Combined transport experiments under in-situ conditions

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In short:

The analysis of flow through fractured rock is a central problem of "Enhanced Geothermal Systems", EGS. Most data are derived from field experiments. There are only a limited number of laboratory experiments available and even less on a well-observable in-situ scale. The latter one require rather low rate injection rates (<0.1 l/s, depending on transmissivity) for observing the flow behaviour of a fractured system whereas high rate injections (>>1 l/s) are used for testing the rock behaviour and fracture propagation under field conditions. The present study focuses on an experiment performed by the Swiss National Organization for Nuclear Waste Disposal (NAGRA) in the Grimsel Rock Laboratory.

Location: BK Site of Grimsel Rock Laboratory (totally 12 boreholes)

Dipole flow field in single fracture: injection BK5 and extraction BK15

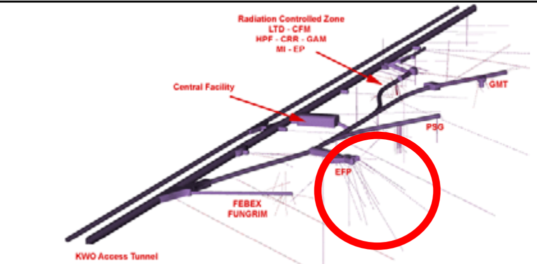
Advantages of the SHT experiment:

- A good observation of a mid-scale experiment (~10 m)
- Heat is non-reactive tracer, not disturbing chemical equilibrium
- Independent salt & heat data by identical experiment
- Reasonable costs

Experimental targets

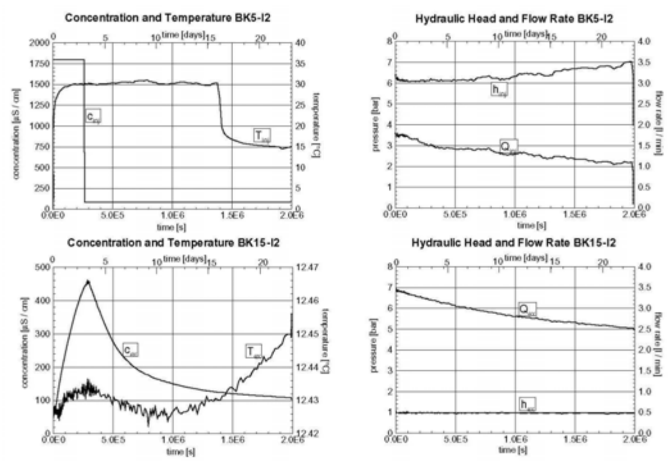
- Scope calculations for design of experimental layout (Q,T,c)
- modelling & interpretation of experimental results

The FE code FRACTure was used for interpretation of combined solute / heat transport processes.

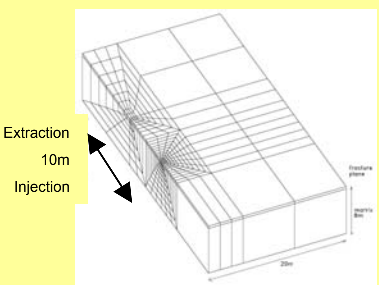


Grimsel rock laboratory: Location of BK site

Data



Numerical Discretisation



Governing Equations

Mass Flow

$$\mathbf{q} = \mathbf{K}_f \cdot \nabla h$$

with

$$\nabla \mathbf{q} = 0$$

$$K_f = \rho \mathbf{g} k / \mu$$

Thermal Transport

$$\overline{\rho c_p} \dot{T} + [\rho c_p]_f \mathbf{q} \nabla T - \nabla[\overline{\Lambda} \nabla T] = 0$$

with

$$\overline{\rho c_p} = (1-\phi_t) \cdot [\rho c_p]_s + \phi_t \cdot [\rho c_p]_f$$

$$\overline{\lambda} = (1-\phi_t) \cdot \lambda_s + \phi_t \cdot \lambda_f$$

Solute Transport

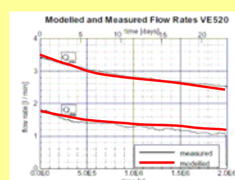
$$\dot{C} + \mathbf{v}_f \nabla C - \nabla[(\phi_t \mathbf{D} + \mathbf{1} \mathbf{D}_m) \nabla C] = 0$$

with

$$D_{ij} = \alpha_T \mathrm{v}_f \delta_{ij} + [\alpha_L - \alpha_T] \mathrm{v}_{if} \mathrm{v}_{jf} / \mathrm{v}_f$$

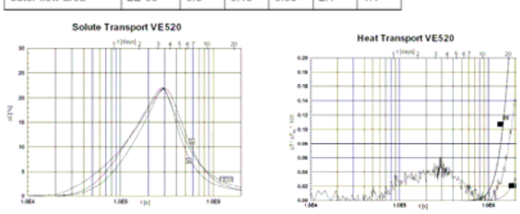
Basic conceptual models

Model	Joint Properties	Matrix Properties	Comments
single joint	homogeneous	-	-
single joint	aperture variability	-	-
double porosity	homogeneous	homogeneous, permeable/impermeable	natural base flow
double porosity	homogeneous	homogeneous, permeable/impermeable	-



Single joint approach

	K_f [m/s]	a [m]	ϕ_c	ϕ_{nc}	α_L [m]	α_T [m]
homogeneous	2E-05	0.5	0.15	0.05	3	3
heterogeneous central flow area	2E-05	0.2	0.15	0.05	2.1	1.4
outer flow area	2E-05	0.5	0.15	0.05	2.1	1.4

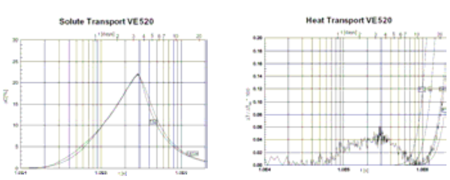


⇨ No fit possible

Different model assumptions from single jointed to multiple heterogeneous conditions were assumed. The results indicate strongly heterogeneous transport properties with dispersion lengths in the same order of magnitude like the dipole field. The thermal match the VE520 dataset requires several partly independent flow paths, each with much larger surface than individual single fracture models. This provides clues that the heterogeneous flow in a fractured medium slows down a thermal front. Under realistic field conditions in a fractured medium a thermal breakthrough can be much slower and its occurrence is less evident in EGS type reservoirs than idealized model might predict..

Double Porosity Approach

	K_f [m/s]	a [m]	ϕ_c	ϕ_{nc}	α_L [m]	α_T [m]
joint plane	2E-05	0.22	0.15	0.15	3	3
permeable matrix	2E-08	0.50	0.05	0.05	0.1	0.01



⇨ Large variability, Fit possible

CONCLUSION SHT Experiment

- Combined Salt / Heat Experiment was successfully conducted
- High Dispersivity lengths
- Solute data cannot differentiate between single / multiple flow zones
- High heat diffusion from matrix
- Heat tracer most sensitive to surface area
  - likely that further transport paths prevent that parts of injected thermal energy is transported to extraction point.
  - main flow path 80% / further flow 20%

EGS Laboratory

Combined field and laboratory experiments

Complexity of flow in fractured media

Elaboration of concepts based on well observable test conditions

Reference

- Kohl T., P. Marschall & L. Rybach, 1995, The salt heat tracer experiment, in: *NAGRA NTB 93-47*, pp 90-125, Baden, Switzerland