EXECUTIVE SUMMARY

Enhanced Oxidative Destruction of PFAS in Investigation Derived Waste Soil and Water

SERDP Project ER18-1545

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ACRONYMS AND ABBREVIATIONS

AOP	Advanced oxidation process
CVOC	Chlorinated volatile organic compounds
DoD	U.S. Department of Defense
DW	Distilled water
EEI	EnChem Engineering, Inc.
EPA	U.S. Environmental Protection Agency
GW	Groundwater
IDW	Investigation-derived waste
JBASWG	Joint Base Naval Air Station Willow Grove
LCMSMS	Liquid chromatography – Mass Spectrometer/Mass Spectrometer
LHA	Lifetime Health Advisor
MassDEP	Massachusetts Department of Environmental Protection
MCP	Massachusetts Contingency Plan
NELAP	National Environmental Laboratory Accreditation Program
PAH	Polycyclic aromatic hydrocarbons
PFAS	Per- and polyfluoroalkyl substances
PFBA	Pentafluorobenzoic acid
QSM	Quality Systems Manual
SERDP	Strategic Environmental Research and Development Program
UV	Ultraviolet light
WG	Willow Grove
XCT®	Extra contact technology

ACKNOWLEDGEMENT

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1.0 INTRODUCTION

In this study, the project team demonstrated the effectiveness of an *ex situ* destructive technology (OxyZone®) for cost-effective and reliable on-site treatment of per- and polyfluoroalkyl substances (PFAS) present in soil and water investigation-derived waste (IDW). Based on PFAS contaminated IDW obtained from the Joint Base Naval Air Station Willow Grove (JBASWG), Pennsylvania (U.S. Navy); in the following referred to as "Willow Grove" (WG) material, the project team demonstrated that PFAS can be mineralized to the degree that disposal might be possible.

The U.S. Department of Defense (DoD) has identified approximately 600 of fire/crash/training sites that are potentially PFAS contaminated (SERDP 2012). The presence of PFAS in soil and groundwater (GW) presents a liability and DoD has begun performing investigations to determine the extent of PFAS contamination across its installations. During the course of these investigations, large quantities of IDW are being (and will continue to be) generated. While incineration is a destructive treatment option for IDW waste disposal, this approach is costly. Hence, there is a critical need for alternative treatment technologies that are more economical and which permit unrestricted disposal, discharge, and/or reuse of IDW on-site.

OxyZone® is a patented advanced oxidation process (AOP) developed by EnChem Engineering Inc. (EEI), which utilizes a proprietary blend of dissolved ozone, sodium persulfate, food grade phosphate-based buffers, and dilute hydrogen peroxide. In this oxidant blend, ozone and hydrogen peroxide (peroxone) are used as an activation agent to facilitate the production of hydroxyl and sulfate radicals and superoxide; these are some of the strongest oxidants available. As a result, OxyZone® is able to break down quickly organic contaminants through primary oxidation reactions, via ozone and persulfate molecules, as well as through more vigorous secondary oxidation reactions, via hydroxyl and sulfate radicals. The more advanced, patented XCT® (extra contact technology) and XCT-OxyZone processes contain a nontoxic, biodegradable desorbing solution that aides in the removal and destruction of PFAS.

2.0 OBJECTIVES

The overall objective of this project was to test an innovative, destructive treatment approach for the *ex situ*, on-site treatment of PFAS contaminated IDW soil and GW matrices. The project team postulated that in most cases, the technology permits the unrestricted disposal, discharge, and/or reuse of IDW on-site. The project team conducted semi-bench scale studies followed by a proof-of-concept, larger volume study to demonstrate that the future on-site destruction of PFAS compounds with the patented peroxone activated persulfate oxidation process is possible and feasible. The research questions and objectives were:

- *Question I*: How fast and to what extent can a peroxone activated persulfate oxidant destroy PFAS compounds when applied to soil or water IDW or mixtures thereof?

  Objective: Subjecting IDW material (soil, water) to a powerful, advanced oxidant to destroy PFAS contaminants.

- *Question II*: Does this innovative IDW treatment approach reduce the environmental risk and cost when compared to conventional disposal methods?

Objective: Assessing the degree of IDW treatment by comparing before/after treatment contaminant concentration and determining if the treated material poses environmental risks that could prevent the unrestricted on-site disposal from a regulatory perspective.

- *Question III*: What data must be acquired to develop a complete proposal for a more extensive follow-on study?

  Objective: Acquiring scientific and economic data in support of technology upscaling under a variety of site conditions and contaminant inventories.

The data generated during the study clearly show that PFAS compounds can be destroyed and that up-scaling to a full-scale, on-site treatment system may be a cost effective alternative to current PFAS IDW treatments.

3.0 TECHNICAL APPROACH

The experimental approach was organized by five tasks, namely:

- **Task 1:** Semi-Batch Experiments (PFAS amended distilled water (DW), IDW PFAS contaminated water);
- **Task 2:** Semi-Batch Experiments (IDW PFAS contaminated soil);
- **Task 3**: Design and Testing of Semi-Batch Scale Continuous Flow Gas Infusion Reactor for IDW Water and IDW Soil Slurry;
- **Task 4:** System up-scaling: Pilot-Scale Gas Infusion Reactor Experiments for IDW Batch Mode Treatment; and
- **Task 5:** Report Preparation.

During the initial stage of the experimental approach (Tasks 1 to 3), the project team performed laboratory experiments to adjust and optimize the treatment approach for the characteristics of the IDW (water/soil) waste that contains PFAS and, possibly, co-contaminants. Based on the initial optimization tests, the project team proceeded to pilot-scale testing (Task 4). All experiments were carried out in semi-batch mode for cost reasons. The studies were carried out largely in the EEI facilities. The data collected along the way was used for studying design, cost, and implementation requirements for proposing a full-scale systems analysis.

The PFAS analysis of solid and liquid samples was performed by BV Laboratories in Mississauga, Ontario, Canada. BV Laboratories (formerly Maxxam Analytics Laboratories) is accredited by the National Environmental Laboratory Accreditation Program (NELAP) for the DoD Quality Systems Manual (QSM) compliant method. The laboratory analyzes 23 (including two telomeres) PFAS by Liquid chromatography – Mass Spectrometer/Mass Spectrometer (LCMSMS) which is compliant with QSM 5.1 Table B-15.

4.0 RESULTS AND DISCUSSION

The treatment of IDW soil is a three-stage process, whereas only two stages are required for treating IDW water. After separating the fine (sand/silt/clay) from the coarse (gravel and larger) fractions of the IDW soil material, the following occurs:

(1) PFAS in the coarse fraction is rinsed off in a tumble reactor, possibly aided by the addition of the XCT solution which promotes desorption of PFAS from the mineral surfaces. The rinse water, either by itself or combined with IDW water, must be further treated;

(2) The fine fraction of the IDW soil is rinsed in a slurry reactor, again aided by XCT solution, until it meets soil standards for PFAS. The process water must be further treated; and

(3) The process water, either by itself or combined with IDW water, is treated by removing and concentrating PFAS from the solution via a stable foam of XCT solution. The concentrate is then subjected to ultraviolet light (UV) irradiation. This final treatment step leads to the mineralization of all 23 PFAS analyzed, except pentafluorobenzoic acid (PFBA). The treatment endpoint for water was the current EPA Lifetime Health Advisor (LHA) concentration for PFAS (70 ng/L PFOS and/or PFOA) compounds in drinking water.

Currently, no generally accepted method existed for determining the endpoint of treating PFAS contaminated soils. The project team addressed this issue by (1) developing a project-specific leachate testing procedure for formulating a possible treatment endpoint for soil; and (2) relying on the Massachusetts Department of Environmental Protection (MassDEP) for cleanup standards for PFAS in soil and GW, values for use in site-specific risk assessment, and notification criteria for soil and GW (MassDEP 2020). The Massachusetts Contingency Plan (MCP) Method 1 Soil Standards consider both the potential risk of harm resulting from direct exposure by dermal contact and inhalation of soil particulates and the potential impacts of leaching to the GW at the disposal site. The MCP Method 1 GW standards consider human exposure to drinking water or exposure by environmental receptors by discharge to surface water. The soil standards are dependent on the applicable GW standards. The cleanup standards have recently been finalized and promulgated under the MCP. In Massachusetts, drinking water standards for PFAS have been proposed and are in the public comment phase.

5.0 IMPLICATIONS FOR FUTURE RESEARCH AND BENEFITS

Based on the data and results contained in this report, the team has demonstrated the proof of concept for the proposed *ex situ* treatment of PFAS containing IDW soil by soil rinsing with a dilute XCT® solution and subsequent treatment of the process water; or treatment of IDW water. The proposed processes of soil rinsing followed by process water treatment or IDW water treatment are relatively low cost, on-site treatment alternatives compared to existing technology. The technology should be tested and evaluated at field scale to assess those variables that can only be evaluated during a field scale pilot test, such as equipment size and site-specific requirements. However, the result of such a field scale test is not expected to change the overall results or outcome as compared to the current pilot scale testing.

During pilot scale testing, it is proposed that a soil slurry be first rinsed with XCT solution to remove PFAS to a very low residual concentration in the soil. The process water would then be treated using enhanced foam fractionation and UV enhanced OxyZone. If there is any PFAS remaining in the soil, then it may be useful to add OxyZone to the soil slurry after the rinse with XCT solution to investigate whether any PFAS residual can be further removed without adding any by-products. This second treatment is likely to provide an even lower PFAS concentration in the treated soil, although the added cost may not prove worthy. The results of bench scale testing reported here support this concept of sequential treatment, although not directly tested in the bench scale testing.

The following benefits of the proposed process are:

- The XCT® soil treatment process has the benefit that the proprietary rinsing agent is non-toxic and can bind to a broad range of PFAS, based on the published literature and from the results. It will also desorb a broad range of possibly co-contaminants, such as chlorinated volatile organic compounds (CVOC) or polycyclic aromatic hydrocarbons (PAH), which is well documented in the literature and from the results.

  Furthermore, the project team is not aware of any other soil treatment technology that uses a non-toxic rinsing solution (e.g., methanol is toxic and flammable) for PFAS removal from soil.

- The IDW treatment is an *ex situ* process and therefore does not leave or create any toxic PFAS or their by-products in the subsurface.

- The enhanced foam fractionation treatment step for process water or IDW water removes greater than 99.9% of PFAS, leaving a very low PFAS concentration nearing regulatory standards for drinking water after the foam is separated from the water.

- The separated foam containing the PFAS is concentrated by a factor greater than 10 times and is destroyed by the UV enhanced OxyZone® process by greater than 99.9%.

- The Team is prepared to perform a field pilot test for *ex situ* soil rinsing to remove PFAS from the soil followed by treatment of the process water (or IDW water, as needed) to demonstrate the process removes greater than 99.9% of the PFAS from the water.

- The technology is a viable cost effective on-site, *ex situ* treatment alternative to incineration of soil and granular activated carbon or/resin technology for PFAS capture and treatment of IDW water.

6.0 REFERENCES

MassDEP. 2020. *2019 Proposed MCP Revisions*. https://www.mass.gov/lists/2019-proposed-mcp-revisions.

SERDP. 2012. *In Situ Remediation of Perfluoroalkyl Contaminated Groundwater*. ERSON-14-02 FY 2014 Statement Need, 1–3.