms of future reservoir productivity. At the intended-production well (GS-4), one large-area waterfrac was created in the low-permeability volcanic rocks, and two gel-proppant fractures in selected sandstone layers. Each fracturing treatment was accompanied by the injection of a water-dissolved tracer slug, followed by a defined volume of tracer-free ('chaser') fluid [3]. Each frac received a different species of a sulfonated aromatic acid salt, as a conservative water tracer. During subsequent backflow tests (either gas-based lifting, or production by means of a downhole submersible pump), each frac can contribute a certain (more or less constant) amount to the measured total discharge (also depending on whether and when each frac 'starts' contributing, and which effective aperture and area it actually 'manifests' during the process). Since these individual-frac discharge amounts cannot be measured directly, it was endeavoured to indirectly determine ('resolve') them from tracer signals as detectable in the overall backflow discharge.

Therefore, we need to examine how these tracer signals depend on local discharge values and on local hydrogeologic parameters (matrix porosity, permeability distribution; frac transmissivity, thickness, effective area and aperture), and to what extent hydrogeological uncertainty will impede the inversion of local discharge values.

To this end, a parameter sensitivity study was conducted on a simplified flow and tracer transport model (using FEFLOW and assuming Darcian flow within the matrix, Hagen-Poiseuille flow within the waterfrac, and either D or H-P flow within the gel-proppant fracs), whose main findings are:

(1) late tracer signals are almost independent on matrix porosity, permeability distribution, frac area (length), thickness and effective aperture, while being highly sensitive to local discharge values; 'late' means a backflow or production volume at least fivefold the injected chaser volume;

(2a) early tracer signals (concentration 'peak' intervals) may exhibit slight 'acceleration' and 'damping' with increasing matrix porosity or increasing frac aperture (a 'paradoxical' behaviour which is not really surprising for single-well 'push-then-backflow' tests, actually owing to flow-field dispersion[4]), and

(2b) a non-monotonous response to varying frac area, being almost insensitive to frac area as long as the linear-flow regime prevails against the radial-flow regime (effects of the latter only becoming visible at very low frac areas);

(2c) the effects of these various factors on early-time tracer signals are not unambiguously discernible from each other, and this ambiguity would persist even if frac-resolved (in-situ) discharge metering were feasible.

For each of the three fracs (k=1,2,3), a 'type-curve' set $C_k(Q,t)$ (parametrized by discharge values Q) can be generated. Since every frac received a different tracer, tracer signals measured within the overall backflow will differ from individual-frac type-curves by mere dilution (no 'superposition'). Type-curve dilution by factor Q_k/Q_{total} can be compared to measured tracer concentrations in the total discharge, $c_k(t_i)$, (i = 1, …, no. of tracer samplings). From a formal point of view, the unknown discharge values Q_k can be determined as the solution of a linear optimization task subject to the constraint $Q_1 + Q_2 + Q_3 = Q_{total}$ (the latter being a measured value). It is recommendable to perform 'optimization' manually, rather than by resorting to automated solutions provided by some linear programming software. The first items to inspect are the *late-time height* and *slope* of measured tracer signal 'tailings': their *height* yields a first approximation to dilution factors, and thus a first estimate for Q_k, while late-time consistency of observed tailing *slopes* can be taken as indicative of the applicability of model presuppositions. To be noted, dilution factors associated with individual fracs can vary with time, since a steady-state discharge pattern might not be reached simultaneously at all fracs. The paper also discusses some reasons why early-time tracer signals are generally unsuited for frac discharge inversion.

References:

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Acknowledgements: Tracer tests at the GroßSchönebeck site were conducted with financial and operational support from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and from the Helmholtz Research Centre GeoForschungsZentrum (GFZ) Potsdam. Modelling work was conducted within the 'gebo' project ('Geothermal Energy and High-Performance Drilling', www.gebo-nds.de), funded by the Lower-Saxonian government and by Baker Hughes (Celle), Germany.