

An Aluminum Hydroxide Formulation Outperforms Activated Carbon in Binding Shorter Chain Per- and Poly-Fluorinated Alkyl Substances (PFAS)

Dr Richard Stewart, Managing Director, Ziltek
24th May 2016



What is RemBind?

- RemBind is a powdered reagent that binds to organic contaminants in soil and water
- Main ingredients are aluminium hydroxide, activated carbon and organic matter
- As an adsorbent it can be used to:
 - Immobilize contaminants in soil
 - Remove contaminants from water

RemBind®

RemBind® Plus

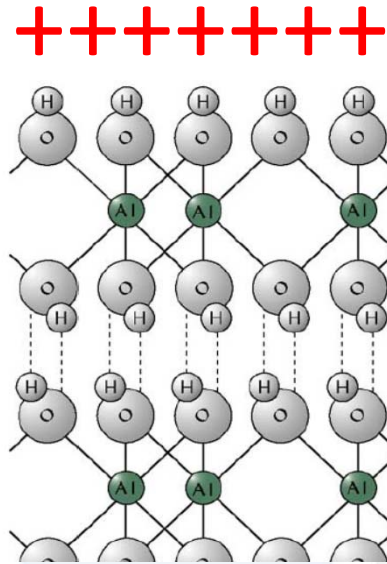




Sydney 2014; 15,000 m³ of PAH contaminated soil was immobilized using RemBind

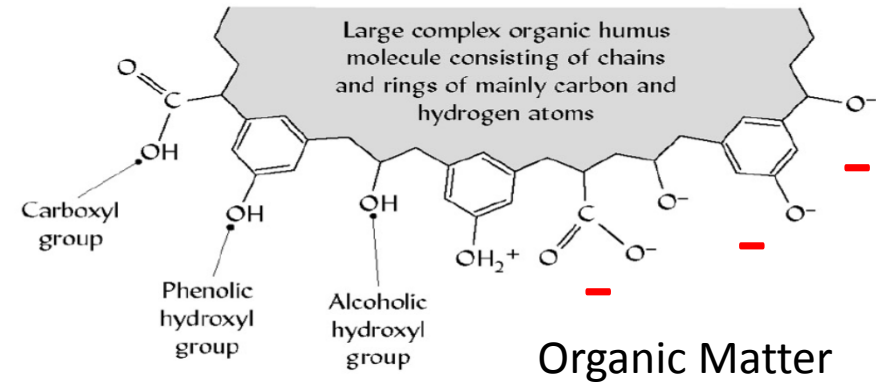
Proposed mechanisms of action

Point of zero charge > pH 7.7



Aluminium Hydroxide (Amorphous)

Electrostatic interactions



Hydrophobic Interactions

Physical Binding

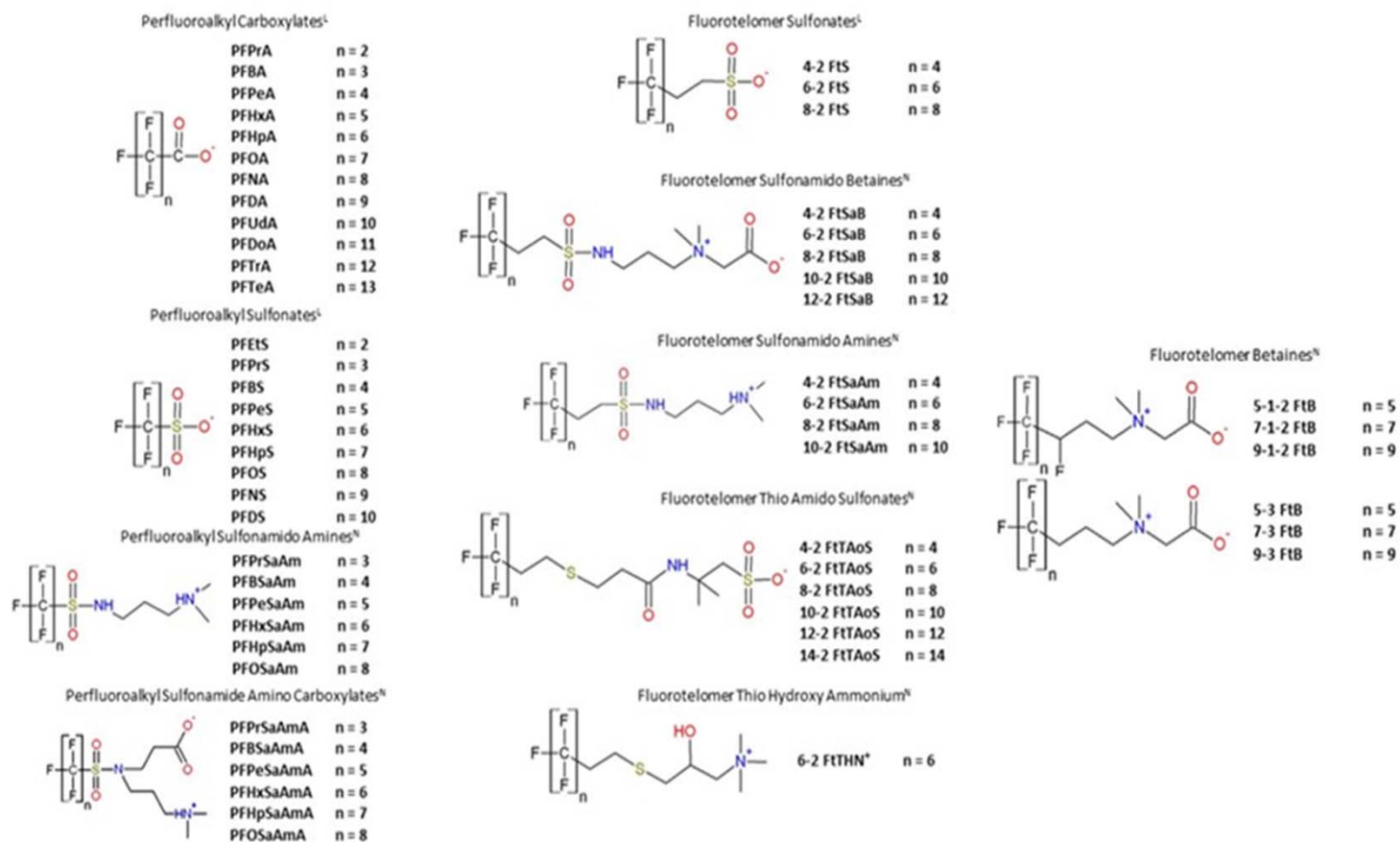


Activated Carbon

Van der Waals



Binding PFAS with RemBind

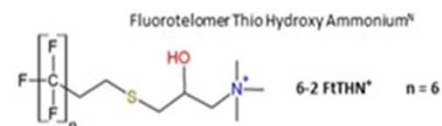
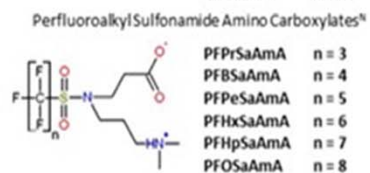
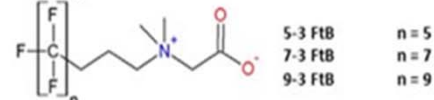
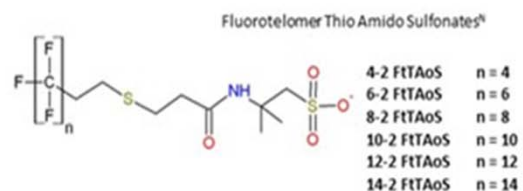
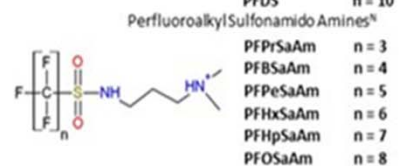
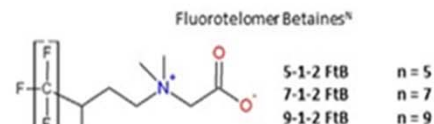
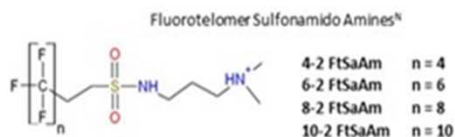
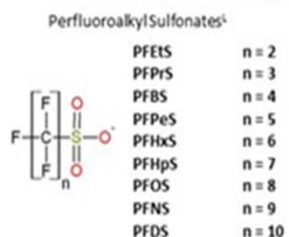
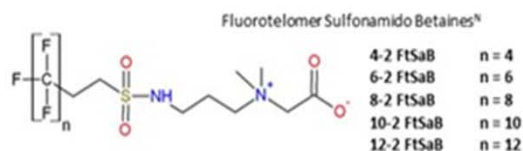
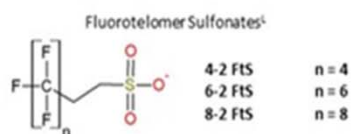
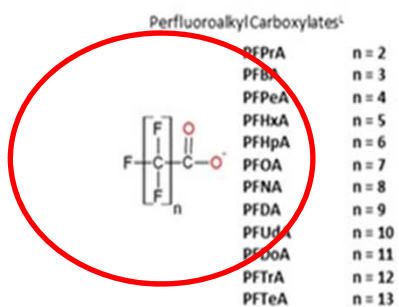


After Backe, et al, 2013; Place and Field, 2012; D'Agostino and Maybury, 2014; and Barzen-Hanson and Field, 2015



Binding PFAS with RemBind

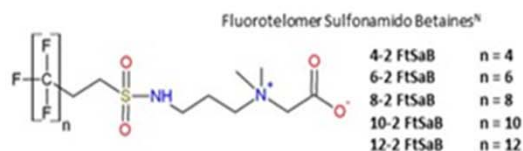
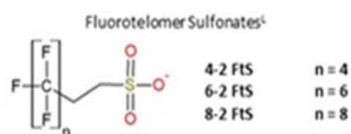
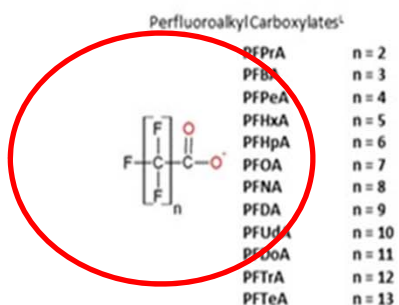
• Anions



After Backe, et al, 2013; Place and Field, 2012; D'Agostino and Maybury, 2014; and Barzen-Hanson and Field, 2015

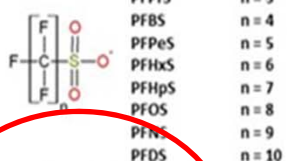


Binding PFAS with RemBind

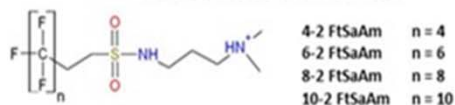


- Anions
- Cations

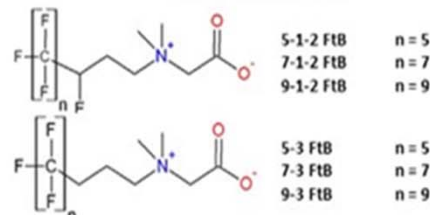
Perfluoroalkyl Sulfonates¹



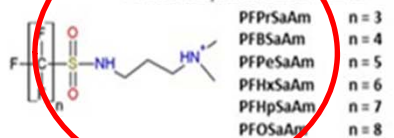
Fluorotelomer Sulfonamido Amines¹



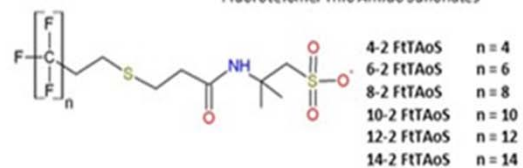
Fluorotelomer Betaines¹



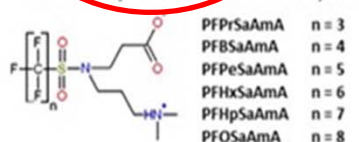
Perfluoroalkyl Sulfonamido Amines¹



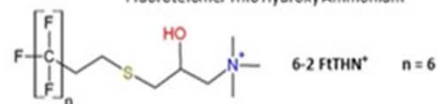
Fluorotelomer Thio Amido Sulfonates¹



Perfluoroalkyl Sulfonamido Amine Carboxylates¹



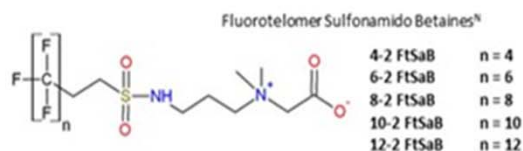
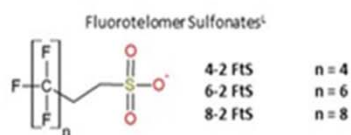
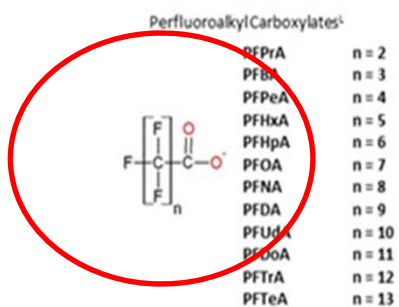
Fluorotelomer Thio Hydroxy Ammonium¹



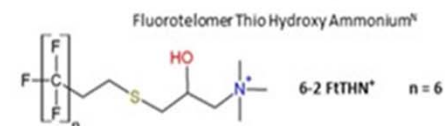
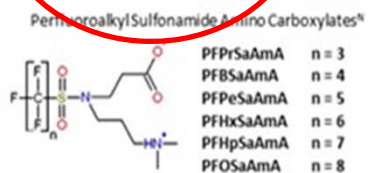
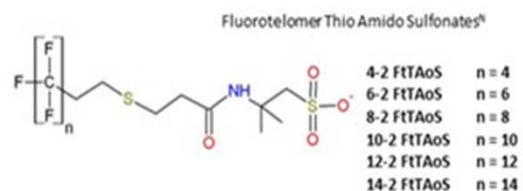
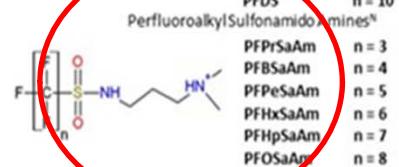
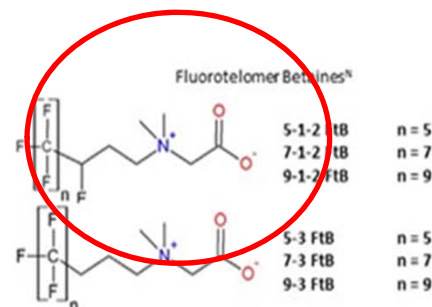
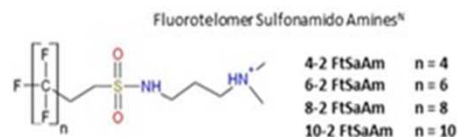
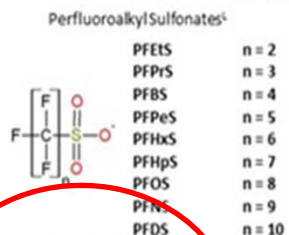
After Backe, et al, 2013; Place and Field, 2012; D'Agostino and Maybury, 2014; and Barzen-Hanson and Field, 2015



Binding PFAS with RemBind



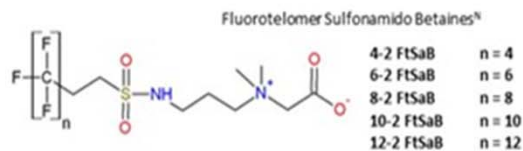
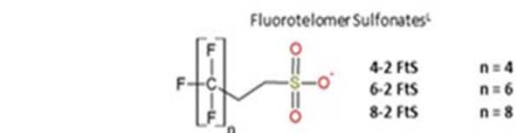
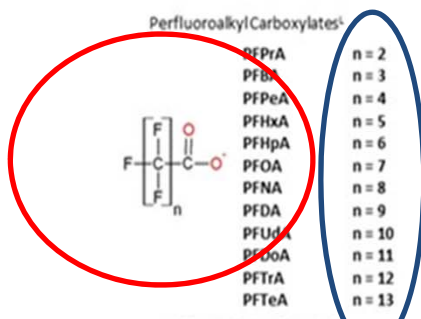
- Anions
- Cations
- Zwitterions



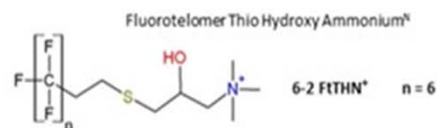
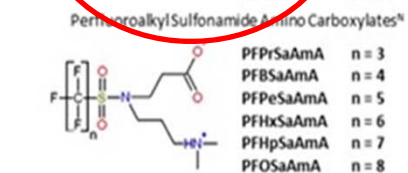
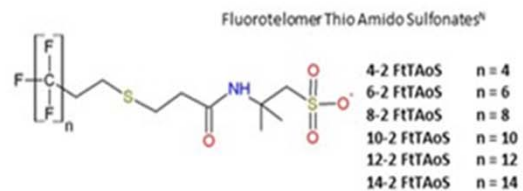
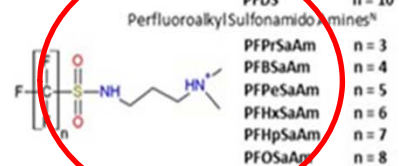
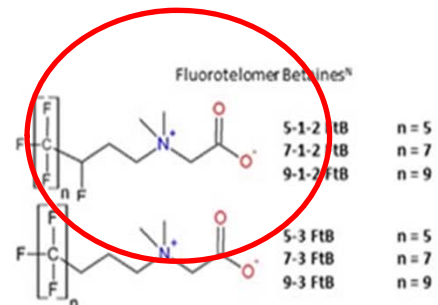
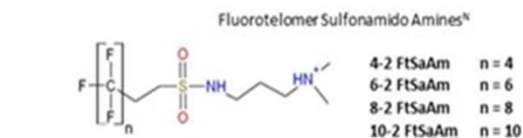
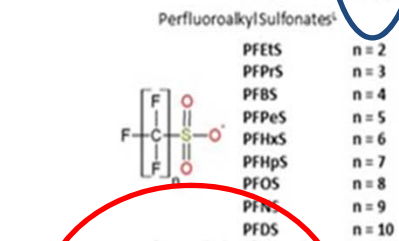
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Binding PFAS with RemBind



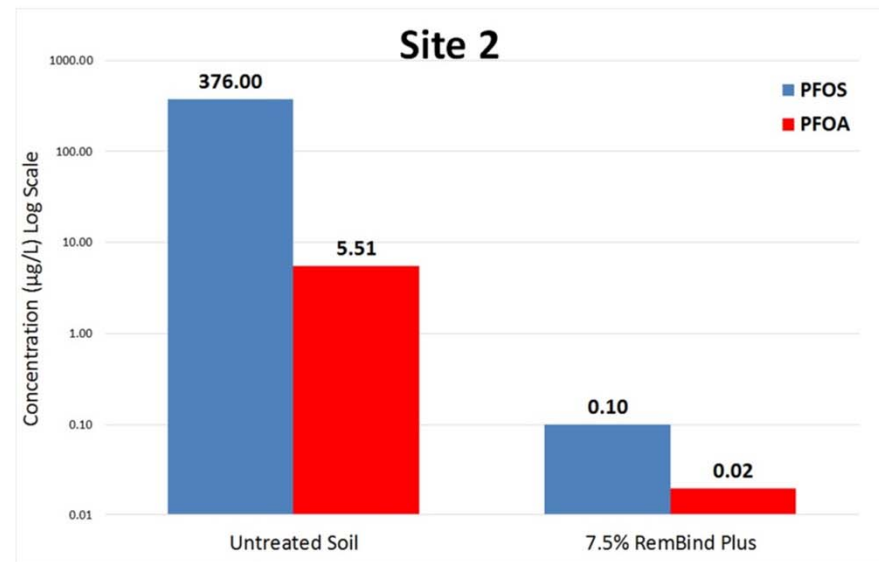
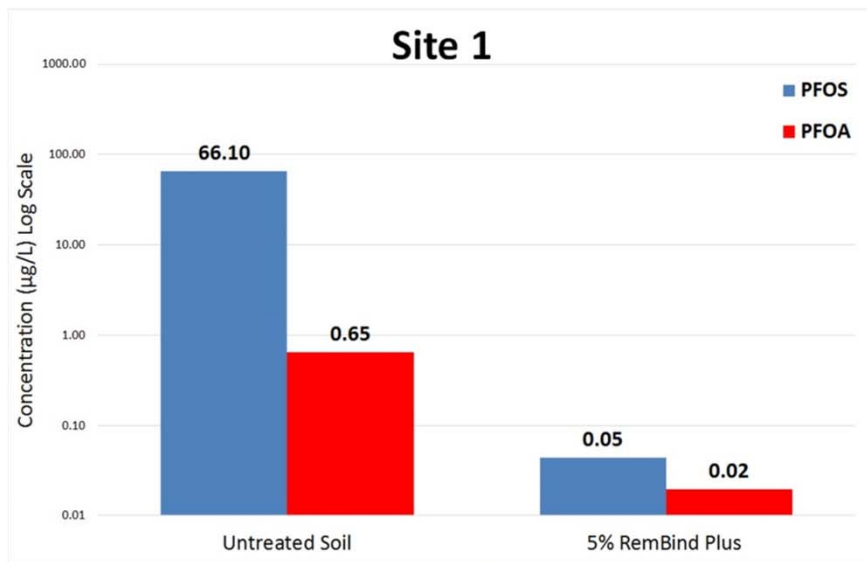
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After Backe, et al, 2013; Place and Field, 2012; D'Agostino and Maybury, 2014; and Barzen-Hanson and Field, 2015



Using RemBind Plus to immobilize PFOS and PFOA in soil from two commercial airport sites in Australia



* Soil leachates prepared using the Toxicity Characteristic Leaching Procedure (TCLP)



Using RemBind Plus to immobilize PFOS and PFOA in soil from two commercial airport sites in Australia

	Constituent Concentration in Soil Leachate (µg/L) ¹											
	PFOS		PFOA		6:2 FtS		8:2 FtS		PFHxS		PFBS	
	pH 5	pH 7	pH 5	pH 7	pH 5	pH 7	pH 5	pH 7	pH 5	pH 7	pH 5	pH 7
Site 1												
Untreated soil	34.15	66.10	0.65	0.50	<0.1	<0.1	<0.5	<0.5	7.30	6.44	0.23	0.28
5% RemBind	0.5	1.12	0.04	0.04	<0.1	<0.1	<0.5	<0.5	0.34	0.36	0.06	0.06
5% RemBind Plus	0.29	0.05	<0.02	<0.02	<0.1	<0.1	<0.5	<0.5	<0.02	<0.02	<0.02	<0.02
Site 2												
Untreated soil	376	492	5.51	7.40	0.25	0.35	2.10	4.35	63.20	88.85	2.08	3.16
7.5% RemBind	1.76	9.50	0.27	0.82	<0.1	<0.1	<0.5	<0.5	2.66	9.45	0.67	0.76
7.5% RemBind Plus	0.10	2.95	<0.02	<0.02	<0.1	<0.1	<0.5	<0.5	<0.02	0.07	<0.02	<0.02



Using RemBind Plus to immobilize PFOS and PFOA in soil from two commercial airport sites in Australia

	Constituent Concentration in Soil Leachate (µg/L) ¹											
	PFOS		PFOA		6:2 FtS		8:2 FtS		PFHxS		PFBS	
	pH 5	pH 7	pH 5	pH 7	pH 5	pH 7	pH 5	pH 7	pH 5	pH 7	pH 5	pH 7
Site 1												
Untreated soil	34.15	66.10	0.65	0.50	<0.1	<0.1	<0.5	<0.5	7.30	6.44	0.23	0.28
5% RemBind	0.5	1.12	0.04	0.04	<0.1	<0.1	<0.5	<0.5	0.34	0.36	0.06	0.06
5% RemBind Plus	0.29	0.05	<0.02	<0.02	<0.1	<0.1	<0.5	<0.5	<0.02	<0.02	<0.02	<0.02
Site 2												
Untreated soil	376	492	5.51	7.40	0.25	0.35	2.10	4.35	63.20	88.85	2.08	3.16
7.5% RemBind	1.76	9.50	0.27	0.82	<0.1	<0.1	<0.5	<0.5	2.66	9.45	0.67	0.76
7.5% RemBind Plus	0.10	2.95	<0.02	<0.02	<0.1	<0.1	<0.5	<0.5	<0.02	0.07	<0.02	<0.02



Using RemBind to remove short- and long-chain PFAS from water

- Independent trials carried out by a remediation specialist in Germany
- Lab-scale batch and column systems
- Compared RemBind Plus with a commercial grade activated carbon

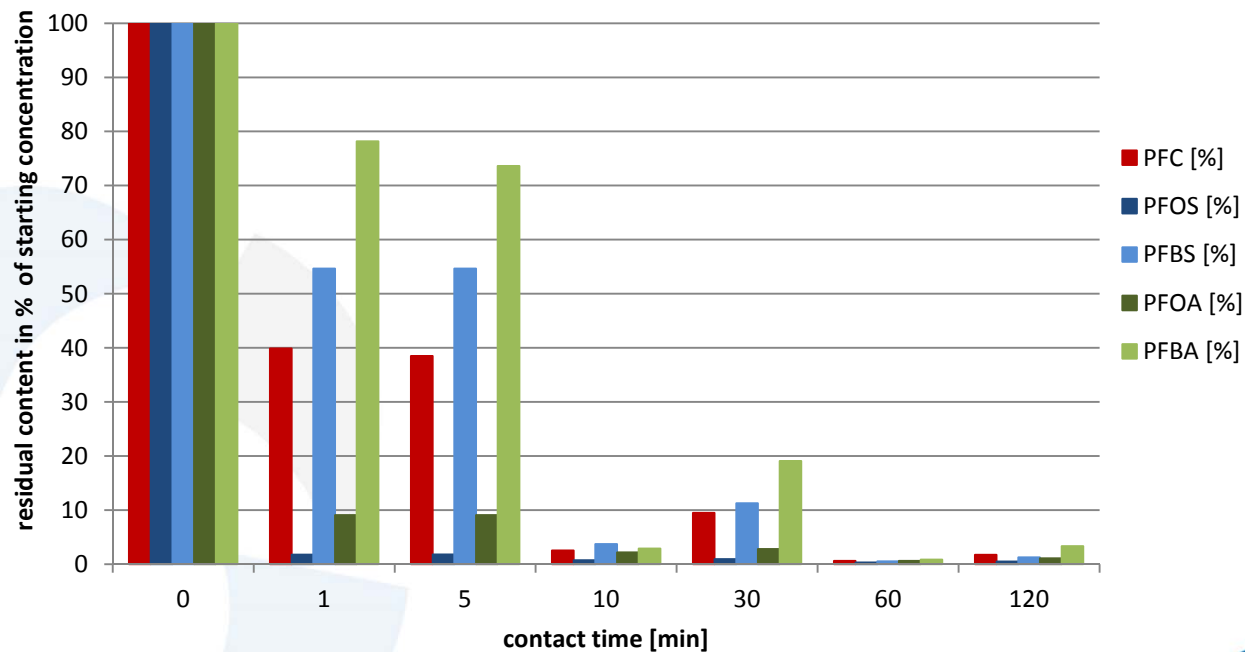


Using RemBind to remove short- and long-chain PFAS from water

Test Compound	C-F Chain Length	Terminal Group
PFOS	n=8	Sulfonic acid
PFOA	n=7	Carboxylic acid
PFBS	n=4	Sulfonic acid
PFBA	n=3	Carboxylic acid

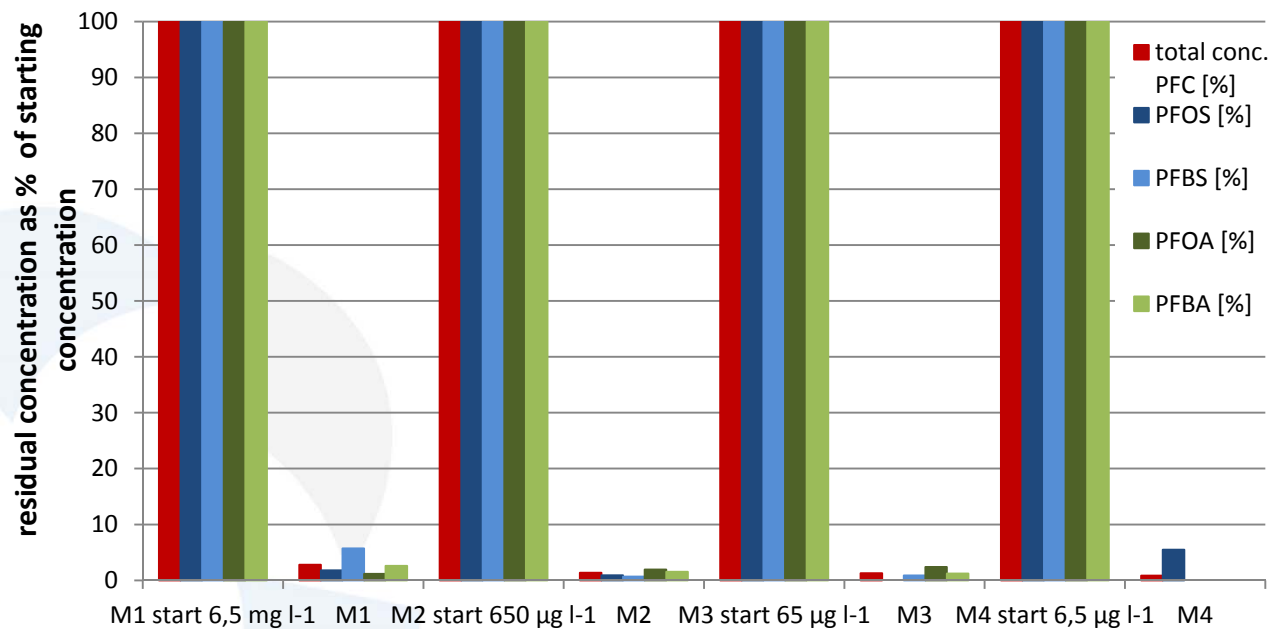
Using RemBind to remove short- and long-chain PFAS from water

Residual PFAS concentration after contact time with 2% RemBind Plus



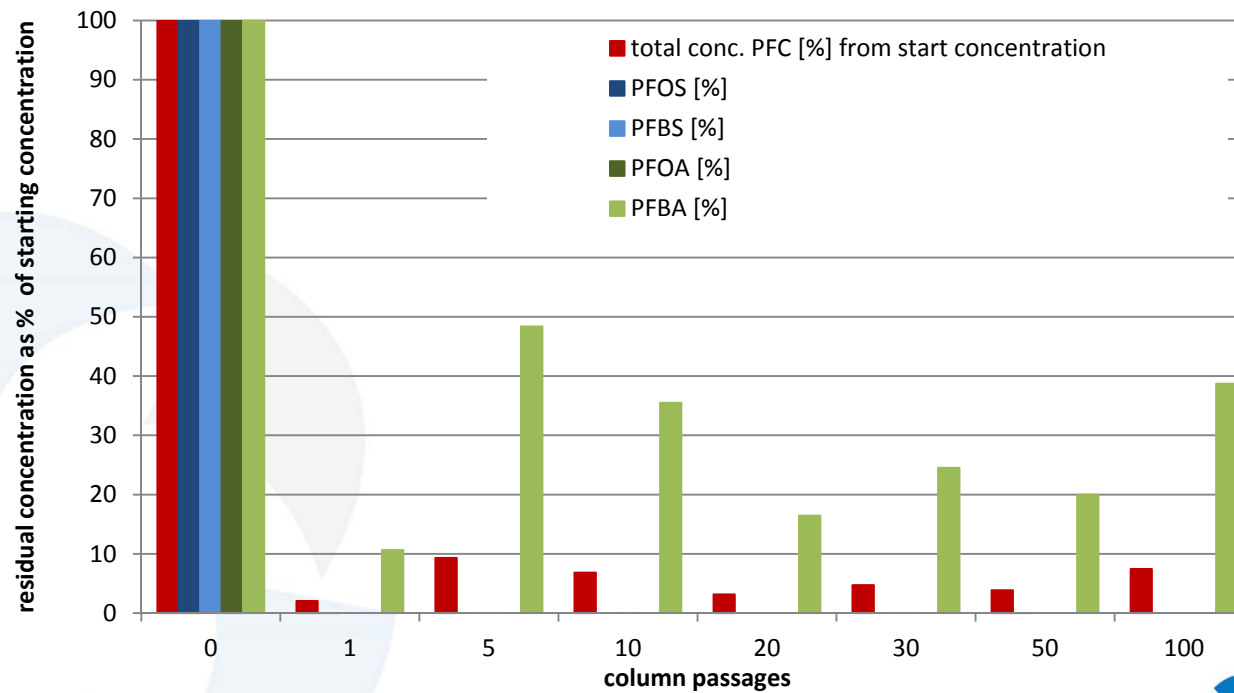
Using RemBind to remove short- and long-chain PFAS from water

Residual PFAS concentration after 60 min contact time with RemBind Plus



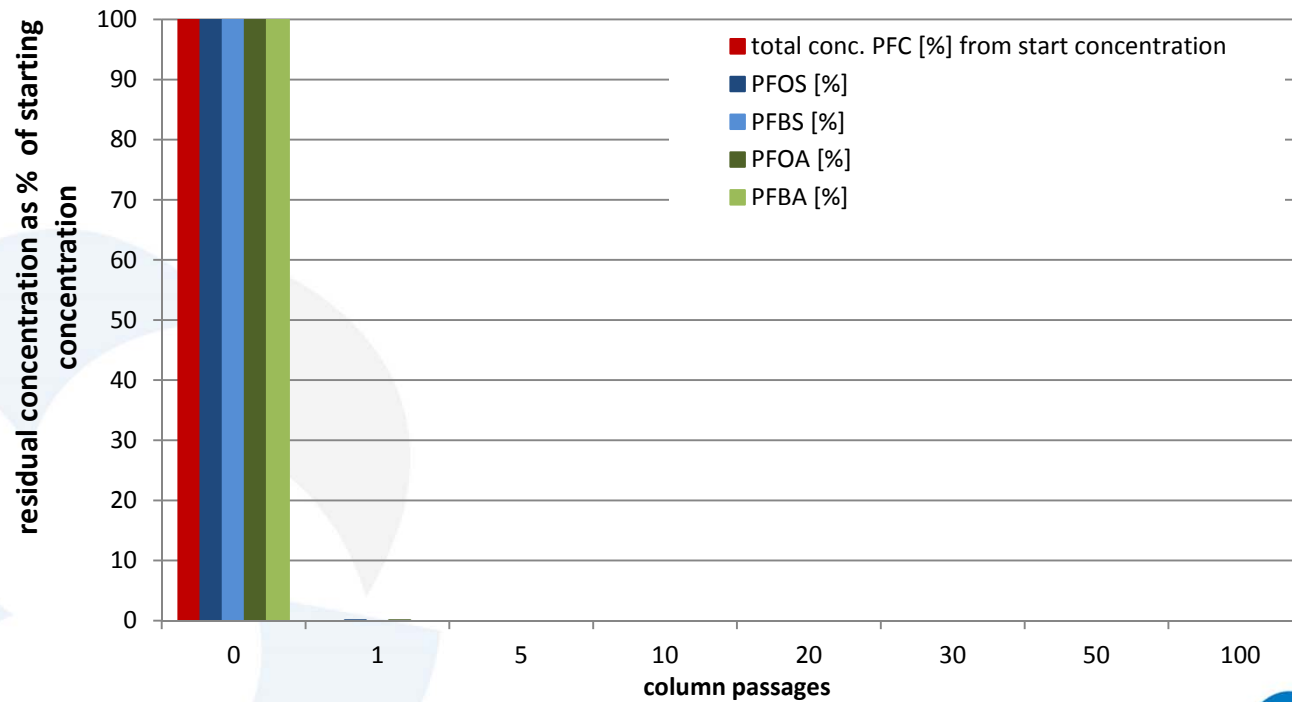
Using activated carbon to remove short- and long-chain PFAS from water

Residual PFAS concentration after 100 passes through activated carbon column



Using RemBind to remove short- and long-chain PFAS from water

Residual PFAS concentration after 100 passes through RemBind Plus column



Using RemBind to remove short- and long-chain PFAS from water

Summary of data:

- RemBind Plus removed shorter chain PFASs more effectively than activated carbon
- 1 hour contact time is optimal
- Estimated PFOS adsorption capacities:
 - ~2,000 $\mu\text{g/g}$ for RemBind Plus
 - ~1,000 $\mu\text{g/g}$ for activated carbon



Removal of PFAS from fire training ground wastewater using RemBind

- Independent trials carried out by BECA using raw wastewater from fire training ground
 - Results summary:
 - PFOS reduced from 50 $\mu\text{g}/\text{L}$ to $<0.02 \mu\text{g}/\text{L}$ at 0.1% (w/v) addition rate
 - PFOS adsorption capacity = 2,560 $\mu\text{g}/\text{g}$
 - 1 hour contact time is optimal
- See POSTER #209 for more details



Removal of PFAS from fire training ground wastewater using RemBind

PFAS compound	Starting concentration in wastewater (µg/L)	RemBind dose (g/L) required to reduce PFAS concentration to <0.3 µg/L
PFOS	51.7	1
PFOA	2.05	2
6:2 FtS	0.84	1
8:2 FtS	12.4	1
PFOSA	0.243	0.04
N-Me-FOSA	<0.10	N/A
N-Et-FOSA	<0.020	N/A
N-Me-FOSE	<0.1	N/A
N-Et-FOSE	<0.1	N/A
PFBS	0.852	10
PFHxS	9.82	2
PFDCS	<0.020	N/A
PFHxA	3.27	10
PFHpA	1.02	10
PFNA	2.13	1
PFDCA	0.676	0.04
PFUnA	0.037	0.04
PFDoA	<0.020	N/A
PFTriA	<0.020	N/A
PFTeA	<0.10	N/A



Overall conclusions

Based on these trials, RemBind:

- Outperformed activated carbon in binding shorter chain compounds PFBS/PFBA
- Showed double the adsorption capacity of the activated carbon used here
- Strongly bound to PFOS and PFOA in soil/water
- Bound to a further 18 PFAS compounds to varying degrees



Future directions

- Regeneration of loaded RemBind
- Field-scale water treatment
 - Wastewater treatment plant (Australia)
 - Pump and treat unit (Europe)
- Field-scale soil treatment
 - Plant and worm toxicity studies near completion
 - *In-situ* mixing, reactive barriers, injectable formulations





For every zone of your plume, we've got you covered!

Distributor Agreement Brings Chemical Fixation / Immobilization Technology to Tersus' Portfolio of In Situ Soil and Groundwater Remediation Technologies

27 March 2015 - Tersus Environmental, LLC (tersusenv.com), a rapidly growing developer and marketer of advanced, innovative technologies for the remediation of soil and groundwater, and Ziltek Pty Ltd, Adelaide, Australia are pleased to announce that the two firms have entered in an agreement wherein Tersus is appointed the North American exclusive distributor for the [RemBind™](#) product. RemBind™ is a unique powdered reagent that binds and immobilizes contaminants in in soils and sediments. RemBind™ treats a broad range of organics including [PFOS](#), [PFOA](#), PCBs, PCPs, [PAHs](#), [TPH](#), various pesticides and heavy metals such as arsenic, chromium and mercury.

