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Heterogeneous modeling of the uranium *in situ* recovery: Kinetic versus solubility control

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The uranium *in situ* recovery (ISR) is a mining technique, which involves injecting an acid or alkaline solution, into the deposit to selectively dissolve uranium. The solution enriched in uranium is pumped out and processed. Once the uranium is removed, reagent is added to the solution, which is then reinjected. This method is particularly suited to deep and low-grade deposits located in confined aquifers. In this work, we focus on the case of the Tortkuduk deposit, in Kazakhstan, where the reagent is sulfuric acid.

The main objective of this work is to understand how the uranium production can be increased while the sulfuric acid consumption is maintained as low as possible. It requires devising and validating an ISR phenomenological model, using all available tools: experiments, production data and numerical simulation, from 1D homogeneous to 3D heterogeneous models.

The main point in the phenomenological model is to determine whether the uranium recovery is limited by its solubility or its dissolution kinetics, along a particular streamline. Batch and column experiments have been performed by Rose Ben Simon, who has notably calculated the kinetic parameters of the controlling minerals. However it must be noted that the samples have probably been very altered by atmospheric oxidation, leading to an uncertainty about uranium solubility. Further analysis of production data has been therefore necessary.

At this stage, the main reactions have been identified but 1D numerical simulations show that the switch between kinetic and solubility control is within the range of the uncertainty on the kinetic parameters. Quantifying the "dilution effect" (the part of the solution that does not go through the mineralized zone) is crucial to properly analyze the production data. A 2D (or ideally 3D) approach is necessary.

3D modeling allows identifying the streamlines, between injector and producer wells, that effectively produce uranium. In a homogeneous case, the contribution of each streamline to the production is directly linked to its velocity. But the homogeneity assumption is not suitable for most real cases. We need, at least, to distinguish permeable from impermeable zones, reduced from oxidized zones, uranium-bearing from sterile zones.
Last, a fine modeling of ISR assesses the potential impact of heterogeneities (particularly permeability and main minerals grade) on production.

From an operational point of view, this work has revealed, for the Tortkuduk deposit, that the uranium recovery was probably controlled by the transport of ferric (oxidized) iron. Simulations on an "average" heterogeneous model should eventually bring conclusions about optimizing the distance between wells, the flow rates and the injection concentrations.