Geophysical Research Abstracts
Vol. 15, EGU2013-12719, 2013
EGU General Assembly 2013

A numerical model of controlled bioinduced mineralization in a porous medium to prevent corrosion

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This paper presents a numerical model of controlled bioinduced mineralization in a porous medium as a possible corrosion protection mechanism. Corrosion is a significant economic problem – recent reports evaluate the annual cost of metal corrosion as 3-4% of the gross domestic product (GDP), in both developed and developing countries. Corrosion control methods currently used are costly and unsustainable as they require the use of larger volumes of materials, hazardous chemicals and regular inspections. As an alternative corrosion control method, bioinduced deposition of protective mineral layers has been proposed. Bioinduced precipitation of calcite has already been investigated for CO_2 geological sequestration and soil improvement. To our knowledge, though, no numerical study of biomineralization for corrosion protection has been described yet. Our model includes three phases - solid, biofilm and mobile water. In the latter the reactive elements are dissolved, which are involved in the precipitation and the biofilm growth. The equations that describe the pore water flow, chemical reactions in the mobile water, consumption of substrate and expulsion of metabolic products by the biofilm are briefly presented. Also, the changes in porosity and permeability of the porous medium through biofilm growth and solids precipitation are included. Our main assumptions are that the biofilm is uniform, has a constant density and composition, that all chemical reactions except for substrate consumption occur in the mobile water, and that the precipitates are uniformly distributed on the surface of the solids. We validate the model with simple analytical solutions and against experimental data. The metabolism of the micro-organisms introduces changes in the physical and chemical characteristics of the environment, such as concentrations of chemicals and pH levels. As an extension to the model, we couple these changes to the rates of biofilm growth and precipitation rates. The influence of these couplings is investigated in numerical experiments. Finally, we investigate how, by modifying the initial and boundary conditions and biofilm parameters, we can control how and where biomineralization takes place. This study demonstrates that controlled biomineralization of protective layers is feasible. However, even this relatively simple model involves complex interactions and numerous assumptions. Further numerical and physical experiments will extend our understanding of the processes involved and the possibilities of "employing" micro-organisms to control the properties of the porous medium. Future development of the model includes multiple chemical species and reactions, multispecies biofilm that grows and detaches, varying coverage of solid grains by biofilms, and reactive solid phase. The predictive capacities of our model will be used to design experiments that will demonstrate the capacity to prevent corrosion in a porous medium by controlled bioinduced mineralization. Developing biological corrosion protection is a first step in developing the future capacity to use nature's constructive forces in assembling functioning structures.