Impact of humidity levels on arsenic leaching in iron-stabilized soil

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Abstract

This work contains further studies of iron (Fe) applications for the stabilization of arsenic (As)-contaminated soil. Its aim is to identify how the leaching of As changes over time depending on the humidity level of the stabilized soil. Two types of iron amendments were used for contaminant stabilization in the soil: iron grit (97% Fe0) and oxygen scarfing granulate (OSG: 69% Fe3O4; 28% Fe0). The soil was placed into a concrete blender and while rotating mixed with 1, 7 and 15 wt% of OSG or 0.1 and 1 wt% of Fe0. Half of the samples were stored at humidity level corresponding to 50% water holding capacity (WHC), and the other half were kept water saturated (100% WHC). Four soil pore water samples were taken during the first year and one a year later (five samples in total). At high concentrations (7 and 15 wt%), OSG was an effective amendment for As immobilization. The effect of 1 wt% iron grit on As was also significant, but lower than observed in the previous studies. Storage conditions of As contaminated soil, even after stabilization with Fe, can be detrimental for As stability. Soil saturated with water increased As release by two orders of magnitude in all mixtures except for the 15% OSG sample. The soil was let to dry after the first year, which showed to considerably influence As mobility in water saturated samples: leaching of As in re-saturated samples was even lower than at the beginning of the experiment.

Introduction

The most common way of handling contaminated soil is excavation for disposal at a landfill. Soil stabilization is considered as less disruptive and more cost-effective soil remediation technique (Mench et al., 2005). But as of now, uncertainties regarding a long-term efficiency still limit the possibilities for this method to be used for in situ applications. Soil stabilization using amendments can also be used ex situ for soil pretreatment to reduce contaminant leaching from the landfill body. However, soil handling prior to its disposal can affect contaminant spread. Contaminated soil accepted to a landfill is stored for separation of large soil fractions, e.g. stones, and is subject to environmental factors such as precipitation. Storage of soil in heaps can cause heterogeneous distributions of air and humidity, which can affect the leaching of contaminants from the treated soil before it actually ends up in a landfill.

This work contains additional studies of iron (Fe) applications for the stabilization of arsenic (As)-contaminated soil. Its aim is to identify how the leaching of As changes over time depending on the humidity level of the stabilized soil.

Material and Methods

Soil was collected from a former wood impregnation site in Northern Sweden. The soil was sandy loam containing 310±17 mg kg⁻¹ As (+SD, n=3). Arsenic concentrations in the soil were determined by digesting 1 g of soil in 10 ml of a hydrochloric acid (HCl) and nitric acid (HNO3) mixture (3v:1v), using microwave digester (CEM Microwave Sample Preparation System, Model MARS 5) according to the EPA method 3051 (USEPA, 1994). Digestates were analysed with ICP-OES (Perkin Elmer Optima 2000 DV). Soil pH was 6.02±0.01, cation exchange capacity 5.04±0.26 cmol kg⁻¹. Water holding capacity was 39.8%. Organic carbon of the bulk soil, determined using a TOC analyzer (TOC- VCPH/CPN Shimadzu), was 0.95±0.18%.

Two types of iron amendments, obtained from steel processing companies in Sweden, were used for contaminant stabilization in soil: iron grit (97% Fe0) and oxygen scarfing granulate (OSG: 69% Fe3O4; 28% Fe0). Control samples, containing only contaminated soil, were homogenised in a concrete blender. Each time, 40 kg of soil was homogenised for 15 min and distributed into 15 l containers (13 kg of soil in each container). The soil samples mixing with Fe0 and OSG were also homogenised in the same manner as the control samples, i.e. soil was placed into the concrete blender and while rotating mixed with 1, 7 and 15 wt% of OSG or 0.1 and 1 wt% of Fe0. Water was added to the mixtures to reach 50% WHC. All soil mixtures were placed indoors and loosely covered to reduce water evaporation. Water content was controlled by weighing the sample containers during a two weeks period and water losses were compensated by watering the containers. After that, the water content was adjusted according to the experimental design (Table 1) and the mixtures were transferred to 15 dm³ columns containing soil moisture samplers.

Soil pore water was sampled into vacuumed 30 ml glass bottles using Rhizon soil moisture samplers four times with five weeks in between. An additional sampling was performed one year later. The bottles were immediately frozen and stored at -20 °C before analyses.
Table 1. Design of the stabilization experiment.

<table>
<thead>
<tr>
<th>Type of amendment</th>
<th>Control</th>
<th>Fe$^0$</th>
<th>OSG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration, %</td>
<td>0.1</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Humidity level, %</td>
<td>50</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

Results

Leaching of As from the samples stored at 50% WHC decreased over time. The decrease being greater in samples with larger amounts of added iron (Fig. 1A). Samples collected from the water saturated soil (100% WHC) showed an increase in As leaching during the first year. An exception was 15% OSG containing soil, where leaching of As in the end of the experiment was lower than in the beginning and the lowest among the other samples stored at 100% WHC (Fig. 1B). But the samples collected the second year contained considerably lower concentrations of As than the first year samples. Leaching of As in half-saturated soil increased in all samples. Untreated soil and that containing 1% OSG leached as much or even more As than at the beginning of the first year.

![Graph A](image1)
![Graph B](image2)

Figure 1. Changes in As leaching over time from untreated (control) and iron (Fe$^0$) and OSG treated soil stored at 50% (A) and 100% WHC (B, logarithmic concentration scale).

Discussion

At high concentrations (7 and 15 wt%), OSG was an effective amendment for As immobilization. The effect of iron grit on As was also significant, but lower than observed in the previous studies (Kumpiene et al., 2006). Based on stoichiometric calculations, the lowest amount of added iron (0.1%) was sufficient for As sorption. Uneven distribution or small contact surface of Fe$^0$ might be the reason of the lower reduction of arsenic leaching compared to OSG.

Storage conditions of As contaminated soil, even after stabilization with Fe, can be detrimental for As stability. Water saturation of soil considerably raises a risk for As release (Fig. 1). The absence of oxygen leads to As(V) reduction to As(III) and also dissolution of Fe(III) oxyhydroxides.

The sample containing 15% OSG stored at 100% WHC kept As bound during four months of observations, while other soil-Fe mixtures leached increasing amounts of As. However, the second year all the samples showed a considerable decrease in As leaching. All samples were left to dry after the first four samplings, which could have caused oxidation of dissolved Fe and formation of iron arsenates. This shows that drainage and aeration of soil is necessary to keep low solubility of As in soil.

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