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On the use of flow-storage repartitions derived from artificial tracer tests for geothermal reservoir characterization in the Malm-Molasse basin: a theoretical study

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Flow-storage repartition (FSR) analysis (Shook 2003) is a versatile tool for characterizing subsurface flow and transport systems. FSR can be derived from measured signals of inter-well tracer tests, if certain requirements are met – basically, the same as required for equivalence between fluid residence time distribution (RTD) and a measured inter-well tracer signal (pre-processed and de-convolved if necessary).

Nominally, a FSR is derived from a RTD as a trajectory in normalized $\{1^{st}, 0^{th}\}$-order statistical moment space; more intuitively, as a parametric plot of 0^{th}-order against 1^{st}-order statistical moments of RTD truncated at time t, with t as a parameter running from the first tracer input to the latest available tracer sampling; 0^{th}-order moments being normalized by the total tracer recovery, and 1^{st}-order moments by the mean RT. Fracture-dominated systems plot in the upper left (high F, low S) region of FSR diagrams; a homogeneous single-continuum with no dispersion (infinite Peclet number) displays a straight line from $\{F,S\}=\{0,0\}$ to $\{F,S\}=\{1,1\}$.

This analysis tool appears particularly attractive for characterizing markedly-heterogeneous, porous-fissured-fractured (partly karstified) formations like those targeted by geothermal exploration in the Malm-Molasse basin in Southern Germany, and especially for quantifying flow and transport contributions from contrasting facies types ('reef' versus 'bedded'). However, tracer tests conducted in such systems with inter-well distances of some hundreds of metres (as required by economic considerations on geothermal reservoir sizing) face the problem of very long residence times – and thus the need to deal with incomplete (truncated) signals.

For the geothermal well triplet at the Sauerlach site near Munich, tracer peak arrival times exceeding 2 years have been predicted, and signal tails decreasing by less than 50% over >10 years, which puts great uncertainty on the (extrapolation-based) normalizing factors needed to calculate FSR. Looking at the Sauerlach example, we find that premature interruption of tracer sampling systematically leads to *overestimating the reservoir's storage* capacity and *underestimating its flow* capacity, with misestimation generally increasing as the bedded/reef interfacial area per volume is increased. It is interesting to correlate these findings with the tracer-based approach to facies identification for the shallower Malm aquifers of the Southern Franconian Alb, proposed by Seiler et al. (1989, 1995) and with expectations from the direct (i. e., distributed-parameter) modeling of matrix-diffusive effects (Maloszewski and Zuber 1985) on measured tracer signals.

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