USE OF TRACERS IN THE GEOTHERMAL INDUSTRY-TRACER FLOW EQUATIONS IN POROUS MEDIA

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1- INTRODUCTION

Inlet-outlet tracer techniques are convenient experimental ways of determining internal characteristics of continuous flow systems. Basically, a chemical species is injected into the inlet stream and the monitoring of the concentration-time relationships at the outlet is used to provide information about the internal flow characteristics.

Besides chemical engineering processes and biology, groundwater reservoir management and use is a very important area for the application of tracer techniques. Formerly, tracers were developed for groundwater resources management and the oil production industry. Presently, the need of tracer experiments in the geothermal industry is rapidly increasing; it is used to identify the transfer parameters which rule the thermal behavior, such as breakthrough time of a doublet.

High enthalpy geothermal exploitation is subject to environmental regulations combined with the need to sustain the reservoir pressure. These conditions have led to an increasing number of reinjection programs. It is now widely acknowledged that a tracer test is one of the best ways to evaluate the real behavior of a reinjection system.

In low enthalpy geothermal exploitation, the doublet technique is wide-spread (especially in France) for environmental reasons, but also to preserve the pressure in the aquifer. Here again the tracer techniques should be useful, in some situations to preclude the risk of thermal breakthrough caused by improper location of the reinjection well.

The research for Hot Dry Rock technology in fractured reservoirs has also led to the development of tracer techniques. Without any doubt the tracer tests are one of the best tools for studying the fractured heat exchanger, characterising its size and shape, and obtaining valuable information on the time period before thermal decline.

In this part we will discuss only the theory and use of tracer techniques in porous media, although many geothermal reservoirs are developed in fractured rocks.

Before the theoretical discussion, some useful definitions and concepts should be recalled.
2- DIFFERENT TYPES OF TRACERS USED IN GEOTHERMAL ENGINEERING

2.1. Definitions

A tracer is a substance that follows the water molecule along its flow path and should have same behavior as the water molecule during its transport underground. However a tracer should exhibit some specific physical properties different than the water molecule itself in order to allow the measurement of its concentration in the water at the outlet. These requirements look a little bit contradictory but the proper selection of a tracer should meet these two objectives. We can define an "ideal" tracer as the one travelling at the same velocity as the water molecule, and facilitating quantitative chemical analysis; inert tracers are chemical substances which are not involved in reactions with other dissolved species.

Tracers are frequently divided into several groups depending on certain chemical or nuclear properties. The following terms are generally employed.

2.2. Chemical Tracers

Chemical Tracers: Molecules or ions that can be analysed by one or several analytical procedures, their concentration-time relationships at the outlet will depend on the hydraulic structure of the reservoir and on the interactions between the tracer and the host rock. The interaction with the minerals (a), chemical reactions between the tracer itself in the fluid phase (b), thermal decomposition. Obviously the extent of the effects of type (a) reactions must be minimal to ensure the practical usefulness of the tracer. Except in the case of special uses (see below "reactive tracers"), the extent of the effect of type (b) reactions should also be minimal.

Organic dyes are a particular class of chemical tracers. These molecules are recognizable by their color or fluorescence. Fluoresceine and Rhodamine are the most common dye tracers. They have been extensively used in tracing groundwater but they are subject to some practical drawbacks in geothermal environment. They are thermally decomposed in hot environment (t > 150°C) and should be restricted to short duration tests. Care must be taken concerning their adsorption properties with respect to minerals. However, they can be measured down to very low levels (around 20 ppb) with an easy to use and inexpensive fluorimeter.

Other types of chemical tracers should theoretically be chosen among all easy to analyse water soluble species. Practically speaking, halogenides Cl−, Br−, I− are most commonly employed since they are very soluble and non reactive with the host rocks. However it is sometimes difficult to use halogenides as tracers; their background level in geothermal fluid could be quite high even for bromide and iodide. In this case the implementation of a tracer test would be too costly. For that reason, iodide which is usually the least concentrated halogenide in natural fluids is preferentially used in tracer tests; one should be aware that, when the geothermal reservoir is located in sedimentary rocks, the reactivity of iodide could be rather high, especially with organic matter.

Very valuable information concerning the choice of chemical tracers can be found in the following references, Breitenbach and Horne (1), Gudmunsson and al. (2), (3).

In the search for new chemical tracers, promising development have been recently made with the use of derivatives (Mc Adams et al., (4), (5)). It mainly consists of multi-substituted aromatic acids (benzoic,