FACT SHEET

Thermal Desorption of Per- and Polyfluoroalkyl Substances (PFAS) from Soil

MAR 2025

Introduction

As evidence mounts that PFAS in source area soil can contribute to large, persistent groundwater plumes, treatment technologies to minimize the mass of PFAS in soil are needed (Weber et al., 2017; Xiao et al., 2015). Solutions to address PFAS in soils are emerging and limited. The majority of these solutions either use sorbents and leave PFAS in place, which could lead to possible leaching of PFAS in the future, or require the excavation, transport, and disposal of soil off site. There is a need for a cost-effective in situ treatment approach that removes PFAS from soil.

Technology Background

Thermal treatment to desorb chemicals from soil has been used for over 20 years and is a well-established, commercially available technology with demonstrated treatment performance for conventional pollutants. Thermal desorption eliminates the need for supplemental chemical, reagent, or adsorbent addition to the subsurface (Davis, 1997; Horst et al., 2021). Examples of technologies applied to thermal soil treatment include thermal conductive heating (TCH), electrical resistance heating (ERH), steam enhanced extraction, and smoldering. TCH is one of the preferred heating technologies for removal of chemicals with high boiling points and low volatility and achieves temperatures greater than 450 degrees Celsius (°C), which are not possible with the other heating technologies. Multiple commercial forms of TCH exist and have been used to thermally desorb chemicals such as dioxins, furans, polychlorinated biphenyls, and other semivolatile organic compounds at temperatures higher than those required for petroleum constituents or chlorinated volatile organic compounds (which are removed near the boiling point of water at 100°C). Previous research (at the laboratory scale or in above-grade treatment systems) has demonstrated that thermal treatment at 350 to 400°C has promise for reducing PFAS concentrations in soil (DiGuiseppi et al., 2019; Crownover et al., 2019; Barranco et al., 2020). TCH is an appropriate method to apply to reach these temperatures in the subsurface.

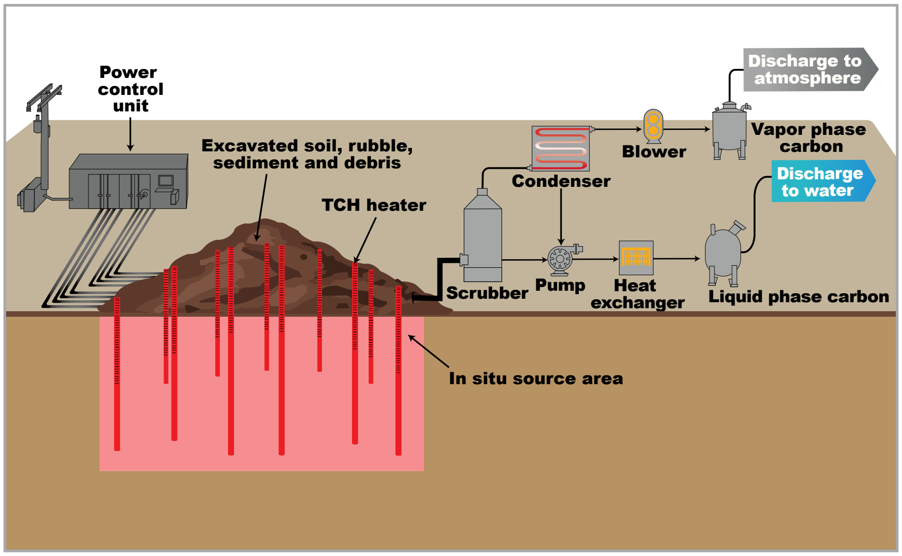

Figure 1. Schematic of an in situ TCH application (Courtesy of ESTCP)

How Does it Work?

Thermal desorption is accomplished by heating the soil (in situ or ex situ in a pile) to reach temperatures where chemicals can desorb, volatilize, or boil for removal from soil. Once reaching the vapor phase, chemicals are removed from the subsurface using conventional soil vapor extraction equipment and aboveground treatment (e.g., wet scrubber and condenser, as well as vapor- and liquid-phase granular activated carbon [GAC]) to address the recovered gaseous and liquid wastes. **Figure 1** illustrates an in situ TCH application.

How Can it Help?

Thermal desorption can provide a viable, onsite remediation alternative in lieu of technologies such as soil washing, stabilization, incineration, or landfill disposal, which currently represent the state of the industry for addressing PFAS sources in soil. Thermal desorption will provide benefits in minimizing long-term liabilities, as well as limiting future chemical migration and reducing life cycle operation cost for future groundwater treatment.

**Case Study 1:
Ex Situ Thermal Treatment
of PFAS-Impacted Soils**

**Case Study 2:
In Situ Thermal Treatment
of PFAS in the Vadose Zone**

Conclusions

CASE STUDY 1

Ex Situ Thermal Treatment of PFAS-Impacted Soils

Project Objective

An ex situ thermal treatment demonstration was performed at Eielson Air Force Base near Fairbanks, Alaska. The demonstration was implemented under Environmental Security Technology Certification Program (ESTCP) Project ER20-5198. The overall objective of the project was to evaluate PFAS removal in an ex situ soil pile and treat PFAS in the vapor and condensate waste streams produced during heating (Stallings et al., 2023).

Site Background and Demonstration Approach

Ex situ TCH was applied to a 134 cubic yard (yd^3) soil stockpile to thermally desorb PFAS. The pre-treatment PFAS concentration ranged from 3.7 micrograms per kilogram (µg/kg) to 233 µg/kg with concentrations of the predominant PFAS between 0.3 µg/kg and 12.1 µg/kg. The system was designed to heat the soil to a minimum temperature of 350°C for at least 10 days. The system consisted of 48 heater wells (spaced in 5.5-foot increments), 9 soil vapor extraction points, and 4 temperature monitoring points in addition to the aboveground components necessary for their operation. Effluent vapors and process water were treated onsite using GAC. Volatilized PFAS were concentrated into a low-volume solution with a scrubber before treatment with GAC to reduce the amount of carbon needed for vapor and liquid treatment.

Results

During treatment, the heaters delivered approximately 80 to 120 kilowatts (kW) of power to the soil stockpile. A cumulative energy balance is shown in **Figure 2**. An average soil temperature of over 400°C was achieved, and the coolest sensors reached a temperature of 350°C at the end of the test. The energy used for the heating was within 5% of the modeled value. The energy used was equal to 775 kilowatt-hours per cubic yard of soil, including heat lost through the surfaces of the relatively small and thin soil pile. Modeling shows that larger soil volumes with less significant heat loss can achieve the same level of treatment with 20% to 30% less energy.

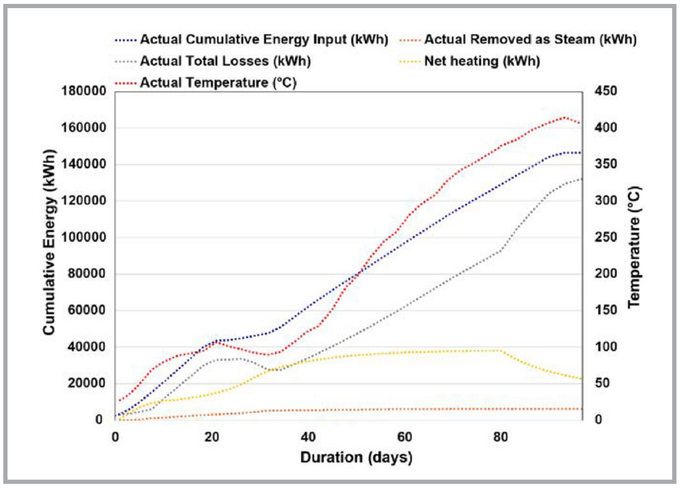

Figure 2. Ex situ thermal pilot-scale study energy balance (Courtesy of ESTCP)

Soil sampling performed before and after thermal treatment showed substantial reductions in PFAS (**Figure 3**), including perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA). The predominant PFAS, PFOS, experienced a 95.3% average reduction from thermal treatment. All soil samples collected post-thermal treatment were lower than detection limits for PFOA.

The post-thermal treatment soil composite had a PFOS concentration of 4.1 µg/kg, with an average of 3.1 µg/kg among all sample locations. The 2024 Environmental Protection Agency (EPA) Regional Screening Levels (RSLs) for PFOA and PFOS in residential soil (0.019 µg/kg and 0.63 µg/kg, respectively) were not attained at all locations. However, greater treatment durations above the target temperature improved removal of PFAS to below detection limits. All soils treated to 400°C or higher were nondetect for all targeted PFAS. PFAS were detected in vapor and condensate phases during heating, but no detections were observed following treatment. The implementation cost of the technology was evaluated for soil volumes up to 15,000 yd^3. Treatment costs ranging from \$550 to \$800 per yd^3 (in 2024 dollars) are projected, with lower unit costs for large volumes. Site location (climate and mobilization distance) and local electricity costs were identified as the main cost drivers.

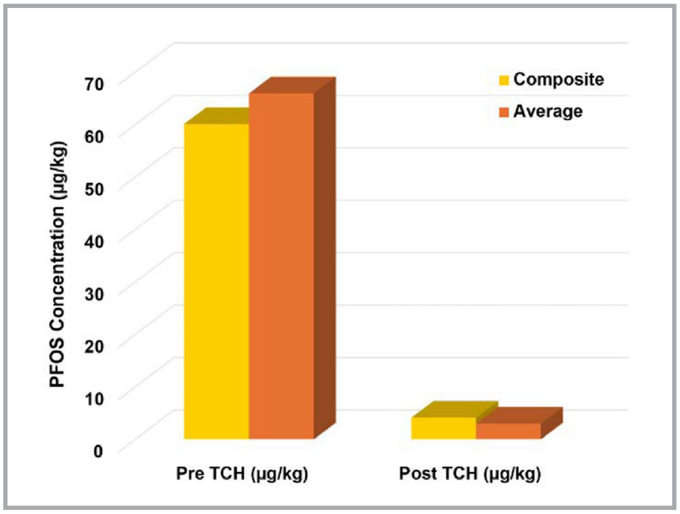

Figure 3. Ex situ thermal pilot-scale study PFAS concentrations in soil before and after treatment (Courtesy of ESTCP)

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CASE STUDY 2

In Situ Thermal Treatment of PFAS in the Vadose Zone

Project Objective

An in situ thermal treatment (ISTT) demonstration was performed at Beale Air Force Base in Yuba County, California. The demonstration was implemented under the ESTCP Project ER20-5250. The pilot-scale ISTT system, including soil vapor and condensate/operating fluids recovery, was intended to validate that PFAS can be thermally desorbed from unsaturated vadose zone soil and treated using viable treatment technologies such as GAC, hydrothermal alkaline treatment, and ultraviolet (UV)-sulfite.

Site Background and Demonstration Approach

The demonstration project was conducted at Fire Protection Training Area 3 within Installation Restoration Program Site FT003 at Beale Air Force Base. Historically, fire training exercises that occurred in this area consisted of placing 55-gallon drums filled with mixed fuels and solvents on elevated metal racks, igniting the drum contents, and then extinguishing the fire.

The pilot project targeted treatment of approximately 3,200 cubic feet of vadose zone soils (244 square feet by 13 feet deep) with an array of 16 electrically powered FlexHeaters installed to 18 feet below ground surface. The treatment area was chosen to target the greatest PFAS concentrations measured in soil during a site investigation. The target temperature for the vadose soils was 350°C. Water, vapor, PFAS, and other chemicals were volatilized and extracted from the subsurface using vapor recovery (five soil vapor extraction wells) and concentrated into a low-volume solution with a wet scrubber. The vapor recovery system conveyed extracted vapors to an aboveground treatment system where vapors were cooled, condensed, and all phases treated onsite using GAC. Temperature was monitored at five borings spaced evenly between the heater wells.

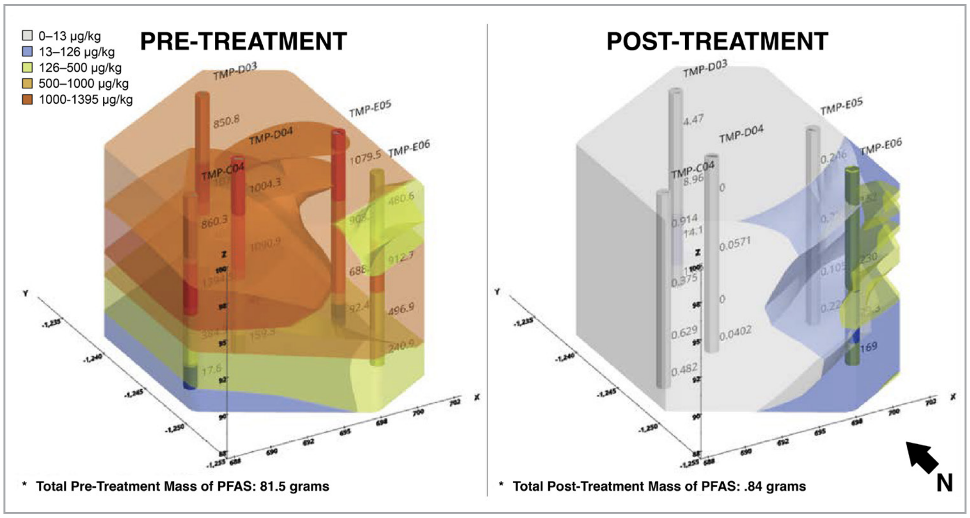
Pre-treatment PFAS included PFOS ranging from 137 µg/kg to 958 µg/kg (approximately 75% of the total measured PFAS) and PFOA up to 29 µg/kg. The pilot test objective was 126 µg/kg for both target compounds.

Results

Subsurface temperatures of 350°C or higher were achieved at 15 of the 20 monitoring locations by the end of heating. Shallow water incursion significantly hindered subsurface heating progress on the east side of the treatment zone, such that target temperatures were not obtained, even with a 47-day extension for heating equipment operation.

Despite the challenges related to subsurface heating, comparison of PFAS concentrations in soil before and after heating correlates to a 98% reduction in the total PFAS mass over the 147 days of test operation (**Figure 4**). At almost all sample locations where subsurface temperatures were maintained above 350°C, concentrations of PFOA and PFOS in subsurface soils were reduced by 97% or greater. The 2024 EPA RSLs for PFOA and PFOS in residential soil (0.019 µg/kg and 0.63 µg/kg, respectively) were not attained in all locations. However, greater treatment durations above the target temperature improved removal of PFAS to below detection limits. Direct comparison of PFAS removal from areas which reached or exceeded 350°C and those which did not suggest PFAS was successfully removed from vadose zone soil when the subsurface temperature was maintained above 350°C for at least 6 days. Treatment of extracted vapor was typically greater than 96% during process operations and vapor-phase GAC. Greater than 99% treatment of process water was achieved using liquid-phase GAC.

The greatest concentrations of PFAS in both the extracted vapor and ISTT system process water were observed when the average subsurface temperature in the treatment cell was around 100°C and water was being removed from the subsurface.



* Total Pre-Treatment Mass of PFAS: 81.5 grams

* Total Post-Treatment Mass of PFAS: .84 grams

Figure 4. Concentrations of total PFAS before and after thermal treatment (Courtesy of ESTCP)

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Conclusions

Overall Conclusions and Lessons Learned

- Thermal desorption at temperatures greater than 350°C can reduce concentrations of target PFAS in soils by one to two orders of magnitude (e.g., 90-99% reductions).
- Heating to those high temperatures can be achieved with TCH, either ex situ or in situ.
- For in situ applications, having a robust conceptual site model (CSM) is needed to fully understand potential presence of subsurface water, which can have a significant cooling effect. Possible sources include a shallow water table, perched groundwater, infiltration of precipitation, or influx of water from leaking storm sewer lines.
- Heating rates are more accurately predicted for ex situ piles than in situ applications, primarily due to the homogeneity of the soil pile and control of operational variables.
- PFAS mass in the recovered vapor and ISTT system condensate was greatest while steam was being removed from the soil. Less heating may be required, depending on target treatment criteria.
- Both vapor and liquid waste streams can be adequately treated with conventional treatment approaches, such as vapor- and liquid-phase GAC.
- Larger soil piles or treatment areas can be heated more efficiently.

Disclaimer

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