

# PFAS LEACHABILITY STUDY TRIALS: MBT TREATMENT OF CONTAMINATED SITE SOIL

**Technology:** MBT Leachable PFAS

**Media:** Soil

**Source:** Remediation Site - Michigan

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**Scale:** Bench-Engineering

**Mode:** Batch

**Mass:** 300g – 25 Kg per treatment

**Testing:** Method 1311 – TCLP  
Method 1312 – SPLP (acid rain)  
Method 1312 (modified) Fluids:

- DI water
- Landfill Leachate
- PFAS Groundwater

**Location:** Blue Q Labs, Lebanon, OR



## MBT TECHNOLOGY HIGHLIGHTS FOR LEACHABLE PFAS IN SOIL

- MBT technology (Molecular Bonding / Binding Treatment) sequesters and fixates PFAS in soil, sediments and solids.
- Mitigates PFAS migration from release/spill site soils to groundwater, e.g., AFFF.
- Reduces leachability of PFAS telomers from soils/solids using variety of USEPA extraction test methods (e.g., Methods 1311, 1312, and modified 1312)
- Treatment end-product is suitable for onsite management or off-site internment at RCRA Subtitle D non-hazardous or Subtitle C hazardous waste landfills
- Exsitu: Batch/continuous feed processing at production rates from <1 to >250 tons/hour
- Insitu: Near surface soil lifts or to >50' b.g. depths with appropriate mixing equipment
- MBT reagents do not chemically alter PFAS compounds, i.e., no by-product intermediaries
- Bench and engineering-scale trials completed ranging from 300g to 50lbs. on soils, sediments, biosolids
- PFAS in MBT treatment end-product is stable to acid rain (Method 1312 – SPLP) where leachable PFAS are <70 ppt (optimizable to below analytical method detection limits - MDL)
- PFAS in MBT treatment end-product is stable to synthetic landfill leachate (Method 1311 – TCLP) where leachable PFAS are <70ppt in TCLP extract (optimizable to <MDL)
- MBT-treated PFAS material end-product can retains its leachable PFAS and with optimization, remove PFAS telomers from RCRA landfill leachate if leachate contacts treated soil.
- MBT-treated PFAS soil end-product can retain its leachable PFAS and with optimization, remove PFAS from PFAS-contaminated groundwater if groundwater interfaces with treated soil - allows for onsite soil management
- MBT treatment viability/treatability studies optimize processing to project requirements, desired leachability limits and prescribed testing methods
- MBT is licensed to Yost Brothers, LLC for treatability studies, field trial/demonstration, and full-scale application through YB Technologies, LLC.

## TRIAL #1

### Eastern Michigan Remediation Site Soil

PFAS Leachability: Method 1311 (TCLP) & ASTM D7979-17

Telomere	Chemical Name	C Atoms	UNTREATED	MBT TREATED Soil			
			Soil	F-1	F-2	F-3	F-4
			Totals in Soil	Soil	Soil	Soil	Soil
Extract	Extract	Extract	Extract	Extract			
			(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)
	Perfluorohexanoic Acid	C6	4.15J	<4.0	<4.0	<4.0	<4.0
	Perfluoroheptanoic Acid	C7	<4.0	<4.0	<4.0	<4.0	<4.0
	Perfluorooctanoic Acid	C8	<4.0	<4.0	<4.0	<4.0	<4.0
	Perfluorononanoic Acid	C9	<4.0	<4.0	<4.0	<4.0	<4.0
	Perfluorodecanoic Acid	C10	<4.0	<4.0	<4.0	<4.0	<4.0
	Perfluoroundecanoic Acid	C11	<4.0	<4.0	<4.0	<4.0	<4.0
	Perfluorododenoic Acid	C12	<4.0	<4.0	<4.0	<4.0	<4.0
	Perfluorotridecanoic Acid	C13	<4.0	<4.0	<4.0	<4.0	<4.0
	Perfluortetradecanoic Acid	C14	<4.0	<4.0	<4.0	<4.0	<4.0
	Perfluorobutanesulfonic Acid	C4	<4.0	<4.0	<4.0	<4.0	<4.0
	<b>Perfluorohexanesulfonic Acid</b>	<b>C6</b>	<b>14.3</b>	<b>&lt;4.0</b>	<b>&lt;4.0</b>	<b>&lt;4.0</b>	<b>&lt;4.0</b>
	<b>Perfluorooctanesulfonic Acid</b>	<b>C8</b>	<b>105</b>	<b>&lt;4.0</b>	<b>16.7</b>	<b>&lt;4.0</b>	<b>&lt;4.0</b>

PFAS Totals: EPA 537M

Telomere	Chemical Name	C Atoms	UNTREATED	MBT TREATED Soil			
			Soil	F-1	F-2	F-3	F-4
			Totals in Soil	Soil	Soil	Soil	Soil
			(ug/Kg)	(ug/Kg)	(ug/Kg)	(ug/Kg)	(ug/Kg)
	Perfluorohexanoic Acid	C6	<.21	<.23	<.22	<.24	<.23
	Perfluoroheptanoic Acid	C7	<.26	<.29	<.28	<.30	<.29
	Perfluorooctanoic Acid	C8	<.26	<.29	<.28	<.30	<.29
	Perfluorononanoic Acid	C9	<.26	<.29	<.28	<.30	<.29
	Perfluorodecanoic Acid	C10	<.26	<.29	<.28	<.30	<.29
	Perfluoroundecanoic Acid	C11	<.26	<.29	<.28	<.30	<.29
	Perfluorododenoic Acid	C12	<.26	<.29	<.28	<.30	<.29
	Perfluorotridecanoic Acid	C13	<.26	<.29	<.28	<.30	<.29
	Perfluortetradecanoic Acid	C14	<.26	<.29	<.28	<.30	<.29
	Perfluorobutanesulfonic Acid	C4	<.26	<.29	<.28	<.30	<.29
	<b>Perfluorohexanesulfonic Acid</b>	<b>C6</b>	<b>0.837J</b>	<b>0.307J</b>	<b>0.543J</b>	<b>&lt;.30</b>	<b>&lt;.29</b>
	<b>Perfluorooctanesulfonic Acid</b>	<b>C8</b>	<b>13.90</b>	<b>3.93</b>	<b>7.21</b>	<b>2.77</b>	<b>2.76</b>
	N-Ethylperfluorooctane	C12	<.52	<.58	<.56	<.60	<.59
	N-Methylperfluorooctane	C11	<.52	<.58	<.56	<.60	<.59

Note: J - analyte was positively identified, but numeric value reported was approximated.

#### TRIAL 1 NOTES – Effects of MBT Treatment to Leachable TCLP and TOTAL PFAS in Soil:

- Soil provided by Job Site Services, Inc. of Bay City, MI was sourced from a remediation site in eastern Michigan.
- A site soil grab-composite sample collected in a 5-gallon bucket was thoroughly mixed at the lab with a small cement mixer. 500g aliquots of soil were subsampled from the mixed sample matrix and treated for each process run. Soil was placed in tared beakers on a top-load analytical balance. MBT reagent blends were added on a gravimetric % weight basis to mixed as-received soil. Water was added for mixing to achieve an apparent “loose” soil consistency, but with no free liquids. MBT reagents, soil, and water were mixed to apparent homogeneity with a spatula by folding and knifing to replicate blending achievable in the field.
- Test methods included EPA 537-M for PFAS as totals in soil, Method 1311-TCLP for soil extraction, and ASTM 7979-17 for PFAS in water and extraction fluids.
- Untreated and MBT treated soil samples were characterized for PFAS telomers as totals in soil and in the soil’s TCLP extract. Leachable PFOS was found in TCLP extract of untreated soil at a 105ng/L (ppt), above the USEPA advisory level of 70ppt for drinking water.
- Two (2) MBT treatment reagent families were applied with MBT System A reagents to samples F-1 and F-3, and MBT System B reagents to samples F-2 and F-3. Variations within each of the MBT reagent systems related to reagent component blend ratio’s, and blended reagent dose rate (wt. %) to untreated soil.
- Treated samples were allowed to react for a period of 2-4 hours before transfer to a sample container and shipment under Chain-

of-Custody protocols to the analytical laboratory.

- g. All MBT treated soils resulted in the reduction of PFAS leachability compared to untreated material, and to below the USEPA advisory level of 70ppt for drinking water. While MBT treated sample F-2 sample did contain leachable PFOS at 16.7 ng/L, MBT treatments F-1, F-3 and F-4 reduced the leachability of PFAS to below the analytical detection limit. Notably, leachable PFOS was reduced by >96% compared to untreated material in these treatments.
- h. MBT treatment also reduced total PFAS concentration where PFOS in samples F-3 and F-4 was reduced by ~80%. MBT treatment technology does NOT destroy PFAS, but it is likely that the MBT treated soil retained PFAS in a manner such that PFAS was not readily eluted from the soil using the methanol solvent eluant prescribed by the analytical method (EPA 537-M).

## TRIAL #2 Western Michigan Remediation Site Soil

PFAS Leachability: (MODIFIED) Method 1312 (Deionized Water Extraction Fluid)									
		UNTREATED Soil					MBT TREATED Soil		
Telomere	Chemical Name	C Atoms	Totals in Soil (ng/Kg)	Totals in Soil (Replicate) (ng/Kg)	Totals in Soil (avg.) (ng/Kg)	Totals in DI Water (ng/L)	Totals in Soil Extract (ng/L)	T-1 Soil Extract (ng/L)	T-2 Soil Extract (ng/L)
PFBA	Perfluorobutanoic Acid	C4	<0.27	264	264	ND	<49	<50	<50
<b>PFOA</b>	<b>Perfluorooctanoic Acid</b>	<b>C8</b>	<b>618</b>	<b>453</b>	<b>536</b>	<b>ND</b>	<b>13</b>	<b>&lt;10</b>	<b>&lt;10</b>
PFDA	Perfluorodecanoic Acid	C10	1,300	1,050	1,175	ND	<49	<50	<50
PFDoA	Perfluorododecanoic Acid	C12	474	313	394	ND	<49	<50	<50
PFTeA	Perfluortetradecanoic Acid	C14	1270	<0.25	1,270	ND	<49	<50	<50
<b>PFOS</b>	<b>Perfluorooctanesulfonic Acid</b>	<b>C8</b>	<b>34,400</b>	<b>24,800</b>	<b>29,600</b>	<b>ND</b>	<b>660</b>	<b>&lt;10</b>	<b>&lt;10</b>
PFNS	Perfluorononanesulfonic Acid	C9	438	254	346	ND	<49	<50	<50
PFDS	Perfluorodecanesulfonic Acid	C10	864	665	765	ND	<9.7	<10	<10
PFOSA	Perfluorooctanesulfonamide	C8	7,240	5,290	6,265	ND	110	<10	<10
EtFOSSA	N-Ethylperfluorooctane	C12	5,100	3,010	4,055	ND	69	<50	<50

### NOTES: Trial 2 – (modified) Method 1312 – DI Water Extraction:

- a. Study soil was obtained from a PFAS remediation site in Western Michigan.
- b. Michigan list of “24” PFAS telomers were analyzed as totals in soils using EPA Method 537M-ID. Telomers below detection limits in untreated soil as totals are not listed.
- c. Thoroughly mixed untreated soil was subsampled in replicate and each replicate was analyzed to evaluate heterogeneity of PFAS telomere concentrations within the matrix.
- d. The average of replicate sample total PFAS telomere results for untreated material are utilized for comparison in other extraction data tables, herein.
- e. PFAS leachability in untreated and MBT treated soil was evaluated using USEPA (modified) Method 1312 where laboratory-grade deionized water was used as the method extraction fluid, replacing acid-rain for the eastern US; and ASTM Method D7979-17 was utilized to evaluate PFAS telomere in the resultant extracts.
- f. Presented PFAS in DI water data was from the laboratory QA/QC report
- g. MBT treatments T-1 and T-2 were applied to duplicate ~2000 Kg split samples of thoroughly mixed untreated material.
- h. MBT treatments T-1 and T-2 were analyzed using other extraction methods and fluids in subsequent analytical evaluations with data presented in the accompanying tables.
- i. PFOS and PFOSA telomers did leach from untreated soil using (modified) Method 1312 – DI water at concentrations that exceeded the USEPA PFAS advisory level of 70ppt for drinking water, and where PFOA and EtFOSSA were present at levels above the detection limit, but below the advisory level.
- j. PFAS telomers in treated material extracts were all below the EPA advisory level of 70ppt, and the analytical detection limits by telomere as indicated.
- k. PFOS leachability, in particular, was reduced from MBT treatment by over 98.4% from its level in untreated soil

PFAS Leachability: Method 1312 (SPLP: acid rain - Eastern U.S.)

	UNTREATED Soil		MBT TREATED Soil	
	Totals in Soil (avg.) (ng/Kg)	Totals in SPLP Extract (ng/L)	T-1 Soil SPLP Extract (ng/L)	T-2 Soil SPLP Extract (ng/L)
<u>Telomere</u>				
PFBA	264	<4.0	<50	<50
<b>PFOA</b>	<b>536</b>	<b>16.9</b>	<b>&lt;10</b>	<b>&lt;10</b>
PFDA	1,175	23.2	<50	<50
PFDoA	394	<4.0	<50	<50
PFTeA	1270	<4.0	<50	<50
<b>PFOS</b>	<b>29,600</b>	<b>742</b>	<b>&lt;10</b>	<b>&lt;10</b>
PFNS	346	5.95	<50	<50
PFDS	765	5.09	<10	<10
PFOSA	6,265	172	<10	<10
EtFOSSA	4,055	87.7	<50	<50

**NOTES: Trial 2 – Method 1312 – SPLP (acid-rain) Extraction:**

- a. Untreated soil and MBT treated soil split samples of T-1 and T-2 from the previous study were evaluated for PFAS leachability using Method 1312 – SPLP (acid rain for the eastern US) with PFAS telomere concentrations quantified in resultant extracts.
- b. PFOS and EtFOSSA telomeres leached from untreated soil into SPLP (acid rain) extraction fluid at levels that exceeded the USEPA advisory level of 70ppt for drinking water while other telomeres were quantified at lower levels, but above the analytical detection limits.
- c. No PFAS telomere leached from MBT treated soil into SPLP acid rain extraction fluid in excess of the EPA advisory limit for drinking water, or in excess of the analytical detection limit.
- d. PFOS leachability was reduced by MBT treatment by over 98.6% in both samples T-1 and T-2.
- e. The data allows for consideration of onsite management options for MBT treated material vs. offsite disposal in that PFAS will not leach from treated materials when exposed to acid rain.
- f. Data supports technology use to mitigate PFAS migration at release/spill sites (such as from AFFF used for fighting fires) from near surface soils to underlying groundwater due to percolation of surface water and precipitation (rain and snow melt).

PFAS Leachability: Method 1311 (TCLP)						
	UNTREATED Soil		MBT TREATED Soil			
	Totals in Soil (avg.) (ng/Kg)	Totals in TCLP Extract (ng/L)	T-1 Soil Extract (ng/L)	T-2 Soil Extract (ng/L)	T-3 Soil Extract (ng/L)	T-4 Soil Extract (ng/L)
Telomere						
PFBA	264	50,000	49,000	50,000	<50	<50
<b>PFOA</b>	<b>536</b>	<b>4,400</b>	<b>1,800</b>	<b>1,000</b>	<b>&lt;10</b>	<b>&lt;10</b>
PFDA	1,175	<50	<50	<50	<50	<50
PFDoA	394	<50	<50	<50	<50	<50
PFTeA	1270	<50	<50	<50	<50	<50
<b>PFOS</b>	<b>29,600</b>	<b>1,700</b>	<b>1,500</b>	<b>630</b>	<b>&lt;10</b>	<b>&lt;10</b>
PFNS	346	<50	<50	<50	<50	<50
PFDS	765	<50	<50	<50	<10	<10
PFOSA	6265	<50	20	<50	<50	<50
EtFOSSA	4,055	62	<50	<50	<50	<50

**NOTES: Trial 2 – Method 1311 – TCLP Extraction:**

- a. MBT treated soil split samples of T-1 and T-2 from the previous study were evaluated for PFAS leachability using Method 1311 – TCLP with PFAS telomere concentrations quantified in resultant extracts.
- b. MBT treatments T-3 and T-4 were performed based on results from analyses of T-1 and T-2. T-3 and T-4 MBT treatments applied the MBT treatment reagent family regimens used in T-1 and T-2, respectfully, however reagent component ratio’s and overall dosing to the soil was adjusted. The PFAS leachability differences between T-1 and T-2 when analyzed by the synthetic landfill leachate of the TCLP extraction method clearly demonstrates the enhanced severity of the test method over those of Method 1312 -SPLP and the modified version using deionized water. The chemistry of the TCLP fluid caused more PFAS to leach from the untreated material, as well as in the MBT treated samples T-1 and T-2. The leachability of PFOA and PFOS telomeres was significantly in untreated and both T-1 and T-2 treated materials
- c. MBT treatments T-3 and T-4 both effectively reduced all PFAS telomere leachability from soil into the synthetic landfill leachate of Method 1311 – TCLP. Leachable PFAS telomeres from treated soil were reduced to below the EPA advisory level of 70ppt in TCLP extract, and also to below analytical method detection limits.
- d. PFOA leachability was reduced by MBT treatment by over 99.7% and PFOS leachability was reduced by over 99.4%
- e. The data indicates that the MBT treated material using the regimes of T-3 or T-4 is suitable for acceptance and disposal by licensed RCRA Subtitle D non-hazardous waste landfill facilities.

PFAS Leachability: (Modified) Method 1312 with Subtitle D Landfill Leachate Extraction Fluid

		UNTREATED Soil and Subtitle D Landfill Leachate			MBT TREATED Soil		
		Totals in Soil (avg.)	Totals in Landfill Leachate	Totals in Soil Extract	T-2 Soil Extract	T-3 Soil Extract	T-4 Soil Extract
<u>Telomere</u>	<u>Chemical Name</u>	<u>(ng/Kg)</u>	<u>(ng/L)</u>	<u>(ng/L)</u>	<u>(ng/L)</u>	<u>(ng/L)</u>	<u>(ng/L)</u>
PFBA	Perfluorobutanoic Acid	264	1,900	1,800	1,500	1,500	1,300
<b>PFOA</b>	<b>Perfluorooctanoic Acid</b>	<b>536</b>	<b>680</b>	<b>490</b>	<b>200</b>	<b>170</b>	<b>110</b>
PFDA	Perfluorodecanoic Acid	1,175	230	57	<50	<50	<50
PFDoA	Perfluorododecanoic Acid	394	<50	<50	<50	<50	<50
PFTeA	Perfluortetradecanoic Acid	1270	<50	28	<50	<50	<50
<b>PFOS</b>	<b>Perfluorooctanesulfonic Acid</b>	<b>29,600</b>	<b>450</b>	<b>&lt;10</b>	<b>52</b>	<b>38</b>	<b>33</b>
PFNS	Perfluorononanesulfonic Acid	346	<50	<50	<50	<50	<50
PFDS	Perfluorodecanesulfonic Acid	765	<10	<10	<10	<10	<10
PFOSA	Perfluorooctanesulfonamide	6265	<10	28	<10	<10	<10
EtFOSSA	N-Ethylperfluorooctane	4,055	<10	<50	<50	<50	<50

**NOTES: Trial 2 – (modified) Method 1312 – Subtitle D Landfill Leachate Extraction:**

- a. Leachate from a licensed RCRA Subtitle D non-hazardous waste landfill leachate collection system was used as the substitute extraction fluid for synthetic acid rain in (modified) Method 1312.
- b. The leachate was analyzed for PFAS telomers as a separate liquid sample prior to extraction of any samples. PFBA, PFOA, PFDA, and PFOS telomers were identified in the leachate at concentrations that exceeded the EPA advisory level of 70ppt, at 1900, 680, 230, and 450 ng/L (ppt), respectively.
- c. Untreated soil and MBT treated samples T-2, T-3, and T-4 were all extracted using (modified) Method 1312 with the landfill leachate as the extraction fluid and PFAS telomers were quantified in the resultant extracts.
- d. Data indicated that the untreated soil was able to remove some of the PFAS telomers from the landfill leachate during the extraction process, however, ~28 ng/L of PFOSA was leached from the soil by the fluid.
- e. PFAS telomers in the landfill leachate extracts of all MBT treated samples were at concentrations that were less than their respective concentrations in the leachate used for the extractions, and in the leachate extract of untreated soil.
- f. PFBA in extracts of treated samples was not significantly reduced in concentration from its concentration in the landfill leachate, thus requiring further optimization of the MBT process.
- g. The MBT treatment regime as applied in sample T-4 reduced leachable PFAS to a larger degree than the regimen applied to T-2 and T-3, with PFOA reduced by >83%, PFDA by >78%, and PFOS by >92% from their respective concentrations in the actual landfill leachate.
- h. MBT treated soil reduced PFAS telomere leaching into leachate to levels below both those found in untreated soil extracts, and in the leachate fluid obtained directly from the landfill
- i. With optimization, MBT treated material will retain its PFAS and can remove PFAS from leachate that contacts the interned material in a Subtitle D landfill.



PFAS Leachability: (MODIFIED) Method 1312 (Site Groundwater Extraction Fluid)

	UNTREATED Soil and Groundwater			MBT TREATED Soil	
	Totals in Soil (avg.) (ng/Kg)	Totals in Groundwater Extract (ng/L)	Totals in Soil Extract (ng/L)	T-2 Soil Extract (ng/L)	T-4 Soil Extract (ng/L)
<u>Telomere</u>					
PFBA	264	640	620	144	144
<b>PFOA</b>	<b>536</b>	<b>100,000</b>	<b>94,000</b>	<b>220</b>	<b>89</b>
PFNA	<0.26	86	70	<10	<10
PFDA	1,175	96	57	<50	<50
PFDaA	394	<50	<50	<50	<50
PFTeA	1270	<50	<50	<50	<50
<b>PFOS</b>	<b>29,600</b>	<b>390,000</b>	<b>190,000</b>	<b>230</b>	<b>121</b>
PFNS	346	<50	<50	<50	<50
PFDS	765	<10	<10	<10	<10
PFOSA	6,265	63	120	<10	<10
EtFOSSA	4,055	<50	140	<50	<50

**NOTES: Trial 2 – (modified) Method 1312: PFAS Contaminated Groundwater Extraction:**

- Contaminated groundwater was collected from a monitoring well at the western Michigan site where the PFAS impacted soil was obtained for this study.
- Site groundwater was analyzed for PFAS telomeres as totals in the fluid. PFOA and PFOS were present at concentrations of 100,000 and 390,000 ppt, respectively, with other telomeres also present at much lower concentrations.
- Site groundwater was substituted for the synthetic acid rain extraction fluid of Method 1312 as a method modification for analytical sample preparations of untreated and MBT treated site soils.
- Untreated and MBT treated soil samples T-2 and T-4 were extracted with the site groundwater and PFAS telomeres were quantified in the resultant extracts.
- As also evident in the previous landfill leachate sample data, leachable PFAS telomere concentrations were reduced during the extraction of the untreated site soil. However, PFOA and PFOS were still present in the extract fluid at 94,000 and 190,000 ppt, respectively.
- PFAS telomeres in the site groundwater extractions of MBT treated samples T-2 and T-4 were significantly reduced in leachability.
- In T-2, PFOA was reduced by >99.7% from its concentration in both groundwater and the groundwater extract of untreated material. For PFOS, the reduction was over 99.9% relative to the groundwater and the groundwater extract of untreated material. In T-4, leachable PFOA and PFOS were reduced by >99.9% relative to both fluids.
- MBT treatments T-2, and to a larger degree T-4, can be readily optimized to meet the EPA 70ppt advisory limit for drinking water in site groundwater extracts.
- MBT treated material will retain its hosted PFAS telomeres and remove PFAS from contaminated groundwater that may contact treated soil should the soil be managed onsite, and such that MBT treatment end-product may be potentially used in a site remedy design to control PFAS migration via contaminated groundwater.