WATER - ROCK INTERACTION DURING REINJECTION OF GEOTHERMAL WASTE WATER

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Dispersion and Diffusion of Chemicals in a Fractured Porous Medium

Imagine a fluid flowing out from a point source into a homogeneous isotropic porous medium. When the pressure distribution is an equilibrium one, $P = \frac{Q\mu}{4\pi k}\,\frac{1}{r}$, where r is radial distance from the origin, k is the permeability of the medium and the fluid volume flux is $U = \frac{Q}{4\pi r^2}$

Now suppose a chemical marker at concentration C_o is added to the fluid at $r = 0$ for $t > 0$, which does not affect μ, k and Q, and that this marker is monitored at a fixed point distance, r, from the injection site. In the absence of diffusion and dispersive mixing, the marked fluid reaches out to a radius r in time t, when the volume of marked fluid inside the sphere of radius r is Qt, and the concentration of marker in the monitored fluid is zero till $t = t_1$ when Qt_1 fills the sphere of radius r, and then jumps to the input concentration (fig. 1 curve a). When dispersion and or diffusion occurs, this step fraction response is replaced by a more gentle diffusive interface, the breadth of which depends on the dispersion and diffusion coefficients.

In large scale porous media things seem to be more complicated. Imagine our homogeneous isotropic medium fractured by cracks and fissures into blocks with a characteristic length, 1, and that on the large scale (over distances much greater than 1) this system of cracks behaves like an isotropic homogeneous porous medium of permeability k_f where $k_f >> k$. then fluid pumped into the fissure system at some source tend[illegible] through the fissures and set up a pressure distribution $P = \frac{Q\mu}{4\pi k_f}\,\frac{1}{r}$, and pressure in the porous blocks are dominated by this distribution.

If a chemical marker is released into this system as before, a more complex response can be expected for the marker concentration monitored at r_1. With k very much less than k_f (in fact so small as to be effectively zero) and assuming a negligible porosity for them, the blocks play no part in the response at r_1 and we see the typical homogeneous porous medium response for a medium of large particle size and very small porosity (fig. 1 curve b). If k is not negligible then the blocks initially bleed marker fluid from the fissure and unmarked fluid into them. The consequence of this is *that* the concentration of marked fluid monitored at r, rises after an initial delay, <u>not</u> to the input concentration, but to some pseudo equilibrium level (fig. 1 curve c) depending on the proportions of short time and long time transit routes from the source to the neighbourhood of the monitoring point and the fluxes along these routes. Eventually the fluid concentration must attain that of the input but there are essentially two time scales involved; one for transport *of* marker via the fissures to the monitor point and one for saturating tha blocks with marker fluid. Even if k is small and the porosity of the fissures is negligible the first transit time need not be negligible since the marker can diffuse initially quite rapidly into the blocks.

Markers with differing diffusivities (e.g. chemicals and heat) would have different first transit times.

In a system of such complexity, the following questions are pertinent:

At any instant in time how is marker fluid distributed between the fissures and blocks?

If the marker is monitored at a sink at r_1, how does the response depend on k, k_f, porosities of blocks and fissures and diffusivity of the marker?

What is the role of convection and dispersion in the blocks and fissures?

How does the system respond to a shut down of the source marker fluid?

A reinjection experiment at Broadlands has allowed the opportunity to observe these effects and allows an analysis in terms of this model. The discussion above relates to a 'conserved' marker (e.g. chloride) which does not enter mineral lattices. Other dissolved components introduce an additional factor into the analysis due to their storage, or release from storage in minerals, due to cation exchange or precipitation reactions.

Field Monitoring of Reinjection

Recently at BR34, 95°C flashed waters (containing 1400 ppm chloride) from BR2 were injected for periods up to 2 months. The injection well and a monitor well (BRM2), 40 metres away, intersected a single zone of very high permeability at 350 and 390 metres respectively. In this part of the field, a kilometre outside the production area, dilute sulphate - bicarbonate waters occur at 55°C with chloride contents of about 110 ppm. Figure 2 shows the chloride response and decay in BRM2 due to commencement and shut-down of reinjection. Since chloride ion does not enter mineral lattices, these data are compatible with the model outlined above. Sodium and lithium behave in a similar fashion but potassium, caesium and rubidium are adsorbed strongly by the formation through cation exchange on montmorillonite, while some boron is released from the rock. About forty percent of the injected dissolved silica was precipitated in the permeable zone and wallrock within forty metres of the injection well. The behaviour of calcium, bicarbonate and $CO_{2(aq)}$ is complex and suggests that in this low temperature injection experiment, calcite solubility buffered solution compositions at the monitor well, the rapid variations in HCO_3/CO_2 and Ca^{++} reflecting the temperature gradient away from the injection well and the high rate of H^+ diffusion through the porous medium. A calcite deposition front may spread through the porous medium as injection proceeds. Stable isotope data follow a simple 'mixing' path during the injection.

Where reinjection of waste waters is practised in a higher temperature environment, dispersion of the thermal and chemical content of the fluid will be analogous to the BR34 pattern. Calcite deposition becomes insignificant due to its lower solubility at reservoir temperatures, but rapid deposition of silica is to be expected close to the injection wells.

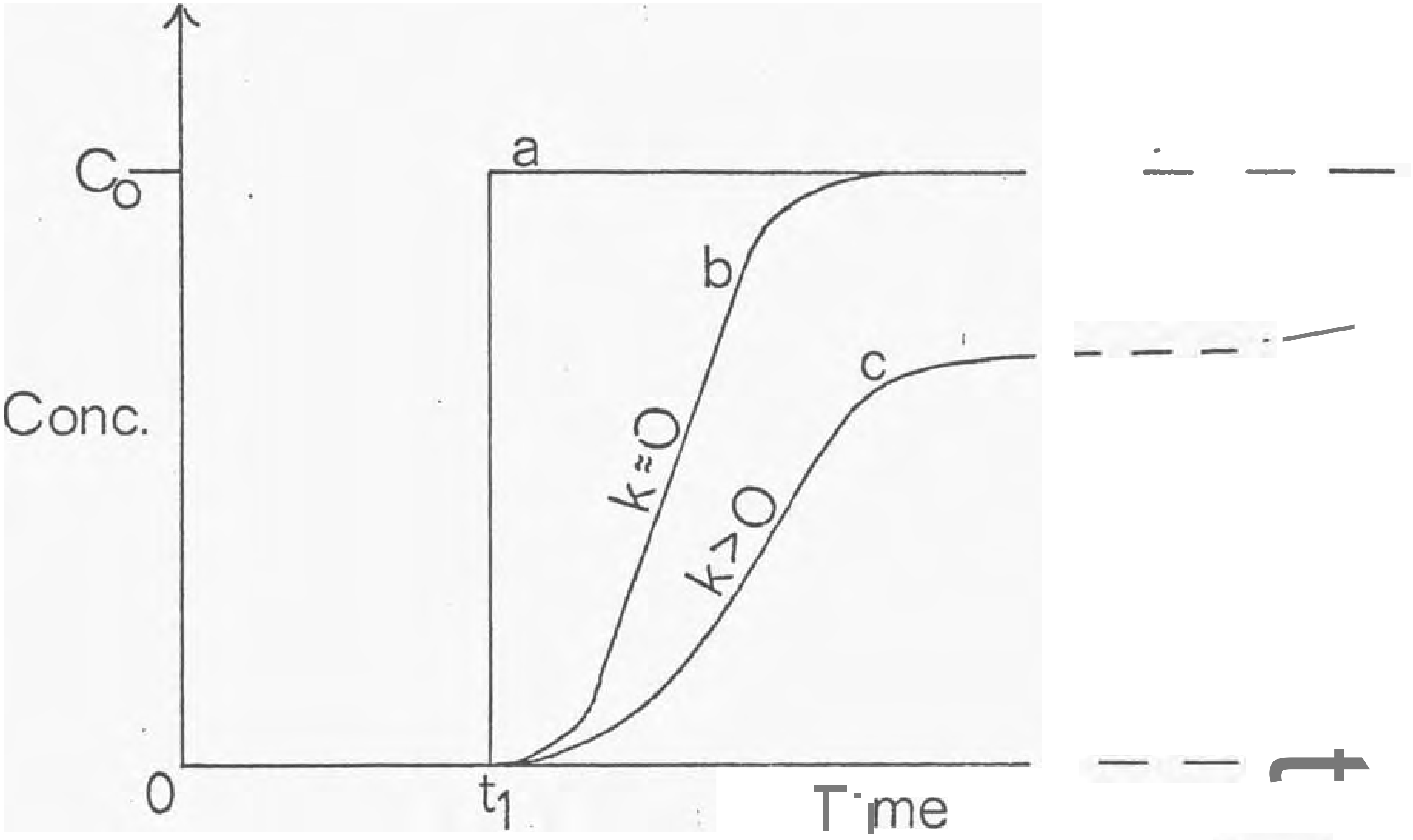

Fig 1

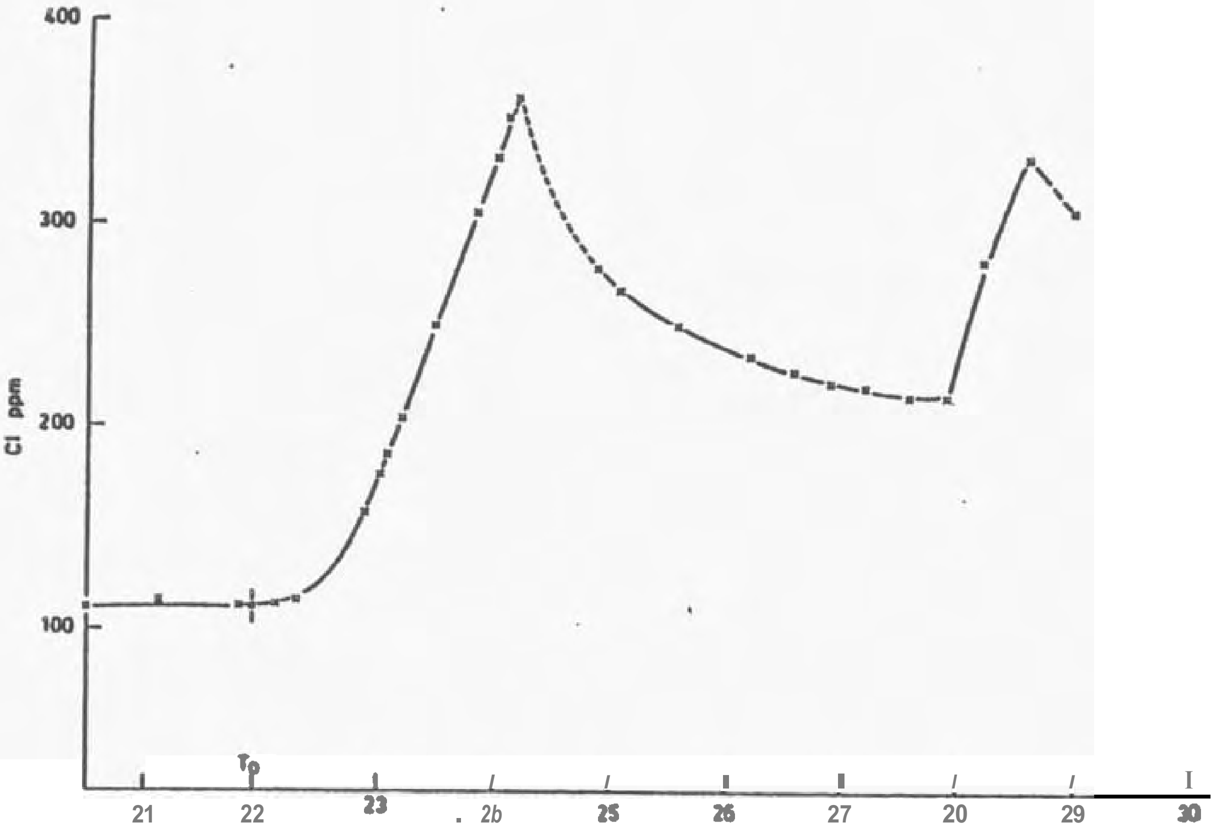

Fig.2a BRM2-Reinjection (Monitoring of Chloride)

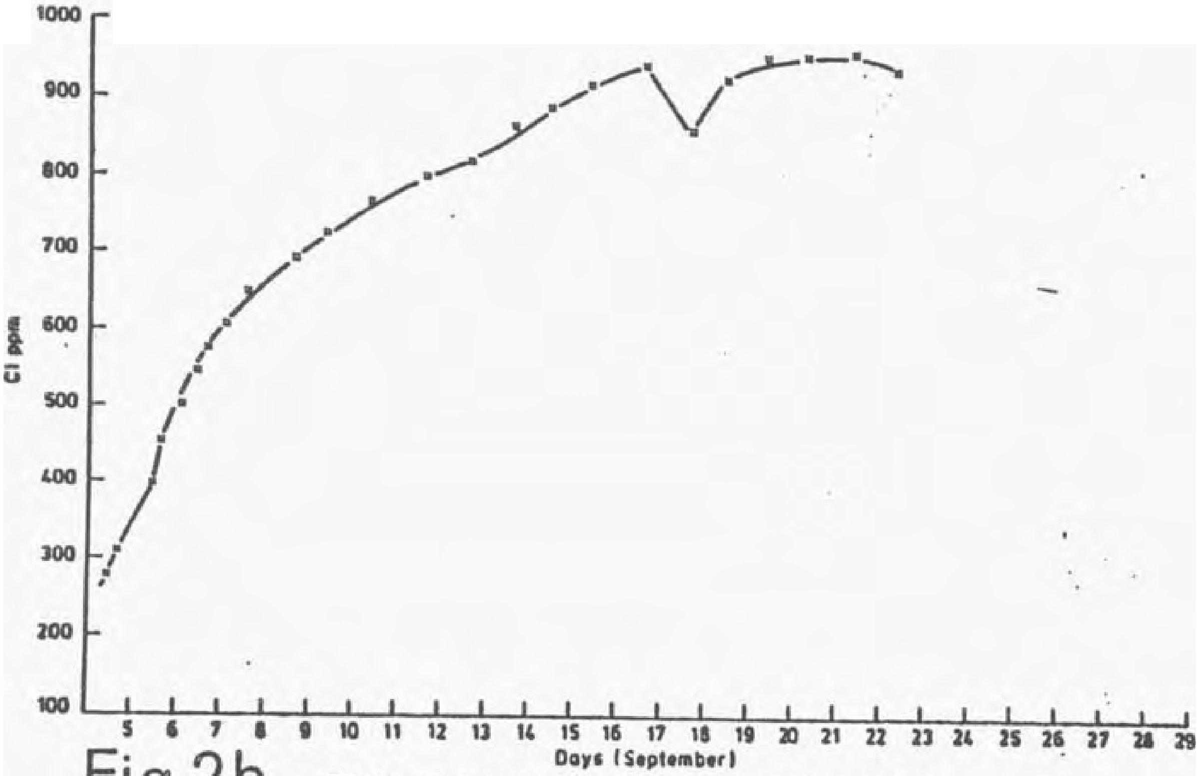

Fig.2b BRM2 - Reinjection (Monitoring of Chloride)