A numerical model of controlled bioinduced mineralization in a porous medium

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INTRODUCTION

Our aim is to demonstrate the feasibility of microbial protection against corrosion in a porous medium. As a first step, we present a numerical model of controlled bioinduced mineralization in a porous medium as a possible corrosion protection mechanism for subsurface infrastructure such as pipelines or sheet pile walls. 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. As an alternative corrosion control method, bioinduced deposition of protective mineral layers has been proposed [1]. Bioinduced precipitation has already been investigated for CO₂ geological sequestration and soil improvement [2]. To our knowledge, though, no numerical study of biomineralization for corrosion protection has been published yet.

MICROBIALLY INFLUENCED CORROSION

The consumption of substrate in biofilm (such as SO₄²⁻) is described by the Monod equation:

\[
\frac{\partial \theta_s}{\partial t} + \frac{D}{\theta_s} \nabla \cdot (\nabla C_i) - SS = 0
\]

where \( C_i \) is the concentration, \( D \) the diffusion coefficient and SS the source-sink term. The consumption of substrate in biofilm (such as SO₄²⁻) is described by the Monod term [4]:

\[
R_s = -q \theta_b X \frac{C_i}{K_s + C_i}
\]

where \( q \) is the substrate utilization rate, \( X \) the concentration of bacteria, \( C_i \) concentration of substrate and \( K_s \) the Monod constant. Change in porosity as a result of precipitation of solids such as FeS is described by:

\[
\frac{\partial \theta_s}{\partial t} = \frac{M_w}{\rho} \frac{R_s}{\theta_s}
\]

where \( M_w \) is the molecular mass, \( \rho \) the density of the precipitate and \( R_s \) the precipitation rate.

REFERENCES


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MODEL VALIDATION

We validate the model using data published by other researchers, such as [2]. Once validated, the model will be used to compare with the results of our experiments and field measurements. The image below shows an example of a simple experiment - plastic container has been filled with sand and a steel rod has been inserted. The container has been filled with water and incubated for several months. Concentration gradients of the corrosion products are clearly visible.

IMAGING CORROSION IN POROUS MEDIA

The distribution of corrosion products, will be imaged in 3D by X-ray computed microtomography (CMT), and compared to the prediction of the model. Due to the similarity in X-ray absorption coefficients the use of pre-coated microspheres and an X-ray contrast agent is required to image biofilm within the experimental matrix using CMT [5]. We will use imaging techniques such as CMT to non-destructively quantify and map the distribution of corrosion products and biofilms inside a porous medium to evaluate the performance of our numerical models.

OUTLOOK

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.