Model-based optimization of field-scale electrokinetic remediation of marine sediments

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ABSTRACT

Several technologies are available for the remediation of contaminated marine sediments, most of which derived from soil remediation techniques, such as sediment washing, thermal treatment, chemical oxidation, bioslurry processes and biopiles. The applicability of such technologies is strongly affected by specific characteristics of sediments which can adversely influence both operation and removal efficiency. Unfortunately, none of available technologies is effective when main pollution is represented by heavy metals and when sediment matrix is characterized by low hydraulic permeability [1]. These conditions pose severe limitations to remediation efficiency, as most decontamination techniques available for treating high-permeability soils are not effective for fine-grained matrices. In this context, electrokinetic remediation is widely recognized as an efficient technique for removing a broad range of contaminants from low-permeability soils and sediments [2].

Despite this technique has demonstrated being very promising for the remediation of marine sediments, the selection of the best operating conditions remains elusive, due to the variety of mechanism involved. Complicating factors include the high complexity of sediment matrix and the strong non-linearity of the processes occurring during electric field application [3]. Complexity is one of the main limiting factors to the spread of electrokinetic remediation technology for "real-world" applications. Complexity directly affects the reliable prediction of achievable results and induces technical challenges when the technique is implemented at the field scale [4]. A thorough understanding of the mechanisms involved in electrokinetic remediation through experimental studies is always needed, for an appropriate design of full-scale treatment schemes. In some cases, the prescribed laboratory experiments can get excessively time consuming, and modelling could become a necessary tool to assess the main remediation parameters and predict achievable results [5]. Despite several mathematical models have been developed to predict electrokinetic extraction of contaminants, their application to plant design and optimization is still unavailable.

This work presents a model-based approach for the optimization of field-scale electrokinetic processes, including the possibility of estimating optimum design parameters and minimizing the costs. We developed a numerical model to simulate the electrokinetic remediation of real contaminated sediments characterized by a heterogeneous solid matrix and aged heavy metal pollution. The numerical model couples a transport model able to simulate electromigration and electroosmosis with a geochemical model, which calculates aqueous speciation, precipitation-dissolution, adsorption and surface complexation reactions. Laboratory-scale experiments were carried out to calibrate and validate the model. The model was able to reproduce experimental data with adequate accuracy. We identified the acid buffering capacity as the most significant factor for the extraction of heavy metals from the sediments as their speciation and mobility were strictly dependent on sediment capacity to prevent the pH shift to the acidic range.

The developed model was then "scaled up", to reproduce electrokinetic processes occurring at field scale, considering a typical field setup consisting of vertical electrodes arranged on a rectangular grid. A parametric study was performed to evaluate the influence of electrode distance and sediment properties on treatment costs. The simulations allowed us to calculate time-dependent contaminant removal rate and to define cost curves for each set of parameters (Fig. 1a). The resulting curves of total cost were obtaining by summing up all individual costs (Fig. 1b). A clear point of minimum could be identified in each case, corresponding to the optimum set of parameters which minimized the costs.
In conclusion, we strongly believe that the methodology and results obtained can be employed as a valuable tool to support evaluation and design of electrokinetic remediation systems.

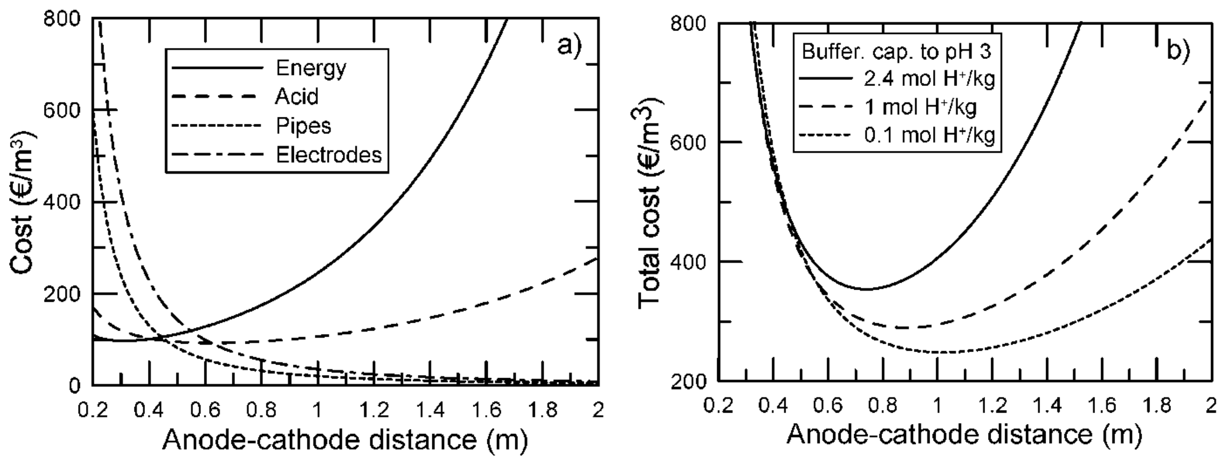

Fig. 1. a) Model-based cost estimation for energy, acid, pipes, and electrodes for a sediment with high buffering capacity (2.4 mol H^+/kg to pH = 3); b) curves of total costs as a function of sediment buffering capacity.

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