



PFAS in Fire Foam Contaminated Soils – The Importance of Precursors for Risk Assessment

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Testing for Life

AFFF Composition



ECF Foams

- 3M – mid/late 1960's
- Sweden early 1980's (?)
- 25-55% PFOS (or higher): 5-40 g/l
- PFOS – 30% branched
- 8-12x less PFHxS
- Other PFSA, PFCA
- Precursors: PFSaAm, PFSaAmA or PFASAC, PFASNO, AmPr-FAAd etc; C3-C8. C6 most abundant
- Up to ~350 PFAS identified

*Change in manufacturing process
ca 1992-93 (as indicated in sci lit)*

- "Cleaner" chemistry (fewer substances) after change
- Lower PFOS content (frequently)
- Higher relative precursor content, especially C6 (frequently)

End of production 2001-02

FT Foams

- Other manufacturers – 1970's
- Sweden 1990's (????)
- Different, primarily 6:2-based PFAS e.g. 6:2 FTAB, 6:2 FTSAS, 6:2 FTSHA, DPOSA (6:2 FTNO), 6:2 FTSAPr-AmHOPrS, 6:2 FTSOOHPrTAm
- 10-30% (?) 8:2-based (+ minor 4:2 to 14:2), except for FTB
- 6:2 FTS, 6:2 FTOH, PFCA (by-or degradation products)
- Concentrations: <1-25 (40) g/l
- "Clean" chemistry (vs ECF), but still ~120 detected

*US-EPA PFOA Stewardship
Program 2006-15*

- Approx. 100% 6:2-based
- So called "C6 chemistry "

Current , ongoing production , but covered by
REACH PFHxA and AFFF restrictions

■ AFFF concentrate (B-foam)

- 15-18% surfactants (non-PFAS)
- 0.1-2.5% PFAS (max 12%)
- 20% solvents, 60% water
- 1%, 3%, 6% dilution

■ Electrochemical fluorination (ECF)

- PFOS dominated foam
- Light Water AFFF (3M)
- Production ceased in 2001-02

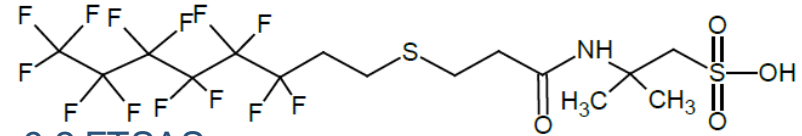
■ Fluorotelomers (FT)

- Older FT foam 6:2 + 8:2, newer "pure" 6:2 chemistry
- Various 6:2/8:2-based molecules
- Still manufactured (although F-free AFFF is taking over) and covered by REACH PFHxA and AFFF restrictions
- Also called C6 chemistry

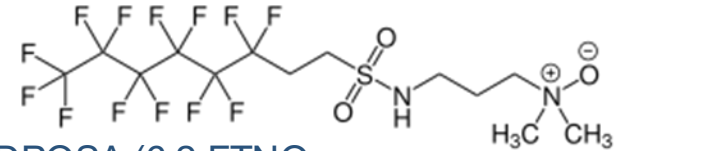
AFFF Content – 6:2 telomer precursors

KEMI PM 6/15

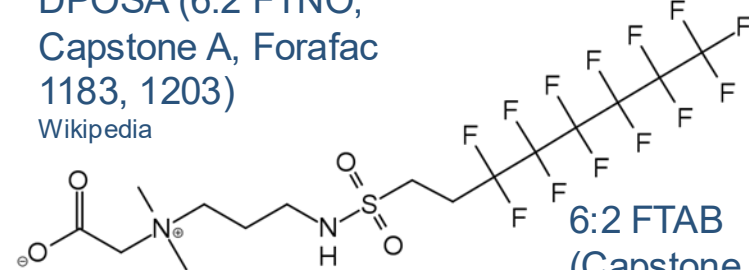
- 6:2 FTSAS: Towalex master, Alcolac 3-6%, foam AFFF 3% (MSB), OneSeven B-AR
- 6:2 FTAB: Sthamex, Alcolac 3-6%, Towalex 3% master
- DPOSA (6:2 FTNO): ARC environment (+ variant with an O-linked to amide group and 6:2 FTAA)
- 6:2 FTSAS-SO and -SO₂ may also be important – at least in degraded foam
- There may be more... (van Hees, 2025)
 - 6:2 FTSAPr-AmHOPrS, 6:2 FTSHA and 6:2 FTTh-PrAm
 - Possibly 6:2 FTS and 6:2 FTAA
- Capstone: Chemour (formerly Dupont) series of 6:2 sulfonamides (production ended 2025)
 - 6:2 FTAB found in drinking/raw water FR, CA, UK (up to 1300 ng/l)
 - 6:2 FTAB in UK DWI48 and FR PFAS22 WWTP lists



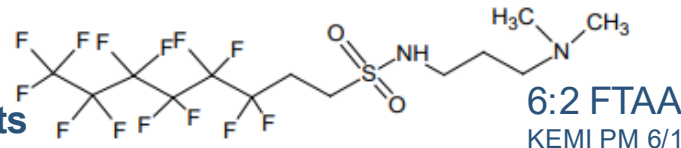
6:2 FTSAS
KEMI PM 6/15



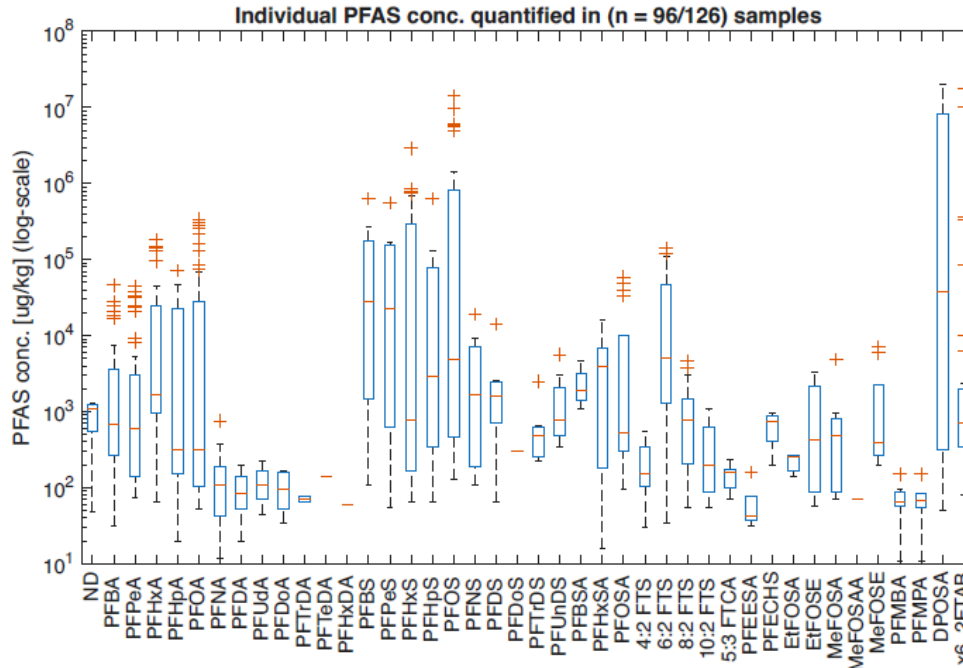
DPOSA (6:2 FTNO,
Capstone A, Forafac
1183, 1203)
Wikipedia



6:2 FTAB
(Capstone
B, Forafac
1157)
Wikipedia



6:2 FTAA
KEMI PM 6/15



- Collected AFFF (n=126) from emergency services, coordinated by MCF (then MSB) for destruction
- DPOSA was found in 41% of the samples, median 28 mg/kg and mean 850 mg/kg
- PFOS in 30%, median 4.9 mg/kg, mean 1460 mg/kg
- 6:2 FTAB in 27%, median 0.7 mg/kg, mean 850 mg/kg
- PFOS (ECF) dominant 1990-2002, 2002- DPOSA

AFFF Content – Eurofins Examples

	AFFF (mg/kg)		
	Foam A	Foam B	Foam C
PFOS	4300		407
6:2FTAB			450
8:2FTAB		2,2	111
10:2FTAB		1,2	21
12:2FTAB			3,4
DPOSA (6:2 FTNO)			610
6:2 FTSAS		4800	
6:2 FTAA			14
8:2 FTAA			1,8
6:2 FTSHA-sulfoxide		120	
6:2 FTSAm			2,1
PFBSA	1,0		
N-AP-FBSA	56		2,4
N-AP-FPeSA	39		2,1
PFHxSA	6,3		
MeFHxSE	1,0		
N-AP-FHxSA	520		48
N-TAmP-FHxSA	270		22
N-HOEAmP-FPeSA	270		19
N-HOEAmP-FHxSE	1300	32	111
N-HOEAmP-FHxSAPS	303		23
N-AP-FOSA	21		1.9
F5S-PFHxS	9.5		
F5S-PFHpS	1.1		
F5S-PFOS	84		7.7
F5S-PFNS	31		4.0
H-PFDS	8.1		
CI-PFOS	3.7		

- Three different AFFF concentrates
- Target + "Selected" suspect screening according to Wang et al (2025)
- Foam A – ECF based on 0.43% PFOS and 0.27% C6-sulfonamides
- Foam B – 6:2 FT based, 0.48% 6:2 FTSAS and smaller proportion of 6:2 FTSHA sulfoxide
- Foam C – 6:2 + 8:2 FT based with a smaller proportion of ECF (mix or contamination?)
- Foam C – DPOSA + 6:2 FTAB (~0.1%)
- Foam C – about 25% 8:2 FTAB vs 6:2 FTAB

PFAS composition in soil



AFFF contaminated soil - Composition

Soil µg/kg DM	Airport 1		Airport 2	Airport 3	Airport 4	Fire fighting training site	Structure
	Soil A	Soil B					
6:2FTAB	8100	5200	2000	900	780	26	6:2 FT
8:2FTAB	7900	99	n.d	59	tr	1,4	8:2 FT
10:2FTAB	1200	18	n.d	7,3	tr	n.d.	10:2 FT
12:2FTAB	140	2,6	n.d	0,8	n.d.	n.d.	12:2 FT
14:2FTAB	4,2	n.d	n.d	n.d	n.d.	n.d.	14:2 FT
DPOSA (6:2 FTNO)	75	n.d	n.d	n.d	n.d.	14	6:2 FT
5:1:2 FTB	1,4	n.d	n.d	n.d	n.d.	n.d.	FT
6:2 FTS _{HA} -sulfoxide	400	740	nd	nd	nd	nd	6:2 FT
6:2 FTAA	-	-	1.1	34	1.1	280	6:2 FT
N-AmCP-FHxSA	210	5.1	nd	1.9	0.2	nd	C6-SA
N-AP-FHxSA	nd	8.6	2.4	10	0.3	nd	C6-SA
N-CMAmP-FHxSA	nd	18	17	46	10	nd	C6-SA
N-CMAmP-FOSA	nd	55	nd	210	5.8	nd	C8-SA
N- HOEAmP - FHxSAPS	nd	28	nd	1.3	0.7	nd	C6-SA
N-HOEAmP-FHxSE	1	66	4	11	nd	nd	C6-SA
N-HOEAmP-FPeSA	nd	50	16	13	0.1	nd	C5-SA
N-TAmP-FHxSA	nd	35	21	17	10	nd	C6-SA
N-TAmP-FOSA	nd	26	nd	7.7	0.2	nd	C8-SA
PFHxSA	0.3	120	18	35	15	3.6	C6-SA
6:2 FTS _{Am}	-	-	110	710	250	3800	6:2 FT
Cl-PFOS	nd	4.8	nd	nd	0.3	nd	PFSA
Ether-PFNS	nd	2.9	nd	nd	nd	nd	PFESA
F5S-PFH _p S	nd	3.2	nd	nd	0.1	nd	PFSA
F5S-PFH _x S	n.d	6,4	n.d	n.d	0,4	n.d.	PFSA
F5S-PFNS	n.d	41	n.d	1,9	n.d.	1,8	PFSA
F5S-PFOS	1,5	150	3	7,4	0,1	5,4	PFSA
PFOS	53	20700	640	750	400	87	PFSA
PFH _x S	1,3	1700	1,8	2,8	2,8	3,0	PFSA
PFOA	10	61	0,3	4,3	5,1	5,9	PFCA
PFNA	7,2	8,2	0,6	4,4	1,1	7,9	PFCA

Four Swedish airports plus one FFT site

- "Selected" suspect screening (Wang et al, 2025)
 - Few standards, largely semi-quantified
- Airports 2 and 4 are included in SGI's (Swe Geotech inst) government assignment
- 6:2 based AFFF (+8:2) can have very high levels
- Higher 6:2 FTAB than PFOS in 4 of 6 soils
- 6:2/8:2 FT and C6/C8 sulfonamides precursors
 - 7 of 9 "major" ECF sulfonamides have quaternary (alkyl) N-head groups
 - The same applies to 7 out of 9 FT substances
- 6:2 FTS_{Am}: "new" substance, degradation product, which can be present in very high concentrations (+ possibly 6:2 FTAA). Formed from DPOSA?
 - Cf. 6:2 FTS 2-16 µg/kg DM (Arpt 2-4, BÖP)
- Good qualitative and quantitative comparison in "right order of magnitude" compared to TOP
- Can never guarantee that this is all...

SMRD - PFAS43 Composition

- Basis consists of 21 PFCA (C4-C14) and PFSA (C4-C13)
 - Includes PFAS4 (PFOS, PFOA, PFHxS, PFNA) and DWD PFAS20 (DK22)
- Numerous precursor substances known to degrade into PFAS4
 - Six PreFOS compounds relevant for PFOS formation are listed (e.g., PFOSA, MeFOSA, EtFOSA).
 - Six PFHxS related precursors (homologues e.g. FHxSA)
 - PFOA precursors include 8:2 FTS and 7:3 FTCA
- Precursor use spans applications such as paper treatment, textiles, polishing, insecticides, AFFF
- Building blocks for larger fluorotelomer substances (e.g. 6:2 FTAB)
- Short chain PFBS and its amide derivatives used in ECF foams and specific industrial processes (e.g. silicon oxide etching)
PFBSA frequently found in fish

PFAS43 – SMRD Annex I, Part C

Perfluorinated butane acid (PFBA)
Perfluorinated pentane acid (PFPeA)
Perfluorinated hexane acid (PFHxA)
Perfluorinated heptane acid (PFHpA)
Perfluorinated octane acid (PFOA)
Perfluorinated nonane acid (PFNA)
Perfluorinated decane acid (PFDA)
Perfluorinated undecane acid (PFUnA/PFUdA)
Perfluorinated dodecane acid (PFDoA)
Perfluorinated tridecane acid (PFTrA)
Perfluorinated tetradecane acid (PFTeA)

Perfluorinated butane sulfonic acid (PFBS)
Perfluorinated pentane sulfonic acid (PFPeS)
Perfluorinated hexane sulfonic acid (PFHxS)
Perfluorinated heptane sulfonic acid (PFHpS)
Perfluorinated octane sulfonic acid (PFOS)
Perfluorinated nonane sulfonic acid (PFNS)
Perfluorinated decane sulfonic acid (PFDS)
Perfluorinated undecane sulfonic acid (PFUnDS)
Perfluorinated dodecane sulfonic acid (PFDoS)
Perfluorinated tridecane sulfonic acid (PFTrDS)

Perfluorinated octane sulfonamide (PFOSA)
N-ethylperfluorooctanesulfonamide (EtFOSA)
N-methylperfluorooctanesulfonamide (MeFOSA)
N-ethylperfluorooctanesulfonamido acetic acid (EtFOSAA)
N-methylperfluorooctanesulfonamido acetic acid (MeFOSAA)
Perfluorooctane sulfonamido acetic acid (FOSAA)

Perfluorinated hexane sulfonamide (FHxSA)
N-ethylperfluorohexane sulfonamide (EtFHxSA)
N-methylperfluorohexane sulfonamide (MeFHxSA)
N-ethylperfluorohexane sulfonamido acetic acid (EtFHxSAA)
N-methylperfluorohexane sulfonamido acetic acid (MeFHxSAA)
Perfluorohexane sulfonamido acetic acid (FHxSAA)

Perfluorinated butane sulfonamide (FBSA)
N-ethylperfluorobutane sulfonamide (EtFBSA)
N-methylperfluorobutane sulfonamide (MeFBSA)
N-ethylperfluorobutane sulfonamido acetic acid (EtFBSA)
N-methylperfluorobutane sulfonamido acetic acid (MeFBSA)
Perfluorobutane sulfonamido acetic acid (FBSA)

6:2 Fluorotelomer sulfonic acid (6:2 FTS)
8:2 Fluorotelomer sulfonic acid (8:2 FTS)

5:3 Fluorotelomer carboxylic acid (5:3 FTCA)
7:3 Fluorotelomer carboxylic acid (7:3 FTCA)

EFSA PFAS4 in bold
PFAS21 in bold and italic

SMRD PFAS43 in AFFF Polluted Soils

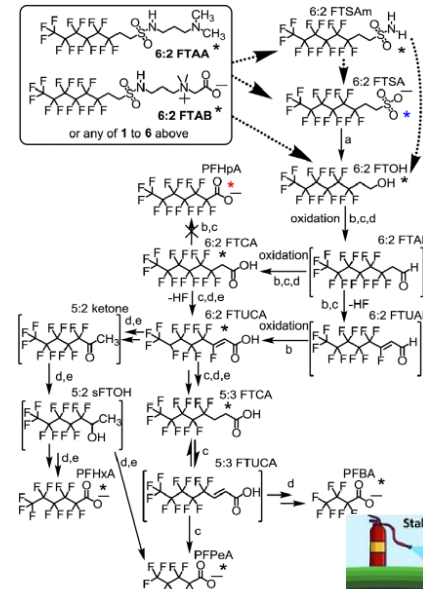
Sample	Airport 2	Airport 3	Airport 4	Fire fighting training site
PFBA	<0,1	0,2	<0,1	15
PFPeA	0,2	1,0	0,4	51
PFHxA	1,3	2,2	0,5	20
PFHpA	0,1	0,8	0,2	6,0
PFOA	0,5	7,3	5,1	5,9
PFNA	0,5	0,8	1,1	7,9
PFDA	0,1	1,4	1,0	67
PFUdA	<0,1	<0,1	<0,1	7,8
PFDoA	<0,1	<0,1	<0,1	21
PFTTrDA	<0,1	<0,1	<0,1	1,5
PFTeDA	<0,03	<0,03	<0,03	3,5
PFBS	<0,03	0,2	<0,03	0,1
PFPeS	<0,1	0,3	<0,1	<0,1
PFHxS	2,6	5,4	2,3	3,0
PFHpS	1,5	0,5	2,8	0,6
PFOS	673	776	281	87
PFNS	0,5	2,5	<0,2	<0,2
PFDS	0,1	0,7	<0,03	0,2
PFUnDS	<1,0	<1,0	<1,0	<1,0
PFDoS	<1,0	<1,0	<1,0	<1,0
PFTTrDS	<1,0	<1,0	<1,0	<1,0
FOSA	1,7	43	3,0	0,2
EtFOSA	<0,2	<0,2	<0,2	<0,2

MeFOSA	<0,03	0,1	<0,03	<0,03
EtFOSA	<0,1	<0,1	<0,1	<0,1
MeFOSA	<0,03	0,2	<0,03	<0,03
FOSA	<0,5	<2,0	<0,2	<0,1
PFHxSA	18	35	15	3,6
EtFHxSA	<1,0	<1,0	<1,0	<1,0
MeFHxSA	1,4	0,1	0,2	0,2
EtFHxSAA	<1,0	<1,0	<1,0	<1,0
MeFHxSAA	<0,1	<0,1	<0,1	<0,1
FHxSAA	0,2	1,3	0,4	0,1
PFBSA	0,1	0,4	0,1	0,3
EtFBSA	<1,0	<1,0	<1,0	<1,0
MeFBSA	<0,3	<0,3	<0,3	<0,3
EtFBSAA	<0,03	<0,03	<0,03	<0,03
MeFBSAA	<0,03	<0,03	<0,03	<0,03
FBSAA	<0,03	<0,03	<0,03	<0,03
6:2 FTS	1,6	16	2,7	13
8:2 FTS	0,2	5,0	0,3	<0,1
5:3FTCA	<0,1	<0,1	<0,1	5,0
7:3FTCA	<0,1	<0,1	<0,1	1,3
Sum PFAS43	703	901	317	320
Sum PFAS4	677	789	290	104
Sum PFAS22	684	858	301	310

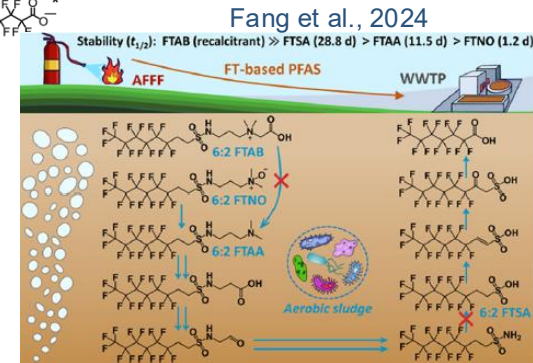
- Four soils from previous slide (NB separate analysis)
- 29 of 43 PFAS identified
- PFOS is major PFAS in all
 - Little difference between PFAS4 and 22/43 in most soils
- PFHxSA > PFHxS in all samples – C6-sulphonamide degradation (!?)
- Minor concentration of FOSA, MeFOSA/AA, MeFHxSA, FHxSAA, PFBSA
- 5:3/7:3 FTCA in FFT soil
- Besides PFAS43 - other PFAS e.g. 6:2 FTAB in soils
- PFAS43 no replacement for broader analysis of source zone soils
- Studies of PFAS43 from other sources but AFFF needed

PFAS precursor degradation in soil

- **Biodegradation of 6:2 AFFF molecules**
 - Research area under development
 - Very likely that 6:2 AFFF molecules biodegrades to PFCA (C4-C6/7) as end products
 - In most experiments with 6:2 AFFF molecules, degradation with sludge/soil/liquid incubation, typically 100 days – few % recovered as PFCA
 - FTAB likely more resistant than e.g. DPOSA or 6:2 FTSAS
 - No or limited amounts of 6:2 FTS are formed during biotic degradation of 6:2 FTAB, but more from 6:2 FTSAS
 - Very slow hydrolysis of 6:2 FTSAm to 6:2 FTS
 - The composition of the N “head group” and the chain length (adsorption) can affect the rate of biodegradation
 - Estimating degradation in the field – several decades?



D'Agostino and Mabury, 2017



- **PFAS composition in AFFF and contaminated soil is a complex issue (structure/chemistry, chemical analysis, risk assessment)**
 - Two main classes of foam ECF (PFOS) and FT (6:2/8:2) – often found mixed on contaminated sites, larger sites may have sub-areas with different (?)
 - Development: target (PFAS7, 11, 21 etc) ➡ TOP ➡ extended analysis of precursors both AFFF content and "rate-limiting" intermediates
 - TOP is a good "screening tool" – PFCA pattern plus lin/br speciation
 - 6:2 FTAB has become the representative for 6:2 based FT, but there are more...
 - Biodegradation of AFFF precursors, especially FT, needs to be evaluated. What are the main degradation products? Rate?
 - 6:2 FTSAm is a "new" intermediate that deserves attention
 - We can no longer see precursors as a "black matter" group (!?)
 - PFAS precursors in the risk assessment and design of remedial actions? Toxicity, groundwater protection? Leaching and behaviour on adsorbents etc?
 - Include PFAS precursors at an early stage of investigation to get a better overview!



Thanks!

Thank you for listening!
Welcome to contact me!
Questions?

Check out our publications at:
<https://www.eurofins.se/publications/>

“Short Facts” - AFFF: PFAS
Composition, Precursors and
Biodegradation

