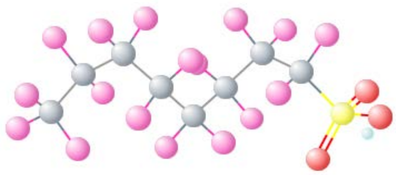
Per- and Polyfluoroalkyl Substances

PFAS – BACKGROUND INFORMATION

Perfluorooctane sulfonate (PFOS)

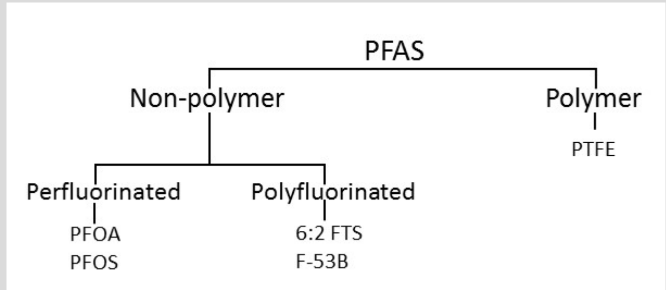


6:2 Fluorotelomer sulfonate (6:2 FTS)

Nomenclature

- "PFAS" = a large number of chemicals that have fluorines bound to carbons in a chain
- Non-polymeric PFAS are the focus of regulatory concern; polymers are large, not bioavailable and currently not a concern
- Non-polymer PFAS can either have carbons that are fully fluorinated (**per**fluorinated) or have some carbons also bound to hydrogen (**poly**fluorinated)
- PFOS and perfluorooctanoic acid (PFOA) are examples of perfluorinated compounds
- 6:2 FTS is an example of a polyfluorinated compound
- "Long-chain" PFAS generally have 6 or more fully fluorinated carbons
- "Short-chain" PFAS generally have 5 or less fully fluorinated carbons

Family Tree



PFAS Relevant to Metal Plating

- PFOS was phased out of chrome mist suppressant formulations between 2012-15
- Today mist suppressant formulations in the U.S. contain polyflourinated fluorotelomers, such as 6:2 FTS
- Some PFAS polymers may be used in electroless nickel plating (e.g. PTFE)

Chemical Characteristics

- PFAS are highly stable and give products heat, oil, and/or water resistant properties and reduce surface tension of solutions
- Perfluorinated compounds do not degrade in the environment
- Current polyfluorinated compounds degrade into short-chain perfluorinated compounds
- Long-chain perfluorinated compounds are of regulatory interest due to their extreme persistence and potential human health concerns
- Short-chain PFAS are generally considered "safer" than long-chain perfluorinated compounds; however, regulatory interest in short-chain PFAS is increasing and data gaps exist

Per- and Polyfluoroalkyl Substances – Background Information

1. PFAS Chemistry and Nomenclature

The term "per- and polyfluoroalkyl substances (PFAS)" encompass a wide range of chemicals that can have very different chemical and physical properties. The two main categories of PFAS include polymeric and non-polymeric PFAS (Figure 1).

Non-polymeric PFAS are the focus of regulatory concern. These small synthetic molecules are the most studied and monitored. This class of PFAS can be further split into two main categories including perfluorinated and polyfluorinated PFAS. Perfluorinated substances have fully fluorinated carbon chains, while polyfluorinated substances are composed of carbon chains that are not fully fluorinated (at least one carbon atom is bound to a hydrogen instead of a fluorine atom). As will be discussed further below, fluorotelomers are a common example of a polyfluorinated molecule. Alternatively, perfluoroalkyl acids (PFAAs), such as perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), are examples of perfluorinated substances. All PFAS are known for their stability and resistance to degradation, is due to the strong bond between the carbon and fluorine atoms.

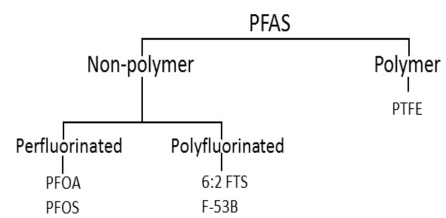


Figure 1. PFAS Family Tree

PFAAs are commonly referred to as "long chain" and "short chain". Long-chain PFAAs generally include substances with ≥ 6 fully fluorinated carbon chains. Alternatively, short-chain PFAAs generally include substances with ≤ 5 fully fluorinated carbon chains.

2. PFAS Relevant to Metal Plating

The metal plating industry historically has used, and continues to use, PFAS in some metal plating applications, most notably in hard and decorative chromium plating, chromic acid anodizing, and chromium etch for plating on plastic processes. Since the 1950s, specific PFAS surfactants have been added to the metal plating baths to reduce hexavalent chromium vapors. There is also use of large PFAS polymers in some electroless nickel plating applications (polytetrafluoroethylene [PTFE]), however, because polymers are generally considered biologically inactive and nontoxic, the primary emphasis related to PFAS in the metal plating industry is on the small non-polymer PFAS molecules used in chromium plating.

2.1 PFOS Phased Out of Use in Chrome Plating between 2012-2015.

Due to unique chemical properties and high stability, the chrome plating and anodizing industry began using PFOS-containing formulations in their manufacturing processes in the late 1980s to suppress the formation of chromium vapors. However, due to concerns related to toxicity and environmental persistence, 3M, the company that manufactures PFOS in the U.S., voluntarily stopped production and use of PFOS and other long-chain perfluorinated compounds, in 2002. In the early 2000s, Minnesota conducted statewide testing of publicly owned treatment works (POTWs)/wastewater treatment plants (WWTPs) and identified chromium-electroplating facilities as a contributor of PFOS to POTWs and

WWTPs. Following this finding, industry – EPA collaborations led to the required phase-out of PFOS-containing mist suppressant formulations between 2012-2015, per the revised Chromium Electroplating National Emission Standards for Hazardous Air Pollutants (NESHAP). New formulations using only "short-chain" fluorochemistry, primarily composed of 6:2 fluorotelomer sulfonate (6:2 FTS), were then implemented.

2.2 Fluorotelomers Used ~2012 to Present.

Fluorotelomers are fluorinated carbon compounds generated via a chemical engineering process called "telomerization", and can exist as alcohols, sulfonates, iodides, aldehydes, and carboxylic acids. Fluorotelomers are named via the "X:Y" designation in which X is the number of fully fluorinated carbons and Y is the number of non-fluorinated carbons. For example, 6:2 FTS is composed of six fully fluorinated carbon atoms, and two non-fluorinated carbon atoms.

Fluorotelomers are often referred to as PFAA precursors, as they can be metabolized or degrade to persistent PFAAs; however, the final PFAA degradation products are dependent upon the number of fully fluorinated carbon atoms in the parent fluorotelomer. For example, 6:2 FTS has been shown to degrade to the short-chain PFAAs perfluorohexanoic acid (PFHxA; 5 fully fluorinated carbons) and perfluorpentanoic acid (PFPeA; 4 fully fluorinated carbons), but does not degrade to long-chain PFAAs such as PFOA or PFOS. Although short-chain PFAAs are persistent in the environment, they are generally considered to be less toxic than long-chain PFAAs and do not bioaccumulate. The full list of fluorotelomer degradation products and their relative safety is an active area of research.