Investigation of zero-valent iron nanoparticle transport for groundwater remediation by means of lab-scale flow experiments.

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1. Introduction

The use of nanoparticles zero-valent iron (nZVI) is one of the most recent and promising techniques for groundwater remediation (Crane & Scott, 2012). nZVI successfully reduces pollutants such as chlorinated hydrocarbons (e.g. PCE, TCE and DDT) and transforms a variety of dissolved metals into an insoluble form fixed to the rock, thereby reducing their ecological impact according to the following removal mechanisms: reduction, adsorption, (re)oxidation, co-precipitation and precipitation (Almeelbi & Bezbaruah, 2012; Lin et al., 2018; O'Carroll et al., 2013; Stefaniuk et al., 2016).

The purpose of this research was to know whether the nZVI suspension moves unrestrained through the soil or whether (part of) the nZVI is retained in the soil and if so, where this retention occurs. To answer these research questions, lab-scale flow experiments were conducted in which barium was chosen as pollutant. Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES) was used to measure the barium and iron content in the fluids and X-ray Computed micro-Tomography (µCT) to investigate the composition and location of possible precipitates of barium and nZVI.

2. Material and methods

A sand pack was used as soil model. As such, all occurring reactions can be ascribed to be reactions of barium with nZVI.

The nZVI product selected for all the experiments was Nanofer 25S, provided by Nano Iron, s.r.o. It contains 20 % nZVI and a mixture of 80 % water and polyacrylic acid. Untreated nZVI particles would oxidize and agglomerate before reaching the contaminant, strongly reducing the efficacy and mobility of the particles. Therefore, nZVI was mixed with carboxymethylcellulose (CMC) in equal amounts to provide electrostatic and steric repulsion between the particles, reducing the aggregation and increasing the reactivity and mobility of nZVI in the soil.

In the flow experiments, first a barium solution was drawn through the sand pack, followed by a CMC-nZVI mixture. Ultimately, the sand pack was flushed with distilled water. The outflow was sampled in small volumes equal to two pore volumes of the sand pack and analyzed with ICP-OES. The sample holder for the sand pack is shown in Fig. 1A. Glass beads and a mesh were placed below and on top of the 3-cm long pack to obtain an even flow through it. The direction of flow was upwards.

After the experiment, the sand pack was scanned with µCT to determine whether and where iron (and/or barium) compounds were precipitated.

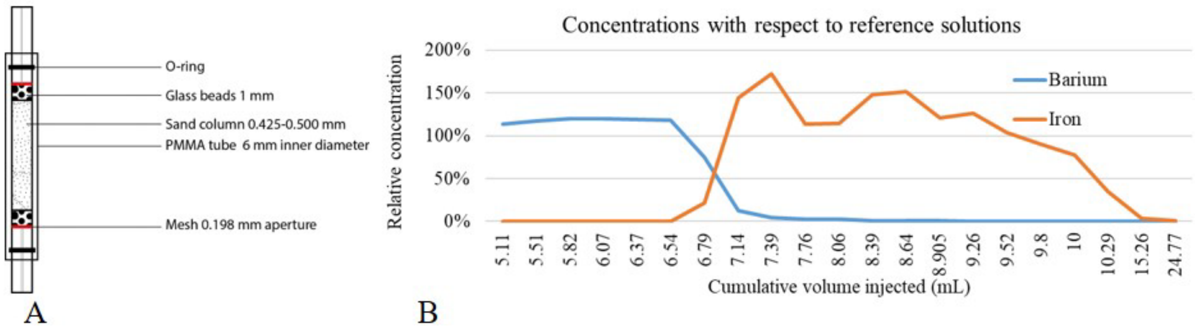

Figure 1. A: Schematic setup of sample holder. B: Evolution of barium and iron concentrations in the outflow of the flow experiment.

3. Results and discussion

Fig. 1B shows the evolution of both barium and iron concentration in the outflow of the flow experiment with respect to the total drawn volume. The delay in the concentration decrease is related to the fact that the fluids first flow through the entire setup before reaching the outlet.

The decrease in barium concentration upon CMC-nZVI injection is much more abrupt than the decrease in iron concentration upon the injection of distilled water. This illustrates the nZVI's tendency to be retained in the soil. An additional explanation for this retention is the difference in viscosity: a less viscous fluid (barium solution or water) is more easily displaced by a more viscous fluid (CMC-nZVI) than vice-versa, in which case 'viscous fingering' can occur: the water passes through the sand pack along a 'preferential flow path', only slightly affecting the rest of the CMC-nZVI. The difference in viscosity between the barium solution and the CMC-nZVI has impeded the interaction between the two fluids, resulting in a negligible amount of barium being removed from the solution.

The µCT analysis showed that in the pore space, more X-rays were absorbed towards the bottom of the sand pack. This is probably due to retained iron particles, as the chemical analysis of the outflow has ruled out the presence of the barium. This indicates that the iron particles are very susceptible to gravitational forces and that a substantial amount of iron is retained in our model, although no barium was coprecipitated with the nZVI.

4. Conclusion and further research

Barium should be immobilized by nZVI, but in these flow experiments the difference in viscosity has led to very limited interaction between barium solution and CMC-nZVI.

Although the setup used in this research is only a simplification of reality, it reveals hitches that also occur in the field. In future research, the setup should be improved and these obstacles overcome for a more efficient application of nZVI in groundwater remediation.

5. References

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