LABORATORY- AND PILOT-SCALE STABILIZATION AND SOLIDIFICATION REMEDIATION OF SOIL CONTAMINATED WITH PER- AND POLY FLUORINATED ALKYL SUBSTANCES (PFASs)

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Contamination of soil and groundwater by per- and polyfluorinated alkyl substances (PFASs) is impacting drinking water delivery systems globally, posing risk to human health and the environment [1–4]. PFAS contaminated hot-spot soils are often caused by unregulated usage of PFAS-containing aqueous film forming foams (AFFFs) at military and civilian firefighting training facilities [5–7]. Even after regulating the use of PFAS-containing AFFFs, the soil contaminants can continue to pollute the groundwater and aquatic environment [8–10]. Due to PFASs unique physiochemical properties [11], few viable remediation technologies have been properly evaluated [12]. Stabilization remediation has shown to reduce PFAS leaching by mixing 2-4% activated carbon into soils (i.e. >99% for perfluorooctasulfonate (PFOS)) [13–15]. However, treatment with high quantities of activated carbon is costly and poor long-term efficiencies of activated carbons of PFAS stabilization has been observed for short chained PFASs [16]. Another promising remediation technique is stabilization and solidification (S/S) [17], where a solidifying binder (i.e. cement, bentonite, lime etc.) is added to the soil, combining chemical binding and physical hydrogeological protection that decreases the leachate transport. The present study investigated the sorption and leaching of PFASs using S/S treatment in laboratory- and pilot-scale. The laboratory -scale study showed that additives (e.g. activated carbon) has a high impact on the leaching behavior of soil using the S/S treatment. The best performance showed S/S treated soil using 10% of a 1:1 (CEM II/A-V 52.5 N Portland-fly ash:ground-granulated blast-furnace slag) binder mixture and 0.2% pulverized activated carbon. This treated soil resulted in a monolith structure with 4000 kPa unconfined compressive strength (UCS) indicating long term physical durability, and reduced leaching of most PFAS (except short chained) >99.9% in conservative leaching tests (crushed to <2 mm) [17]. However scale is critical for soil treatment, therefore in extension to this study [17], a pilot-scale flow-through (50 % of soil column were water saturated and 50% unsaturated, respectively) leaching experiment was performed (1.2 m×2 m×0.5 m), treating over 6 tons of PFAS contaminated soil (n = 2). The aim was to compare the PFAS leachate concentration of 11 PFASs (as regulated for drinking water by the Swedish EPA ($\sum_{11}$PFAS < 90 ng L^{-1})[18]) in S/S treated and untreated soil columns (n = 2). The soil originated from an industrial site polluted with PFAS containing AFFF, containing $\sum_{11}$PFAS up to 160 μg kg^{-1} dry weight. In particular PFOS, regulated by the Stockholm Convention for persistent organic pollutants, was dominant with concentrations up to 140 μg kg^{-1} dry weight. The S/S treatment consisted of a 15% addition of a cost-efficient binder mixture (CEM II/A-V 52.5 N Portland-fly ash) and 0.2% granulated activated carbon, based on dry weight of soil. Irrigation with tap water (25 L day^{-1} $soil^{-1}$ for 15 min) was used to simulate long term leaching at "near" natural field conditions. The pilot-scale experiment was initialized in November 2018 and planned to continue for 2 years, simulating over 15 years of natural precipitation. The experiment is discontinued during winter when the ground is frozen. Initial results showed that, for example, PFOS concentrations in leachates were reduced by 99%, from 18,000 μg L^{-1} to 200 ng L^{-1} after application of 300 L irrigation water, corresponding to 4 months of natural precipitation. For the other PFASs detected in the treated soils, leachate

concentrations of perfluorohexasulfonate (PFHxS), perfluorooctanoate (PFOA) and 6:2 fluorotelomer sulfonate (6:2 FTSA) were reduced by >99.6%, >99.6% and 98%, respectively, compared to the reference soil leachates. The pilot-scale leaching experiment showed on average 10 times lower concentration of PFOS in leachates compared to concentrations obtained in standardized laboratory 24 h batch leaching tests (liquid solid ratio (LS) = 2). This is in accordance to a previous study comparing laboratory and field soil/water partitioning behavior[19]. Ultimately, S/S treatment method shows promising performance for *in-situ* and *ex-situ* (e.g. landfills) long term treatment of PFAS contaminated soil.

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