QUARTERLY PROGRESS REPORT

[January 01, 2023 – March 31, 2023]

PROJECT TITLE: Fate of PFAS and Other Contaminants During Leachate Evaporation

PRINCIPAL INVESTIGATORS:
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Project summary: As more wastewater treatment plants reduce or cease acceptance of landfill leachate, more solid waste facilities have been moving to implementation of leachate evaporation using heat from the combustion of landfill gas and/or heat from the exhaust of landfill gas-to-energy generators. Residuals (*i.e.*, leachate concentrate) from this process are dried and then returned to the landfill. The objective of this project is to answer the following questions:

1) What happens to per- and polyfluoroalkyl substances (PFAS) and other contaminants when the leachate is evaporated? Do they concentrate within the residue? Are they emitted into the atmosphere?
2) What affects the distribution coefficient of PFAS (= PFAS in gas emission due to evaporation/PFAS in leachate residue after evaporation)?
3) What are the effects of reintroduction of the concentrated leachate residuals into the landfill on the chemical concentrations of future leachate?

The project, if successful, will provide information to landfill managers who plan to move from the discharge-to-sewer method to the leachate evaporation method.

Work Accomplished during this Reporting Period:

The project has three tasks. We have completed ~30% of Task 1, ~30% of Task 2, and 0% of Task 3. The completed work in each task is described below:

<u>Task 1: Effects of leachate evaporation on the fate of PFAS and contaminants regulated by 40 CFR 445.11</u>

We purchased a rotary evaporator (See Figure 1) to evaporate landfill leachate sampled from three landfills in Florida. We compared various combinations of vacuum and water bath temperature to boil a simulated leachate, and found that 1.6 liters of simulated leachate could be evaporated within 10 hours at a temperature of 75 °C in the water bath and a pressure of - 650 mm Hg (relative to the atmospheric pressure of 750 mm Hg). This combination of temperature and pressure is among the range used in the leachate evaporation industry (Belmar company., 2023; IWE company., 2023) and lab-scale research (Bouchareb et al., 2022; Zhang et al., 2022; Hsu et al., 2023).

Figure 1. The rotary evaporator for leachate evaporation in this study

We also developed methods for measuring volatile PFAS and 14 contaminants regulated by 40 CFR 445.11. The 14 contaminants include five-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), ammonia, α-terpineol, aniline, benzoic acid, naphthalene, p-cresol, phenol, pyridine, arsenic, chromium, zinc, and pH. In our previous quarterly report, we detected the following contaminants in at least of one the three leachates sampled from landfills by solid phase microextraction (SPME)-gas chromatography/mass spectrometry (GC/MS): α-terpineol, aniline, naphthalene, p-cresol, and phenol. In the last reporting period (the second quarter), we further detected benzoic acid and pyridine by using the recently purchased standards. We made standard curves for these compounds based on the selected ion monitoring (SIM) mode for the MS. The selected mass to charge ratios are summarized in Table 1. The standard curve equations and detection limits for these compounds are summarized in Table 2.

Table 1. CAS number and selected mass to charge ratios of compounds in GC-MS measurement

Compounds	CAS number	Selected mass to charge ratios
Aniline	62-53-3	93, 66, 65
Phenol	108-95-2	94, 66, 65
Pyridine	110-86-1	79, 52, 51
p-Cresol	106-44-5	108, 107, 77
α-terpineol	98-55-5	93, 121, 136
Benzoic acid	65-85-0	122, 105, 77
Naphthalene	91-20-3	128, 127, 129

Table 2. Detection limits and standard curve equations for the contaminants detected in the leachate sampled from landfills

Compounds	**Quantifier (mass to charge ratio)**	**Qualifier**		**Detection Limit (parts per trillion, ppt)**	**Standard curve equation**
α-Terpineol	93	121	136	200	0.0198x-0.022
Naphthalene	128	129	127	100	0.0032x+0.009
p-Cresol	108	107	77	150	0.0019x+0.008
Aniline	93	66	65	150	0.0057x+0.018
Phenol	94	65	66	200	0.0084x+0.006
Pyridine	79	52	51	250	0.0098x-0.008
Benzoic acid	122	105	77	2,000,000	5. 71x-.0031

Task #2: Distribution coefficients of PFAS

Task 2 is an extension of Task 1, but focuses on PFAS only. In this Task, we used a synthetic leachate. The synthetic leachate in each evaporation tests is 1.6 L of deionized water containing 1,000 mg/L of humic acid and 1,500 mg/L of NH_4Cl. We spiked the synthetic leachate with 4:2 fluorotelomer alcohol (4:2 FTOH), 6:2 fluorotelomer alcohol (6:2 FTOH), and 8:2 fluorotelomer alcohol (8:2 FTOH) at 1 parts per million (ppm). We evaporated the synthetic leachate and took a sample from the leachate concentrate and a sample from the condensate when 25%, 50%, 75%, and 90% evaporation was completed. Figure 2 and Figure 3 show the concentration of FTOHs in the concentrate and condensate, respectively. As shown in Figure 2, the concentration of FTOHs quickly decreased in the leachate concentrate (*i.e.*, evaporation residual) during the first quarter of evaporation: The concentration of FTOHs reached below the detection limit within 25% evaporation. The concentrations of FTOHs in the condensate first increased and then decreased due to the vacuum-caused evaporation and dilution in the condensate collector. FTOHs are highly volatile; therefore, they could escape from the condensate. These initial experiments show that all

FTOHs disappeared in the concentrate in the first quarter of evaporation and more than 98% of FTOHs partitioned into the gas and less than 2% partitioned into the condensate.

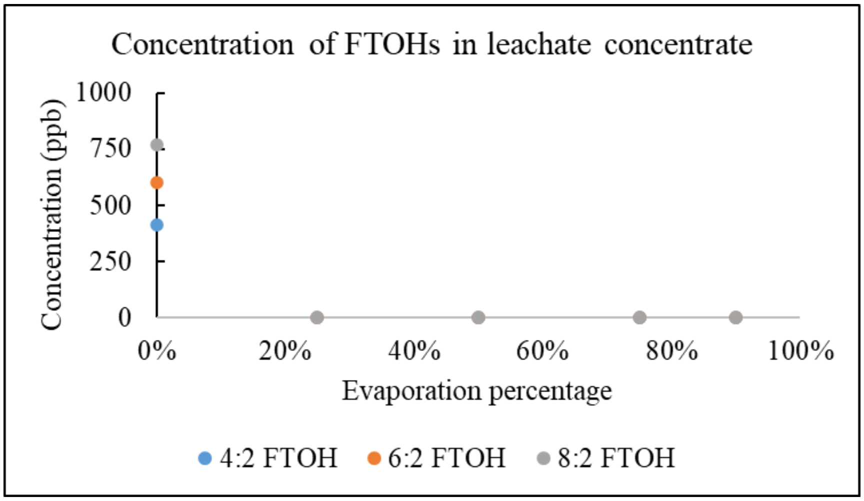

Figure 2. The concentration of FTOHs in concentrate during the evaporation

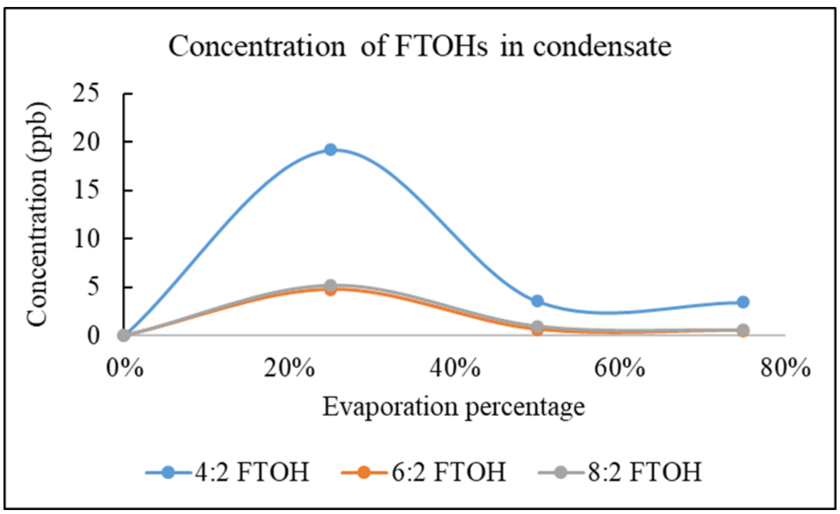

Figure 3. The concentration of FTOHs in condensate during the evaporation

Task #3: Effects of reintroduction of the concentrated leachate residuals on the fate of PFAS and other contaminants

No work was done during this reporting period.

References:

Belmar company, https://belmar-technologies.com/waste-treatment-recycling/thermal-evaporation/., (2023)

Bouchareb, Raouf, Zelal Isik, Yasin Ozay, Ahmet Karagunduz, Bulent Keskinler, and Nadir Dizge. "A hybrid process for leachate wastewater treatment: Evaporation and reverse osmosis/sequencing batch reactor." *Water Environment Research* 94, no. 4 (2022): e10717.

Hsu, Che-Jung, Yan-Ze Xiao, Adrienne Chung, and Hsing-Cheng Hsi. "Novel applications of vacuum distillation for heavy metals removal from wastewater, copper nitrate hydroxide recovery, and copper sulfide impregnated activated carbon synthesis for gaseous mercury adsorption." *Science of The Total Environment* 855 (2023): 158870.

IWE company, https://www.iwe-evaporators.com/IWE-HWS-DE-eng.php (2023)

Zhang, Qun, Menglei Guo, Jiawei Xie, Xiaoming Yang, and Chongjun Chen. "Investigation on characteristics of landfill leachate and feasibility study of low-temperature vacuum evaporation treatment." *Journal of Environmental Chemical Engineering* 10, no. 5 (2022): 108451.

Metrics:

1. List research publications resulting from THIS Hinkley Center project.

   None in this reporting period.

2. List research presentations resulting from (or about) THIS Hinkley Center project.

   None in this reporting period.

3. List who has referenced or cited your publications from this project.

   None in this reporting period.

4. How have the research results from THIS Hinkley Center project been leveraged to secure additional research funding? What additional sources of funding are you seeking or have you sought?

   We have submitted a full proposal regarding volatile PFAS measurement to DoD.

5. What new collaborations were initiated based on THIS Hinkley Center project?

   None in this reporting period.

6. How have the results from THIS Hinkley Center funded project been used (not will be used) by the FDEP or other stakeholders?

   None in this reporting period.