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Calcium carbonate precipitation and strontium co-precipitation in porous media flow reactors

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Strontium-90 (Sr-90), a toxic and carcinogenic radionuclide, is the product of uranium fission and is found in soil and groundwater at numerous DOE sites.1 Sr can also enter the environment through mine tailings leachate, produced water ponds (oil and gas extraction) or can occur naturally in rock formations.
A potential technology for groundwater remediation is the use of subsurface microorganisms to induce calcium carbonate (CaCO3) precipitation resulting in the partitioning of metal contaminants into CaCO3 precipitates for long-term sequestration. Precipitation can be facilitated by an increase in alkalinity as a result of urea hydrolysis, which can be induced by microbes in a process called microbially induced CaCO3 precipitation (MICP). Thus, Sr co-precipitation studies have the potential to provide insight into Sr-90 partitioning into CaCO3.
Our studies in three flow systems have aimed to characterize and control CaCO3 distribution and Sr co-precipitation through MICP by manipulating fluid flow and CaCO3 saturation conditions. First, the effects of flow rate and Ca-concentration on the strontium partition coefficient (DSr) were determined in porous media flow cells (FC), similar to those described in Lauchnor et al.1 Second, spatio-temporal analysis of strontium partitioning was performed using a novel modified flow cell; this spatially-sampled flow cell (SFC) enabled fluid sampling from different locations within the porous medium during the experiments. Finally, a laboratory-scale reactor, wherein glass beads formed a packed porous bed, was used to investigate MICP under radial flow conditions.
Two flow rates and two calcium concentrations were studied in the FC. The calcium precipitation rate in FC experiments suggested that under the conditions chosen, MICP was limited by calcium transport. The low calcium concentration and low flow rate experiment led to the highest MICP efficiency and Sr co-precipitation.
SFC experiments revealed that calcium and strontium gradients did not remain constant over time. Spatially collected samples aided in DSr calculations to study the spatio-temporal behavior of strontium co-precipitation. The calcium precipitation rate decreased with time in all three replicates. A decrease in strontium partitioning with distance into the SFC was coupled with an increase in the size of the precipitates.
For effective field employment of MICP, it is important to control MICP specifically under radial flow conditions relevant in near-well environments. Porous media radial flow systems were utilized to evaluate spatial distribution of CaCO3. MICP experiments were performed at three fluid flow rates and three calcium concentrations. MICP efficiency showed an inverse relationship to flow rate and the greatest precipitation efficiency was observed at the lowest calcium concentration. Preferential flow paths developed due to precipitates formed via MICP, affecting fluid flow.
These results allow for predicting MICP distribution and the effect of MICP on porous media flow properties and lend insight to potential MICP strategies for remediating Sr-contaminated groundwater.

1. Lauchnor, E. G.; Schultz, L. N.; Bugni, S.; Mitchell, A. C.; Cunningham, A. B.; Gerlach, R., Bacterially Induced Calcium Carbonate Precipitation and Strontium Coprecipitation in a Porous Media Flow System. Environmental Science & Technology 2013, 47 (3), 1557-1564.

References

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