

Technical Fact Sheet – Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA)

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TECHNICAL FACT SHEET – PFOS and PFOA

At a Glance

- ❖ Manmade chemicals not naturally found in the environment.
- ❖ Fluorinated compounds that repel oil and water.
- ❖ Used in a variety of industrial and consumer products, such as carpet and clothing treatments and firefighting foams.
- ❖ Extremely persistent in the environment.
- ❖ Known to bioaccumulate in humans and wildlife.
- ❖ Readily absorbed after oral exposure. Accumulate primarily in the blood serum, kidney and liver.
- ❖ Toxicological studies on animals indicate potential developmental, reproductive and systemic effects.
- ❖ Health-based advisories or screening levels have been developed by EPA and state agencies.
- ❖ EPA has not issued a Maximum Contaminant Level (MCL) for drinking water.
- ❖ Standard analytical methods use high-performance liquid chromatography coupled with tandem mass spectrometry.
- ❖ Resistant to most chemical and microbial conventional treatment technologies. Most common groundwater treatment method is extraction and filtration through granular activated carbon filters.

Introduction

This fact sheet, developed by the U.S. Environmental Protection Agency (EPA) Federal Facilities Restoration and Reuse Office (FFRRO), provides a summary of two contaminants of emerging concern, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), including physical and chemical properties; environmental and health impacts; existing federal and state guidelines; detection and treatment methods; and additional sources of information. This fact sheet is intended for use by site managers who may address these chemicals at cleanup sites or in drinking water supplies and for those in a position to consider whether these chemicals should be added to the analytical suite for site investigations.

PFOS and PFOA are part of a larger group of chemicals called per- and polyfluoroalkyl substances (PFASs). PFASs, which are highly fluorinated aliphatic molecules, have been released to the environment through industrial manufacturing and through use and disposal of PFAS-containing products (Liu and Mejia Avendano 2013). PFOS and PFOA are the most widely studied of the PFAS chemicals. PFOS and PFOA are persistent in the environment and resistant to typical environmental degradation processes. As a result, they are widely distributed across all trophic levels and are found in soil, air and groundwater at sites across the United States. The toxicity, mobility and bioaccumulation potential of PFOS and PFOA result in potential adverse effects on the environment and human health.

What are PFOS and PFOA?

- ❖ They are human-made compounds that do not occur naturally in the environment (ATSDR 2015; EPA 2009b).
- ❖ PFOS and PFOA are fully fluorinated, organic compounds. They are the two PFASs that have been produced in the largest amounts within the United States (ATSDR 2015; EFSA 2008).
- ❖ PFOS and PFOA are part of a subset of PFASs known as perfluorinated alkyl acids (PFAAs).

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PFAS Chemistry

- ❖ The PFAS group is made up of two subgroups: perfluoroalkyl substances and polyfluoroalkyl substances.
- ❖ PFOS and PFOA are **perfluoroalkyl substances** (compounds for which all hydrogens on all carbons (except for carbons associated with functional groups) have been replaced by fluorines).
- ❖ **Polyfluoroalkyl substances** are compounds for which some hydrogens (but not all) on the carbon atoms have been replaced by fluorines.
- ❖ PFASs are extremely persistent in the environment primarily because the chemical bond between the carbon and fluorine atoms is extremely strong and stable.

Source: Buck and others 2011

- ❖ PFOS and PFOA can also be formed by environmental degradation or by metabolism in larger organisms from a large group of related PFASs or precursor compounds (ATSDR 2015; UNEP 2006).
- ❖ PFOS and PFOA are stable chemicals that are comprised of chains of eight carbons. Because of their unique ability to repel oil and water, these chemicals have been used in: surface protection products such as carpet and clothing treatments; coatings for paper, cardboard packaging and leather products; industrial surfactants, emulsifiers, wetting agents, additives and coatings; processing aids in the manufacture of fluoropolymers such as nonstick coatings on cookware; membranes for clothing that are both waterproof and breathable; electrical wire casing; fire and chemical resistant tubing; and plumbing thread seal tape (ATSDR 2015).
- ❖ Through 2001, PFOS and other PFAS chemicals were used in the manufacture of aqueous film forming foam (AFFF), which is used to extinguish liquid hydrocarbon fires (ASTSWMO 2015; EPA 2016f; DoD SERDP 2014; Place and Field 2012). Manufacturers of AFFF in the United States now use PFASs other than PFOS; however, existing stocks of PFOS-based AFFF remain in use.
- ❖ By 2002, the primary U.S. manufacturer of PFOS voluntarily phased out production of PFOS. In 2006, eight major companies in the PFASs industry voluntarily agreed to phase out production of PFOA and PFOA-related chemicals by 2015. EPA is concerned about a limited number of ongoing uses of PFOA-related chemicals, which are still available in existing stocks and from companies not participating in the PFOA Stewardship Program. In addition, exposure could occur via goods imported from countries where PFOS and PFOA are still used (EPA 2016b, 2016c, 2016f).

Exhibit 1: Physical and Chemical Properties of PFOS and PFOA (ATSDR 2015; EFSA 2008; EPA 2016b, 2016c)

Property	PFOS (Free Acid)	PFOA (Free Acid)
Chemical Abstracts Service (CAS) number	1763-23-1	335-67-1
Physical description (physical state at room temperature and atmospheric pressure)	White powder (potassium salt)	White powder/ waxy white solid
Molecular weight (g/mol)	500	414
Water solubility at 25°C (mg/L)	680	9.5 X 10 ³
Melting point (°C)	No data	54
Boiling point (°C)	258–260	192
Vapor pressure at 25°C (mm Hg)	0.002	0.525
Organic carbon partition coefficient (K _{oc})	2.57	2.06
Henry's law constant (atm-m ³ /mol)	Not measurable	Not measurable

Abbreviations: g/mol – grams per mole; mg/L – milligrams per liter; °C – degree Celsius; mm Hg – millimeters of mercury; atm-m³/mol – atmosphere-cubic meters per mole

Existence of PFOS and PFOA in the environment

- ❖ During manufacturing processes, PFASs were released to the air, water and soil in and around manufacturing facilities (ATSDR 2015). Recently, PFOS and PFOA contamination has also been observed in facilities using PFAS products to manufacture other products (secondary manufacturing facilities).
- ❖ PFOS has been detected in surface water and sediment downstream of production facilities and in wastewater treatment plant effluent, sewage sludge and landfill leachate at a number of cities in the United States (OECD 2002; Oliaei and others 2013).
- ❖ The environmental release of PFOS-based AFFF may also occur from tank and supply line leaks, use of aircraft hangar fire suppression systems, firefighting training activities, and use at airplane crash sites (DoD SERDP 2014).
- ❖ PFOS and PFOA products often contain residuals from manufacturing and formulation that are PFASs. PFOS- and PFOA-based products often contain impurities and residuals which may be precursors to PFOS and PFOA. Biological and abiotic environmental processes have been shown to transform these precursors into PFOS and PFOA (Liu and Mejia Avendano 2013; Buck and others 2011; Conder and others 2010).
- ❖ In general, PFOS and PFOA are stable in the environment and resist typical environmental degradation processes. As a result, these chemicals are persistent in the environment (OECD 2002; ATSDR 2015).
- ❖ PFOS and PFOA are detected in environmental media and biota in many parts of the world, including oceans and the Arctic, indicating that long-range transport is possible (ATSDR 2015).
- ❖ The wide distribution of perfluoroalkyl substances, such as PFOS, in higher trophic level organisms is strongly suggestive of the potential for bioaccumulation and/or bioconcentration (EPA 2015; UNEP 2006).
- ❖ PFOS has been shown to accumulate to levels of concern in fish. The estimated bioconcentration factor in fish ranges from 1,000 to 4,000 (EFSA 2008; MDH 2017a). PFOA has been shown to bioaccumulate in air breathing species, including humans, but not in fish (Vierke and others 2012).

What are the routes of exposure and the potential health effects of PFOS and PFOA?

- ❖ Studies have found PFOS and PFOA in the blood samples of the general human population and wildlife, indicating that exposure to the chemicals is widespread (ATSDR 2015; EPA 2015).
- ❖ Reported data indicate that blood serum concentrations of PFOS and PFOA are higher in workers and individuals living near facilities that use or produce PFASs than for the general population (ATSDR 2015; EPA 2009b).
- ❖ Potential exposure pathways include ingestion of food and water, use of consumer products or inhalation of PFAS-containing particulate matter (e.g., soils and dust) or vapor phase precursors (ATSDR 2015; EPA 2009b).
- ❖ PFOA and PFOS have been found in drinking water supplies, typically associated with manufacturing locations, industrial use or disposal.
- ❖ Human epidemiological studies found associations between PFOA exposure and high cholesterol, increased liver enzymes, decreased vaccination response, thyroid disorders, pregnancy-induced hypertension and preeclampsia, and cancer (testicular and kidney) (EPA 2016e).
- ❖ Human epidemiological studies found associations between PFOS exposure and high cholesterol and adverse reproductive and developmental effects (EPA 2016d).
- ❖ PFOS and PFOA are toxic to laboratory animals, producing reproductive, developmental and systemic effects in laboratory tests (Austin and others 2003; EPA 2016d, 2016e; Post and others 2012).
- ❖ EPA found that there is suggestive evidence that PFOS and PFOA may cause cancer (EPA 2016d, 2016e).
- ❖ The American Conference of Governmental Industrial Hygienists (ACGIH) has classified PFOA as a Group A3 carcinogen – confirmed animal carcinogen with unknown relevance to humans (ATSDR 2015).
- ❖ The World Health Organization's International Agency for Research on Cancer has found that PFOA is possibly carcinogenic to humans (Group 2B) (IARC 2016).
- ❖ In 2009, the Stockholm Convention on Persistent Organic Pollutants added PFOS to Annex B, restricting its production and use. PFOA was proposed for listing in 2015 (Stockholm Convention 2016).

Are there any federal and state guidelines and health standards for PFOS and PFOA?

- ❖ EPA derived oral non-cancer reference doses (RfDs) of 0.00002 mg/kg/day for both PFOS and PFOA (EPA 2016d, 2016e). The RfD is an estimate of the daily exposure level that is likely to be without harmful effects over a lifetime.
- ❖ In May 2016, EPA established drinking water health advisories of 70 parts per trillion (0.07 micrograms per liter (µg/L)) for the combined concentrations of PFOS and PFOA. Above these levels, EPA recommends that drinking water systems take steps to assess contamination, inform consumers and limit exposure. The health advisory levels are based on the RfDs (EPA 2016b, 2016c).
- ❖ EPA found that there are insufficient data to derive inhalation non-cancer reference concentrations (RfCs) for PFOS and PFOA (EPA 2016d, 2016e).
- ❖ For PFOA, EPA estimated a cancer slope factor of 0.07 (mg/kg/day)⁻¹. Based on this slope factor, EPA calculated that a PFOA drinking water concentration of 0.5 µg/L would correspond to a one-in-a-million increased risk of cancer (EPA 2016c, 2016e).
- ❖ EPA has not issued a Maximum Contaminant Level (MCL) for drinking water.

- ❖ Various states have established drinking water and groundwater guidelines, including the following:

State	Guideline (µg/L)		Source
	PFOA	PFOS	
Delaware	0.4	0.2	DNREC 2016
Maine	0.13	0.56	MDEP 2016
Michigan	0.42	0.011	MDEQ 2015
Minnesota	0.035	0.027	MDH 2017b
New Jersey	0.04	NA	NJDEP 2016
North Carolina	2	NA	NCDEQ 2013
Texas	0.3	0.6	TCEQ 2016
Vermont	0.02	NA	VTDEC 2016

- ❖ Some states have fish consumption advisories for certain water bodies where PFOS has been detected in fish (MDH 2017c; MDHHS 2016).
- ❖ PFOS and PFOA are included on the fourth drinking water contaminant candidate list, which is a list of unregulated contaminants that are known to, or anticipated to, occur in public water systems and may require regulation under the Safe Drinking Water Act (EPA 2016a).

What detection and site characterization methods are available for PFOS and PFOA?

- ❖ Detection methods for PFOS and PFOA are primarily based on high-performance liquid chromatography (HPLC) coupled with tandem mass spectrometry (MS/MS) (ATSDR 2015).
- ❖ EPA Method 537, Version 1.1, is a liquid chromatography/tandem mass spectrometry (LC-MS/MS) method used to analyze PFOS, PFOA and other PFAAs in finished drinking water. While most sampling protocols for organic compounds require sample collection in glass, this method requires plastic sample bottles because PFASs are known to adhere to glass (ATSDR 2015; EPA 2009a). In addition, the method notes that analytes are found in common lab supplies and equipment such as PTFE (polytetrafluoroethylene) products, LC solvent lines, solid phase extraction sample transfer lines, methanol and aluminum foil (EPA 2009a).
- ❖ Currently, there are no standard EPA methods for analyzing PFASs in groundwater, surface water, wastewater or solids. EPA is developing analytical methods for these media. EPA expects to have draft methods for water and solids by fall 2017.

EPA will also develop standard operating procedures for field sampling (EPA 2017).

- ❖ ASTM has published standards for analyzing PFAAs in soil (D7968-14) and in water, sludge, influent, effluent and wastewater (D7979-15). Both standards use LC-MS/MS (ASTM 2014, 2015). These methods have not been multi-lab validated.
- ❖ The available detection methods report sensitivities of low picograms per cubic meter (pg/m³) levels in air, high picograms per liter (pg/L) to low ng/L levels in water, and high picograms per gram to low ng/g levels in soil (ATSDR 2015).
- ❖ Experimental techniques are available to measure PFASs in air samples. Some studies have used gas chromatography mass spectrometry (GC/MS) to measure PFASs in air samples (ATSDR 2015). In addition, some precursor chemicals and transformation products are measured by GC/MS/MS or LC/MS/MS (Liu and Mejia Avendano 2013). An oxidative technique has been proposed to estimate precursor levels by LC/MS/MS (Houtz and Sedlak 2012).

- ❖ Researchers are developing a new analytical method that uses particle induced gamma emission (PIGE) to quickly and non-destructively

detect the presence of PFASs in consumer products and other solid materials (National Science Foundation 2015).

What technologies are being used to treat PFOS and PFOA?

- ❖ Chapter 10 of the PFOS and PFOA health advisories discuss the performance of common drinking water technologies to treat these chemicals (EPA 2016b, 2016c). In general, PFOS and PFOA resist most conventional chemical and microbial treatment technologies. Technologies with demonstrated effectiveness include granular activated carbon sorption and ion exchange resins (EPA 2016b, 2016c).
- ❖ PFAAs can be formed when precursor chemicals are transformed in the environment or in the body (EPA 2016b, 2016c). Therefore, if precursors are not addressed during remediation, over time they may be transformed to PFAAs, such as PFOS and PFOA. The presence of other contaminants, including PFAS precursors, can also impact design and performance of remedial technologies.
- ❖ The most common groundwater treatment is extraction and filtration through granular activated carbon. However, because PFOA and PFOS have moderate adsorbability, the design specifics are very important in obtaining acceptable treatment (EPA 2016b, 2016c). Other potential adsorbents include: ion exchange resins, organo-clays, clay minerals and carbon nanotubes (EPA 2016b, 2016c; Espana and others 2015). Evaluation of these sorbents needs to consider regeneration, as the cost and effort required may be substantial (EPA 2016b, 2016c).
- ❖ Other ex situ treatments including nanofiltration and reverse osmosis units have been shown to remove PFASs from water (EPA 2016b, 2016c). Incineration of the concentrated waste would be needed for the complete destruction of PFASs (MDH 2008; Vecitis and others 2009).
- ❖ Research into other treatment approaches for PFOS and PFOA in groundwater is ongoing (DoD SERDP 2016).
- ❖ One soil management approach is excavation and off-site disposal. Capping may also be an option.
- ❖ High-temperature incineration can also be used to destroy PFOS and PFOA (ASTSWMO 2015).
- ❖ Stabilization methods for PFAS-contaminated soil may be effective (Kupryianchyk and others 2016).

Where can I find more information about PFOS and PFOA?

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